Air-pollution and the Risks to Human Health
– Integrative report –

AIRNET
- INTEGRATIVE REPORT -

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INTEGRATIVE REPORT

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CONTENTS

1 KEY MESSAGES

I. Air pollution seriously affects health in Europe today, and will remain to do so for a long time to come.

Air pollution is a serious threat to human health in Europe today. Impact estimates reveal that for ozone and fine particles, two major air pollutants, the extent of the effects on life expectancy is in the order of several tens to hundreds of thousands of premature deaths per year in Europe. Even if the air quality policy targets are being met, considerable health effects are still likely. The map in Figure 1 shows the estimated loss in life expectancy associated with fine particles produced by human activities in Europe in the year 2000. For many millions of Europeans, life expectancy is more than one year less than it could have been under conditions of clean air such as prevails in northern Scandinavia. In addition to life shortening, also a number of diseases have been associated with fine particle exposure.

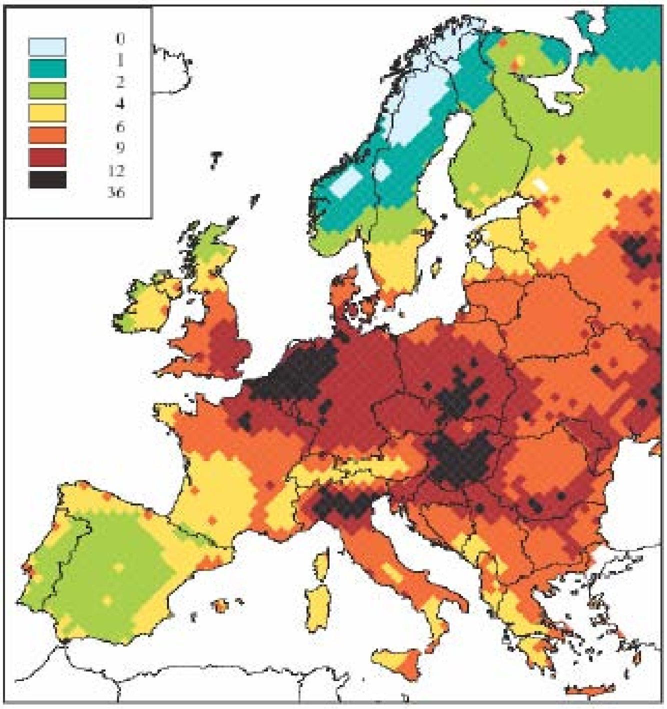

Figure 1: *Loss in statistical life expectancy that can be attributed to the identified anthropogenic contributions to PM2.5 for the emissions of the year 2000 (in months). The calculation is for the meteorological conditions of 2003 (source: Amann et al., Baseline Scenarios for the Clean Air for Europe (CAFE) Programme, final report, October 2004.* http://europa.eu.int/comm/environment/air/cafe/general/pdf/cafe_lot1.pdf)

In addition to fine particles, ground-level ozone is also significantly contributing to mortality and disease in Europe. For this air pollutant, with enhanced levels particularly during summer (smog) episodes, and rising background levels, there exist a large epidemiological and human toxicological database on a variety of health effects. The summer of 2003 in Western Europe was characterised by a serious heat wave and a substantially higher mortality rate. During this heat wave, the concentration of air pollution, in particular ozone, broke records and frequently reached levels exceeding the EU alarm levels. It has now been calculated that this ozone-related summer air pollution contributed considerably to the observed mortality rate.

In recognition of these threats, a large number of abatement measures have been taken or are being planned in Europe. As a result, concentrations of most major air pollutants are slowly declining, despite significant increases in economic activity and e.g. traffic volumes. Nevertheless, the 'Baseline Scenarios' report shows that even in 2020, significant risks to human health will remain from ozone and fine particle exposures if further stringent measures are not being taken.

II. EU funded research within the 4th and 5th framework programs has significantly contributed in the past to better understanding of air pollution health effects but major questions remain. The current, 6th framework programme is ill-equipped to address the major remaining questions.

In the 4th and 5th Framework Programmes, European Commission DG Research funded several collaborative studies in Europe that have contributed to our understanding of air pollution health effects. These include the EXPOLIS project which has provided many new insights into distributions and determinants of personal exposure to several air pollution components in Europe; the APHEA projects which have, in great detail, shown the effects of short-term variations in air pollution on mortality and hospital admissions for respiratory and heart disease; the TRAPCA study linking exposure to traffic-related air pollution to the onset of respiratory disease in young children; the APHEIS study providing quantitative estimates of the health impact of air pollution for many European cities; and the RAIAP and HEPMEAP studies which very much increased our understanding of the toxicological properties of airborne particles and the role of possibly important sources. Many other projects were funded, which are discussed in more detail below.

Despite the advances that were reached, many questions remain. One concerns the magnitude of the effects of long-term exposure to particles and other components in the air on life expectancy. The estimates shown in Figure 1 are based on exposure-response relationships which were derived from one U.S. based study [1]. No studies have been conducted in Europe that provide data for deriving exposure-response relationships for various regions in Europe except for a small study from the Netherlands [2]. Clearly, in view of the enormous burden estimated from exposure to fine particles, it would be of utmost importance to conduct research within Europe to provide Europe-specific, and region-specific exposure-response relationships for long-term exposure. The need for this is even stronger because European air quality and contribution of pollution sources may be distinct from the U.S. situation which may require a different abatement strategy.

Another question concerns the composition and toxicological properties of the various size fractions of airborne particles. It is now clear that ultrafine particles (smaller than 100 nanometers), fine particles (between 100 nanometers and about 1-2.5 micrometers), coarse particles (between about 1-2.5 and 10 micrometers) and 'large' particles (over 10 micrometers) have very different chemical compositions and physical properties. However, we are only beginning to understand their precise toxicological properties in relation to the health effects observed in epidemiological studies conducted among human populations. To inform a more targeted abatement policy, further research in this area is therefore urgently needed. Again, a European dimension to this research is important, as the variety of sources, populations and climatic circumstances within Europe is large and differs from other continents. Although a solid basis for further research collaborations was created in the 4th and 5th Framework programmes, the 6th Framework programme only offers scattered options for continuation of this research. This is in contrast to the situation in the United States, where a highly targeted research agenda has been developed in a series of reports from the National Research Council 3-6. This agenda is being implemented through a variety of means including the funding of five so-called 'PM centres' over two periods of five years each.

III. AIRNET has brought together, through a variety of activities, researchers and users of scientific information such as policy makers, industry and NGOs in Europe and has improved communication about air pollution and health between them.

Thematic Networks in environmental health projects are increasingly viewed as promising mechanisms for improving the link between science and policy, particularly in light of further reducing environmental exposures such as air pollution which will require substantial financial investments and will therefore need broad public, stakeholder, and policy support. In its three years of existence, AIRNET (EC funded project QLRT-2001-00441, http://airnet.iras.uu.nl/) has successfully brought together European researchers in the field of air pollution and health, as well as various stakeholder organisations representing industry, policy makers, patient organisations and other non-governmental organisations (NGOs). It has provided users with five relatively concise reports, written in non-specialist language, to inform about the state of the art in the field. The reports cover the three basic disciplines of air pollution and health research, i.e. Exposure Assessment, Toxicology, and Epidemiology. A fourth report informs about the important and emerging field of Health Impact Assessment, and the fifth report discusses the Science-Policy Interface. All reports are the product of Working Groups which brought together scientists and representatives of stakeholder organisations. In addition to these reports, AIRNET conducted a Project Inventory, a Stakeholder Survey, and set up the AIRNET Alert, a collection of non-specialist summaries of recent scientific papers. In the last year, AIRNET developed a science-policy communication model for the so-called 'NETwork days', designed to bring together national and regional scientists and stakeholders to discuss research and policy needs at the national and regional level. The procedure for organising these NETwork days was successfully applied in the Netherlands, Sweden, Hungary, and Spain, representing diverse areas of Europe with distinct air quality situations and different information and policy needs. Three annual conferences within AIRNET were held, in London (2002), Rome (2003), and Prague (2004) respectively. An informative website was developed to inform a wider audience about all AIRNET activities and products.

Although AIRNET has officially ceased to exist by the end of 2004, it has significantly contributed to creating a network of researchers and stakeholders, who will continue to interact through other means for years to come. AIRNET has been invited to many other projects and networking activities to share its experience. The AIRNET experience demonstrates that networks do not develop spontaneously and that a variety of impulses may be needed to link the different players in the field. With regard to communication it is AIRNET's experience to consider science-policy interface and networking as a joint responsibility of all parties involved.

2 BACKGROUND

The health impacts of air pollution in Europe are substantial. It is likely that no other environmental factor has so large an influence. Thousands of people die prematurely every year in Europe, and tens of thousands more become ill, or find their illness becoming worse because of air pollution. Various measures have been taken in the past to reduce air pollution, and more will be taken or are being contemplated to try to set up proper abatement measures to reduce the outstanding impacts on human individuals'quality of life and well-being. Yet, our understanding of why it is that air pollution has so large an effect on public health remains incomplete at best and Europe should be aware of the need to establish an adequate exposure and health database to build its abatement policy on.

In the EU Fifth Framework Programme, environmental health research was a priority issue, and several studies were funded by the EU to find out more about the health effects of air pollution. The AIRNET project grew out of a need, jointly felt by researchers and the EU Research and Environment Directorates, to disseminate the results of this research in a coordinated fashion to potential users such as policy makers, Non Governmental Organisations (NGOs), Industry and other stakeholder organisations. A proposal was developed in early 2001, and the AIRNET project was funded for the period of 2002-2004. This report provides an integrated summary of the various parts of the project.

3 THE AIMS AND STRUCTURE OF THE AIRNET THEMATIC NETWORK

The objective of the Network on Air Pollution and Health (AIRNET) was to create a widely supported basis for public health policy related to improving air quality in Europe and regulatory needs to achieve that goal.

Specific objectives were to:

1. Develop an interpretation framework for the (final and intermediate) result of research supported by the FP4 and FP5 programmes, as well as nationally funded studies.
2. Collect, discuss and interpret the (final and intermediate) results of research supported by the FP4 and FP5 programmes, as well as nationally funded studies.
3. Draw policy-relevant recommendations from the activities mentioned.

In order to fulfil these aims, coordinators of recently completed and ongoing or approved (as of 2001) EU funded research on air pollution and health were invited to become partners. In addition, several stakeholder organisations were brought in to represent the needs of the societal users of the information produced by the research.

