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editors, Paul Monks and Peter Borrell, 2005

2. 2005
The Remote Sensing of Atmospheric Constituents from Space; the AT2 Strategy Document
editors, John Burrows and Peter Borrell, 2005

3. 2005
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Trace Gas and Aerosol Flux Measurement Techniques
ACCENT- BIAFLUX Workshop Report
editors, David Fowler and Jennifer Muller

2. 2006
Towards Robust European Air Pollution Policies: constraints and Prospects for a wider dialogue between scientists, experts, decision-makers and citizens ASTA-ACCENT Workshop Report
editors, P. Grennfelt, L. Lindau, R. Maae, G. Sundqvist, R. Lidokog, F. Raes, J. Arnell

3. 2006
Understanding and quantifying the atmospheric nitrogen cycle; the 2nd ACCENT Barnsdale Expert Meeting, 2005
editors, R.A. Cox, David Fowler, Paul Monks, 2006 and Peter Borrell
This Position Statement and Recommendation Report is an outcome from the Common Issues Meeting held in Dublin, Ireland, January 9th - 11th January, 2006.

Editors
Hans-Christen Hansson
Colin D. O'Dowd
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1. Executive Summary

There exist significant overlaps in research, monitoring and prediction of aerosol impacts on Air Quality and Climate Change. These areas are defined here as Common Issues. Development of Common Issue strategies in Air Quality and Climate Change research and policy development is necessary to achieve cost-effective solutions for mitigation-strategies and research requirements.

The key Common Issues exist in basic research, policy, monitoring and observing systems, and predictive models. This Position Statement aims to highlight these areas in order to optimize efforts to reduce the impacts of atmospheric aerosols/particulate matter on Air Quality and Climate Change.

The main conclusion of the workshop is that an integrated policy framework, that addresses abatement strategies in Air Quality and Climate Change issues, is necessary and that research should provide the basis for this, through support for the coupled development of models and observing systems that are necessary to provide integrated analysis in order to support policy development.
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Recommendation 1. From the process level, there still lies considerable scope for the improvement of emission inventories (including aerosol formation) adjusted for use at different scales.

Significant research effort in this area, and integration of research with emissions data from statutory regulation, is strongly recommended to improve input and output of the Air Quality and Climate Change models. The development of a process by which data obtained for regulatory purposes are combined with emissions data from other sources is required and should respond to the needs of advanced models as well as basic reporting requirements.

Recommendation 2. Aerosol formation, transformation, and removal processes need to be further elucidated.

Air Quality and Climate Change models must interface better. Improved urban-to-regional scale nesting is required. An urban-scale spatial resolution down to 1 km x 1 km is a necessity. In addition to improved nesting, improved treatment of aerosol parameters such as mass, number, chemistry, hygroscopic and optical properties is also a requirement.

Recommendation 3. Monitoring strategies for Air Quality and Climate Change observation systems should be developed in a harmonized manner to ensure comparable databases of key Common Issues measurements.

In particular, the modeling and monitoring of aerosol number concentration and the contribution of combustion aerosols (in particular “soot”) to the aerosol population is essential to facilitate better description of the physical and chemical processes of particles, thereby, enabling the possibility of future studies to quantify aerosol impacts on health and climate.

As both Climate and Air Quality are undergoing notable change, and given that the two systems are not decoupled, it is strongly advisable to develop research and policy in these two systems in an integrated manner.

4. Common Issue Questions and Key Working Group Recommendations

Question (1) What are the Common Issues between Air Quality and Climate Change at the process level?

The working group on Common Issues between Air Quality and Climate Change with respect to atmospheric aerosols at the process level came to the conclusion that it is essential to use particle number and its size distribution to be able to give a physically and chemically correct description of how different processes affect aerosol distributions. Further, a set of essential processes central to both Climate Change and Air Quality assessments are identified to be included in assessment models - in order of priority, these are aerosol emissions, secondary aerosol formation, aerosol water uptake, interaction of aerosols with clouds, wet deposition of aerosols, nucleation and aerosol heterogeneous chemistry.
Question (2) What are the Common Issues between model development, application and validation?

Air Quality models in Europe need to be developed at spatial scale resolutions higher than 5 km x 5 km and need to be nested in Climate Change models, particularly in terms of up-scaling to capture the urban-to-regional scale aerosol transformation processes. Aerosol-Cloud interactions, including wet deposition require significantly better development in both model types at all scales. Dry deposition also represents a limitation of the models. Operational Air Quality models must contain number-based schemes as well as mass-based aerosol modules. Air Quality and Climate Change models need to grow consistently and in a more complex manner, consequently, the need for more elaborate evaluation methodologies also increases and improved methods for providing a better understanding of their accuracy have to be established. In particular, number-based models exert additional demands on appropriate data from observing networks for evaluation purposes.

Question (3) What are the Common Issues in measurement and monitoring strategies for Air Quality & Climate Change?

Although there are a multitude of Air Quality and Climate Change observing networks and systems, there needs to be a more coupled strategic development of these systems. There is a need for comparable datasets from both long-term operational monitoring programmes and shorter-term super-site studies, particular on the urban-to-regional scale transformation of pollutants. Aerosol number and related physico-chemical properties are urgent requirements on all observing systems to facilitate adequate monitoring for Climate Impact Assessment but, at this stage, they are not monitored for health impacts. Number concentration as a function of size is required to determine the amount of mass (or chemical composition more specifically) that can be transmitted to different parts of the respiratory system. Quantification of combustion aerosols (in particular the carbonaceous fraction) and the relative natural and anthropogenic contributions remains an important but currently lacking measurement in all networks. Ground-based networks can be significantly enhanced through the use of satellite observing systems.

Question (4) What are the Common Issues between Air Quality in terms of Integrated Assessment Modeling for policy development?

Integrated Assessment Modeling (IAM) is the primary tool used by policy-makers to negotiate emission reductions. Presently the abatement strategies have developed separately for Air Quality and Climate Change. However there now exists strong scientific evidence highlighting that it is necessary to include both issues in an integrated assessment analysis to reach the most economically efficient abatement strategy. Trends in Climate Change are not considered in the present Air Quality assessments or abatement strategies. Considerable evidence is at hand indicating that the effects of aerosols and thus Air Quality on the rate of Climate Change will vary substantially over time, and perhaps even more substantially on a regional scale. Consequently, the need for integration of climate models in the integrated assessment modelling activities (where only Air Quality models are integrated) seems quite urgent. The Air Quality models are today integrated in the IAMs. However risk estimates needs to be differentiated such that the effect of different sources, e.g. road dust and combustion, can also be isolated in terms of impacts.
5. Detailed Working Group Reports & Recommendations

5.1 Working Group 1: What are the Common Issues between Air Quality and Climate Change with respect to atmospheric aerosol at the process level?

Sandro Fuzzi, Spyros Pandis, Robert Flanagan, H-C Hansson, Martin Schaap, Svetlana Tsyro

A range of atmospheric processes concerning aerosols are of importance for both air quality and climate change. The list that follows outlines these processes organized in a priority order with respect to commonalities.

**Aerosol Emissions:** Emission of aerosol particles must be included in models as a process and not just as fixed number input from a database (i.e. emission factors) since emission rates (mass and/or number) change depending on atmospheric conditions (temperature, wind speed, etc.). For example, semi-volatile organics may change phase and their phase-partitioning depends on temperature and dilution factors. Natural sources of aerosol (sea-salt, dust) are presently poorly known and poorly represented in both Air Quality and Climate models. Natural aerosols are, of course, important for global climate models, but also for Air Quality legislation. It has been recently recognized that natural aerosols can contribute significantly to regional and urban Air Quality levels and that in new EU Air Quality directives, the natural component must be quantified in order to effectively control anthropogenic exceedance levels.

Emissions of primary organics and their precursors must be known with much better temporal and spatial accuracy. Of particular importance are biogenic primary aerosol and biomass burning aerosol. Black carbon emissions need to be better quantified; however, there is a pressing need to harmonize measuring techniques to improve these emission data (data presently available are only rarely comparable to each other). All the above emissions need to be known both in terms of aerosol size and chemical composition. In addition to the above emissions, the effect of environmental conditions (temperature, solar radiation, relative humidity, etc.) on aerosol emissions needs to be taken into account. It is recommended to evaluate emissions inventories using top-down approaches (tracers, inverse modeling, etc.). Evolution of the number size distribution near sources and at different scales must be known, both for climate modeling and Air Quality purposes. In fact, while current policy criteria are mass-based, potential future policy issues related to human health may evolve to number-based. *(Note. Significant uncertainties are still present about the effect of different aerosol components on health. To date, no strong evidence is available from epidemiology studies linking a specific compound to statistically observed health effects).*

**Secondary Organic Aerosol Formation:** The relative contribution of secondary organic aerosol versus primary organic aerosol is still an open issue with implications for both Air Quality and Human Health and Climate Change.
The balance between biogenic organic aerosols (products of isoprene, monoterpenes, sesquiterpenes) versus anthropogenic organic aerosol in different environments needs to be quantified. Interactions of biogenic and anthropogenic organic aerosol components and oxidants are poorly known (for example, increased ozone levels may increase the formation rate of biogenic secondary organic aerosols). Models at local, regional and global scale make use of laboratory (smog chamber) measurements to predict secondary organic aerosol formation. It is necessary to bridge the gap between laboratory data and model calculations making use of field observations using both existing and newly developed techniques in the future.

