GreenFacts
Facts on Health and the Environment

Scientific Facts on

Air Pollution

Particulate Matter

Source document:
WHO (2003 - 2004)

Summary & Details:
GreenFacts

Level 2 - Details on Air Pollution

This Digest is a faithful summary of two leading scientific consensus reports produced in 2003 and 2004 by the World Health Organization (WHO): *"Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide (2003)" and "Answer to follow-up questions from CAFE (2004)"*

The full Digest is available at: https://www.greenfacts.org/en/particulate-matter-pm/

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- Each question is answered in Level 1 with a short summary.
- These answers are developed in more detail in Level 2.
- Level 3 consists of the Source document, the internationally recognised scientific consensus report which is faithfully summarised in Level 2 and further in Level 1.

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1. What is Particulate Matter (PM)?

Particulate matter is the sum of all solid and liquid particles suspended in air many of which are hazardous. This complex mixture includes both organic and inorganic particles, such as dust, pollen, soot, smoke, and liquid droplets. These particles vary greatly in size, composition, and origin.

Particles in air are either:

- directly emitted, for instance when fuel is burnt and when dust is carried by wind, or
- indirectly formed, when gaseous pollutants previously emitted to air turn into particulate matter.

1.1 Why does particle size matter

The aerodynamic properties of particles determine how they are transported in air and how they can be removed from it. These properties also govern how far they get into the air passages of the respiratory system. Additionally, they provide information on the chemical composition and the sources of particles.

Particles have irregular shapes and their aerodynamic behaviour is expressed in terms of the diameter of an idealised sphere. The sampling and description of particles is based on this aerodynamic diameter, which is usually simply referred to as 'particle size'. Particles having the same aerodynamic diameter may have different dimensions and shapes. Some airborne particles are over 10,000 times bigger than others in terms of aerodynamic diameter.

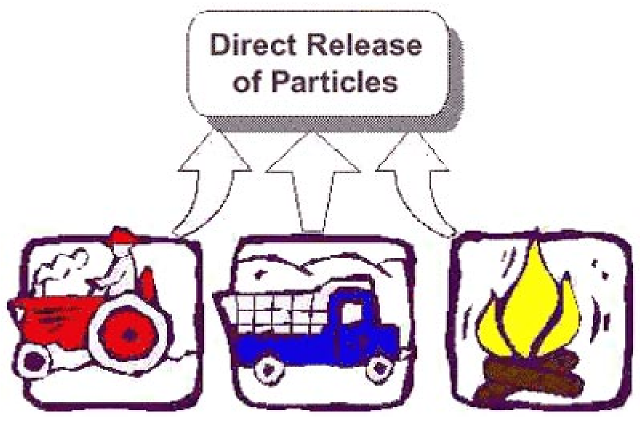
Based on size, particulate matter is often divided into two main groups:

- The **coarse** fraction contains the larger particles with a size ranging from 2.5 to 10 µm (PM_{10} - $PM_{2.5}$).
- The **fine** fraction contains the smaller ones with a size up to 2.5 µm ($PM_{2.5}$). The particles in the fine fraction which are smaller than 0.1 µm are called **ultrafine** particles.

Most of the total mass of airborne particulate matter is usually made up of fine particles ranging from 0.1 to 2.5 µm. Ultrafine particles often contribute only a few percent to the total mass, though they are the most numerous, representing over 90% of the number of particles.

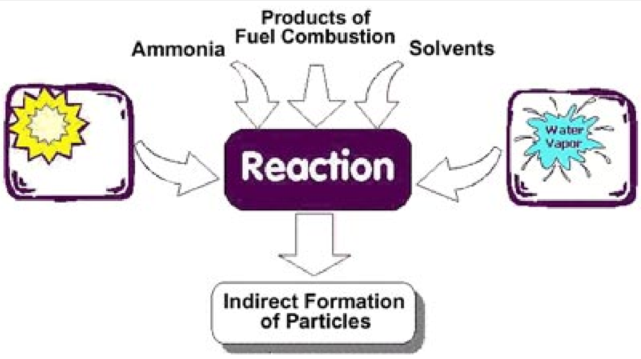
1.2 How are particles formed?

Coarse particles are produced by the mechanical break-up of larger solid particles. The coarse fraction can include dust from roads, agricultural processes, uncovered soil or mining operations, as well as non-combustible materials released when burning fossil fuels. Pollen grains, mould spores, and plant and insect parts can also contribute to the coarse fraction. Finally, evaporation of sea spray can produce large particles near coasts.