4 STRUCTURE OF THE AIRNET PROJECT

The core of AIRNET consisted of five working groups on, respectively, Exposure Assessment, Toxicology, Epidemiology, Health Impact Assessment and Science-Policy Interface. These working groups met regularly, and produced reports aimed at a non-specialist audience to explain contributions from these fields and disciplines to our understanding of the health effects of air pollution. Stakeholder needs were incorporated into these working groups by having the reports address a number of 'frequently asked questions' originating from stakeholder presentations and a specific survey among stakeholders conducted in the early stage of the project.

In addition to the working group activities, three annual conferences were held in London (2002), Rome (2003) and Prague (2004) respectively.

As part of the AIRNET activities, a Project Inventory and a Stakeholder Survey were conducted to identify non-EU funded studies in the field of air pollution and health, and to identify research questions and needs from a wide collection of stakeholder organisations respectively.

During the second year of the project, it became clear that there was a need for more intensive interaction between the scientific community and the various stakeholder organisations interested in air pollution and health. Especially, it was felt that more emphasis should be placed on creating national and regional platforms for discussion (in view of the diversity of air pollution circumstances in Europe). In consultation with the EU, it was decided to redirect some of the resources to including communication professionals to develop and implement a communication strategy. So, in the last year, AIRNET developed a science-policy communication model for so-called 'NETwork days', designed to bring together national and regional scientists and stakeholders to discuss research and policy needs at the national and regional level. The procedure for organising these NETwork days was successfully applied in the Netherlands, Sweden, Hungary and Spain, representing diverse areas of Europe with distinct air quality situations and different policy information needs.

An informative website was developed to inform a wider audience about all AIRNET activities and products.

5 SUMMARY OF AIRNET RESULTS

In this chapter, a summary is provided of the various AIRNET products. A more detailed account can be found in the reports of the various activities. All can be found at the AIRNET website (http://airnet.iras.uu.nl).

5.1 EXPOSURE ASSESSMENT

AIR-POLLUTION EXPOSURE ASSESSMENT

Exposure assessment is the science of identifying the human exposures that are currently experienced or anticipated under different conditions. The discipline is an essential component in epidemiology, which identifies the cause of a disease by studying its occurrence in a population in relation to exposure. Recent epidemiological findings have driven much of the increasingly strict air-pollution policy in Europe and elsewhere in the world.

Estimating human exposure levels to air pollutants is very challenging. Numerous considerations come into play, including the size and make-up of population groups and a wide range of factors affecting exposure (frequency, duration, magnitude, etc.). In an ideal world, scientists would like to measure the exposure of every individual. But in reality, of course, that is impractical and costly.

Therefore, exposure assessment is often obliged to rely on indirect exposure estimates, such as proxies and modelling. Thanks to the growing use of sophisticated models, i.e. geographical information systems (GIS), the discipline has made tremendous advances over the last decade. However, those involved in exposure assessment still recommend the combination of actual field measurements with models.

IDENTIFYING KEY RESEARCH AND END-USER NEEDS

Launched in 2002, the European Union’s (EU) AIRNET initiative on air pollution and health is in keeping with the recent trend for more openness and multi-country research. The AIRNET Exposure Assessment workgroup, one of five in the project, has identified end-user questions and key studies in its own field. It has also assessed the policy implications of its exposure findings.

Among the workgroup’s chief goals was to improve the understanding of the plausibility behind the health effects of air pollution. It also sought to determine the conditions of exposure leading to such effects. In addition to examining the concept of exposure, this summary introduces the main pollutants of outdoor air pollution. The pollutants considered here are particulate matter (PM), ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and polycyclic aromatic hydrocarbons (PAHs).

Ambient concentration levels are also being considered – measured for example through the thousands of monitoring stations scattered throughout Europe, temporal and spatial variations of air pollution, exposure modelling and personal exposure. Special consideration is given to intake fraction, biomarkers of exposure and exposure misclassification in epidemiological studies. Lastly, future exposure research priorities and the policy implications of exposure assessment findings so far are highlighted.

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WHAT DO END-USERS WANT TO KNOW?

The starting point was ongoing research in air-pollution exposure. Much of this research has been funded under the EU's Fourth and Fifth Framework Programmes. Though not exhaustive in its coverage, the 'Exposure Assessment' report looks at important EU-funded projects, their goals and results. It then puts these projects' findings into perspective, comparing them with other European and non-European research.

AIRNET's ultimate objective is to create a platform for public-health policy to improve air quality. One of the thematic network project's first tasks was to survey stakeholders – including policymakers, environmental organisations, healthcare professionals, patient-support groups and industry – to identify their information needs on air pollution and health (http://airnet.iras.uu.nl/). Some of the survey's most frequently asked questions (FAQs), as well as answers to them, are listed in Annex 2 of the 'Exposure Assessment' report.

In general, the survey found that stakeholders prefer information to be presented in short overviews using non-specialist language. They also want to receive information that provides a practical linkage between research findings and policy implementation. More specifically, end-users want to know which indicators should be used for different air-pollution components.

They also seek information on critical sources of personal exposure and wonder whether this exposure is determined by a subject's characteristics or time activity. Other questions concern the relevance of short- and long-term exposures, the relationship between personal exposure and/or indoor and outdoor concentrations, and the importance of obtaining quality measurements.

THE CONCEPT OF EXPOSURE

Simply put, exposure to a pollutant is the 'event when a person comes into contact with a pollutant of a certain concentration during a certain period of time'. This definition distinguishes exposure from concentration on the one hand and dose on the other. As far as air pollution is concerned, the most important point of contact is the respiratory tract and the heart, the organs most likely to be affected by air pollution. Air-pollution exposure assessment is 'the study of the distribution and determinants of air pollutants among people'.

Measuring human exposure to air pollution is no trivial matter, because air-pollution levels show substantial changes over time and space. Exposure estimates, however, are only approximations for someone's 'true' exposure. Since direct measurements are mostly not feasible, scientists often rely on indirect measurements (traffic density, distance from source, ambient concentration). Use of this type of measure normally involves some form of modelling (i.e. GIS) as a tool to assess exposure in the population at large or under study.

GATHERING INFORMATION ON AIR POLLUTION

Ambient-air monitoring networks are spread across Europe, providing much of today's air-pollution data. The information they generate is essential for everyone from scientists modelling exposures to policymakers deciding what will go into tomorrow's environmental legislation. Other air quality data sources include short-term monitoring studies, many of which are funded by European and national agencies.

Europe's monitoring networks are increasingly numerous and sophisticated. These networks belong to various agencies at the municipal, regional or national level, serve different purposes and monitor different pollutants. Extracting meaningful information from these systems is challenging, due to lack of consistency and coherence. The EU AirBase system, with some 9,000 sites, is the only useable source at the continental scale that attempts to provide a more coherent and integrated database for air quality in Europe.

TRENDS IN AMBIENT AIR POLLUTION

Trends in ambient air pollution over time are difficult to assess due to changes in the underlying monitoring databases. However, some general impressions can be gleaned from the available information. These include a significant reduction in levels of SO_2, some reduction of PM levels, and a possible increase in background O_3 levels.

Clearly the spatial and temporal variations in air pollution are complex. The best way to understand and predict pollutant concentrations is to see the atmosphere as an ever-changing and dynamic medium. Moreover, this medium is influenced by equally dynamic and spatially varying inputs of pollution coming from both human and natural sources. Dynamic modelling (dispersion and GIS) is increasingly being used to estimate air-pollution concentrations and subsequent exposure.

IS MODELLING REALLY NECESSARY?

For both epidemiological and policy purposes, exposures often need to be assessed for large numbers of people at a local or individual scale. When that is not feasible, scientists turn to indirect approaches such as modelling. Models range from the simple to the highly sophisticated. Some use specific exposure markers for particular pollutants. Others call on emerging techniques known as deterministic and dispersion modelling, often complemented by the use of GIS. Another approach is probabilistic simulation techniques to predict population exposure distributions without information as to who is exposed, where or when.

Another solution is to use proxy measures for exposure, examples being source activity and distance. However, the relationships between these proxies and actual exposure are certainly not simple. In addition, it should be remembered that neither distance nor source intensity alone define exposure, but rather the interaction of the two. Thus, when combined together (as well as incorporating more complex modelling methods as mentioned above), these two measures provide a better description of exposure.

Personal exposure vs. outdoor measurements

AIRNET focused on exposures to and health effects of air pollution coming from outdoors. For instance, outdoor air is a major source of indoor particles. This is one reason why data from the monitoring of outdoor air is often used as a surrogate for exposure of a population or group. Furthermore, day-to-day variations of air pollutants measured at central sites are often used as exposure estimates when applied in short-term and panel studies.

Similarly long-term cross-sectional and cohort studies may rely on fixed site monitoring if the pollutant is homogeneously distributed within different study areas and penetrates well from outdoors to indoors. This is the situation for fine PM of outdoor origin, several validation studies have documented that measurements at central sites correlate well, in time, with personal measurements. For most other air pollution components (i.e. gases), this relationship between central sites and personal exposure is not so good.

Nonetheless, any measurement of total personal exposure should include indoor sources, such as environmental tobacco smoke. Europeans spend around 90% of their lives indoors, so the ability to accurately measure their exposure to indoor air-pollution sources is important. New techniques, such as source apportionment, are helpful when assessing sources of personal exposure and ambient-air concentrations. Recent research in this area has highlighted the importance of time activity patterns (i.e. time spent in transit) and subject characteristics (socio-economic status [SES] among other population demographics such as age and gender).

Exposure assessment experts readily acknowledge the need for more research in areas such as the degree of applicability of the findings of short-term personal exposure studies on long-term exposures.

Traffic pollution

Motor-vehicle traffic is increasingly seen as a major public health problem in urban areas, notwithstanding the steady emission reductions on a per car basis as a result of improved engine technology, exhaust treatment, and fuel quality. For example, recent studies indicate that road-users have higher exposure for pollutants such as carbon monoxide (CO) than people who spend little time in traffic. Furthermore, a person standing in a street with heavy traffic will be exposed to several times more soot, CO and other traffic-related pollutants than someone located elsewhere in the city.

Exposure to air pollution (and the traffic-related contribution) depends on the type of pollutant. For instance, time spent outdoors can be crucial for exposure and risk assessment for reactive pollutants such as O_3. As mentioned above, other factors also require careful consideration. These include non-conventional exposure determinants such as low education and SES that are associated with higher exposure to ambient-air pollutants at home and work.