**Aerosol Water Uptake:** Hygroscopic growth of atmospheric aerosol is important both for climate modeling (radiative effects such as increased scattering of solar radiation) and for Air Quality/Human Health issues (hygroscopic particles are more efficiently retained in the respiratory system).

Hygroscopic properties of mixed (multi-component) particles as a function of their composition/mixing-state needs to be better evaluated for different aerosol types. The role of organics is of particular importance, also because it can vary considerably with aerosol ageing, thus changing the hygroscopic properties.

**Interaction of Aerosols with Clouds:** Cycling of particles through clouds may change their composition and physical properties considerably. This is of importance for both Climate Change (radiative properties) and Air Quality/Human Health.

Chemistry within cloud and fog droplets needs to be better understood (particularly organic chemistry). Cloud Condensation Nucleus (CCN) activity of aerosols determines particle lifetime at regional scales and cloud microphysics (indirect effect on climate). Again, the role of organics is of particular importance.

Wet deposition of aerosols is the primary mechanism for the removal of climatically relevant particles on the global and regional scale. Similarly, it is important for Air Quality. The precipitation fields can be driven by aerosol-cloud interactions (i.e. cloud lifetime and precipitation onset) as well as dynamics. Careful evaluation of the descriptions of precipitation-onset and subsequent wet removal used in models through comparison with data from field experiments should be better developed. In fact, in spite of several decades of studies by the cloud physics community the effect of precipitation on aerosol as a function of chemical composition is still poorly known - wet processes remove selectively particles according to size-dependent chemical composition and change considerably the size distribution of particles.

**Nucleation of New Particles:** It has become more and more evident that formation of new nanometer sized particles takes place in many different areas and different environments around the world. The relevance of this process at the global scale has been postulated, but has not been firmly established. New particles formed by nucleation from the gas phase may potentially be important for Human Health, but this has not yet been tested and proven.

Convincing theories have been formulated for new particle formation, but they remain to be tested experimentally. The importance of nucleation and growth of new particles as a source of
1. Executive Summary

There exist significant overlaps in research, monitoring and prediction of aerosol impacts on Air Quality and Climate Change. These areas are defined here as **Common Issues**. Development of Common Issue strategies in Air Quality and Climate Change research and policy development is necessary to achieve cost-effective solutions for mitigation-strategies and research requirements.

The key Common Issues exist in basic research, policy, monitoring and observing systems, and predictive models. This Position Statement aims to highlight these areas in order to optimize efforts to reduce the impacts of atmospheric aerosols/particulate matter on Air Quality and Climate Change.

The main conclusion of the workshop is that an integrated policy framework, that addresses abatement strategies in Air Quality and Climate Change issues, is necessary and that research should provide the basis for this, through support for the coupled development of models and observing systems that are necessary to provide integrated analysis in order to support policy development.
2. Background

Research, monitoring, and policy development in the areas of Air Quality and Climate Change have largely developed as separate processes. This has occurred for a variety of reasons including the differing life-times and spatial scales associated with the main pollutants and the perception of impacts. However, the most recent studies suggest that Air Quality and Climate Change have many overlapping and inter-linked problems, or Common Issues. This would suggest that Air Quality and Climate Change should be handled in a coupled manner from the research and the policy perspective.

It is thus of common interest to both scientific and policy communities to be aware of these Common Issues. The ACCENT\(^1\) European Network of Excellence Joint Research Programme\(^2\) on “Aerosols: Air Quality & Climate” had identified four key questions on Common Issues in research and policy aspects of aerosol impacts on Air Quality and Climate Change.

These were considered at the Common Issues workshop was held in Dublin, January 2006 and this document outlines the current **Position on Common Issues** from the research and policy communities and makes an assessment of future Common Issue recommendations.

3. Major Conclusions and Recommendations

Integrated Air Quality & Climate Change policy is essential to optimize the environmental effectiveness and investment required in end-of-pipe, structural, and behavioral change measures. Consideration of the Common Issues will result in significant economic savings in terms of abatement and mitigation strategies.

Climate sensitivity, i.e. the projected warming due to doubling of GHG concentration, is a key concern in the present development of climate policy. However it is now recognized that the direct and indirect aerosol radiative forcing contributes to the uncertainty in global radiative forcing, which can significantly influence climate sensitivity. Climate Change can also impact on Air Quality and exacerbate the impacts of air pollution on human health, agricultural production and ecosystems. Such connections imply the need for increased integration in the understanding of Air Quality and Climate Change Common Issues in order to develop the appropriate synergistic abatement strategies.

The recent establishment of the hemispheric task force on long-range pollution transport and its impacts on Air Quality provides an incentive to address Air Quality issues on a similar domain as Climate Change. This development provides a basis for further integration of these issues and exploration of win-win scenarios in relation to abatement options for both areas.

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\(^2\) Aerosols: Impact on Air Quality & Climate is one of four Joint Research Programmes under ACCENT.
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particle number (sizes of tens of nanometers or larger) at different scales needs to be evaluated. Mechanisms of nucleation and growth of particles in different environments (clean marine, clean continental, polluted, etc.) need to be quantified. The role of organics seems to play an important role but appears only relevant in the growth stage only, rather than the nucleation stage. The coupling between nucleation and growth needs further investigation. All these processes need to be evaluated in conjunction with laboratory and field measurements.

**Aerosol Heterogeneous Chemistry:** Chemical reactions on or within the particles may modify their chemical composition and physical properties. Ageing of particles may potentially be important for human health effects due to changes in chemical composition of particles. Organics are a major candidate for these processes (oligomerization processes, oxidation processes, etc.). Nitrate formation is still a problem for air quality models (size dependence, role of other particles such as dust, sea-salt, etc). Comparisons with measurements often show problems. Heterogeneous reactions on or within aerosol particles interact with gas phase chemistry (e.g. ozone) and, in certain conditions, may modify it.
5.2 Working Group 2: What are the Common Issues between model development, application and validation?

*John Seinfeld, Johan Feichter, Roy Harrison, Colin O’Dowd, Leonor Tarrasón.*

Climate is changing, and will continue to change. The driver for climate change is the increasing levels of greenhouse gases in the Earth’s atmosphere. As climate changes, urban and regional air quality will as well change. The focus of the ACCENT Common Issues Workshop is primarily on atmospheric particles although every aspect of air quality can be expected to be affected by climate change. Ozone and particulate matter are, in many respects, coupled through the complex web of tropospheric chemistry.

To assess how a changing climate will affect urban and regional air quality requires regional atmospheric models. Output from the global climate models serve as input to regional and then to urban scales atmospheric models, a process that is referred to as “downscaling”. On the other hand, if a regional model is used to simulate the processing of emissions for input into the climate model grid, then this process is referred to as “up-scaling”. At present, downscaling from climate modes is more common that upscaling. At the regional level, most air quality models use downscaling (also called one-way nesting) from grids of the order of 100 km down to about 5 km.

Despite the many advances that have been made in European urban and regional atmospheric models, there remain significant needs to improve these models to make credible predictions of particulate (and ozone) air quality in response to climate change.

**Model Resolution and Operation Predictions:** Resolution needs to be improved for European cities; the traditional 5 km x 5 km grid, which is probably sufficient for US cities, is not adequate for the densely populated and more complex European cities.

The capability to operationally predict particulate matter at the regional and urban scale needs further development. Most climate and regional-scale models predict only total particulate mass. Such modules are neither state-of-the-art nor sufficient for evaluating health impacts, which depend on particle size. Models need to be advanced to predict both particle number and composition as a function of particle size. This advance is needed so that model predictions can be matched to epidemiological studies.

**Upscaling & Downscaling:** Climate modes rely on emissions input; ordinarily these are made at the grid scale of the climate model. Methods for up-scaling from regional scale models need to be developed that will allow simulation of transformations that occur involving emitted pollutants before they have been dispersed to the scale of the climate grid. These transformations include the coating of freshly-emitted soot by gas-phase material, organic aerosol transformations, and the general transition of particulate matter from a relatively hydrophobic state to one more hydrophilic. The state at which soot, in particular, ages to become hydrophilic is one of the key uncertainties in global predictions of aerosol radiative forcing and such up-scaling models have great promise to improve this aspect. In summary, regional models can feed into climate models: upscaling is an issue for (a) emission...
inventories, (b) PM number and size distributions, and (c) aerosol ageing, specifically the hydrophobic to hydrophilic transition.

**Aerosol-Cloud Interactions & Wet Deposition:** Clouds impact climate and air quality in important decisive ways. Clouds determine the level of direct radiative forcing of aerosols and changes in aerosol amounts can alter the properties of clouds themselves (a 5% increase in global cloud cover could negate the entire greenhouse gas forcing). In air quality at the regional level, cloud droplets serve as sites for the production of PM, as well as the means to remove PM through wet deposition. Treatment of clouds in climate models and of wet removal is one of the most challenging aspects of atmospheric modelling. Current algorithms in models at both scales are relatively primitive. The improvement of the treatment of clouds represents a main step forward in reaching better accuracy.

