

CARP WORKSHOP REPORT

Policy Summaries

Policy Summary – Theme 1, Project 1

Sources of ozone precursors and atmospheric chemistry in a typical Australian city

Ian Galbally, Sarah Lawson and Martin Cope

Centre for Australian Weather and Climate Research – A partnership between the Australian Bureau of Meteorology and CSIRO, CSIRO Marine and Atmospheric Research

Introduction

Ground-level ozone is not emitted directly into the air, but is formed when the precursor pollutants, oxides of nitrogen (NO_x) and volatile organic compounds (VOC), react in the presence of sunlight. The process of ozone formation is complex and highly non-linear with respect to precursor emissions, photochemistry and meteorology. Sources of ozone precursors include motor vehicles, oil refining, printing, petrochemicals, lawn mowing, aviation, bushfires and prescribed burning. Biogenic emissions from vegetation can also be a significant source of VOC. For example, up to 20% of ambient VOC in Melbourne and up to 64% in Brisbane is estimated to be emitted from vegetation.

Ozone is an air pollutant of major concern in Australia, in terms of human health impacts. The highest ozone levels are found in Sydney and Melbourne, with Brisbane and Perth also experiencing occasional high levels. From 1994 to 2004, the Sydney region experienced a total of 108 exceedence-days for the one-hour NEPM standard and 138 exceedence-days for the four-hour NEPM standard, with no clear trends established for ambient ozone levels in the Sydney basin.

In recognising the significant health impacts of ozone, all jurisdictions have established, as part of their air quality management plans, measures to reduce emissions of ozone precursors. To aid the development of effective precursor emission measures, jurisdictions have developed air emission inventories. These inventories include emissions from all known precursor sources. Photochemical smog models are then applied to inventory data to assess the likely impacts of potential emission reduction measures.

The purpose of this study was to develop and demonstrate techniques for validating the various components of the air emissions inventories and photochemical models. A subsidiary aim of the study was to compare methods for measuring ambient levels of selected air toxics.

Principal Findings

The study assessed emission estimates for Sydney from three inventories, the NSW Department of Environment and Climate Change (DECC) 2007 Inventory, the National Pollutant Inventory (NPI) and the Model inventory (currently used for photochemical smog modelling in Sydney), for their utility in airshed modelling.

- For the key pollutants CO, NO_x, toluene and xylenes (the latter two being both ozone precursors and air toxics), there was good agreement of atmospheric observations with the three inventories, with the exception being that toluene emissions from the Model inventory were over estimated.

- Inventory emissions of benzene (an air toxic), methanol, methyl ethyl ketone and acetonitrile were also tested against atmospheric observations and were shown to have differences that are statistically significant.
- The DECC 2007 and Model inventories for isoprene (the dominant VOC emitted from trees) required a minor correction in order to correspond with the atmospheric observations (note that the NPI inventory does not include vegetation-based [biogenic] emissions).
- An additional group of important VOCs including formaldehyde, acetaldehyde (both of which are ozone precursors and air toxics), and acetone are both directly emitted and formed in the atmosphere from chemical reactions and thus could not be tested by the techniques used here.

The differences between emissions inventories and atmospheric observations were minor for the anthropogenic photochemically active VOCs in Sydney. However, they were more significant in the case of benzene.

The second objective of this work is to make atmospheric measurements to test the chemical mechanisms of photochemical models. The key results are:

- The production of secondary oxidation products in the models was tested, with the production of formaldehyde predicted by the model being low and the production of acetaldehyde being well simulated by the model.
- The concentrations of isoprene, a biogenic VOC, were initially underestimated by the models at Bringelly, probably due to incorrect characterisation of the emissions in that area. A revised isoprene emissions inventory improved both the modelled isoprene and ozone concentrations.
- The revised biogenic isoprene emissions inventory makes a measurable improvement to the ozone modelling across the Sydney airshed.

Finally, the limited analyses that were carried out indicated that both measurement systems measured comparable concentrations of benzene, toluene, ethyl benzene and xylenes under the low concentrations observed.