Intake fraction and biological markers

Practitioners of exposure assessment have a range of tools at their disposal. For instance, calculating intake fractions can better reflect the actual amount of a pollutant that becomes biologically available. However, this approach still requires some development to maximise its influence on policy. Biomarkers of exposure go further by actually measuring the concentrations of markers of air pollutants (e.g. metabolites, DNA adducts) in the body or excreta - integrating the degree of exposure and amount of intake of a medium (air, water).

Various biomarkers are useful since they can measure internal and effective doses. On the other hand, most biomarkers give little information of the route of entry into the body, of which air pollution may or may not be significant. Though used for decades, biomarkers are becoming more sophisticated and the instruments/techniques used to measure them have become more specific and sensitive. Such advances have had a great impact on the growth of molecular epidemiology - enabling scientists to merge traditional with modern, more sensitive epidemiological methods to measure specific markers.

IMPACT OF EXPOSURE MISCLASSIFICATION

Exposure, in most studies of air pollution and health effects, is based on outdoor concentrations measured at fixed monitoring sites. It is almost impossible to measure a subject's 'true' exposure to air pollution exactly, so approximations are commonly used in studies of large groups of people. Though useful, these approximations make it harder to detect an existing association between air pollution and health.

As a result, epidemiologists have coined the phrases 'exposure misclassification' or 'exposure error' to describe the extent to which approximations differ from the 'true' exposure. This is important, because a poor correlation between a surrogate measure of exposure and the true exposure can compromise a study's ability to detect a pollutant's health effect or an existing lower threshold of effect. Thus, exposure measurements or estimates that are accurate and precise are needed so that the effect of exposure can be estimated with minimum bias and maximum efficiency.

KEY ISSUES FOR FUTURE RESEARCH

Scientists and other experts involved in exposure assessment and urban air quality need to attribute air-pollution exposure more accurately to well-defined sources and to understand the relationships between personal and ambient exposure.

Other important challenges include the following:

- measuring exposure to potential causal agents of air pollution that increase mortality and morbidity.
- identifying the effect of host factors and socio-economic status on exposure for population groups.
- developing and validating models to assess exposure levels and distribution within a population.
- continued harmonisation of monitoring techniques and networks in Europe to create meaningful databases for research and policy purposes.
- developing and validating intake-fraction models that include individual intake fractions for different sources, compounds and target populations.

POTENTIAL POLICY IMPLICATIONS

The AIRNET 'Exposure Assessment' report offers plenty of food for thought. Its findings clearly underline the need for scientists and policymakers to focus on air pollutants and their primary sources that are deemed the greatest health risk. The report also stresses the need to reduce air-pollution emissions and exposures. In order of preference, population exposures (and their associated risks) can be controlled at emission source, in the microenvironment or at an individual level.

In the case of traffic-related air pollution, this may require a combination of emission controls, zoning and traffic planning, in addition to efficient mass-transit systems with clean interior air.

Therefore, areas where policy makers should prioritise their work are in:

- targeting the sources responsible for the largest fraction of exposure to the population expected to be at highest risk.
- maximising exposure reduction by understanding intake fractions as well as micro-environmental characteristics.
- evaluation of the alternative risk-management options (based on set policy objectives) using exposure modelling techniques.

5.2 TOXICOLOGY

Exposure to air pollution is a known risk to human health. However, decision-makers wishing to put in place cost-effective and health-beneficial measures to reduce air pollution are hampered by limitations in the knowledge base and by a number of uncertainties. In particular, a better understanding is needed of the contribution made by air-pollution components to human health, as well as of the biological mechanisms behind the toxicity of these components.

For example, 'Are we at greater risk from short-term exposure to high pollution, such as diesel particulates in traffic tunnels?' 'Or is the risk greater from long-term exposure to lower levels, such as ozone in rural areas?' 'Which groups of the population are at greatest risk, for genetic and/or physical reasons?

Toxicology is the scientific discipline from which we may expect answers to these types of questions. Toxicology aims to understand the processes of how pollutants affect people's health, and to identify the factors influencing those processes.

SIX KEY AIRBORNE POLLUTANTS

The 'Toxicology' report focuses on six ambient air pollutants that are known to provide a risk to human health. There are others, for example volatile organic compounds (VOCs) including irritating aldehydes. However for reasons of space this document must limit itself to the known major pollutants.

These six pollutants are:

- Particulate matter (PM)
- Ozone (O_3)
- Nitrogen dioxide (NO_2)
- Polycyclic aromatic hydrocarbons (PAHs)
- Carbon monoxide (CO)
- Sulphur dioxide (SO_2)

IMPACT ON HUMAN HEALTH

Particulate matter (PM)

Particulate matter (PM) originates partly from natural sources (wind-blown soil, sea-spray and organic compounds) and from man-made activities (combustion of fossil fuels and industrial emissions) and may therefore have a heterogeneous composition depending on weather conditions, type and strengths of sources, and exposure location. Emissions by road traffic may, especially in urban environments, contribute substantially to PM, and comprise exhaust pipe emissions, friction processes and re-suspension of road dust. Inhaled PM can range in size from a few nanometres to tens of micrometers.

Different-sized particles, i.e. coarse, fine, and ultrafine PM, deposit differently on the various walls of the airways and lungs. Coarse particles tend to deposit higher up in the airways, whereas fine particles tend to deposit in the lower airways and lungs. It is not yet clear whether the health effects observed in relation to PM exposure are caused by particles of specific sizes and/or composition.

Currently both coarse and fine particles seem capable of inducing toxicity. Whether the ultrafine particles, tested at environmentally relevant levels, are also toxic remains unclear. Clarification on this issue would be a great help in the development of plans to control PM emission sources. On the issue of the chemical composition of particles and their toxicity, there are preliminary indications that primary, carbonaceous PM components may have more significant health effects than secondary components such as sulphates and nitrates. Toxicological studies in humans and animals suggest that PM pollutants could affect the functioning of the lung, the blood vessels and the heart. Most of the results however, arise from in vitro studies using cell systems or from direct high dose administration of PM to laboratory animals into their airways and lungs. This makes it difficult to extrapolate this data to the actual human ambient exposure conditions. However, these results do indicate the potential ability of PM to induce toxicity. The few inhalation studies available from laboratory animals and human volunteers indicate that different types of PM may induce toxicity at relatively high levels.

In studies testing the inhalation exposure of PM at concentrations well above ambient levels, the results show exacerbation of symptoms in patients with mild or moderate pre-existing lung diseases such as asthma, as well as heart and blood vessel disease. Toxicological studies suggest that these effects are due to induction of lung inflammation, disturbances in heart rhythm, alterations in blood viscosity or oxygen deprivation. Remarkably, PM deposition models suggest that these individuals receive much higher doses in their airways and lungs compared to healthy individuals. It could very well be that the more severely affected individuals receive even higher doses and/or that their tissue responds more extensively to a certain dose. All these effects may partly explain why individuals with pre-existing disease are at increased risk for PM. Analogous effects, albeit at much lower intensity, have also been observed in healthy individuals. There is also evidence linking PM exposure with lung cancer, however, the basis of PM-related cancer development is poorly understood.

Ozone (O_3)

Ground-level ozone has become one of Europe's most serious air pollutants. Despite slight reductions in peak ozone levels during the latter years, each year ozone concentrations in ambient air exceed the EU Limit Values established to protect human health and the ecosystem, and that will probably continue to occur for the next decades. Ozone is the major component in photochemical smog.

Because of its very low solubility in water, ozone is carried over into the deep lung, with the greatest deposition and the most pronounced damage where the small airway branches enter the air sacs of the lung. Health effects include reduced pulmonary function, pulmonary inflammatory processes, increased airway permeability, heightened hyper-reactivity at first, then irreversible structural changes to the airways. Some 20% of the general population, regardless of airway disease, are more susceptible to ozone's effects. Repeated or long-term exposure to higher levels of ozone may lead to irreversible effects and perhaps increase the risk of developing chronic lung disease such as asthma.

Toxicological studies show that acute ozone exposure in humans and laboratory animals results in lung inflammation and tissue injury in the small airways and the gas exchange region of the lung, causing a reduction of the lung function. There are few long-term studies of ozone in experiments on laboratory animals, but changes in lung and airway structures and cell types have been reported.

Nitrogen dioxide (NO_2)

Nitrogen dioxide is one of the major components of air pollution in densely populated areas. Nitrogen dioxide levels in ambient air are normally in the order of ten to 50 µg/m^3, but may reach some hundred µg/m^3 (as an 1-hour average) in pollution hot spots (such as road tunnels or street canyons) during high pollution episodes.

The gas acts as an effective indicator of (traffic-related) air pollution, although it is not considered a major causal influence on human health by itself at ambient levels. That said however, exposure to extremely high levels of the gas, or the mixture it represents, has been shown as able to negatively affect human health. It is therefore important to continue to monitor its ambient levels and to investigate the health effects.

Nitrogen dioxide is a highly reactive, poorly water-soluble gas that reacts with components in the lining fluid of the respiratory tract. Its effects seem to depend more on the level of exposure than on the duration. Asthmatic individuals are more sensitive than healthy subjects, reacting to high-concentration episodes of the gas with narrowing of airways and increased responsiveness to irritants and allergens.

Nitrogen dioxide can at high levels exacerbate, independently of other pollutants, allergic reactions in asthmatics. Susceptible groups include allergic asthmatics, patients with chronic obstructive lung disease and possibly children. However, some individuals may be affected at lower concentrations. Animal studies indicate long-term effects of nitrogen dioxide on lung structure and function at much higher than ambient concentrations.

Polycyclic aromatic hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are a large family of related organic compounds that arise mainly from the incomplete combustion of fuels. They include some powerful animal carcinogens, and therefore could well act as carcinogens in humans. In addition, recent evidence suggests that they can cause inflammation of the lung and adverse birth outcomes.

Individual PAHs present in the ambient air mixture, in the vapour phase or bound to particulate matter, have widely varying carcinogenic potencies, with particulate-bound PAHs generally having the highest carcinogenic potency. Currently it is not possible to distinguish between the toxic effects of airborne PAHs alone, or in combination with particles to which they are bound.

Benzo[a]pyrene, used as a qualitative marker of PAHs, is usually found in urban air at levels below 1 ng/m^3, but sometimes found at significantly higher levels. The European Union has proposed a limit value for benzo[a]pyrene of 1 ng/m^3.