**Dry Deposition:** The other main removal path for PM is dry deposition. While all models employ a resistance formulation of dry deposition, the surface resistance, which is the most important component of the resistance, is not well constrained by measurements. Predictions by models at all scales are hampered by uncertainties in the representation of PM uptake at the surface. Advances need evaluations with flux measurements. Comparisons of data and predictions between 2002 (very wet summer) and 2003 (very dry summer) might offer insight into the effect of the nature of the surface on dry deposition removal of pollutants. More gradually, there is a significant need for evaluation of regional-scale models with existing and future, better formulated and consistent datasets.

**Model Validation:** Observing systems for both Air Quality and Climate Change must be better developed to provide operationally-required model validation parameters. In particular, observing stations and networks should provide number distributions as well as PM mass distributions, preferably at PM1, 2.5, & 10 size resolution, along with organic fraction.
5.3 Working Group 3: What are the Common Issues in measurement and monitoring strategies for Air Quality & Climate Change?

Kjetil Torseth, Gerrit de Leeuw, Harry ten Brink, Fabrizia Cavalli, Colin O’Dowd, Maria Cristina Facchini, Gerard Jennings, Paolo Gobi, Thomas Sandstrom, Karl-Espen Yttri.

Common Issues in the monitoring strategies between Air Quality and Climate Change include ground based point measurements and remote sensing on various spatial and temporal scales. There is a need for comparable datasets, both from long-term observations and intensive campaign-based data, to better support modeling-based predictive and quantification activities. There is a further need for easy access to harmonized database formats.

Mass versus Number: Typical ground based point measurements include aerosol mass and physical characterization of inorganic species with limited characterization of carbonaceous material or water content. In terms of mass, PM2.5/10 is widely used for Air Quality regulation; however it is not the best choice of parameter for climate effects and perhaps not for health effects impacts.

In addition to aerosol mass, aerosol number as a function of size is critically important in determining Climate Change impacts. Size resolved number concentration should be made between 10 nm and 1 μm, complimented by PM1 measurements in conjunction with PM2.5 and PM10 mass measurements. With currently technologies, these data should be taken with a quasi-continuous temporal sampling period of 30 minutes.

Aerosol Chemistry: Aerosol sources can only be assessed from composition measurements. In particular, the anthropogenic part is the most relevant in terms of Air Quality & Climate Change abatement strategies. Sulphate aerosol is quite well understood now, however, there are still gaps in operational monitoring of sea-salt and dust (which can contribute significantly both to regional Air Quality and Climate Change). Natural and anthropogenic dust components should also be resolved. Time resolution recommended is of the order of 3-6 hours.

Carbonaceous material provides one of the major challenges in terms of Air Quality and Climate Change measurements. Black Carbon monitoring is better developed compared to organic carbon and comprises major contributions to degraded Air Quality and Climate Change through increased atmospheric heating. Black Carbon should be monitored on a time basis of the order of 1 hour.

In terms of organic aerosols, there are significant open questions relating to sources and production mechanisms. In particular, measurements which can elucidate the relative contribution of anthropogenic and natural sources to secondary organic aerosol formation are crucial. Similarly, measurements which could quantify the relative importance of primary and secondary organic aerosol production to the total organic aerosol load is also essential. Water soluble and water insoluble characteristics of organic aerosols are also important in terms of interactions with clouds (for Climate Change) and retention in the respiratory systems (for Air Quality/Health).
**Water Content of Aerosol:** Water content of aerosol is critical for mass-closure studies leading to improved quality control of monitoring networks. Also, it is critical for determining aerosol optical properties and the formation of clouds. Measurements of aerosol hydrosphericity should be taken in improved monitoring networks.

**Aerosol Optical Properties:** Aerosol optical properties are directly relevant to Climate Change issues, however, less so to Air Quality. Nevertheless, observations of their optical properties such as Aerosol Optical Depth (via satellites) and extinction (through LIDAR) can provide extremely useful information on transport and dispersion of pollution plumes. Some studies have also shown good correlations between AOD and PM levels, thus, these platforms can provide spatial enhancement of the quantification of PM fields compared to point-measurements on ground based networks.

Aerosol Optical Depth is operationally available, but needs better accuracy for constraining models (e.g. through data assimilation). In order to achieve this improved accuracy, algorithm improvement and validation/calibration activities need to accelerate. LIDAR provide additional information to satellites in terms of the capability to provide vertical structure of aerosol fields in the atmosphere. These point measurements can compliment space column-based remote sensing instruments. Cost-efficient commercial eye-safe LIDARs could be implemented in monitoring networks.

**Monitoring Programmes:** Existing networks directly supporting Common Issues include EMEP Levels 1 (base), 2 (advanced monitoring), 3 (research) stations; WMO – GAW (ground based monitoring); AIRBASE; EUSAAR; EARLNET/ASOS. Significant advancement needs to be achieved in terms of developing common data formats and harmonisation between these networks. IGACO recommendations for common Air Quality/Climate Change observations centre on harmonising satellite and ground based data (GEOSS 10 year implementation plan).

**Urban to Regional Scale:** There is a clear need to build better links in terms of monitoring on the urban and regional scales and to introduce more commonality in parameters measured. In this context, the development of urban-to-regional scale super-site measurement networks are very important.
5.4 Working Group 4: What are the Common Issues between Air Quality & Climate in terms of Integrated Assessment Modelling for policy development?

Frank Raes, Markus Amman, Sösser Brodersen, Hans Eerens, H-C Hansson, Pat Goodman, Peringe Grennfelt, Aodhagan Roddy, Frank McGovern

It is important to broaden our perspective and discuss various issues simultaneously because:

(1) in societal and practical terms, one usually tries to reduce multiple risks simultaneously through a range of policies. The development of such an integrated set of policies must be underpinned by scientific research that identifies synergies and trade-offs between these policies. This can be done by developing and applying Integrated Assessment Models (IAM),

(2) in addressing various issues together, the resulting integrated policy is less vulnerable to uncertainties that might exist regarding one single issue, resulting in a more robust policy,

(3) we need to especially avoid lock-in solutions that might be good for one issue but bad for another

There is an issue of how accurate the representation of individual processes (for example, atmospheric chemistry or aerosol processes) should be in IAMs. As IAMs are primarily used for policy development, the answer is: only as accurate as to allow robust results for decision making purposes. (Results or statements are robust when they will not change as the accuracy of the model increases). In this respect, it is of interest to say that policy makers often want answers of a relative nature: e.g. “how different will ozone levels be with and without certain policy measures?”. Models more easily converge on such results than on absolute concentrations.

Within Europe, the revision of today’s air pollution policies (i.e. new policies starting in 2007) will be made with the IAM RAINS (Regional Air pollution Information and Simulation). The scientific community might think about the IAM/RAINS requirements for the development of policies post-2010 (e.g. do we need to include climate models in such an IAM system?)

The issues of Air Quality and Climate Change have been tackled separately because of the different temporal and spatial scales involved. Climate Change policies (reducing CO₂ emissions by structural and behavioral changes) will generally improve Air Quality. Hence Air Quality policy makers need to be aware of these Climate policies, extend their horizon and consider developments in the energy and transport sectors up to 50 – 100 years into the future, in the same way Climate Change policy does. Air Quality also needs to extend its spatial scale from local regional to hemispheric and global scales. At the latter scales, links between Air Quality and Climate Change policies become more evident. For example, a reduction in the levels of the greenhouse gas methane will reduce background tropospheric ozone levels, thereby contributing to achieve Air Quality standards at the local level.
Life Cycle Analysis (LCA) is important when considering structural measures such as fuel changes to reduce CO₂ emissions, (for example, hydrogen does not produce CO₂ the moment it is burned, but the production of H₂ might involve the use of fossil fuel and significant CO₂ emissions). LCA is less relevant when end-of-pipe technologies are used to cut emissions of conventional pollutants (the emissions involved in producing a filter are much less than the emissions avoided with that filter). Optimizing the mix between structural and end-of-pipe technologies to address Air Quality and Climate Change simultaneous will require an analysis that goes beyond LCA, towards a more general System Analysis.

Looking at “targets” or “end-points” other than Air Quality standards or global mean temperature, will make more obvious the linkages between Air Quality and Climate Change. An example of such a target is the rate of global/regional temperature change: controlling CH₄ will have an immediate (within a decade) effect on the levels of CH₄ and background O₃, hence reducing the rate of temperature change; controlling the overall PM will reduce the cooling effect of PM and thus enhance the rate of temperature increase. More quantification is needed. Further, it is expected that carbonaceous aerosol from fossil fuel combustion (diesel) has a warming effect, and hence dedicated policies to reduce such aerosols will have health benefits and reduce the rate of temperature increase. Again, more quantification is needed. Targets could also relate to the effects of particles on hydrological cycle, floods, droughts.

An integrated Air Quality and Climate Change policy means to optimize the combination of end-of-pipe, structural and behavioral measures, and find a most (cost-) effective solution. This requires, however, more systematic economic studies on cost and benefits of control options: cost and benefits in terms of health, energy security, and creation versus loss of jobs.