Policy Implications and Limitations

This work has implications for policy development relating to the management of ozone (and also secondary aerosol) in Australian cities. Biogenic VOCs, coupled with the contribution of anthropogenic VOCs, make an important contribution to ozone exceedences. Modelling results can clarify the relative contributions of anthropogenic and biogenic VOCs and the relative advantages of VOC vs. NO_x control strategies for reducing ozone exceedences within a particular airshed.

Further development of the biogenic emissions inventory is likely to have a significant impact on improving the accuracy of ozone modelling in the downwind regions of the Greater Metropolitan Region in Sydney. This procedure would also lead to better targeted ozone management strategies in other Australian airsheds.

A key emerging issue is how ozone and other photochemical pollutants will respond to climate change. In this regard, there is currently an incomplete understanding of how both biogenic and anthropogenic emissions will respond to climate change to robustly answer this question. The analytical techniques applied in this project can be used to further this understanding and lead to more robust modelling of air quality and climate change.

The atmospheric measurements have provided new tests of the chemical mechanisms within these atmospheric photochemical models. When the results of these tests are assimilated into the models through improvements to the chemical schemes, then current optimal control strategies may be slightly altered.

Policy Summary – Theme 1, Project 2

Development of tools for the identification and quantification of secondary organic aerosol in Australian cities

Melita Keywood and Martin Cope

Centre for Australian Weather and Climate Research – A partnership between the Australian Bureau of Meteorology and CSIRO, CSIRO Marine and Atmospheric Research

Introduction

Particulate matter (PM) has been identified as the largest contributor to air pollutant health impacts and costs in Australia. PM is caused by direct emissions (i.e. domestic wood combustion, diesel exhaust, bushfires) and from chemical reactions in the atmosphere (secondary PM). Secondary PM can be inorganic (i.e. sulphate and nitrate) or organic in composition. The presence of secondary PM is an issue for regulators because it reduces the efficiency of gains made through the control of direct emissions of PM alone. Because of this, the control of the precursor chemicals which lead to the formation of secondary PM should also be considered. However, such a step can only be considered if the relative contribution of secondary PM to the total PM mass is known, and if the pathways of secondary PM generation are understood.

While secondary inorganic PM generation is reasonably well observed and understood, secondary organic PM, or aerosol, (SOA) is currently difficult to measure directly, and the methods of generation are poorly understood. SOA is produced in the atmosphere by the oxidation of volatile organic compounds (VOCs) of biogenic or anthropogenic origin, to produce semi-volatile compounds that can partition between the gas phase and the surface of existing particles.

Until this work, the contribution of the secondary organic fraction to ambient PM has been unknown, and there has been no accepted method for the identification and quantification of SOA. This work has explored the development of a number of tools for the measurement of SOA and has provided, for the first time, an estimate of the SOA concentration within the Melbourne airshed.

Principal Findings

The tool developed in this project offers the most practical, potentially cost effective and accurate method for the measurement of SOA. The tool while initially involving additional cost and effort (for up to two-years) due to a requirement to collect particulate samples for the organic chemical analysis, utilises existing criteria pollutant monitoring data to derive estimates of organic carbon concentrations from which hourly SOA concentrations can be determined. The tool has proven successful at one location in the Melbourne airshed and further work is currently underway to ensure the method can be applied to other airsheds.

Using this tool the daily averaged SOA concentration at Aspendale, Victoria, between 1 May 2005 and 31 January 2007 to be $2.04 \pm 2.09 \mu\text{g m}^{-3}$, and the annual average concentration for 2006 to be $2.11 \pm 2.27 \mu\text{g m}^{-3}$. The $\text{PM}_{2.5}$ annual average for 2006 ($11.8 \mu\text{g m}^{-3}$) is almost 50% greater than the NEPM advisory of $8 \mu\text{g m}^{-3}$. During 2006, SOA was estimated to comprise 18% of the $\text{PM}_{2.5}$ mass.

The 24-hour $\text{PM}_{2.5}$ advisory standard was exceeded on 21 days during 2006 and 30 days over the entire measurement period. While most of the $\text{PM}_{2.5}$ exceedences occurred during autumn/winter (due to woodsmoke from domestic heating) and summer (due to bushfires), the highest fractions of SOA could not be consistently ascribed to a particular season. Hence, for days with $\text{PM}_{2.5}$ exceeding the NEPM advisory standard, the average SOA fractions in winter and summer are similar (10% and 11% respectively). However, on the days the NEPM $\text{PM}_{2.5}$ was exceeded, the maximum SOA fraction (49%) occurred in association with bushfire smoke in January 2007. It is considered that SOA present in this smoke resulted from the emission of volatile organic compounds within the bushfire smoke, and the subsequent reaction of these VOCs during transportation of smoke from its source to the measurement site at Aspendale.