PAHs are animal and human carcinogens, acting through a genotoxic mechanism (i.e. they damage DNA and cause mutations). For such compounds, it is considered that there is a human health concern without any exposure threshold. Recent studies have suggested that the soluble components of atmospheric particles, including PAHs or their derivatives, can play a role in the induction of inflammation, with a potential role both in the development of cancer and the exacerbation of asthma and heart and blood vessel effects.

Carbon monoxide (CO)

Carbon monoxide (CO) is formed mainly from the incomplete combustion of fuels, and has traffic as its main source. At ambient air concentrations of carbon monoxide, healthy individuals do not experience any adverse health effects. For individuals with pre-existing heart disease however, the heart may be affected at carbon-monoxide levels relevant in high concentration episodes.

Carbon-monoxide exposure can result in reduced oxygen supply to organs and tissues, due to binding to blood haemoglobin, thereby forming carboxy haemoglobin (COHb). This ability of carbon monoxide to bind to haemoglobin is central to its impact on human health. The level of carboxy haemoglobin varies in the population, depending on smoking habits, environmental exposure and reproductive state (both mother and unborn child have higher levels). Although high, accidental exposures to carbon monoxide may induce adverse health effects and even death, healthy people do not normally stay in highly polluted areas for sufficiently long periods to attain adverse levels of COHb.

Sulphur dioxide (SO_2)

Sulphur dioxide (SO_2) is a colourless gas with a pungent odour. The main man-made sources are combustion of fossil fuels containing sulphur (mainly coal and heavy oils), and the smelting of ores containing sulphur. Ambient concentration levels have fallen considerably in most parts of Europe in recent decades, and most measurements are in compliance with the air quality standards, i.e. 24 hour average of 125 µg/m^3, and hourly 350 µg/m^3. At low ambient levels, SO_2 is not considered anymore to elicit health effects.

Sulphur dioxide is potentially an upper respiratory tract irritant. At least 95% of inhaled sulphur dioxide is absorbed in the nose and throat during resting conditions, while penetration to the lower airways is greater during mouth breathing and with exercise. Short-term exposure to sulphur dioxide may cause mild narrowing of the airways, which is reflected as a measurable decrease in lung function and increase in airway resistance. However, among healthy individuals these reactions are only shown at concentrations markedly in excess of current ambient levels. Asthmatics, on the other hand, have shown to be more responsive than healthy subjects, and may possibly react at concentrations pertinent to hot spots, such as those that could occur near certain industrial plants without proper emission controls.

For long-term exposure, there is no experimental evidence on whether ambient concentrations of sulphur dioxide are harmful, either to healthy individuals or to asthmatics.

ROLE OF TOXICOLOGY

Environmental policymakers today are faced with the need to develop new risk management tools to incorporate toxicological findings and the growing understanding of the hazards of air pollution. Key questions for toxicology for example include:

- What are the actual risks associated with exposure to hazardous pollutants?
- To what extent will public health benefit from reduced exposures to toxicants?
- Will the costs of abatement be acceptable given the level of risk?
- How certain or uncertain are we about health-effective abatement policy?

Increases in toxicological knowledge and judgement help to answer the first of these questions. Toxicological studies can be especially valuable in reducing uncertainties over the causative role of a single pollutant appearing in a complex ambient mixture.

Improved understanding of the modes of toxicological action also helps to interpret data on air pollution and health. For ozone the toxicological database is extensive and for PM it is growing rapidly, if still limited. However, a few preliminary suggestions can be made. Primary carbonaceous PM components, for example, may be considered as more important than secondary components such as sulphates and nitrates. It will take many more years before the remaining questions can be answered in much more detail.

Policy-makers increasingly request a more integrated judgement of the source-risk relationships and abatement scenarios, both from the point of view of cost-effective abatement control and that of effective health risk reduction. Meeting the needs of such integrated judgements requires the development of better descriptions, improved evaluations and sustainable decision points on health effect and risk assessments, so that all can be accepted by policy-makers, stakeholders, the public and the scientific community.

A key objective for toxicological research on air pollution is to complement epidemiological studies as inputs for assessments of the risk to human health. In many cases there is a need to reduce uncertainty in the relationship between exposure to gaseous and particulate pollutants and observed health effects, as well as to identify the causative characteristics of complex pollutant mixtures. In certain cases, such as for PAH in air, toxicological research has a larger role, because little epidemiological data is available on PAH in common urban environments.

EU-funded Toxicological research into Airpollutants

Toxicological research within the EU Fourth and Fifth Framework Programmes has contributed significantly to a better understanding of the health effects associated with exposure to air pollution. The programmes have funded a number of toxicological projects on air pollution (AULIS, EXPAH, HELIOS HEPMEAP, RAIAP, PAMCHAR, etc.).

The projects have also helped develop further competence in establishing risk assessments for exposure to air pollutants. In addition, they have produced extensive collaboration across Europe and established strong research networks that will be of benefit in the future.

However, there are still considerable gaps in the toxicological knowledge about the risks associated with hazardous air pollutants, which is hampering an effective and optimal preventative strategy.

Filling in the gaps

To meet the needs outlined above, there is a need for more short-term human and animal studies of heart and respiratory functional responses, as well as local and total-body inflammatory responses. Studies into PM from specific source environments, i.e. high traffic densities, residential heating, metal industries, etc. are required. Research into PM from urban background locations is also needed for the climate seasons with the highest adverse outcomes, as assessed by epidemiological data. The results of such toxicological research are strengthened when conducted in parallel with epidemiological panel studies.

Human clinical studies are also required into various types of PM in potentially susceptible individuals, including those with mild asthma, chronic obstructive pulmonary disease or heart and blood vessel disease. More attention needs to be paid to chemical characterisation and toxicity associated with the large organic proportion (including PAHs) of ambient air PM.

Since human exposures are to combinations of various pollutants, there is obviously a need to perform studies on the combined effects of particulate matter and gaseous pollutants. For example, it would be valuable to examine the effects of combined concentrated ambient particle and ozone exposure on the heart and blood vessel system in animal and clinical human studies.

Greater knowledge on the long-term effects of PM in animals would be helpful, especially on concentrated ambient particles of different sizes and their effect on the heart and blood vessel system, lung development and ageing. European multi-centre toxicological approaches on ambient air PM, using common PM sampling, concentration and chemical analysis instruments and protocols, can support epidemiological studies in finding explanations to geographical and seasonal differences in adverse health outcomes. Much more may be learned from mechanistic studies with various types of PM in molecular, cellular and animal models with respect to lung, heart, inflammatory and genotoxic responses. Important mechanistic information may also be gained from examining whether particles of various sizes, especially ultrafine particles, become blood-borne from the lungs and enter and exert adverse responses in more distant organs such as the brain, liver and kidneys. Such cellular/mechanistic studies are also needed into the impact of particles on blood clotting pathways, in order to understand the involvement of particles in heart and blood vessel disease.

Finally, toxicological investigations into the effects of exhaust pollutants from different combustion systems and fuel types (vehicle engines, residential stoves, etc.) would aid in the evaluation of new fuel combustion technologies. Such investigations are necessary because new technologies may well alter the chemical and physical properties of both exhaust particles and gases. Predictive toxicology studies are needed to assess which of the various new technologies offers the most promise in reducing toxic emissions.

5.3 EPIDEMIOLOGY

The health effects of air pollution became evident during severe air pollution episodes in the first part of the 20th century. In response, air pollution abatement policies were initiated that reduced air pollution concentrations substantially during the 1960s and 1970s in many developed countries. Many felt that these lower pollution levels were no longer a public health problem. New studies conducted since the mid- 1980s have, however, raised concerns about the safety of these lower air pollution concentrations. Epidemiology - which identifies the causes of a disease by studying its occurrence in a population - has mostly driven this change in assessment. The science employs statistical methods to assess whether exposure and disease are related to one another.

Over the last 15 years, European epidemiological research has highlighted how air once considered ‘safe’ may contain concentrations of pollutants that are hazardous to human health. Several studies demonstrated the public-health dangers of particulate air pollution, as well as of pollution by ozone, nitrogen dioxide and other gases. Other studies indicated that long-term exposure to air pollution probably affects people more adversely than short-term exposure.

AIRNET’s ‘Epidemiology’ report identifies key studies in its own field. The findings are summarised by pollutant. In addition to the main pollutants of outdoor air pollution, the report examines the effects of air pollution in general on cancer. It also highlights future epidemiology research priorities and the policy implications of findings so far.

The starting point was research in air-pollution epidemiology funded under the EU's Fourth and Fifth Framework Programmes. It puts this research into perspective, comparing it with other European and non-European research.

PARTICULATE MATTER AIR POLLUTION

Many recent epidemiological studies have looked at particulate-matter air pollution - the small solid and liquid particles suspended in the air. These particles can be of natural origin or produced by vehicle emissions and processes such as industrial combustion or domestic heating and cooking.

Since the 1990s, numerous epidemiological studies have indicated that *short-term* increases in particulate-matter air pollution are linked with increased daily mortality and hospital admissions for respiratory and cardiovascular disease. The two EU-funded APHEA studies, for instance, have generated a database allowing researchers to evaluate health effects in numerous European cities. Much less evidence is available on effects of *long-term* average exposure to air pollution. But the existing evidence does suggest that such exposure may adversely affect human health considerably more than short-term exposure.

Particles from different sources

Many epidemiological studies have assessed the health effects of particulate matter characterised by the mass of the particles in the air. It is however very unlikely that all particles have the same health effect. Therefore researchers have tried to identify more specifically which particles are of importance. There is growing evidence that primary combustion particles are more important than particles of geological origin (wind blown dust) or secondary particles such as sulphate and nitrate (however the latter can and are still be used as good proxy's to index the pollution mix). Emissions produced by motor vehicles appear to be quite dangerous to humans, and may especially contribute to health effects in urban exposure situations with a high traffic intensity.

Residential wood combustion is in some regions a major source of local air pollution, especially particles and hydrocarbons. Epidemiological studies of ambient air from locations where residential wood combustion was a major source of air pollution all reported clear links between short-term variations in air-pollution levels and one or more adverse health outcomes.

Secondary particles form as a result of reactions of gases in the atmosphere and are a dominant component of fine particles. Epidemiological studies of secondary particles, especially sulphate particles, mostly conducted in Northeast America have documented associations of these compounds with short-term effects on mortality and hospital admissions. Although serving as good proxies for the air pollution mixture, there is a growing body of toxicological evidence to suggest that these secondary particle fractions are much less toxic than their primary (carbonaceous) counterparts at ambient concentrations.