Marginal cost curves are at the heart of cost-benefit (cost-effectiveness) calculations. Of particular interest is determining at what ambition of emission reductions (call it point X), the marginal cost starts to become high and have an effect on the macro-economy of a country. It is important to relate that point X to environmental end-points (e.g. is the corresponding emission reduction avoiding or not an irreversible change in the climate system). Point X depends on how costs are calculated, e.g. whether co-benefits are included or not. Point X will also change in time because new and cheaper control options become available.

Stabilizing global temperature will require big changes in energy production systems, transport systems etc. Industry has invested in research and development of prototypes of the required new systems and the more favourable the political climate is in engaging in global action to fight climate change, the more these systems will be implemented. These large changes will have effects on the environment, including the atmosphere (e.g. a hydrogen economy will have to deal with effects of H₂ on atmospheric chemistry). Massive introduction of biofuels might lead to further deforestation with its effects on atmospheric dynamics and chemistry. Further research must quantify such effects.
6. Abstracts of Presentations

6.1 Integration of Air Pollution and Climate Change Mitigation Policies.

*Frank Raes*

*Climate Change Unit, Institute of Environment and Sustainability*

*European Commission, Joint Research Centre*

Policy development requires a full understanding of the drivers (e.g. need for energy and fossil fuel use etc.), pressures (e.g. emissions, etc.), the state of the atmosphere (increasing concentrations, etc.) and the impacts (e.g. on human health, ecosystems, climate, etc.). Policies eventually aim at reducing these negative impacts at the least cost. A science base approach to policy making means the use of so called Integrated Assessment Models (IAMs), which link the various processes, and allow the optimization of the policy response in terms of environmental and cost effectiveness.

Figure 6.1.1 The separation between air pollution policy making and climate change policy making, as it developed in Europe during the past two decades.

Figure 6.1.1 illustrates the separation between air pollution policy making and climate change policy making, as it has developed in Europe during the past two decades. There have been good reasons to keep these two policy areas separated. These reasons relate to the physico-chemical properties of the pollutants that needed to be controlled. Conventional air pollutants (SO₂, NOₓ, PM, ..) are reactive, giving them a short life time in the atmosphere, leading to local/regional-scale problems which could, to a large extent, be solved with technical measures such as end-of-pipe technologies. Greenhouse gases, on the other hand, are much less reactive,
leading to a global problem, which primarily must be resolved by structural or behavioural changes.

Figure 6.1.2 shows the inter linkages between the two policy areas. The integration between them, e.g. within the framework of IAMs, is driven by the need to optimize the mix between technical, structural and behavioral control measures, to address both problems in the most effective way.

**Figure 6.1.2 Inter linkages between the Air Quality and Climate Change policy areas.**

While optimizing control measures, integrated assessment modelers and policy makers should be aware of various physical and chemical linkages that exists between conventional air pollution, greenhouse gases, radiation, etc., which can lead not only to synergies, but also trade-offs between various measures. Three examples of such linkages are indicated in Figure 6.1.2, by the thick arrows: the fact that the greenhouse gas CH$_4$ is also a precursor for background O$_3$, which itself is a GHG, and also damages ecosystems and human health (synergy!); the fact that Particulate Matter (aerosol particles) as a whole has a cooling effect in the climate system, hence the PM reductions required to protect human health will lead to warming (trade-off!); the fact that PM might have an immediate impact on convective clouds and hence on atmospheric dynamics and the hydrological cycle.
6.2 Synergies and Trade-Offs Between air Pollution Control and Greenhouse Gas Mitigation

Markus Amann  
International Institute for Applied Systems Analysis (IIASA)

Introduction: A surprisingly wide body of new literature addresses synergies and trade-offs between air pollution control and greenhouse gas mitigation strategies. This presentation abstract provides a summary of a review of about 50 scientific papers that have appeared since 2000 in the peer reviewed literature. Papers have explored, for different regions in the world, co-benefits from GHG mitigation and air pollution control on health effects and agricultural and ecosystems impacts as well as savings in emission control costs. Based on these findings, a number of Common Issues for emission control strategies have been identified, pointing out the need for an integrated approach in which aerosol issues play an important role.

Co-benefits of GHG mitigation on health: Several dozens of studies conducted for North America, Europe, Asia and Latin America consistently demonstrate a significant decline of SO₂, NOₓ and PM emissions associated with moderate CO₂ mitigation strategies (studies explored up to 20 percent reductions in CO₂ emissions). These lower emissions cause less health impacts, especially through reduced population exposure to primary and secondary aerosols. The magnitude of health gains depends on the contribution of the emission source sector to population exposure (e.g., low levels sources vs. emissions from high stacks), and the extent to which air pollution is controlled at the specific source. Due to such differences, studies typically estimate several 1000 avoided cases of premature deaths per year for European countries, where mitigation strategies affect predominantly centralized coal combustion facilities, and several 10,000 cases per year for countries in Asia and Latin America, where cost-effective measures involve the domestic sector.

A number of studies conducted an economic evaluation of these physical co-benefits. Estimates range from $7/t C (for the USA) to several $100/t C (for China). Differences are explained by (i) the range of pollutants considered in a particular analysis (e.g., for SO₂ and NOₓ) only for the US study versus a more comprehensive assessment including PM and O₃, as performed for China, (ii) the source sector and its impact on population exposure, and (iii) the level of applied pollution control. These monetized benefits account between 50% (the US study) up to 400% (in the Chinese study) of the carbon mitigation costs.

Furthermore, some studies conducted an assessment of the macro-economic impacts of such combined pollution control strategies, taking account of the economic feedbacks of pollution control expenditures. Studies found for India, China and Chile mitigation potentials between 13 and 20 percent of the CO₂ emissions from the business as usual cases in 2010 that would not lead to a net losses in welfare. Inclusion of non-CO₂ greenhouse gas emissions is expected to lead to an even enlarged potential for no-regret measures.

Co-benefits of GHG mitigation on agriculture and ecosystems: A range of studies explored co-benefits of greenhouse gas mitigation strategies for improved agricultural and ecosystems productivity resulting from lower levels of ground-level ozone. For instance, studies demonstrate for China that monetary benefits of increased agricultural productivity are...
comparable to the monetized health benefits, offering a potential for a 17% reduction of CO₂ emissions without net welfare loss. Because these welfare gains emerge for poorer rural populations (in contrast to health benefits, which favor urban dwellers), there are potentially important social implications associated.

A number of studies show beneficial effects of carbon mitigation strategies for natural ecosystems via reduced ozone damage and acid deposition, although the exact physical and economic quantification remains difficult. The extent and location of such co-benefits have been shown to be highly sensitive towards the location of emission reductions, which can be critically influenced by the actual use of flexible instruments, since traditional climate related instruments do not consider the location of sensitive ecosystems.

**GHG mitigation reduces air pollution control costs:** An increasing number of studies point out that for industrialized countries with stringent air quality legislation GHG mitigation reduces the costs for complying with air quality legislation. For European conditions, costs for complying with the EU emission ceilings could decline by 10-20% with a Kyoto-compliant energy pathway. The saving depends on the use of flexible instruments, i.e., to which extent countries fulfill their reduction obligations by acquiring carbon permits abroad and thus do not change the domestic energy structures. For the US, studies suggest that the decline in coal use with the aim to reduce CO₂ emissions could drive the price for SO₂ allowances to zero. Another study estimates for a 15 $/t C carbon tax direct savings on air pollution control costs of 4-7 $/t C. These savings are immediate, they are uncontroversial since they do not depend on subjective value judgments, e.g., about the monetary value of a human life, and these benefits to those actors who have to invest into mitigation. They will gain increasing importance in developing countries.

**Common Issues on emission controls:** A number of Common Issues shared between GHG mitigation and air pollution control strategies emerge from these analyses. There are measures with simultaneous impacts on GHG and air pollutant emissions. These can have synergistic effects (e.g., energy efficiency improvements, increase use of natural gas, certain agricultural measures). Other measures bear the potentials for trade-offs, such as air pollution control equipment with high energy use, or the danger for technological lock-in situations, e.g., into air pollution friendly but GHG intensive energy supply structures. A number of studies point out the scope for reductions of methane emissions that yield multiple benefits on (i) direct radiative forcing, (ii) lower ground-level ozone, and (iii) its indirect radiative effects. An enhanced use of bio-fuels, while beneficial for CO₂ emissions, could increase PM emissions and their associated health impacts if combusted in small domestic stoves. In addition, a complete calculation of the radiative effects of the VOC and PM emissions from incomplete combustion could compensate the positive effect of the carbon reduction. Also carbon mitigation strategies building on enhanced diesel use could result in detrimental health impacts due to their higher PM emissions, if no advanced particle filters are applied. Again, the radiative impacts of the associated black carbon emissions could counteract the benefits from lower CO₂ consumption.