The project also explored the incorporation of an SOA formation mechanism into a three-dimensional regional airshed model. The SOA model in its current form under-estimated SOA (compared with observed concentrations) by a factor of 10-20. This level of under prediction for SOA is typical of models reported in other work around the world.

Policy Implications and Limitations

This work has implications for policy development governing the management of fine particle pollution in Australian cities. Management of fine particle loadings and exposure in large cities including Sydney and Melbourne, for the PM_{2.5} advisory standard are likely to be a significant challenge due to the contribution of natural aerosol components and particles generated within the atmosphere by SOA production, from precursor VOCs both of biogenic and anthropogenic origin.

The fraction of PM_{2.5} comprised of SOA during NEPM exceedences (11%) is lower than the fraction of PM_{2.5} comprised of SOA during all of 2006 (18%), suggesting that during exceedences, the primary sources of aerosol are more significant. This implies that controlling the primary sources of aerosol will make a greater contribution to controlling PM_{2.5} exceedences than controlling secondary sources. However, when considering health costs of PM_{2.5}, the SOA contribution of up to 20% of PM_{2.5} mass, and the complicated, potentially toxic compounds that comprise SOA, should be considered significant.

SOA can be produced from the oxidation of VOCs of both anthropogenic and biogenic origin. In terms of policy it will be important to understand whether anthropogenic or biogenic VOCs contribute more to SOA production in a particular air shed. The contribution of each of these VOC precursor groups has not been quantified in this work, although the organic chemical components of the SOA predominantly consisted of products formed by the oxidation of biogenic compounds. Biogenic VOCs contribute to the background concentration of VOCs in the urban environment, making them difficult to control (short of removing vegetation or reducing the concentration of oxidants such as ozone). Recent work in Sydney has indicated that biogenic VOCs make a major contribution to ozone formation in the Sydney airshed (see Galbally et al. 2008: CARP Project No. 17).

While modelling results thus far under predict the measured SOA, only a limited group of precursor VOC compounds have been incorporated into the model, so that further development of the model is required. However, the SOA model is a potentially powerful tool for understanding the contribution of biogenic and anthropogenic VOCs to SOA formation. Continued model development and verification of the model by measurement data (including organic speciation and carbon isotopes) will provide the information for which policy governing the control of fine particles (with respect to the contribution of SOA to fine particles) can be based.

Policy Summary – Theme 1, Project 3

Composition and structural studies of the secondary organic aerosol component of PM_{2.5} arising from the NEPM air toxic precursors: toluene and m-xylene

Dennys Angove¹, Stephen White^{1,2}, Melita Keywood^{3,4} and Merched Azzi¹

1. CSIRO Energy Technology, PMB 7, Bangor, NSW, 2234
2. Macquarie university, Department of Chemistry & Biomolecular Sciences, NSW, 2109
3. CSIRO Marine and Atmospheric Research, PMB 1, Aspendale, VIC, 3195
4. Centre for Australian Weather and Climate Research, PMB 1, Aspendale, VIC, 3195

Introduction

Health studies consistently demonstrate that exposure to particulate matter (PM) can lead to significant health impacts. PM can be emitted directly from a range of sources, such as motor vehicles and woodheaters, or can be formed through atmospheric reactions (secondary PM). Secondary PM can be either inorganic or organic. The mode of formation for inorganic secondary PM is reasonably well-understood. In contrast, far less is known about the atmospheric chemistry relating to the formation of secondary organic aerosol (SOA).

This study examines the formation of SOA from the smog precursors toluene and m-xylene, which are covered by the Air Toxics NEPM. These compounds are emitted in significant quantities from motor vehicles and previous research indicates that they can contribute to the formation of SOA.

In this study, toluene and m-xylene were introduced into a smog chamber and the formation of SOA was tracked. A total of 39 smog chamber experiments were performed. Field studies were also conducted.