Polycyclic Aromatic Hydrocarbons (PAH) -which are found for example in soot, coal tar and cigarette smoke -have been suspected to be carcinogenic in humans. Recent evidence suggests that carcinogenic PAH may have other effects than cancer, adversely affecting the health of foetuses and infants.

Particles of different size

Researchers have also attempted to study the effects of particles from different sizes. Particle size determines how far particles travel in the atmosphere, how easy particles penetrate into homes and where in the human airways the particle deposits. Studies distinguished coarse (>2.5 μm), fine (<2.5 μm) and ultrafine (<0.1 µm) particles. Various studies have documented that fine particles may have a larger health effect than coarse particles. Nevertheless, there is also evidence that coarse particles may contribute at least to short-term effects.

Because of the lack of routine monitoring data for ultrafine particles, there are very few epidemiological studies. These studies, funded by the EU, suggest that ultrafine particles may affect the cardiovascular system. An important finding is that in many locations, the concentrations of fine and ultrafine particles correlate only weakly. Thus the original expectation that the large number of ultrafine particles in the air could explain the earlier findings of health effects related to particle mass, is unlikely. Instead, in risk assessment, ultrafine, fine as well as coarse particles should be considered as separate pollutants. Toxicological studies on environmentally-relevant ultrafine particles at realistic near-ambient concentrations have not shown clear effects.

GASEOUS AIR POLLUTANTS

Because of the emphasis on particulate matter, less research has been performed on gaseous air pollutants in recent years. Epidemiological studies of three key gaseous pollutants can be summarised as follows:

- Ozone: Short-term exposures are associated with mortality, hospital admissions and compromised lung function, but there is little epidemiological evidence for long-term effects.
- Nitrogen dioxide (NO_2): Studies have found both short- and long-term effects in association with high concentrations of NO_2. It has been difficult to separate the health effects of NO_2 itself and other components that are simultaneously increased in the atmosphere because they are emitted by the same source (e.g. traffic) or are formed in the atmosphere from NO_2. At the usually low ambient concentrations NO_2 is not considered to cause significant health effects by itself. NO_2 can be used as a proxy for particulate, traffic-associated air pollution in urban areas.
- Sulphur dioxide (SO_2): There are many studies suggesting that high level exposure to this pollutant is harmful to humans, affecting mortality, respiratory and cardiovascular health. However, because SO_2 levels are now so low, it is unlikely that SO_2 itself causes these effects. SO_2 is probably an indicator for a relevant mixture containing other pollutants that are responsible for health effects.

DOES AIR POLLUTION CAUSE CANCER?

Over the last 50 years, epidemiological studies have indicated that ambient air pollution causes cancer of the lung. This evidence comes from various types of studies, among them comparisons between urban and rural areas or between communities, as well as case-control, cohort and occupational research studies. It is difficult for epidemiological studies to disentangle the contribution of lung-cancer risk of single pollutants. But researchers conclude that particulate mater is probably responsible for an increased risk of lung cancer. They have not found convincing evidence that traffic-related air pollution causes childhood cancer.

POLICY IMPLICATIONS

Environmental policies are increasingly based on the use of scientific evidence either directly or via the use of risk or health impact assessment. Epidemiological studies have contributed in various ways to the information need: identification of the amount of risk associated with a certain exposure, identification of important pollutants, identification of a (lack of) threshold. The introduction of evermore stringent air-quality guidelines throughout Europe and elsewhere can be attributed directly to recent epidemiological research.

AIR-POLLUTION RESEARCH PRIORITIES

There is little doubt that particulate air pollution has short-term as well as long-term effects on health. But many questions still need answering. For instance, which physical and chemical characteristics determine the toxicity of the particle mixture?

Research should concentrate on several areas: The long-term effects of particulate-matter exposure; characterisation of source-specific mixtures instead of single pollutants; direct study of health effects related to policy interventions; and effects on children, elderly people and people with compromised cardiopulmonary systems. Pollutants requiring more attention are ultrafines and $PM_{2.5}$, primary carbonaceous particles and carcinogenic PAH. To compensate for the lack of recent epidemiological studies into air pollutants other than particulates, further research into the role of ozone, and mixtures containing nitrogen dioxide and sulphur dioxide is also warranted.

5.4 HEALTH IMPACT ASSESSMENT

AIR-POLLUTION HEALTH IMPACT ASSESSMENTS (HIAS)

There is now a strong and well-established body of evidence to show that higher levels of outdoor air pollution are linked with more illness, higher use of health services and earlier death among exposed population groups. Air pollution has thus become a substantial public health problem across the globe. Since it is a risk that is usually considered involuntary, control of air pollution deserves greater priority than would a voluntarily accepted risk.

In this context, the air-pollution health impact assessment (HIA) has become well established in Europe over the past 10 years. A working definition of a HIA is ‘the estimation of the effect(s) of specified action(s) on the health of a defined population’. It is a key tool in helping policymakers make decisions about the consequences policy decisions that may have an impact on air pollution, as well as providing options for mitigation of the adverse health effects of air pollution as a consequence of policy decisions.

WHY SHOULD HIAS BE UNDERTAKEN?

HIAs provide estimates of the health (at a minimum) or economic impacts of air pollution (i.e. monetary valuation). This information provides a means by which policymakers can estimate, for example, the effects of proposed changes in air pollution.

From a policy perspective, an air-pollution HIA can be seen as a methodology that systematically draws on and organises knowledge related to air pollution and health to help inform policy development. The HIA is inherently a multi-disciplinary and participatory approach to predicting the health effects of air pollution. Furthermore, HIA methodologies need continuous adaptation and refining if they are to deliver accurate assessments of the risk to public health. Such development is necessary to ensure that the best information available enters the policymaking arena and translates into good public policy decisions.

This need for continuous development of the methodology (i.e. agreement on the desired output) and exercise of judgement explains why HIA practitioners need to strive for as wide a stakeholder involvement as possible. Wide participation helps to ensure that all the pollution components and related issues are properly discussed and dealt with adequately from the outset, and that the most useful and relevant questions are addressed appropriately.

WHEN SHOULD HIAS BE UNDERTAKEN?

There have been tremendous advances in HIA methodologies during the past 10 years, and many of the developments during this period have been brought about via EU-funded projects such as 'ExternE' (http://www.externe.info/ and http://externe.jrc.es/) and 'APHEIS' (www.apheis.net). Although there are still many areas of uncertainty, including the various sorts of databases needed to perform a full scale impact assessment, HIAs in the field of air pollution are now sufficiently developed to be carried out for all new EU policies aimed at reducing air pollution in Europe. The outcome of a prognostic HIA should be treated with caution due to uncertainties related to changing air pollution mixtures and possible reduction of non-causal factors.

HIAs can be performed in advance of policy decisions and using emission reduction scenario's to predict future concentrations, concurrently with them and/or retrospectively after policies have been formulated. Ideally, a HIA should be undertaken before any decisions are made to adopt and implement a policy, programme or project - including 'no action' decisions. For example, an air pollution HIA is part of the evaluation of various policies that the EU is carrying out as part of the Clean Air for Europe (CAFE) programme. In other words, it is extremely useful to perform a HIA whenever one requires predictions of how proposed policy changes impact health effects.

In practice, carrying out impact assessments in advance of policy changes is not always possible. A HIA may therefore need to be carried out concurrently (during the implementation stage) or retrospectively in order to monitor the on-going development of existing work. In the USA for example, it is a legal requirement of the Clean Air Act that a full cost/benefit analysis including a HIA is carried out every few years.

Recent years have seen an increasing interest in post-completion analyses, which examine whether the actual benefits (and costs) of policies are in line with those that were estimated. Clearly, if a HIA is attempted too early in the policymaking process, the policy options will not be developed enough to identify their impact on air pollution. On the other hand, if the HIA is postponed, its results may be too late to influence policy development.

The solution may lie in looking at a HIA not as a one-off event, but as a process to make health risk predictions at different stages with different degrees of scope and of rigour. Simple early scoping studies can give useful information about which policies, and which aspects of the HIA itself, may need to be refined during the decision-making process.

KEY ELEMENTS OF THE HIA

HIAs integrate scientific results and judgements from various thematic disciplines such as toxicology, exposure assessment and epidemiology. The overall air-pollution HIA process involves several linked stages, which can be summarised as follows:

- monitoring air quality and mapping of pollutant distributions.
- identifying and characterising the population-at-risk.
- deciding which pollutant-effect (or impact) pathways will be quantified.
- choosing concentration-response (C-R) functions, including judgements on thresholds.
- characterising the background rates for each health endpoint (mortality, morbidity, health service usage, etc.) in the population-at-risk.
- prediction of the chosen health effects.
- valuation of health effects (optional stage of a HIA).

How HIAs measure death or disease

The health outcomes commonly used as measurements in air-pollution HIAs are various levels of cardio-respiratory mortality (deaths) and morbidity (disease), as well as other indicators such as lung function changes, medication use, and usage of health services. Recently however, there have been efforts to widen the definition of adverse health effects. Disrupters of personal well-being can also include sleep disturbance for example, or aggravation of pre-existing disease symptoms. These considerations take the viewpoint of the Ottawa Charter into account, in that health is defined not merely by the absence of illness but by a general state of well-being.

One key issue in HIAs is how best to express the effects of air pollution on mortality -via numbers of premature deaths, or through changes in life expectancy. It seems that for some people, death as a consequence of air pollution is indeed advanced by only a few days (known as 'harvesting' of the most vulnerable). However these individuals are a minority. For most others it is likely that death is 'brought forward' by a few months or perhaps even years.

Another important issue is how soon the target population will gain any benefit (e.g. improved mortality rates) from reduced pollution. This issue is particularly important if a monetary valuation is performed (i.e. what assumptions are being used). Many HIA studies tend to be based on comparisons between cities with differing air pollution levels, and give no information about changes of pollution within a location. Such studies give no direct answer to the question of the time lag between pollution reduction and any associated change in death rates.

However it is possible to make some informed judgements about the time lag to impact. For example, it is clear that the changes to mortality rates influenced by particulate matter (PM) for some causes are more or less immediate. It is possible that PM in ambient air contributes to the development or acceleration of chronic lung or heart disease, with a time lag of the order of several years. The contribution of PM to the development of lung cancer may presumably take even longer.

Measures of morbidity are also important indicators of adverse health effects in addition to those of mortality. Here, common measures are use of health services (e.g. acute hospital admissions, or emergency room visits). Morbidity is relevant because, while the health outcomes may be less severe (than early death), they often affect a greater number of people, frequently with symptoms such as respiratory problems. In addition, morbidity effects may cause a large burden of disease in monetary terms and costs of health care.