Source: US EPA www.epa.gov/urbanair/pm/ [see http://www.epa.gov/urbanair/pm/]

Fine particles are largely formed from gases. Ultrafine particles (up to 0.1 µm) are formed by nucleation, which is the initial stage in which gas becomes a particle. These particles can grow up to a size of 1 µm either through condensation, when additional gas condensates on the particles, or through coagulation, when two or more particles combine to form a larger particle. Particles produced by the intermediate reactions of gases in the atmosphere are called secondary particles.



Source: US EPA www.epa.gov/urbanair/pm/ [see http://www.epa.gov/urbanair/pm/]

Combustion of fossil fuels such as coal, oil, and petrol can produce

- coarse particles from the release of non-combustible materials such as fly ash,
- fine particles from the condensation of materials vaporized during combustion, and
- secondary particles through the atmospheric reactions of sulphur oxides and nitrogen oxides initially released as gases.

1.3 Which materials are the main components of particulate matter?

On average, the two main components of particulate matter in Europe are sulphate and organic matter. This is true both for fine particles ($PM_{2.5}$) and for coarse and fine particles combined (PM_{10}).

However, near roads mineral dust is also a main component of PM_{10}.

On days when the levels of particulate matter in the air are high (PM_{10} exceeds 50 µg/m^3), nitrate is also a major component of both PM_{10} and $PM_{2.5}$.

Soot, also referred to as black carbon, makes up 5 to10% of fine particles and somewhat less of coarse particles; near certain roads the proportion of soot can reach 15 to 20%.

2. How does Particulate Matter affect human health?

2.1 Effects of long-term exposure to levels of PM observed currently in Europe

WHO states:

2.1.1 "**Long-term** ambient exposure to current ambient PM concentrations may lead to a marked reduction in life expectancy. The reduction in life expectancy is primarily due to increased cardio-pulmonary and lung cancer mortality.

Increases are likely in lower respiratory symptoms and reduced lung function in children, and chronic obstructive pulmonary disease and reduced lung function in adults."

See also our Digest on Respiratory Diseases in Children [see https://www.greenfacts.org/en/respiratory-diseases/index.htm]

2.1.2 "Cohort studies have suggested that life expectancy is decreased by long-term exposure to PM. This is supported by new analyses of time-series studies that have shown death being advanced by periods of at least a few months, for causes of death such as cardiovascular and chronic pulmonary disease."

Source & ©: WHO Europe (2003)

2.2 Is PM per se responsible for effects on health?

2.2.1 WHO states: "Ambient PM per se is considered responsible for the health effects seen in the large multi-city epidemiological studies relating ambient PM to mortality and morbidity such as NMMAPS [National Morbidity, Mortality and Air Pollution study] and APHEA [Air Pollution and Health: A European Approach]. In the Six Cities and ACS [American Cancer Society] cohort studies, PM but not gaseous pollutants with the exception of sulfur dioxide was associated with mortality. That ambient PM is responsible per se for effects on health is substantiated by controlled human exposure studies, and to some extent by experimental findings in animals."

Source & ©: WHO Europe (2003)

2.2.2 A large number of epidemiological studies show that PM_{10} (which includes both fine and coarse particles) has adverse health effects. The fewer studies considering the fine particle fraction ($PM_{2.5}$) separately show that there are also health effects specifically from this fraction. Only recently have investigators begun to separately address health effects of coarse particles ($PM_{10-2.5}$).

Time series studies have assessed whether coarse particles are associated with health effects independently of the fine fraction ($PM_{2.5}$). They provide limited evidence for an association with mortality, as well as evidence for an association with specific health effects (morbidity endpoints) such as respiratory hospitalizations. One study that investigated the effect of long-term exposure to coarse particles did not show an impact on life expectancy.

Studies considering the way different particles deposit in the lungs, their chemical composition, and their toxicity provide further evidence of adverse health effects of coarse PM. For example, some effects that are seen with the coarse particles may be due to the presence of microbial structures and toxins which are less frequently found associated with fine particles. Therefore, there is sufficient concern about the health effects of coarse particles to justify their control.