**The need for an integrated analysis:** The literature clearly points towards the need for an integrated analysis in order to harness synergies between air pollution control and greenhouse gas mitigation and to avoid potential trade-off situations. The new GAINS (Greenhouse Gas Air Pollution Interactions and Synergies) model developed by IIASA provides a tool for a systematic analysis to maximize the potential benefits. It extends the current multi-
pollutant/multi-effect air pollution framework of the RAINS model towards greenhouse gases. It provides a tool for the search for cost-effective set of emission control measures that simultaneously meet air quality objectives and targets on greenhouse gas emission reductions at least costs (Figure 6.2.1). Obviously, the quantification of the radiative impacts of air pollutants needs further research before it can be fully included into such an assessment framework.

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<th>NH₃</th>
<th>CO₂</th>
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Figure 6.2.1: The multi-pollutant/multi-effect approach of the GAINS model to search for cost-effective solutions that simultaneously meet air quality and climate objectives

Conclusions: A wide body of literature reveals important co-benefits on health and agriculture and direct cost-savings from the interactions between GHG mitigation and air pollution control. From an economic perspective, a partial analysis might not deliver cost-effective solutions and might lead to stranded investments. Controls of aerosol emissions can make CO₂ mitigation economically more viable. An integrated approach is necessary for a comprehensive assessment.
6.3 Challenges in the Inclusion of Climate Aspects in Treaties Concerning Air Quality and Ecosystems Effects

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Air pollution policies in Europe has been driven by science and been closely interrelated with scientific research all the time since the acid rain problem became part on the scientific and policy agendas about 40 years ago. It was through a joint research project led by OECD and involving several west European countries the transboundary dimension of sulphur dioxide emissions first was studied and evaluated. It then formed the basis for the Convention on Long-Range Transboundary Air Pollution (CLRTAP) signed in 1979, under which a large number of scientific activities have taken place, including the establishment of EMEP.

The policy role has since 2000 partly been taken over by the European Union and its programme Clean Air For Europe (CAFE) but most of the supporting scientific research still takes place through the Convention, which has a bottom-up approach requiring initiatives and support from the parties of the Convention.

Climate change has not been a key issue in the work under the Convention but it has been brought up in a couple of cases. The Kyoto protocol has been included in the scenario studies for the policy development. There have also been discussions on the relevance of including the very hot summer 2003 with very high ozone concentrations in the policy development. If climate change should be included to a full extent, there are several aspects that need to be considered. A changing climate may change the anthropogenic and natural emissions, source-receptor relationships (transport, chemistry and deposition) and ecosystem sensitivities. For some of the ecosystem effects, climate change will have a minor influence, for others the influence may be large.

Table 1. Ecosystem effects from climate change

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<tr>
<th>Ecosystem effect</th>
<th>Influence from climate change</th>
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<tr>
<td>Acidification of soils and waters</td>
<td>Small</td>
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<td>Eutrophication of terrestrial ecosystems</td>
<td>Moderate (increased N mineralisation)</td>
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<tr>
<td>Ozone effects to vegetation</td>
<td>Large (increased biogenic emissions, ozone formation, changes in uptake and effects)</td>
</tr>
<tr>
<td>POPs</td>
<td>Large (changes in transport and bioaccumulation in the Arctic region)</td>
</tr>
<tr>
<td>Mercury</td>
<td>Large (changes in transport and bioaccumulation in the Arctic region)</td>
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In 2005 a new Task Force on Hemispheric Transport of Air Pollution (TFHTAP) was set up with the objective to estimate the hemispheric (intercontinental) transport of air pollution. It is mainly considering ozone, particles, POPs and mercury. This task force has many issues in common with climate change. When e.g. considering ozone on a hemispheric scale, methane emissions are important and methane is both a climate gas and an ozone precursor. In addition
background ozone may reach concentrations causing negative growth effects on forest ecosystems over large parts of the N hemisphere and thus reduce carbon uptake and storage.

European air pollution problems will not be solved through the expected outcome of directives related to the CAFE strategy or the revision of the Gothenburg Protocol under CLRTAP. New strategies and negotiations are expected sometimes after 2010 and they may at that time need to consider expected changes in climate both over Europe and the Northern Hemisphere. If climate change is to be included, it is necessary to further develop our understanding on ecosystem behaviour and how the exchange of pollutants between the atmosphere and biosphere is influenced.
6.4 Cleaning the Air with Climate Change Policies?

Hans Eerens, Rob Swart and Chris Coppens  
Netherlands Environmental Assessment Agency (MNP), Netherlands

Introduction: In 2005 the EEA (European Environmental Agency) launched The European Environment: State and Outlook 2005, as part of this project a special EEA report, to be published in early 2006, “Air quality and ancillary benefits of climate change policies” has been prepared by the EEA’s topic centre Air and Climate change. The report describes the development of air quality in Europe up to 2030 under baseline assumptions and assuming a European climate action policy scenario. The report analyses the impact of climate action on the resulting air quality in Europe and considers the costs savings incurred by the climate action on air pollution control.

Air and climate policy: the need for integration: The report demonstrates that air pollution policy alone is insufficient to reach enough benefits to meet climate change targets, specific climate policies remain needed. Also climate policies alone are insufficient to reach air quality targets, air pollution policies remain needed. But policies to achieve European air quality goals (e.g. impact on number of coal fired power stations) make it easier and significantly cheaper to reach climate goals, and even more significantly; policies to reach climate goals make it easier and significantly cheaper to reach air quality goals. Hence, the two problems should not be considered in isolation!

Integration of air and climate policies reduces costs. Relative abatement cost savings for NOx, SO2 and PM are estimated at 20, 12 and 14 % by 2020, and more than 35, 25 and 25 % by 2030 compared to baseline assumptions without climate action. The costs that would be needed to reach the same air quality impact levels as in a “Climate Action” scenario by 2030 in

Figure 6.4.1 Development of emissions control costs (2000-2030) under baseline and climate action assumptions.
the EU25 with specific air pollution abatement measures would amount to about 12 billion Euro. The costs estimated to implement the CAFE Strategy through air pollution policies alone will increase significantly, up to 5 billion euro a year, if post-2012 climate change agreements will fail (see Figure 6.4.1).

**Climate action policies reduces air pollutant emissions:** In the Climate Action scenario, assuming no specific additional air quality control measures fine particulates emissions reductions occur, even for small CO₂ reductions. On the average 1% reduction in CO₂ results in 0.55% reduction in PM emissions, with the highest benefits in new Member States. In one case the increase in biomass use causes the PM emissions to rise, see Figure 6.4.2.

![Figure 6.4.2](image)

**Figure 6.4.2:** Expected CO₂ reductions in the climate action scenario, from baseline assumptions, in 2030 in the 30 EEA member countries and its impacts on PM emissions

**Climate action policies reduces air pollutant impacts:** Reduced emissions will lower the costs of emission control and simultaneously lower the impact of air pollution. Ozone impacts (SOMO35) are reduced by an average of 1.4% in the old EU-15 countries and 2.9% in the new (EU-10) member countries. The benefits for PM2.5 are even larger, -5.1% in the EU15 and 6.5% in the EU10, see Figure 6.4.3.

For ecosystems, the average accumulated exceedance (AAE) for nutrients decreases by 6% for EU25 and by 12% for acidification. The area of ecosystems which exceeded the critical loads for nutrients and acidification decreases by 1 percentage point for the EU25 (see Figure 6.4.4).
Conclusions and recommendations: Benefits of optimal air quality strategies for climate change policies requires more attention and integrated assessment models that can both address climate change policy options and air emission control options simultaneously should therefore further be developed (see presentation of Amann). Biomass is an option to reduce GHGs emissions but not all type of biomass use can be recommended from an air quality perspective. Therefore there is a need to differentiate “good” and “bad” biomass options from an air quality perspective. Further research in life cycle analysis of biofuels, addressing both GHG’s and air pollutants simultaneously, is required to resolve this important potential trade-off between the need for climate action and improving air quality.

Figure 6.4.3: Air quality benefits due to climate action by 2030

Figure 6.4.4: Eutrophication and acidification in Europe for 2030 under baseline, climate action and MFR (Maximum Feasible Reduction) assumptions.
6.5 Needs for Future Epidemiological Research

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Epidemiological research can be used to elucidate the causation and natural history of disease. It is also a useful tool in the description of health status and particularly in the evaluation of interventions to affect health. Air pollution epidemiology historically was mainly the investigation of episodes such as Dun Aura in 1948, Pozo Rico in 1950, London in 1952, The Meuse Valley in 1930, London in 1962 and Dublin in 1982. The Dublin smog was associated with the cold spell of weather with the temperature inversion and occurred some 30 years after the infamous London 1952 smog. It was noticed in that episode that the case fatality rate in a Dublin hospital, St James’, doubled during one week in January 1982. In that episode, levels as high as 1400 $\mu g/m^3$ were recorded during the smog. The mortality averaged 16 deaths per day for January, 22 deaths per day during the smog episode and a maximum of 38 deaths on a single day on the 14th June.

One of the interesting aspects of that episode was that half of the cardiovascular excess mortality occurred during the week of the smog which means that half of the excess mortality occurred after the smog was finished. Likewise, two thirds of the respiratory mortality excess occurred after the smog had subsided, as shown in Figure 6.5.1. The event gave rise to 33 excess deaths per 100,000 of population whereas London in 1952 was said to have given rise to 47 excess deaths per 100,000. Using epidemiological tools to look at episodes has limited effect and more recent approaches have widened this with the development of better methodology particularly in statistical analysis and especially with the development of time series analysis.