The morbidity effects of air pollution include respiratory symptoms (asthma, chronic obstructive pulmonary disease, etc.) and cardiovascular hospital admissions (myocardial infarction, congestive heart disease, etc.). Further relevant health indicators are the incidence of chronic bronchitis, bronchitis episodes, asthma attacks in adults and children, and emergency hospital admissions.

The severity of a disease is also relevant for HIAs. Measures of severity can be objective (e.g. lung function measures) or more or less subjective such as restricted activity days or questionnaire data. Such measures can depend on cultural, economic and conditions of health service use, and thus may not be strictly comparable between one location and another. Nevertheless, they add an important economic and quality-of-life dimension to the HIA.

QUALITY-OF-LIFE ASPECTS AND MONETARY VALUATION

The common health impact measures mentioned above do not pertain to the full range of relevant health dimensions. As a result, health-adjusted life years (HALYs) aim to incorporate quality-of-life aspects related to air pollution that are relevant to the individual. Two main approaches to express HALYs exist: 'quality-adjusted life years' (QALYs) and 'disability-adjusted life years' (DALYs).

Another optional dimension of assessing health risks in HIAs is the economic impact or evaluation. This can take the form of an evaluation of the 'willingness-to-pay' (WTP) for a reduction in the mortality/morbidity risk. Alternatively, the 'willingness-to-accept' (WTA) can be determined for an increase in risk, i.e. the amount of payment that would be necessary as compensation if a negative impact takes place.

Utilising cost/benefit or cost/effectiveness analyses also aim to quantify benefits in monetary terms in order to make 'direct' comparisons of goods that are per se incomparable. Whereas the monetary value of material goods or services can be readily quantified on the basis of market considerations/mechanisms, attributing monetary terms to areas such as the good health or death of a person will always be ethically difficult.

Obviously, the weightings assigned to the quality-of-life aspects and economic valuation will differ according to whom is asked. This fact that much will depend on societal and individual values must not be forgotten in the decision-making process where strong ethical positions are taken. Cost-benefit analyses based on HIA's should therefore always be treated with great caution.

THE IMPORTANCE OF TRANSPARENCY

To ensure transparency, HIA practitioners need to clearly record and communicate the methodologies and data used, judgements and assumptions made, and where practicable, the consequences of different assumptions and hypotheses. This kind of rigour is essential to build and maintain the credibility of an assessment. Transparency also contributes to wider stakeholder involvement and a multi-disciplinary or participatory approach to problem-solving.

A sufficiently documented HIA has at least two major advantages. Among those who trust and accept its conclusions, the HIA results cannot be misused to close discussion when there are legitimate uncertainties to be taken into account, thus avoiding the problem of 'The experts say there is no alternative'. In the longer-term, good reporting and avoiding misuse of the results will not damage the credibility of a HIA and limit its usefulness in policy development and assessment.

HIA results should include assessments of the reliability of the impact estimates that are reported (both qualitatively and quantitatively). More importantly, clear and detailed reporting of the methods used and assumptions made will help to ensure that policymakers and stakeholders can understand what was done, have the information necessary to evaluate the assessment critically, and can ask relevant questions.

GOOD COORDINATION AND DIRECTION

Good overall coordination is needed within a HIA to ensure that all the different HIA elements are dealt with appropriately. Air-pollution HIA resources need to be directed towards the issues that have most influence on the final outputs of the HIA -the estimates of health impacts, their costs, and the uncertainties associated with both.

Such management is necessary because the subject-matter specialists working on a HIA can be pre-occupied with long-standing issues, knowledge gaps and approximations in their own specialist areas. Similarly, some stakeholders may have interests in particular aspects of the HIA, above and beyond those that impact on the final HIA results.

HIAs need to be not only reliable, but also affordable and timely. Since the vast majority of HIA studies are carried out with limited time and funding resources, it is essential that the key impact pathways that will most influence the final results be identified as early as possible, and those pathways focused upon. Firmness may be needed to prevent HIA project members from being side-tracked into investigating a multiplicity of issues.

Lastly, HIAs tend to progress more efficiently if it is applied as an iterative process. An initial rough ‘sweep’ through the assessment as a whole will allow the entire team (including decision-makers and stakeholders) to gain a first impression of the key issues in each HIA area, and the key linkages between issues. A second sweep will allow greater ‘drilling down’ into these areas; and so on. In this way, efforts can be directed to achieving the best results with the resources (monetary and human) available.

Dealing with uncertainty

Case studies such as COMEAP, APHEIS and the Helsinki study, together with examples such as ExternE, exemplify some of the uncertainties associated with each HIA stage and the linkages between them. These are unavoidable due to inherent uncertainty over the input data and assumptions. For example, they tend to focus on individual pollutants (e.g. due to model simplification) rather than the effects of the complex pollution mixtures that exist in real life.

In consequence, while HIA-influenced policies have the potential to limit the effect of one pollutant, they can also exacerbate the impact of another. However, the value of a well-performed and documented HIA is that it provides the basis for an informed judgement in the absence of any other information. There are many ways to evaluate and represent uncertainty and these can best be seen as complementary to one another. The use of a variety of approaches will give a more accurate picture than the choice of any single one.

Maintaining HIA credibility

HIAs incorporate a great deal of methodological and participatory complexity, so it is not surprising that they can sometimes be carried out poorly. Undesirable approaches include using ‘off the shelf’ templates without careful judgement about what is distinctive about the situation being assessed, and without effective communication of methods and results.

Such poorly-framed HIAs can be counter-productive to the specific application being assessed. They can also, ultimately, be counter-productive to the overall programme of research into air pollution and health, by damaging the credibility of the entire programme. This is why proper framing of the issues, and agreement with all the parties involved at the outset, can pay dividends in terms of results that are widely trusted.

HIAs are established methodologies that can be very useful in a variety of air-pollution assessment applications. They are very cost-effective when major policy changes, with their consequent benefits and costs, are being considered. The cost of a comprehensive HIA in policy development or assessment is small compared to the potential usefulness of the results it can provide.

The issue of what is affordable is perhaps a starker one when considering specific local developments such as a new road or an industrial site. Here the costs of even a comprehensive HIA are small when compared with overall development costs. Even where budgets are restricted HIAs can be done well, relatively cheaply and yet effectively, provided that they are carried out in an informed manner, and communicated in a way that informs rather than pre-empts wider discussion.

Equally important, HIAs are but one aspect of wider research into air pollution and health. The integrating role of the HIA and its identification of specific research priorities make it a value-for-money aspect of the overall research. Combined with openness and transparency to public scrutiny, good management and direction of a HIA will go a long way towards ensuring a programme's overall credibility.

5.5 SCIENCE POLICY INTERFACE

While significant improvements in air quality across Europe have been made in recent years, air pollution is still one of the major environmental factors affecting human health. Studies indicate that health effects still occur at low air pollution levels, even when Air Quality Limit Values have been met. Further emission reductions to reduce remaining health risks will require substantial investment. As such investments have to be cost-effective and need broad public and political support, an effective interface between science, policy and society is necessary.

An effective interface should focus on increasing coherence between scientific knowledge and policy needs to ensure that air pollution and health information is of real use in developing control policy, facilitated by a framework for interaction and communication.

AIRNET initiated the Science/Policy Interface (SPI) workgroup for this very purpose. This report from the AIRNET SPI workgroup focuses on the point at which science meets policy and society, discusses some of the problems therein, and puts forward methods to resolve such issues.

As well as the functioning of the science/policy interface itself, this SPI report also examines policy tools such as integrated assessments and health-based air quality guidelines. It also looks at various ways of dealing with the uncertainties present in many analyses and in framing different air pollution problems, ways of dealing with sustainable control options, as well as how to approach the different understandings of risk.

EFFECTIVE INFORMATION FLOW IS TWO-WAY

Probably the best way to describe the functioning of the science/policy interface is to think of a series of interactions and feedback loops between policymakers, scientists and other stakeholders. Science and policy do not operate in separate, isolated spheres and the information flow between knowledge and resulting policy is cyclical. Policy feeds into and influences the scientific community, as scientific information feeds into and influences policy decisions.

Ideally, the science/policy interface is an open, two-way communication and discussion of facts and figures, methods of analysis, decision principles, outcomes and values between all parties. The desired objective is to improve the alignment between scientific research results and policymaker information needs.

Reliable information is key to the effective functioning of that interface, and to the formulation of effective and sound policy. Yet providing such information can pose real challenges. Among the key issues here are providing quantitative health impact assessments, establishing the causality between air pollution and health effects and communicating where any uncertainty lies. Air pollution and health scientists need to explain such issues in plain language. Although there are still many uncertainties in the links between air pollution and human health, there are tools available which can be used to develop robust policy strategies.

Which end-users make use of air quality research results also needs to be considered. For research results to be truly useful, a clear understanding of the needs of the various end-users is necessary. AIRNET completed a stakeholder survey to identify the various end-user information needs on air pollution and health. A number of questions were taken from that stakeholder survey and are presented, together with answers, in the SPI report .

In general, the survey found that stakeholders prefer information to be presented in short overviews using non-specialist language. They also prefer to receive information that provides a practical linkage between research findings and policy development.

Clear communication is essential for an effective science/policy interface. Listening to and understanding each other's needs is one part of it; developing and implementing communication processes to achieve dialogue between the different players is another.

Improving the effectiveness of the science/policy interface also requires correct 'framing' of the air pollution and health issues, uncertainty analysis and development of new philosophies to deal more sensibly with risks. Finding an effective and workable solution can depend a great deal on having clear agreement over the exact nature of any problems, and the most appropriate solutions to those problems, right from the start.

Making further improvements in air quality

The existing EU Framework Directive and its associated emission control legislation are successful tools that have been proven to improve air quality and reduce adverse health effects in recent years. The current Framework is a valuable decision-support tool based on health effects information, public health protection, numerical concentration limits, costs and benefits, but it has both strengths and weaknesses, and incorporates a number of uncertainties.

That said, a number of complementary policy options and management instruments could help bring about further improvements in air quality. However, particular attention needs to be paid here to the relationship between broad and targeted instruments.

Broad instruments (air quality standards and national emission ceilings) usually oblige significant polluters to achieve sufficient reductions in their emissions. Targeted regulations, by contrast, require comparisons between the health benefits of reducing emissions of a pollutant and the costs of such a reduction.

Optimal formulation of such targeted control measures requires health-impact assessments of much greater detail than for the broad instruments. Detailed assumptions must be made about the effects of each air pollutant, and of the air pollution mixture as a whole.