2.3 Which physical and chemical characteristics of PM are responsible for health effects?

WHO states: "There is strong evidence to conclude that fine particles (< 2.5 µm, $PM_{2.5}$) are more hazardous than larger ones (coarse particles) in terms of mortality and cardiovascular and respiratory endpoints in panel studies. This does not imply that the coarse fraction of PM_{10} is innocuous. In toxicological and controlled human exposure studies, several physical, biological and chemical characteristics of particles have been found to elicit cardiopulmonary responses. Amongst the characteristics found to be contributing to toxicity in epidemiological and controlled exposure studies are metal content, presence of PAHs, other organic components, endotoxin and both small (< 2.5 µm) and extremely small size (< 0.100 µm)."

2.4 Are health effects of PM influenced by the presence of other gaseous air pollutants?

WHO states: "Few epidemiological studies have addressed interactions of PM with other pollutants. Toxicological and controlled human exposure studies have shown additive and in some cases, more than additive effects, especially for combinations of PM and ozone, and of PM (especially diesel [exhaust] particles) and allergens. Finally, studies of atmospheric chemistry demonstrate that PM interacts with gases to alter its composition and hence its toxicity."

2.5 Characteristics of individuals that may influence how PM affects them

Are effects of PM dependent upon the subjects' characteristics such as age, gender, underlying disease, smoking status, atopy, education etc? What are the critical characteristics?

In short-term studies, elderly people and those with pre-existing heart and lung disease were found to be more susceptible to effects of ambient PM on mortality and morbidity. In panel studies, asthmatics have also been shown to be more vulnerable to ambient PM compared to non-asthmatics. Responses of asthmatics to PM exposure include increased symptoms, larger lung function changes, and increased medication use.

In long-term studies, it has been suggested that socially disadvantaged and poorly educated populations respond more strongly in terms of mortality. PM exposure is also related to reduced lung growth in children.

In cohort studies, no consistent differences have been found between men and women nor between smokers and non-smokers in PM responses.

2.6 Is there a threshold below which nobody's health is affected by PM?

"Epidemiological studies on large populations have been unable to identify a threshold concentration below which ambient PM has no effect on health. It is likely that within any large human population, there is such a wide range in susceptibility that some subjects are at risk even at the lowest end of the concentration range."

See also: General Issues and Recommendations on Air Pollutants:

Source & ©: WHO Europe (2003)

- Question 5.3 on uncertainties in defining thresholds
- Question 7.1 recommendations regarding the concept of thresholds

3. How are we exposed to Particulate Matter?

3.1 Critical sources of PM or its components responsible for health effects

WHO states: "Short-term epidemiological studies suggest that a number of source types are associated with health effects, especially motor vehicle emissions, and also coal combustion. These sources produce primary as well as secondary particles, both of which have been associated with adverse health effects. One European cohort study focused on traffic-related air pollution specifically, and suggested the importance of this source of PM. Toxicological studies have shown that particles originating from internal combustion engines, coal burning, residual oil combustion and wood burning have strong inflammatory potential. In comparison, wind-blown dust of crustal origin [that is, from the Earth's crust] seems a less critical source."

3.2 Relationship between ambient levels and personal exposure to PM

Can the differences influence the results of studies?

See also our summary on Indoor Air Pollution [see https://copublications.greenfacts.org/en/indoor-air-pollution/index.htm]

Personal exposure to PM and its components varies from person to person and is influenced by outdoor sources as well as by indoor sources, such as tobacco smoke.

On a population level and considering variations over time, there is a clear relationship between the ambient level of PM and the level of personal exposure to PM, especially for fine combustion particles. Thus, measurements of PM in ambient air can serve as a reasonable approximation of personal exposure in time-series studies.

Fewer studies have addressed whether ambient long-term PM concentrations are a good indicator of average/long-term PM exposure. Contributions to personal PM exposure from smoking and professional activities need to be taken into account.

3.3 Short-term exposure to high peak levels and exposure in hot spots for PM

Adverse health effects have been documented after short-term exposure to peak levels of particulate matter (PM), as well as after long-term exposure to moderate concentrations. However, the impact of long-term exposure on public health is probably larger than that of short-term exposure to peak concentrations. Long-term exposure to moderate levels of fine PM has been estimated to reduce life expectancy by as much as several months. Nevertheless, numerous deaths and serious cardiovascular and respiratory problems have been attributed to short-term exposure to peak levels.