Such programmes include EU funded programmes such as COST 613, APHEIS 1 and 2, Aphea 1, 2, ENHIS, AIRNET, and CAFÉ. These by and large looked at short term health effects using routinely collected data analysed by time series analysis and concentrating on respiratory and cardiovascular effects, mainly mortality and hospital admissions. These studies have allowed the investigation of lags and longer duration effects. This was done in Dublin with the evaluation of an intervention on the 1st September 1990 when the sale, distribution and marketing of bituminous coal was made law and a subsequent analysis showed a dramatic decline in both black smoke and mortality from both respiratory and cardiovascular causes (Figure 6.5.2). These analyses have shown the effect on mortality not only extends beyond the immediate period but for several months. At the same time, these studies are limited and further research is badly needed into some characteristics of particles in particular their composition, and also an investigation of the importance of size and indeed their deposition in the respiratory tract. It is felt that only with this knowledge will it be possible to understand the varying effects of the various episodes and the variation, which undoubtedly occurs when the source of the particles is different.

One approach to this may be the investigation of environmental tobacco smoke (ETS), which is often controllable particularly at present when many countries are introducing or considering introducing bans on smoking in the work...
29th March 2004 and this afforded the opportunity to investigate the reduction in particles in terms of PM$_{10}$ and PM$_{2.5}$ (Figure 6.5.3) and in benzene as well as looking at the respiratory health effects by means of respiratory questionnaire, exhaled breath carbon monoxide and cotinine analysis as well as qualitative measurements of pulmonary function before and after the ban. These showed dramatic falls in exposure with demonstrable improvements in pulmonary function as well as dramatic improvement in symptoms.

It is suggested that this type of intervention research is very important if we are to understand the differences and the possibilities from environmental control.

**Research Approach:** It is suggested that research should be trans-disciplinary with epidemiology including molecular, public health, toxicology, genetic, psycho-social, and economic including behavioural economics and legal scientists, being involved from the beginning before studies are performed, rather than just in the analysis afterwards. Intervention allows this type of approach and the opportunities should be carefully sought and pursued in environmental research. It is also very important that research is translated so that it becomes accessible and understandable to the stake holders including the general population as well as the decision makers and policy controllers.

**Future Research Recommendations:** It is felt that routinely collected data will not answer all of the mechanistic questions and must be complimented by focused studies hopefully many of them being interventional. It is suggested that the research should be trans-disciplinary but this is not only in terms of scientists involved but also in the scientists who look at different aspects of the same problem *i.e.* outdoor and indoor exposures as well as health effects scientists. This should be translated quickly so that the policy makers and the public are appraised of the research outcomes.

![Figure 6.5.1](image_url) Mortality associated with acute episode of smog in Dublin in 1982 showing lag effect
Figure 6.5.2 Immediate and permanent drop in Black Smoke mass concentration following the ban on sale marketing and distribution of coal in Dublin in 1990

Figure 6.5.3 PM2.5 levels in Dublin pubs pre and post workplace Ban on smoking introduced on 29th March 2004
A range of different health effects have been associated with ambient air pollution. This includes increase in symptoms as well as worsening of pre-existing respiratory diseases such as asthma and COPD (Chronic Obstructive Pulmonary Disease) and cardiovascular disease including myocardial infarctions and stroke. Respiratory and cardiovascular diseases are also associated with increased mortality in relationship to variability in air pollution levels. While air pollutants in general may be associated with adverse health effects, the associations are often strongest in relationship to particulate matter air pollution. Health effects have for long been associated with black smoke or PM10, but in several studies there have been indications of more pronounced effects of the small particle range in terms of PM$_{2.5}$. In this respect, nitrogen dioxide, which often correlates with health effects, is largely seen as a surrogate marker indicating mainly traffic associated air pollution.

An increasing interest over the last years has been directed to what features of air pollution particles are causing biomedical effects. Several critical aspects have been identified and judged especially important to investigate:

- Size – coarse, fine, ultra fine and nanoparticles
- Chemistry - metals, hydrocarbons
- Source – traffic, wood, coal and other combustion, crustal material and road dust
- Particles of different chemical characteristics and size give different biological effects

Following the traditional focus on health effects associated with PM10, there have during the last years been assumptions that fine particle matter (< 2.5 $\mu$m) would carry more or less all of the toxicological potential of PM pollution. This was readdressed in a recent systematic epidemiological review. The authors systematically reviewed all literature which contained parallel measurements of fine and coarse PM (< 2.5 $\mu$m vs. 2.5 – 10 $\mu$m). The review by Brunekreef and Forsberg demonstrated that course PM also carry epidemiological health effects that sometimes are more pronounced that fine PM.

This was further addressed in a recent EU FP5 project (Health effects of particles from motor engines and ambient air, acronym HEPMEAP). This multicenter project included systematical collection and characterization of PM at a number of European sites with contrasting traffic, industrial and other contributions to local PM pollution. The particle samples from the two week sampling campaigns underwent detailed chemical characterization, which was followed by in-vitro screening of a range of toxicological aspects. Oxidative potential, cytokine production, arachidonic acid release and several other key components in inflammatory responses were investigated. Selected particles were taken forward for in-vivo experiments to evaluate coherence between in-vitro systems. An overall chemistry – toxicological – epidemiological evaluation was organized (see www.hepmeap.org). This first project, subsequently was followed by two sister projects (www.raiap.org and www.pamchar.org). The projects were able...
to confirm the recent epidemiological review indicating that at various sites, at various time points, it varies whether the main toxicological potential is carried by the fine or coarse particle fractions. The finding was systematical through a range of different assays. This indicates that course particles cannot be discarded as harmless, but carry adverse health effect potential. It was also demonstrated that oxidative stress appears to be a major pathway through which particulate matter air pollution can induce adverse biological effects. Production of arachidonic acid products in-vitro from alveolar macrophages correlated well with oxidative stress measured in-vitro with a series of tests. The majority of the toxicological potential was carried by metals with contributions by hydrocarbons. Endotoxin was also associated with high contributing effects.

In order to evaluate coherence between in-vitro and in-vivo experiments, selected particles from the preceding studies were instilled during bronchoscopy in human volunteers. Instillation of equal particle mass for different PM samples in different lung lobes, as compared with the diluents alone, demonstrated qualitative similarity and responses between the collected ambient particulate matters with diesel engine exhaust. Fine and coarse PM exerted similarities as well as differences in lung cell effects. Again like in the preceding studies, what effects were carried by what size fraction could vary.

From a toxicological point of view the very smallest airborne particles, often referred to as nanoparticles, carry considerable toxicological potential and are able through their sheer size to damage cells and cause adverse biological functions. These smallest particles are mainly produced through combustion, for example traffic, but carry very little particle mass due to their very minute size. Therefore, there can be major fluctuations in nanoparticle numbers in ambient air, which does not easily translate into mass particle measurements, which may be more affected by larger particles that carry substantial mass.

Organic compounds contribute to mass and substantially appear to contribute to toxicological capacity by particulates. The organic components can be of aliphatic, aromatic and polar types. They are very source dependent and many act through oxidative stress, are pro inflammatory and may cause cytotoxic and genotoxic effects. It has been demonstrated that polyaromatic hydrocarbons may be very reactive to cells. Additionally recent focus has been addressing the polar organic compounds called quinones. Investigators have demonstrated that different aliphatic, aromatic and quinone components from for example diesel engine exhaust contribute substantially to different cell effects. The most reactive can be the quinones which even affect cell breathing.

A series of experimental studies have been performed in which human subjects have been investigated after an air exposure as well as after concentrated ambient particulates (CAPs) or diesel engine exhaust exposure. Diesel engine exhaust appears to have produced the most pronounced inflammatory effects in the airways, with asthmatic subjects suggested to be particularly sensitive. Their sensitivity in the airways to respond to irritants with airway narrowing was doubled a day after diesel exposure. Cardiovascular effects have also been identified in terms or alterations of the cardiac rhythm which can potentially be dangerous in diseased individuals. A most important recent study demonstrated diesel engine exhaust to be able to substantially reduce the capacity in the blood vessels to widen in demand for more blood flow, as well as reduce the release of a key anti-coagulation component from the blood vessel wall. These effects by an air pollutant mainly consisting of nanoparticles rich with
organic components may be critical for the atherosclerotic blood vessels in individuals at risk for heart attacks and stroke, conditions known to exacerbate in association with PM air pollution.

Conclusions and potential policy implications of toxicological findings on particulate matter: PM from traffic generally have a high toxic potential. Coarse and fine PM are both capable of inducing toxicity. The chemical composition of PM plays an important role and although the view on causative components is not definite, metals and hydrocarbons appear to be most strongly associated with the biological responses studied. Ambient PM was shown to be potent in producing a Th-2 shift and allergy type responses in animals, which also has support in several experimental studies in humans.

Toxicological mechanisms elicited by PM pollution in general and diesel exhaust in particular, have been identified in healthy as well as diseased human subjects investigated in experimental studies. People with pre-existing diseases in the lungs and cardio-vascular system appear to be especially sensitive.