Air quality management options and tools that could be utilised further include quantitative exposure and health impact assessments, comparative risk analyses, integrated assessments, cost-effectiveness and cost/benefit analyses, as well as taking a sustainable development perspective into account.

Integrated assessments, for example, aim to identify all the different aspects of a particular problem and how they relate to each other. International bodies have long provided integrated assessments of the health issues associated with air pollution. Since the 1990s, agencies such as the WHO (World Health

Organization), CLRTAP[1] and others have increasingly cooperated to develop a common focus and integrated strategy in this area.

In addition, local authorities have been given greater responsibilities for environmental health issues, thus increasing their need for integrated assessments. These differences in the players involved in integrated assessment increase the need to carefully monitor any potential differences in framing when cooperating in this way.

When planning the use of new tools, it is important to remember that air pollution issues are rarely straightforward. For example traffic is known to be a major source of PM, an air pollutant of major concern. While city planning can help to relieve traffic congestion and thus cut local emissions, PM can travel hundreds or thousands of kilometres from its source. Therefore local, national, and international efforts have to be included in the toolbox of effective policies.

COST-BENEFIT ANALYSES AND OTHER MONETARY EVALUATIONS

Most government interventions in the past, although often successful in reducing air pollution levels, were not subjected to any cost/benefit analysis before passage into law. These days, specific policy proposals are carefully evaluated before application to ensure that they are cost-effective and that they will not entail unexpected side effects. Cost-effectiveness and health benefit evaluations, as well as targeted research programmes, are therefore high on the agenda of environmental policymakers and researchers.

Cost-effectiveness and cost/benefit analyses, including integrated assessments, produce a number of pollution reduction options which can be ranked on their cost-effectiveness. In addition they allow decision-makers, stakeholders and the public to decide the level of action on health benefits that they prefer.

Monetary evaluations of environmental benefits, however, possess a number of uncertainties, for example how to quantify environmental damage and attribute economic value to human life and health. The outcome of these evaluations should therefore be treated with caution, i.e. emphasising the relative change rather than the absolute figure.

In sum, cost-effectiveness and cost/benefit analyses should not be regarded as the only tools for policymakers. They should be regarded as an integral part of multi-criteria analyses, together with all the other relevant information.

FUTURE APPROACHES

Short-term and long-term exposure to mixtures of pollutants such as ground-level ozone, nitrogen dioxide, PM10 and some smaller PM fractions appears to have substantial adverse health consequences, even at the lower end of the concentration range. Equally, in situations where the relative risk may be considered small, a serious public health problem can become apparent when large numbers of people are exposed and/or specific population sub-groups face increased risk.

However, a key question for policymakers, scientists, stakeholders and the public is whether one can propose measures and provide evidence that pollution reduction will indeed result in lower human exposures to pollutants, and consequently improved human health. Quantifying the exposure and health impact of air pollution, and providing evidence that air quality regulations do indeed improve public health have therefore become critical components in policymaking.

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[1] Convention of Long-Range Transboundary Air Pollution

For air pollution, both policymakers and research scientists need to develop their activities within a general framework, showing the levels at which the intervention and effectiveness of abatement measures can be studied, and how these results can feed into the decision-making process. The US Health Effects Institute (HEI) has outlined a research strategy with just such a purpose of dealing with these ‘accountability’ and benefit issues (see section 4.2).

Ideally, emission and risk control strategies should target the pollutants associated with the most significant emission sources. However, quantitative health-impact assessments and assessments of the health benefits of an intervention face many uncertainties, with concerns over areas such as health effects, concentration-response relationships, and identifying which pollutants are the most suitable targets to control.

Nevertheless, substantial improvements in air quality have already been achieved in Europe. And it is generally recognized that present-day intervention actions also need to focus on reducing the total burden of health effects, by reducing longer-term average exposures to healthy levels.

The number of studies investigating the health benefit of short-term and long-term interventions is limited, but they do report significant improvements in human health, i.e. a decrease in respiratory and cardiovascular deaths, decreasing prevalence of non-asthmatic and non-allergic respiratory symptoms, and improvements in lung function.

Policymakers planning future intervention actions could well consider taking a more risk-based approach, i.e. aiming to achieve the highest level of human protection in the most cost-effective manner. Particular focus could be placed on tools such as source-exposure-risk chain analyses, comparative risk analyses, and analysis of mixtures instead of single pollutants.

In addition, fertile subjects for further evaluation include also areas such as long-term health-effects studies, tailor-made health indicators for policy, public information and communication, exposure and health benefits from both implemented and future control measures, and re-evaluation of public health targets.

AIRNET, including the SPI group, has made headway in increasing science-policy-stakeholder interactions by encouraging and implementing participation in the AIRNET workgroups and in other activities such as annual conferences, European-wide stakeholder survey, multi-stakeholder AIR-NETwork days in Europe, and AIRNET Alert (web-based tool for disseminating non-specialist summaries of research). Therefore, a structured framework and recognised platform, such as AIRNET, is essential to optimise and strengthen the science/policy interface process and to bridge the information, communication and action gaps.

AIR-NETWORK DAYS

In recent years, expert workshops in Europe and internationally have been used to discuss the scientific and policy issues related to ambient air quality and human health. For instance, the World Health Organization regularly performs expert reviews of air pollution and health information for Europe. In comparison, few workshops are organised by involving all stakeholders, as well as in the development of the meeting itself. By organising events aimed at bringing a diverse audience together, AIRNET gave stakeholders a responsibility to create, broaden and intensify their own 'personal' network, as well as to share their knowledge.

This section presents the findings from the national network workdays (AIR-NETwork days) organised to communicate and discuss air pollution and health issues in Western, Northern, Central/Eastern and Southern regions of Europe. Additionally, the findings from parallel regional breakout sessions held at the 3rd AIRNET annual conference are included as the focal point at the European level.

METHODS

In the past few years, a strong coherent network has grown within AIRNET and the layers directly surrounding it. Nonetheless, AIRNET strived to further widen this network by including all relevant stakeholders. In order to succeed in making the wealth of gathered and interpreted information available to a broader spectrum of stakeholders, two things were considered paramount. First, a further fine-tuning of the information required to meet the needs of different stakeholders. Secondly, a well-focused effort undertaken to actively involve more stakeholders, including those that previously might not have had any direct contact with AIRNET.

To this end, in the final year of AIRNET activities, the communication strategy focused on the concept of national network days (AIR-NETwork days). These meetings were organised to actively involve local stakeholders in four countries: the Netherlands, Sweden, Hungary and Spain. Each meeting was organised to get a snap shot of the air pollution and health issues in countries representing Western, Northern, Central/Eastern and Southern Europe, respectively. A focus on these regions, particularly for stakeholder issues on air pollution and health in Central/Eastern Europe, was also included in the development of the 3rd AIRNET annual conference.

As European regions are different in several respects, emphasis was given to tailor all communication activities to the specific needs of local target groups. A standardised model was used to organise each workday, as illustrated in Figure 2. On a national level, the following parties were involved in the development of each workday: 1) national AIRNET co-ordinator(s), and2) local communications agency. At the European level as a whole, the following parties were responsible for overseeing all activities of the national parties: 1) AIRNET management team and 2) the Korbee & Hovelynck communications firm based in the Netherlands.

The first step was for the national parties to identify the relevant target groups by identifying their interests concerning air pollution and health. A list of stakeholders was then compiled and reviewed in a national context. The second step was to perform focus group discussions or interviews with representative stakeholders. The objective here was to get a good feel of what these stakeholders, per interest area, need and what they could contribute at the meeting. The number of focus group discussions or interviews was dependent on the types of interests that were identified in the stakeholder analysis.

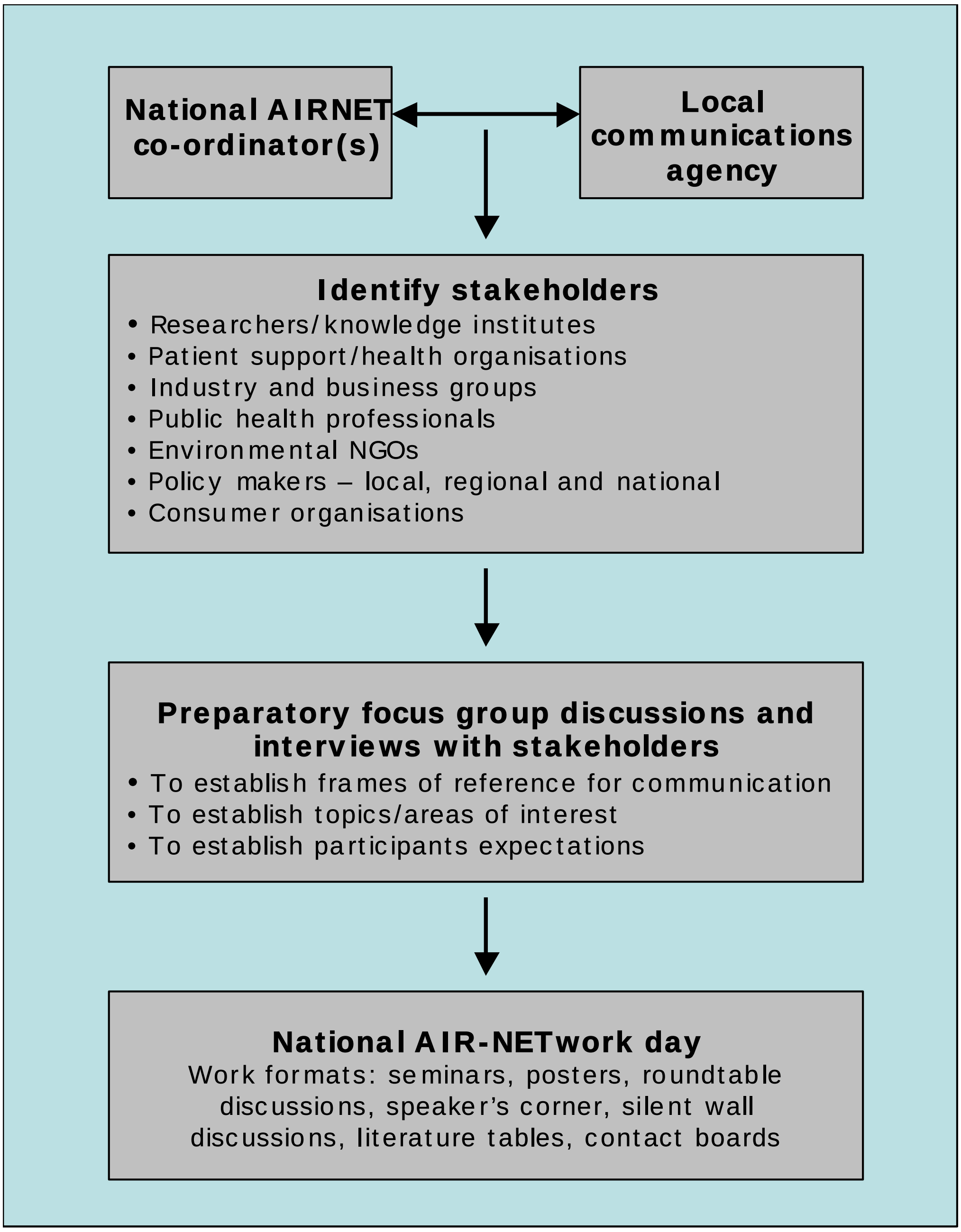

Figure 2: General schematic of the AIR-NETwork day model.