Areas near busy roads where concentrations of PM components, such as elemental carbon and ultrafine particles, are particularly elevated are referred to as “hot spots”.
In urban areas, up to 10% of the population may be living in these hot spots. The public health burden of such exposures is therefore significant. Unequal distribution of health risks between groups of people also raises concerns of environmental justice and equity.

4. Should current PM guidelines be reconsidered?

4.1 Impacts on public health of PM reductions

WHO states: "Positive impacts of reductions in ambient [PM] concentrations on public health have been shown in the past, after the introduction of clean air legislation. Such positive impacts have also been reported more recently in a limited number of studies. Toxicological findings also suggest that qualitative changes in PM composition could be of importance for the reduction of PM-induced adverse health effects."

Source & ©: WHO Europe (2003)

4.2 Averaging period most relevant for PM standards to protect human health

WHO states: "As effects have been observed from both short-term and long-term ambient PM exposures, short-term (24 hours) as well as long-term (annual average) guidelines are recommended."

Source & ©: WHO Europe (2003)

4.3 Reconsideration of the current WHO Guidelines for PM

WHO states: "The current WHO Air quality guidelines (AQG) provide exposure-response relationships describing the relation between ambient PM and various health endpoints. No specific guideline value was proposed as it was felt that a threshold could not be identified below which no adverse effects on health occurred. In recent years, a large body of new scientific evidence has emerged that has strengthened the link between ambient PM exposure and health effects (especially cardiovascular effects), justifying reconsideration of the current WHO PM Air quality guidelines and the underlying exposure-response relationships.

The present information shows that fine particles (commonly measured as $PM_{2.5}$) are strongly associated with mortality and other endpoints such as hospitalization for cardio-pulmonary disease, so that it is recommended that Air quality guidelines for $PM_{2.5}$ be further developed. Revision of the PM_{10} WHO AQGs and continuation of PM_{10} measurement is indicated for public health protection. A smaller body of evidence suggests that coarse [particle] mass (particles between 2.5 and 10 µm) also has some effects on health, so a separate guideline for coarse mass may be warranted. The value of black smoke as an indicator for traffic-related air pollution should also be re-evaluated."

Source & ©: WHO Europe (2003)

See also: General Issues and Recommendations on Air Pollutants:
- Question 5.3 on uncertainties in defining thresholds [see https://www.greenfacts.org/en/particulate-matter-pm/level-2/05-uncertainties.htm#3]
- Question 7.1recommendations regarding the concept of threshold [see https://www.greenfacts.org/en/particulate-matter-pm/level-2/07-recommendations.htm#1]

5. What are the uncertainties regarding this study?

5.1 Uncertainties of the WHO answers, guidelines, and risk assessments

How could these influence the conclusions for policy-makers?

Uncertainties linked to gaps in knowledge exist and will continue to exist in the future. The expert group which wrote the reference documents for this Digest was aware of these uncertainties, and tried to take them into account – to the best of their knowledge – when drawing their conclusions.

Uncertainties were addressed in a systematic way, following the recommendations of a WHO guideline document. It was not feasible to quantify the uncertainties linked to all answers within this study.

It was stressed that, in accordance with the precautionary principle, uncertainties should not be taken as a cause for not acting, if the potential risks are high and measures to reduce the risks are available at a reasonable cost.

Examples of uncertainties related to this study are:
- Potential **publication bias**. For example, studies that have found no association between a pollutant and a particular effect may not have been published (see question 5.2).
- **Diverging evidence**. For example, data suggesting either the existence or non-existence of a threshold for ozone (see question 5.3).
- Uncertainties regarding the **contribution of different sources** of particulate matter to health effects (see question 5.4).
- Uncertainty related to the use of different **models** (see question 5.5).
- Uncertainties regarding **regional differences** in the effects of air pollution (see question 5.6).

5.2 Consideration of publication bias in the review

WHO states: Publication bias occurs when the publication process is influenced by the size of the effect or direction of results. The bias is usually towards statistical significant and larger effects. It can be detected and adjusted for using statistical techniques. Bias may also occur when literature is selectively ascertained and cited.

This review used a systematic approach to identify all short-term exposure studies, but it did not formally investigate publication bias. The reviewers were aware that evidence of publication bias has been identified in meta-analyses of single city time series studies, but when estimates were corrected for this bias, significant positive associations remained. Furthermore, the multi-city time series studies, which have published results from all participating cities and are free from publication bias, have reported significant positive associations.