Principal Findings

In all experiments where SOA formation was observed, the SOA mass concentration yields varied with time. For a fixed hydrocarbon concentration, the SOA mass concentration was observed to increase, and onset time was earlier with higher ROC/NO_x ratios.

Components such as glyoxal, methylglyoxal, pyruvic and oxalic acid were identified but, since they are common gaseous products that arise during photo-decomposition of many non-aromatic as well as aromatic compounds, their presence in SOA can only be considered evidence of SOA formation from non-specific precursors. Benzaldehyde and dihydroxytoluene, which are specific for toluene, were also identified.

SOA is likely to form from toluene or m-xylene when these precursors are in sufficient concentration to promote the oxidation of NO to NO₂ to a concentration below which NO₂ is no longer able to control O₃ by titration to form NO₂ and O₂. Generally this condition occurs under high ROC/NO_x ratios. If the absolute hydrocarbon and NO_x concentrations increase whilst maintaining a fixed ROC/NO_x ratio, then the SOA mass concentration is expected to increase with increasing absolute concentration.

Comparisons were made between Fourier Transform Infra Red (FTIR) spectra collected from field samples obtained from Rozelle, Sydney, during winter and summer with smog chamber samples of SOA formed during toluene, m-xylene and unleaded petrol photo-decomposition. There were some obvious similarities between the FTIR spectra of the field sample collected in summer with all smog chamber samples. This was not the case for the winter sample. The FTIR spectra of the winter sample suggested that organic incorporated oxygen was very low. The solubility of the summer sample in water was high whereas the winter sample was low. These comparisons support the view that the summer sample was produced by strong oxidising conditions and was therefore, predominantly SOA. It should be noted that these results were based on one winter sample and one summer sample, only.

Policy Implications and Limitations

The results demonstrate that, under conditions of high ambient toluene m-xylene concentrations, significant SOA may be generated even with relatively low ambient NO_x levels. However, the SOA contribution to total PM_{2.5} needs to be determined in a definitive manner. In any assessment of ambient SOA concentrations where a direct tracer species is not used, it is difficult to determine whether the SOA is produced from biogenic or anthropogenic precursors.

Under ambient conditions in air, there are many hydrocarbons that can contribute to SOA formation, according to their reactivity. Moreover, SOA formation from a given anthropogenic hydrocarbon precursor depends on the ambient plume interacting with it, since such a plume would also contain hydrocarbons emitted from biogenic sources. More research is required to investigate the interaction of anthropogenic and biogenic emissions as well as the chemical mechanism of SOA formation before air quality modelling can accurately predict the contribution of SOA to the urban aerosol burden. Outcomes from such research would also assist in clarifying the effect that SOA formation has on modifying climate processes.

SOA is characterised by low volatility and potentially poses a significant health threat, as this work shows that much of the mass is comprised of particles significantly smaller than 2.5 µm.

The smog chamber experiments conducted in this study indicate that air quality management actions that reduce the ROC/NO_x ratio may be effective in reducing the generation of SOA resulting from toluene and xylenes emissions. It should be noted that any SOA control strategy may influence air quality in other ways ie changes to the ROC/NO_x ratio will also influence ozone formation. It should also be noted that policy conclusions arising from this study need to be treated with some caution when applying to ambient air, as real world conditions were not simulated in these smog chamber experiments.

Policy Summary – Theme 1, Project 4

A methodology for determining the impact of climate change on ozone levels in an urban area

Martin Cope, Sunhee Lee, Bill Physick, Debbie Abbs, Kim C Nguyen and John McGregor

Centre for Australian Weather and Climate Research – A partnership between the Australian Bureau of Meteorology and CSIRO Marine and Atmospheric Research

Introduction

There is concern that the impacts of climate change in many regions in Australia may include significant increases in the frequency of drought, hot days and high fire risk weather. Such events have important implications for air pollution and health, with photochemical smog severity (as typified by near-surface ozone concentrations) linked to the frequency of hot, sunny days. Also, high particle concentration days are typically linked to the presence of bushfire plumes and/or wind blown dust. In addition, particles and ozone are also linked, with enhanced ozone concentrations often observed on bushfire days and with 50% or greater of fine particle mass potentially of photochemical origin.