The work formats and themes were based on the nature of the messages to be shared and the wishes expressed during focus group discussions or interviews. Experience and results from previous AIR-NETwork days were then used to fine-tune the model workshop (Figure 2), which could be used to organise similar events. The goal of these network activities was to bridge the gap between scientists, policy makers and other stakeholders. Thus, resulting in a more profound exchange of each other's interests and information on issues relating to air pollution and health.

RESULTS

Overview of stakeholder participation

Participants were classified into several stakeholder categories (Table 1). These included scientists (air quality, health) who perform research, policy makers (local, regional, national), industry representatives (such as automobile, oil and gas) and NGOs (patient rights, environment). With the exception of the Netherlands network day, researchers were represented in the highest proportion. In general, policy makers were second, followed by NGOs and industry representatives – all of whom typically use research findings. Although the proportion of researchers was higher at the 3rd AIRNET annual conference compared to the network days, the same relative trend between stakeholder categories was evident.

Workday	Meeting Length (hrs)	No. of Participants	Stakeholder group					
			Research (%)	Industry (%)	Health Care (%)	Environment (%)	Policy (%)	Transport/ Mobility (%)
Netherlands	4	52	23	12	10	8	42	6
Sweden	5.5	54	56	13	2	4	20	6
Hungary	5	40	43	3	18	15	10	13
Spain	6	33 (no breakdown provided)						
3rd Annual Conference	2 ½ days	138	64	9	7	5	15	-

Table 1. *Overview of AIR-NETwork day attendance by stakeholder groups.*

Major themes of stakeholder interest

Focus group discussions and/or interviews resulted in workday themes that varied slightly according to country (Table 2). The most prominent theme for all AIR-NETwork days was traffic-related air pollution and human health. With the exclusion of Spain, air quality standards were also a major theme of interest at the workdays. Next issues on asthma and allergy, as well as children/infant health, were a major focus for three out of the five workdays. With the exception of Hungary, policy options aimed at air pollution and health were also included in the initial program.

Workday	Traffic	Allergy / Asthma	Children / Infants	Indoor Air	Air Quality Standards	Other Policy Options
The Netherlands	x				x	x
Sweden	x			x	x	x
Hungary	x	x	x	x	x	
Spain	x		x			x
3rd Annual Conference	x	x	x	x	x	x

Table 2. *Major themes of interest included in the AIR-NETwork day programs.*

Available communication formats

Use of conventional formats (seminar presentations, poster presentations, roundtable discussions) was the preferred communication formats for all AIR-NETwork days. At three of these meetings, non-conventional activities (silent wall discussions, speaker's corner, literature table, events calendar, contact board) were also used to stimulate participation. The conventional formats were devised to ensure that the messages were relevant and communicated in a clear and concise manner. In other words, easily understood by all players in the field of air pollution and health.

Discussion

Why do we need network days?

End users of information often times may not be able to express their needs directly towards the producers of information. When exchanging knowledge between different groups of people, the receiver of the information can help decide upon the mode of communication. This is important since the receivers of information will be the ones who use it. Consequently, the network days were a good opportunity for stakeholders to try out different modes of communication. Information providers could then focus more on the information itself and less on the process of dissemination.

Overall, AIRNET's efforts to achieve a balanced participation between producers of knowledge and those that use it were successful. This is put into context by the participation of the final annual conference where researchers represented over 60% of all participants (Table 1). Note that, in general, network days tailored to national interests increased the level of participation from the information users. In essence, each network day acted as a multi-stakeholder forum for discussions and activities centred around local, regional or national air pollution and health issues.

European scope of the network days

The geographical spread of the network days (Northern, Western, Central/Eastern and Southern Europe) allowed discussion of air pollution and health issues specific to each region. The network days were held in the local language, effectively removing potential barriers to communication caused by language. This aided in attracting policy makers and other stakeholders (i.e. environmental and health organisations) working at either the local, regional or national level – see Table 1. Most participants, through a variety of activities, communicated and exchanged ideas on how best to collect and disseminate air pollution and health knowledge.

Topics of major discussion

Although the network days were organised along the same basic principles (Figure 2), the content and available work formats varied little from country to country (Tables 2 and 3). Overall, at all network days, the principle focus of discussion was on traffic-related air pollution and urban transport, as well as future air quality standards. For more detailed summaries of the network days and the regional breakout sessions, see the AIRNET website (http://airnet.iras.uu.nl/).

For example, the Netherlands and Hungary roundtable discussions focused on the need to: 1) increase and improve public transportation, and 2) attract and encourage the public to take environmentally friendly behaviour in order to reduce the volume of traffic. Similarly, participants from the Sweden network day indicated that health-orientated decision-making would benefit from: 1) the development of traffic-related indicators of air quality, 2) acute and chronic health effect studies for traffic, and 3) integration of traffic and health policy with air pollution reduction policy.

Although the topics of interest varied relatively little between countries, the key messages emerging from each workday were different in scope (Table 3). For instance, issues specific to certain European regions were evident. The effects of wood burning and spring dust were important topics in Sweden. In Hungary, many of the discussions focused on the health effects of ragweed exposure. Participants at the Netherlands workday placed a greater focus on actions for the government and policy makers.

Netherlands (Western Europe) network day: ❑ Development of an integrated air pollution and climate policy ❑ Harmonisation and validation of the models used to assess urban air quality ❑ Investigate methods to protect the environment, with open options for managing local hotspots
Sweden (Northern Europe) network day: ❑ Need for action and research is most important for particulate matter from road and tyre wear ❑ Health effects of ozone have been somewhat forgotten – a need to refocus some attention ❑ Maintain an air quality standard for the coarse fraction of particulate matter
Hungary (Central/Eastern Europe) network day: ❑ Air quality limit value system should be as dynamic as possible, and monitored continuously ❑ Means of transportation and urban planning should be developed in consideration of health issues ❑ Allergy is the endemic of the 21st century, necessitating suitable preventative measures
Spain (Southern Europe) network day: ❑ The objectives of the measuring stations are not well defined and distinguished: stations that control the air quality with criteria of exposure of a zone, or the impact of a focus directed on air quality ❑ Support healthier lifestyles (potential sections for walking and cycling) in combination with the use of public transport and open spaces. ❑ Major improvement of public transport (quality, frequency, competitive pricing, use of clean technologies) ❑ A process to change models: from epidemiological surveillance (focussed on illness) to surveillance of public health, including vigilance of risk factors like air pollution.

Table 3. *Examples of key messages resulting from the AIR-NETwork days. Note: network day summaries in English are available on the AIRNET website* (http://airnet.iras.uu.nl/).

As a converging point for the national network day activities, answers to several questions posed during the parallel regional breakout sessions at the 3rd AIRNET conference are listed in Table 4. Discussions related to policy and decision-making priorities, as well as the value of regional meetings, reinforced AIRNET's activities. Overall, for all regions of Europe, improved communication between scientists, decision makers and stakeholders was seen as highly desirable to increase the effectiveness of decision-making processes for environmental health improvement.

Within our region what air pollution and health problems and abatement needs do we have in common?	
Northern Europe:	Road dust, noise and traffic emissions
Western Europe:	Primarily particulate matter and ozone and traffic related air pollution – nitrogen dioxide is still a problem because the Limit Value is being exceeded and because of legally binding obligations to reduce emissions
Central/Eastern Europe:	Air pollutants affected by local heating and traffic
Southern Europe:	Traffic emissions, desert dust and secondary air pollutants
What have we learnt from this conference which we can take home/apply to our region?	
Northern Europe:	Promotion of bicycle use to decrease traffic-related air pollution
Western Europe:	Lack of clear communication between scientists, policy makers and stakeholders
Central/Eastern Europe:	Improvement in the public understanding of environmental health issues
Southern Europe:	Good public transportation is needed to decrease traffic in cities
What are the research priorities for our region?	
Northern Europe:	Confirmation of the improvement in air quality as a result of implemented policy
Western Europe:	Carrying out long-term health studies of low-concentration air pollutants and identification of health relevant emission sources
Central/Eastern Europe:	Impact of changing air pollution to human health, especially in children
Southern Europe:	Research targeted on defining source and composition of ambient air pollution

Table 4. *Summary of the 3rd AIRNET Annual Conference regional breakout sessions. Note: session summaries in English are available on the AIRNET website* (http://airnet.iras.uu.nl/).

Participant feedback

Generally, participant feedback from the network days was positive. For example, on a scale of 10 (bad to good), the overall rating by the participants in the Netherlands. Sweden, Hungary and Spain was 7.9, 7.2, 8.4 and 8.1 respectively. The majority of the participants at each network day felt that the objectives of the day, to exchange knowledge and strengthen networks, were well achieved. Moreover, participants were also generally positive about the work formats used despite not having worked in such ways before. The majority of the participants felt it is was valuable to hold such events in the future.

Conclusion

AIRNET's communication activities indicate that national network days can be developed to stimulate active involvement and dialogue amongst the different stakeholders. Within the network day model, equal responsibility can be given for participation.–where every person had the possibility to contribute something. Although the air pollution and health issues are big – and the meeting time short –it is seen as a beginning or continuation of the dialogue.

Overall, during the AIR-NETwork days, both proven knowledge and 'good thoughts' were freely discussed without the weight of the printed word. From a transparency and clarity point of view, AIRNET's experience is that these types of meetings are important (if not necessary) due to the many different stakeholders with different or competing interests. They give the opportunity for those who may not be, as yet, plugged into a network where they learn or offer their own experiences in the field.

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