Because of the size and experience of the review group and referees, it is unlikely that any important published long-term study has been missed. Formal assessment of a possible publication bias has not been undertaken. Every effort was made to systematically ascertain long-term exposure studies.

Source & ©: WHO Europe (2004)

5.3 Consistency of epidemiological and toxicological evidence in defining thresholds

5.3.1 WHO states:

Multiple factors determine whether a threshold is seen [for effects due to exposure to air pollutants] and the level at which it can occur. Exposure-response curves depend on the age and gender of the subjects, their health status, their level of exercise (ventilation) and, especially the health effect selected. For highly uniform population groups, with a specific exposure pattern, a full range of concentrations, and a specific health outcome, one could identify a specific threshold. However, when there are different exposure-response curves for different groups, thresholds are harder to discern in population studies, and may ultimately disappear. Therefore, the evidence coming from the epidemiological and toxicological studies is not contradictory.

5.3.2 Ozone: "Chamber studies [(controlled exposure studies)] may show thresholds for mean effects of ozone on lung function and airway inflammation but a few individuals show these responses below these levels. As mentioned previously, a particular threshold in a particular experimental situation does not necessarily contradict a finding of effects below these levels in other situations. The time-series results often have insufficient data to distinguish between a linear and non-linear model with confidence. In addition, the statistical analyses applied to investigate thresholds in datasets on particles have not been applied to the same extent to datasets on ozone. There remain uncertainties in interpreting the shape of exposure-response relationships in epidemiological studies due to different patterns of confounding by other pollutants and correlations with personal exposure across the range of ozone concentrations. Although there is evidence that associations exist below the current [ozone] guideline value, our confidence in the existence of associations with health outcomes decreases as concentrations decrease. The answer and rationale [in question 2.3] refer to acute effects of ozone, as this is most important for health impact assessment of the effects of ozone.

5.3.3 Particulate matter: "Most epidemiological studies on large populations have been unable to identify a threshold concentration below which ambient PM has no effect on mortality and morbidity. It is likely that within any large human population, there is a wide range in susceptibility so that some subjects are at risk even at the low end of current concentrations.

Source & ©: WHO Europe (2004)

5.4 Contribution of different sources to PM-related health effects

WHO states: Only a few epidemiological studies have addressed source contributions specifically. These studies have suggested that combustion sources are particularly important.

Toxicology, because of its simpler models and potential to tightly control exposures, provides an opportunity to determine the relative toxic potency of components of the PM mix, in contrast to epidemiology. Such toxicology studies have highlighted the primary, combustion-derived particles having a high toxic potency. These are often rich in transition metals and organics [organic compounds and matter], in addition to their relatively high surface area. By contrast, several other components of the PM mix are lower in toxic potency, e.g. ammonium salts, chlorides, sulphates, nitrates and wind- blown crustal dust such as silicate clays.

Despite these differences among constituents under laboratory conditions, it is currently not possible to precisely quantify the contributions from different sources and different PM components to health effects from exposure to ambient PM.

Source & ©: WHO Europe (2004)

5.5 Impact of methods of analysis used in epidemiological studies

WHO states: This answer addresses matters relating to uncertainties in methods of analysis used. Epidemiological studies use statistical models of various types, including Poisson and logistic regression. The estimates of effect provided by air pollution studies are generally accompanied by confidence intervals. These convey the precision of the estimate or statistical uncertainty that arises because the analyses are subject to a degree of random error. To a varying degree, the results of these analyses are sensitive to the details of the model and the specification of confounding and interacting factors. Extensive sensitivity analyses have shown that associations between air pollution and health remain irrespective of the methods of analyses used.

Source & ©: WHO Europe (2004)

5.6 Possible regional characteristics modifying the effects of air pollution

WHO states: Potentially this could be a very influential issue since the characteristics of populations, environments and pollution (including particle concentration, size distribution and composition) vary throughout Europe. However, at this stage there is not sufficient evidence to advocate different guidelines for particles or other priority pollutants in different parts of Europe.

Several studies on short and long-term effects of particulate matter have consistently reported an association between pollution levels and mortality; however, there are differences in the size of the estimated effects of PM according to geographical region or according to the levels of other variables (potential effect modifiers). For example, it has been reported that the short-term effects of PM_{10} are greater where long term average NO_2 concentration is higher, when the proportion of the elderly is larger and in warmer climates. Modification by socioeconomic factors, such as the level of education, has also been reported. Plausible explanations for some of these observations have been proposed.