The principal objective of this Clean Air Research Project was to develop a methodology that is able to give estimates of photochemical smog concentrations (as ozone) under climate change conditions, for any period or location in Australia and, specifically, to give an insight into the impact of climate change on ozone levels in Sydney in 20 and 50 years time. Successful demonstration of such a goal is also considered a prerequisite for undertaking the more ambitious goal of developing projections of particle-related health impacts under climate change.

The methodology developed for this project comprised a combined weather and air quality modelling system which uses a global climate model climatology to generate suburb-level variations in weather and air pollution for a designated urban area. This process was undertaken for the current decade for Sydney in order to test the ability of the system to model the existing suburb-scale weather and ozone pollution behaviour, and then run using a single climate projection for 2020–2030 and 2050–2060 to examine potential future changes in ozone pollution.

Principal Findings

We were able to demonstrate that it is possible, under summer conditions in eastern Australia, to take a global climate model climatology and, using the detailed meteorological and air quality modelling system, to generate realistic suburb-scale weather and ozone pollution patterns for the Sydney region for the current decade.

Projected changes in Sydney weather and peak ozone concentrations were calculated for a global climatology based on an A2 SRES greenhouse gas emission scenario (a high end CO₂ emissions growth scenario) and for a range of Sydney air pollution emission scenarios. When air pollution emissions were held fixed at current decade levels, it was found that the climate change scenario resulted in a 40% (2020–2030) and 200% (2050–2060) increase in the projected number of hospital admissions due to ozone pollution relative to 1996–2005. Analysis of the model results suggests that the increase in ozone-related morbidity resulted from an increase in daily maximum temperatures and the subsequent flow-on effects to factors which control ozone generation, such as the emissions of volatile organic compounds (which react to form ozone and are emitted at higher rates as temperatures increase), and increases in ozone precursor production rates (which also increase with ambient temperature).

The project also modelled the emission reductions required to achieve compliance with Ambient Air Quality National Environment Protection Measure (AAQ NEPM) ozone standards in Sydney, for ozone generated under the 2051–2060 climatology conditions. Ozone concentrations were predicted on the basis that emissions of carbon monoxide, volatile organic compounds and oxides of nitrogen (i.e. the precursors required for ozone generation) were progressively decreased by 40% and 60% compared to current decade

emission rates. It was found that, although the most stringent emission reductions lead to a 25 and 36% reduction in peak 1-hour and 4-hour ozone concentrations, respectively, this was not sufficient to achieve compliance with the current AAQ NEPM standards for ozone.

Policy Implications and Limitations

The modelling indicates that ozone concentrations in Sydney are sensitive to small increases in temperature due to climate change. It is likely that this outcome would also apply to other major cities in Australia, and that airsheds which currently comply or marginally comply with the AAQ NEPM objectives for ozone may have the potential to become non-compliant under climate change conditions unless anthropogenic precursor emissions are reduced to offset the effect of increasing temperatures. This situation is likely to be more pronounced if a stringent eight-hour ozone standard is introduced.

The climate projection modelling undertaken in this project was restricted to a single A2 SRES greenhouse gas emissions scenario and a small suite of anthropogenic emission scenarios. This limits the application of the results for policy use because there is no accompanying estimate of uncertainty. An accepted methodology to estimate uncertainty is through the generation of an ensemble of downscaled results based on alternative International Panel of Climate Change (IPCC) emission scenarios, and other global climate models.

The modelling did not consider the impact of bushfire smoke on ozone generation. The relationship between ozone enhancement and bushfire smoke is well recognised in Australia and climate projection modelling indicates that a substantial increase in fire risk is likely in some regions of Australia.

The largest air pollution health impacts and health costs in Australia are associated with fine particles. Emissions from many of the particle sources are strongly dependent on meteorology and thus will respond to climate change. For example, daily fuel usage for domestic wood combustion and associated particle emissions will be influenced by projected increases in overnight minimum temperatures. Similarly, paved road dust emissions are a function of rainfall frequency and thus such emissions may increase in a drier climate. Bushfire risk is a function of wind speed, relative humidity and precipitation history and wind blown dust incidence is a function of soil dryness, ground cover and wind speed. Both bushfire and dust storm frequencies are influenced by the frequency of droughts, with the frequency of the latter projected to increase under global warming. Given these facts, it is considered that the expansion of the model to include fine particles is a priority area for future work.