Decision-makers should integrate PM composition in terms of size and chemical characteristics, and toxicity research findings in further refining PM risk assessment, as well as in designing and improving air quality management strategies.

Figure 6.6.1 Bronchoscopy investigation of research subject after PM air pollution exposure

Figure 6.6.2 Alveolar macrophage after ingestion of air pollution particles
6.7 Requirements and Challenges facing the EMEP Model and Operational System

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Introduction. The EMEP models have been used as basis for chemical transport calculations under policy development of air quality control in Europe. The latest model, the Unified EMEP model, was used to support the development of the new Thematic Strategy on Air Pollution, adopted by the European Commission last September. The robustness of the Unified model formulation, the performance of the model for long-term simulations and the modeled response to emission changes were evaluated in a scientific review in 2003 (http://www.unece.org/env/documents/2004/eb/ge1/eb.air.ge.1.2004.6.e.pdf). The review of the model identified the premises that allowed for its use in the recent air quality policy development.

Future air quality control policies will require a better understanding and better quantification of the effects of aerosols and gases, and will have to deal with the impact of air pollution on climate change. Below follows a short overview of how such requirements affect the current development of the EMEP modeling system.

Development of EMEP as a community model: the nested model system: In the last few years, the EMEP Unified model has been developed to allow a flexible choice of the horizontal resolution and domain extension. This implies that the EMEP model can be now extended to cover the entire northern hemisphere, providing information on the hemispheric background contribution to regional air quality. At the same time, it can also be used for dispersion model calculation in a limited European region with higher spatial resolution. Since the actual levels of ozone and fine particles are affected by emissions, transport and chemical processes at different scales, the nested modeling system is intended to facilitate the use of the EMEP model at national level.

The description of physical and chemical transformation and removal processes in the EMEP model is appropriate for describing synoptic scale processes, down to a scale of 5*5 km². This scale is however not sufficient to describe local air pollution problems and needs to be further coupled with national, mesoscale and street canyon models in order to determine the change in the air pollution levels when moving from the regional scale to urban air.

The open source code of the EMEP model is already in use in the United Kingdom and further national applications are under discussion. The system provides a consistent methodology to evaluate different source contributions to observed air, from hemispheric background, to regional levels, to urban air and pollution impacts on different ecosystems. However, it requires yet a considerable effort to validate the hemispheric and the mesoscale versions of the EMEP model in a level comparable to what has already been achieved at regional scale. Cooperation at national level is absolutely necessary to carry out the validation of the model at different scales and establish the robustness of its assumptions on source allocation.

Improved evaluation of Particulate Matter. The present focus of the Unified model development for Particulate Matter (PM) is on its chemical characterisation, since it is an important component to understand the origin of fine particulates in air. The work to support
the Thematic Strategy has been mostly concerned with a proper representation of the main anthropogenic components of PM, namely secondary inorganic aerosols and primary PM. Natural sources and the formation of secondary organic aerosol (SOA) were not included in the work for the Thematic Strategy, mostly because natural sources are not eligible to policy control, and because the scientific understanding of the formation of SOA was not considered to be robust enough to support policy conclusions. However, to understand the mass closure of PM, such sources need to be considered in the EMEP model.

Recently, natural emissions of PM from sea salt, wind-blown dust and biomass burning have been included and tested in the model. In addition, secondary aerosol formation both from biogenic terpene emissions from vegetation and from anthropogenic VOC emissions is also included and under evaluation. The inclusion of the natural component of the aerosol introduces a considerable number of assumptions which require additional validation. While the work on these natural sources is helpful to indicate the relative contribution of these sources to PM levels in different European regions, the actual extent of their contribution requires further evaluation. Even for sea salt, where production over the ocean is relatively well established, the comparison of modelled results with observations in air and in precipitation shows discrepancies that require further attention.

The main uncertainties, however, are related to the carbonaceous content of PM. The general underestimation of modelled elemental (EC) and organic carbon (OC) in PM has significant policy implications because it relates to the robustness of the existing emission estimates for primary PM. Sensitivity tests for the different anthropogenic and biogenic components of OC and EC are presently carried out and are validated against chemical tracer measurements, in order to determine the robustness of primary emission inventories from different activities. The initial results are similar for OC and EC and indicate residential combustion and wood burning as a major uncertainty sector. Further evaluation is needed in order to assess the policy implications of such findings.

Links from air quality to climate change. The detailed analysis of the chemical speciation of aerosol presently carried out under EMEP is relevant also for a better understanding of the hygroscopic properties of the aerosol and can contribute to an improved representation of the role and contribution of aerosols in future climate. Up to now, policy applications have requested from the EMEP model to provide a robust characterisation of the meteorological variability of air quality in order to represent possible weather conditions 20 years from present. Traditionally, the meteorological variability has been characterised with a series of multiyear runs and has shown that for particulate matter, year to year meteorological conditions in the present climate can change the aerosol mass concentrations in Europe by 20 to 30%. The most significant removal mechanism for long range transport of PM is wet removal and the frequency of rainfall is more important than the total amount of rainfall to determine such removal. The time between precipitation events determines the lifetime of aerosol in the free troposphere. A key question for future impact analysis of PM is to determine how precipitation is changing with climate.

The characteristics of precipitation are apt to change as climate changes and prospects are greater for changes in extremes of floods and droughts than in total precipitation amounts. These changes in the hydrological cycle will have consequences for the distribution of aerosols,
their size distribution and chemical composition and in return, changes in the aerosol characterization and loading will have implications in future climate conditions.

Results: Annual Average OC, year 2003 (ug/m3)

Figure 6.7.1 Modeled calculations on annual averaged concentrations of organic carbon (ug/m3) and percentage contribution of biogenic secondary organic aerosols to total organic carbon. (David Simpson, personnel communication.) http://www.emep.int/
6.8 Atmospheric Aerosols at the Urban, Regional, and Global Scales

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During the 80s and 90s the urban air quality problems related to aerosols (PM$_{10}$, PM$_{2.5}$, visibility) and the aerosol-climate interactions were viewed as two different research areas with relatively little overlap. The problems in major urban areas were considered as local issues that could be solved by proper accounting of the local sources of primary particles. At the same time, the research on remote marine, desert dust, free tropospheric, and biomass burning aerosols on global scales appeared to have little to offer towards the solution of urban aerosol problems. At the same time the modeling tools used at the urban, regional, and global scales were quite different. The urban scale models were attempting to be as comprehensive as possible including the fundamental science while the most of the first global aerosol chemistry models were semi-empirical.

During the last few years it has become apparent that while there are significant differences in the research and policy driving forces at the urban, regional, and global scales there is also a lot of overlap. Most of the overlap exists at the atmospheric process level. The same processes take place at all scale. The fundamentals of condensation/evaporation are the same for particles over Los Angeles, Dublin, and the Fiji islands. The relative importance of the different processes may change at different scales or areas of the world, but the fundamentals do not. Often measurements at regional or even urban background sites provide excellent opportunities to learn about processes important at the global scales (water uptake, nucleation, aerosol thermodynamics and partitioning, secondary organic aerosol formation, etc.). Such sites can provide multiple benefits for the solution of research problems at all scales and more of them are required. The recent work in the US PM Supersites has strongly suggested that semi-continuous physical and chemical measurements of aerosols for long periods of time (a year or more) are valuable. These measurements can be used both for improving our understanding of atmospheric aerosol processes but also for improving the existing Chemical Transport Models used in all scales.

There are efforts in creating modeling tools that describe aerosols at all scales (from urban to global). The US EPA is funding six such efforts investigating the effect of climate change on regional and urban air quality in the US. These efforts are leading to numerical models that describe at the same time the global climate, global atmospheric chemistry, but also the local air quality. These efforts are also leading to the gradual convergence of the tools that are used for the description of the aerosol processes at all scales. The development of comprehensive global scale aerosol models that can be used as benchmarks will allow the improvement of the “engineering” versions of these models.

Applications of the chemical transport models in the Eastern US have suggested that the response of the ultrafine particle concentrations to emission controls can be counterintuitive. For example, reductions in emissions of sulfur dioxide by as much as 40% in an effort to reduce PM$_{2.5}$ mass concentrations are predicted to cause increases of the frequency of sulfuric acid-ammonia-water nucleation events during the summer (thus increasing total PM number...
concentration). On the other hand reductions of ammonia emissions reduce the frequency of nucleation events in this area in all seasons.

Figure 6.8. Modeling framework used by the Carnegie Mellon team for the simulation of the global, regional, and urban scale aerosols.
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6.9 Status on Global Climate Model Performance

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In the public perception air pollution is a priority issue only in numerous urban areas and, practically all megacities, whereas climate change is recognized as a global problem. However, air pollution is largely driven by the same emissions as climate change (i.e. traffic, energy sector, agriculture: e.g., CO, hydrocarbons, SO\textsubscript{2} and NO\textsubscript{x} emissions). Emission control for the environment and climate protection requires to quantify source attribution to specific aerosol effects by modelling. In addition, climate respectively weather controls transport and removal of pollutants as well as emissions from natural sources. Most studies so far neglected the impact of climate change on emissions and cycling of atmospheric trace substances.