Effect modification, for example by the age distribution in a population and by climate should, if possible, be taken into account in sensitivity analysis of health impact assessments or risk assessments.

Possible effect modifiers of other criteria pollutants have not been investigated to any extent so far.

Source & ©: WHO Europe (2004)

6. Are certain population groups particularly vulnerable?

Are there specific population groups that should be brought into special attention?

WHO states: A number of groups within the population have potentially increased vulnerability to the effects of exposure to air pollutants.

These groups comprise:
- those who are innately more susceptible to the effects of exposure to air pollutants than others,
- those who become more susceptible for example as a result of environmental or social factors or personal behaviour and
- those who are exposed to unusually large amounts of air pollutants.

Members of the last group are vulnerable by virtue of exposure rather than as a result of personal susceptibility.

Groups with innate susceptibility include those with genetic predisposition that render them unusually sensitive, for example, to the broncho-constrictor effects of ozone or liable to produce an unusually marked inflammatory response on exposure to allergens. Very young children and unborn babies are also particularly sensitive to some pollutants.

Groups which develop increased sensitivity include the aged, those with cardio-respiratory disease or diabetes, those who are exposed to other toxic materials that add to or interact with air pollutants and those who are socioeconomically deprived. When compared with healthy people, those with respiratory disorders (such as asthma or chronic bronchitis) may react more strongly to a given exposure both as a result of increased responsiveness to a specific dose and/or as a result of a larger internal dose of some pollutants than in normal individuals exposed to the same concentration of pollutants. Increased particle deposition and retention has been demonstrated in the airways of subjects suffering from obstructive lung diseases.

Lastly, those exposed to unusually large amounts of air pollutants perhaps as a result of living near a main road or spending long hours outdoors, may be vulnerable as result of their high exposure.

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7. General Conclusions

7.1 Recommendations

Clean air policies aim to develop strategies to reduce the risk of adverse consequences of ambient air pollution for human health and for the environment as a whole. In the case of air pollutants, the concept of thresholds may no longer be useful in setting standards to protect public health. This is because certain population groups are very susceptible and are affected even at low levels, and because we are now able to detect even rare cases. Therefore, the application of the policy principle of providing an adequate margin of safety in order to eliminate adverse effects even for the most susceptible groups may not be realistic.

Risk reduction strategies are nevertheless effective in promoting public health. To develop such strategies, both qualitative and quantitative knowledge about the most relevant effects is required.

Therefore, for ozone and particulate matter, a meta-analysis of available data was recommended. This analysis should evaluate the relative risk increase (risk coefficients) related to ozone and to specific fractions of particulate matter for different health effects (endpoints).

It was also recommended:

- to update the concentration-response table for ozone in the current WHO Air quality guidelines,
- to identify which risk coefficients should be used in order to estimate long term mortality in relation to PM exposure, and
- to carry out a more comprehensive monitoring programme for PM-related health effects (not only relying on $PM_{2.5}$) in different European cities.

7.2 What other aspects of air pollution are important to address in the development of air pollution policy in Europe?

Other substances and pollutants posing risk to health which are currently not adequately addressed in the development of air pollution policy in Europe include:

- Carbon monoxide (CO) and sulphur dioxide (SO_2), with new evidence of links to severe health effects.
- Persistent organic pollutants (POP) such as PAH.
- Heavy metals, in particular lead and some transition metals. Lead is of concern since there are new studies suggesting effects at low concentrations.
- The carcinogenic volatile organic compounds 1.3-butadiene and benzene.
- Nitrogen trichloride, since there is evidence of health effects from this substance from epidemiological studies.

Few experts suggested assessing the health effects from diesel versus gasoline exhaust fumes.

An important issue that remains unresolved concerns the combined effects on health of urban air pollution mix.

7.3 Concluding remarks

- The body of evidence has grown stronger over the past few years regarding the health effects of air pollution at levels currently common in Europe.
- There is sufficient evidence to strongly recommend further policy action to reduce levels of particulate matter (PM), nitrogen dioxide (NO_2), and ozone (O3) in air. This would lead to considerable health benefits.
- Further targeted research and subsequent systematic evaluation is needed to reduce the existing uncertainty.