Policy Summary – Theme 2, Project 1

Assessment of different approaches to determining personal exposure

W Physick¹, J Powell¹, M. Cope¹, K Boast¹, S Lee¹, W Lilley², R Gillett¹ and G Edgar³

¹CSIRO Marine and Atmospheric Research, ²CSIRO Energy Technology, ³Environment Protection Authority Victoria

Introduction

Population exposure to air pollution is typically assessed through measuring air pollutant levels at ambient (outdoor) monitoring networks. In reality, people are exposed to air pollution in a range of indoor and outdoor environments. Therefore, to accurately assess exposure to air pollution requires the quantification of all the important sources of exposure, not just ambient exposure.

Knowledge of the relationship between personal exposure (including indoor environments and particular outdoor environments such as near-road) and ambient levels of air pollutants allows more certainty in the setting of ambient air quality standards. A more accurate methodology for estimating personal exposure in epidemiological analyses (which generally only consider urban exposure as determined through ambient monitoring) would lead to greater certainty in quantifying the impacts of air pollutants on population health.

The primary aim of this research project is to evaluate methodologies for estimating personal exposure from ambient monitoring data and from simulation data obtained through complex ambient air quality models. Ultimately, it is hoped that our recommended methodology can be used in epidemiological studies.

We focus our efforts on nitrogen dioxide (NO₂), but also present measurements and modelling of fine particulate matter (PM_{2.5}). Our conceptual model of NO₂ exposure involves linking personal exposure to ambient exposure using indoor-outdoor ratios. We evaluated three approaches to calculating ambient exposure and three methods of estimating indoor-outdoor ratios. We field tested our methods by having between 15 and 17 volunteers wear personal passive NO₂ samplers across Melbourne for four two-day periods in May and June 2006, and April and May 2007. Participants also wore additional samplers for sub-periods of each 48-hour exposure, at home, at work and in transit. Participants recorded their activities in a diary. PM_{2.5} concentrations were continuously measured over the same periods by four volunteers with portable DustTrak monitors.

Principal Findings

A wide range of NO₂ personal exposures (average concentrations over 2 days), from 6.1 ppb to 19.8 ppb, was experienced across the different activity profiles of the participants. The highest exposures were measured in the transit microenvironment (maximum value of 46.2 ppb), but the major portions of the total exposure (exposure multiplied by time spent in an environment) were experienced at home and at work.

The highest personal exposure did not exceed the maximum ambient NO₂ concentration measured by the EPA Victoria monitoring network, suggesting that, for our people profile (office workers, stay at home people and one outdoor worker), the maximum monitored concentration is a likely overestimate of the city's population exposure. However, for 19% of measurements, the personal exposure was less than the minimum concentration measured across the monitoring network, indicating that assigning the city's maximum ambient concentration to everyone would, in fact, strongly overestimate exposure.

Ratios of indoor to outdoor concentrations in homes varied from 0.12 to 1.37 (mean 0.57 ± 0.27), with extreme values attributed to indoor NO₂ sources and to low ventilation rates in new houses. Ratios at workplaces were all less than 1.0 (no indoor sources) and showed much less variability (mean 0.74 ± 0.16). For each home, a mass balance equation was used to calculate indoor NO₂ concentrations,

given the outdoor concentration. This approach gave good agreement with the measured indoor concentrations (correlation 0.78).

For PM_{2.5}, the range of personal exposure (two day mean concentration for each event) lay within the range of two day mean ambient values measured across the EPA Victoria monitoring network. The indoor concentration trends tracked hourly-averaged ambient concentrations from the nearest monitor, with short-term deviations associated with activities in the home. The one minute averages of PM_{2.5} in each microenvironment showed short-period concentration variations (two to 15 minutes) reaching values five to 10 times higher than the longer-term average concentration. These findings are relevant in the light of epidemiological and toxicological work showing stronger respiratory health impacts from PM_{2.5} concentrations measured over intervals shorter than the NEPM Advisory Reporting Standard, which has an averaging period of 24 hours.