Development of air quality and climate models occurred independently by different communities although the processes represented in models are the same. Both climate change and air quality models specify aerosols according to sources, both need to capture spatial and temporal subscale processes and use surface networks for evaluation. Climate models make in addition use from satellite retrieved optical properties as aerosol optical depth and Angstroem parameter. For the performance of global aerosol models see AeroCom model comparison, Kinne et al., 2003\&2005; Textor et al., 2005 or browse the web page http://nansen.ipsl.jussieu.fr/AEROCOM/objectives.html.

For most locations the highest air pollution health risks are posed by fine and ultrafine aerosols, by polycyclic aromatic hydrocarbons which are mostly associated with fine and ultrafine aerosols. Thus, air quality models include rather detailed hydrocarbon chemistry, whereas in aerosol models applied in long-term climate simulations (=order of hundred to some thousand years) secondary organic aerosol are highly parameterized or even neglected. On the other hand, air quality models predict often just mass concentrations for PM2.5 or PM10 regulations, whereas advanced aerosol schemes in climate models simulate not only aerosol mass concentration but additionally internal properties such as size distribution and state of mixture in order to assess the aerosol indirect effects. An example of such advanced schemes is shown in Figure 6.9.1 for the ECHAM model where the HAM multi-modal aerosol scheme is used. In this scheme, multi-component aerosol number and mass, and state of mixing, is represented.

Global model based aerosol distributions are uncertain and due to the coarse resolution and the lack of data for evaluation, these models do not fulfill requirements of air quality issues on a local scale. Air pollution models capable to address human health may need a spatial resolution large enough to resolve concentration gradients in street canyons, i.e. on the order of some meters. However, impact from remote sources by long-range transport may be important for longer-lived species and has to be taken into account.
The aerosol size-distribution is resolved by a superposition of seven log-normal modes, three externally mixed and unsolvable, four internally mixed and soluble. With this approach, mass concentration, number concentration and state of mixture can be predicted.

The most recent global climate model simulations have supported the concept that anthropogenic aerosols have been masking the greenhouse-gas induced global warming and that with future reductions in emissions of sulphur, the rate of global warming is likely to increase. The recent day masking is demonstrated through examination of the increase in SO\textsubscript{2} emissions from 1950 to 2000 (Figure 6.9.2) and the associated reduction in global warming over the same period (Figure 6.9.3). Future predictions with constant and reduced (to zero) SO\textsubscript{2} emissions illustrate significant impacts on increasing temperature, with the largest temperature rise associated with reduced emissions.
Figure 6.9.3: CO₂ concentrations from 1850 to 2000 (insert) and observed global temperature increase. Note the temporary levelling off of warming from 1940 to 1980, after which temperatures begin to rise significantly again.

Figure 6.9.4: Observations and predictions of surface air temperature from 1950 to 2100. Prior to 2000, data in black are from observations while the blue and red lines are the model predicted temperature from ECHAM. The blue data corresponds to constant SO₂ emissions while the red line corresponds to zero SO₂ emissions post 2000.
6.10 On the Interaction of Climate Change and Air Quality

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We have examined the impact of an equilibrium climate in year 2100 driven by the projected change in CO2 concentration from IPCC SRES A2 on predictions of global ozone and aerosols by online GCM simulation of coupled tropospheric ozone-NOx-hydrocarbon chemistry and sulfates, nitrate, ammonium, black carbon, primary organic carbon, secondary organic carbon, sea salt, and mineral dust aerosols.

Using the GISS GCM II’ with a q-flux ocean, we predict an increase of 4.8°C in global mean surface air temperature in year 2100, as a result of the projected increase in CO2 from 368 ppmv in year 2000 to 836 ppmv in year 2100. Year 2100 global mean precipitation is predicted to be 10% higher than that for year 2000; predicted changes in temperature and precipitation agree qualitatively with those of previous studies. The model predicts a weakening of the Hadley cells in the warmer 2100.

We have performed four chemistry simulations, denoted CL2000EM2000, CL2100EM2000, CL2000EM2100, and CL2100EM2100, to assess the roles of CO2-driven climate change and IPCC projected changes in emissions in influencing levels of tropospheric O3 and aerosols. The differences between simulations CL2100EM2000 and CL2000EM2000 indicate that, with no changes in anthropogenic emissions, the CO2-driven climate would change global O3, sulfate, nitrate, BC, POA and SOA burdens by -11%, -9%, -47%, -13%, -9% and +9%, respectively. Although the global O3 burden is predicted to be reduced as a result of lower net chemical production of O3 in the warmer climate, surface-layer O3 concentrations over populated and biomass burning areas are predicted to increase as a result of climate change, owing to slower transport and enhanced biogenic hydrocarbon emissions. Climate change influences aerosol burdens mainly by altering wet deposition, climate-sensitive emissions, and aerosol thermodynamic equilibrium.

Accounting for both the CO2-driven climate change and changes in emissions in simulation CL2100EM2100, the year 2100 global burdens of O3, sulfate, nitrate, BC, POA and SOA are predicted to change by +49%, -16%, +181%, +109%, +111% and +54%, respectively, as compared with simulation CL2000EM2000. Based on the IPCC SRES A2 scenario, the changes in anthropogenic emissions play a more dominant role in determining future levels of tropospheric ozone and aerosols than does climate change. Sea salt and mineral dust burdens are predicted to be reduced by 19% and 16%, respectively, in year 2100.

We also examine the effects of CO2-driven climate change on estimates of year 2100 direct radiative forcing by O3 and aerosols. By comparing simulations CL2000EM2100 and CL2100EM2100, the effect of climate change alone on radiative forcings can be discerned; accounting for ozone and aerosols from both natural and anthropogenic sources, the predicted global mean TOA direct radiative forcings of O3, sulfate, nitrate, BC, OC, internal mixture (internally mixed sulfate, nitrate, BC, and OC), and external mixture (externally mixed same aerosols) change from +1.06, 0.97, -1.09, +1.26, -0.56, -0.26, -1.22 W m-2 in CL2000EM2100 to +0.85, -0.93, 0.78, +0.97, -0.58, -0.48, -1.20 W m-2 in CL2100EM2100,
respectively. The CO$_2$-induced changes in global burdens, surface albedo, and clouds have a large influence on radiative forcing of absorbing species and nitrate aerosol.

The climate induced percentage changes in global O$_3$ and aerosol burdens as well as the absolute changes in year 2100 direct radiative forcings summarized above for the simulations in the absence of heterogeneous reactions agree closely with those obtained in their presence. When the reactions of N$_2$O$_5$, NO$_3$, NO$_2$, and HO$_2$ on wet aerosols, the uptake of SO$_2$ by sea salt, and the uptake of SO$_2$, HNO$_3$ and O$_3$ by mineral dust are considered, although hydrolysis of N$_2$O$_5$ is less in the warmer climate and the uptake by sea salt and mineral dust is reduced as a result of lower burdens of sea salt and mineral dust in year 2100, heterogeneous reactions are still influential in year 2100 concentrations of O$_3$, sulfate, and nitrate; accounting for the changes in both climate and emissions, the year 2100 burdens of O$_3$, sulfate, and nitrate predicted in the presence of heterogeneous reactions are 14%, 26%, 15%, respectively, lower than those predicted in their absence.

The results of this study suggest several avenues for improvement and future research. First, biogenic emissions of O$_3$ and SOA precursors as well as the mineral dust emissions are based on fixed vegetation and land types, which can be improved with a prognostic treatment of vegetation and land type. Second, O$_3$ transport from the stratosphere is fixed in all the simulations reported here; this is expected to be climate-sensitive and can be improved with a GCM having a better representation of the stratosphere. Finally, and most importantly, the radiative effects of predicted ozone and aerosols in future years should be fed back into the GCM to assess complete chemistry-aerosol-climate coupling.
Figure 6.10.1. Effects of Climate Change and Projected Emissions on global burdens of O₃ and aerosols.
7. List of Participants

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<tr>
<th>Name</th>
<th>Institution</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markkus Amann</td>
<td>International Institute for Applied Systems Analysis (IIASA)</td>
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<td>Science Shop DTU / Videnskabsbutikken DTU</td>
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<td>Fabrizia Cavalli</td>
<td>EC-Joint Research Centre</td>
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<td>Luke Clancy</td>
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<td>Hans Eerens</td>
<td>EEA - European Topic Centre</td>
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<td>Maria Cristina Facchini</td>
<td>CNR-ISAC, Bologna</td>
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<td>Peringe Grennfelt</td>
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<tr>
<td>Leonor Tarrason</td>
<td>Met Norway</td>
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<td>Kjetil Torseth</td>
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<td>Ib Troen</td>
<td>European Commission DG Research</td>
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<tr>
<td>Michael Young</td>
<td>Department of Environment</td>
<td>Ireland</td>
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<tr>
<td>Svetlana Tsyro</td>
<td>Met Norway (EMEP)</td>
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<tr>
<td>Patrick O'Sullivan</td>
<td>Department of Environment</td>
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<td>Saji Varghese</td>
<td>NUI, Galway</td>
<td>Ireland</td>
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