The concentration of NO₂ at a nearest network monitor (e.g. to work or home) is a good proxy for ambient concentration/exposure at that microenvironment. This ambient value is then used with an indoor/outdoor ratio to estimate personal exposure in the microenvironment. Estimates from an air quality model's gridded fields blended with monitor values gave equally good results, but the method is more cumbersome. Evaluation statistics were considerably poorer for a commonly-used method whereby each person is assigned the same ambient concentration, taken to be the mean concentration across all network monitors.

For estimation of the personal exposure to NO₂ of a large number of people, such as in an epidemiological study, it is recommended that best results would be obtained with the indoor/outdoor ratio calculated from a mass balance method that requires participants to record daily gas cooking periods and approximate house age, although a simpler but slightly less accurate method (which only recorded the existence, or otherwise, of a gas cooking appliance) also produced satisfactory results.

Policy Implications and Limitations

This study has identified a simple exposure methodology that can be widely applied, without the use of air quality models, using only minimal information collected from respondents. The work contributes to the debate about the degree to which data from the NEPM monitoring networks are capturing population exposure, as opposed to just providing an assessment of the upper bound of regional air quality. Certainly for NO₂, the study findings suggest that the existing EPA Victoria network for Melbourne provides data that are representative of population exposure to ambient air pollutants.

The study takes ambient exposure estimates one step further by calculating personal exposure, which is strongly influenced by personal behaviour and activities. At all times, the study found that 2-day average personal exposure levels were below the highest ambient concentration measured by the monitoring network. Results from personal PM_{2.5} measurements have policy implications, particularly in relation to including a shorter averaging time for the AAQ NEPM PM_{2.5} Advisory Reporting Standard.

At this stage, the findings of the study can only be related to NO₂ and to the existing EPA Victoria monitoring network, although it is expected that the methodology would also be valid for cities with networks of similar density to that of Melbourne. The design of the measurement program could also easily be applied to other pollutants, to provide similar information on population and personal exposure. Following our finding that the major exposure components occur in the home and work environments, we omitted the transit environment from our model. We also assumed that all participants were at home between 1800 Eastern Standard Time (EST) and 0800 EST, and at work between 0800 EST and 1800 EST. Consequently, the findings are only relevant to persons who spend the majority of their time at indoor work and/or home during standard working hours. Results may be different for those who drive for a living or who spend a significant amount of time near roads. To better characterise exposure for those situations, further work should be done to relate transit exposures to key variables, including traffic volume and ambient concentration from the nearest monitor.

Repetition of the work, ideally in another city and with a higher number of participants, is highly desirable and would strengthen the findings of this project. More participants would also widen the variety of homes, workplaces and even ages, so that the findings can be applied more widely.

Policy Summary – Theme 2, Project 2

Development of metrics for individual exposure assessment to traffic related air pollution

Christine Cowie¹, Nectarios Rose¹, Guy Marks¹, William Lilley³, Rob Gillett², Bin Jalaludin⁴, Geoff Morgan⁵, Bill Physick²

¹Woolcock Institute of Medical Research; ²CSIRO Marine and Atmospheric Research; ³CSIRO Energy Technology; ⁴School of Public Health and Community Medicine, University of NSW; ⁵Department of Rural Health (Northern Rivers), University of Sydney.

Introduction

Air pollution is linked to a range of health effects including increased risk of mortality, hospitalisation, respiratory symptoms, decline in lung function, and abnormalities in various biomarkers that indicate cellular-level effects. More recently, research has focused specifically on health effects attributable to exposure to traffic-related air pollution. However, establishing a clear quantitative relationship between health effects and exposure to traffic-related air pollution is challenging, often because of poor or inadequate exposure information.

This project explored a number of methods for assigning individual level (household) exposure to traffic-related air pollution using nitrogen dioxide (NO₂) as a marker of traffic pollution. We measured NO₂ at 35–40 locations using passive gas samplers (ambient and personal samplers) and used data from four fixed site air quality monitors in the study area, as well as traffic and land use data to develop the exposure assessment methods.

The methods used for estimating the spatial distribution of NO₂ included:

- land use regression modelling (three models) based on data from passive samplers
- interpolation based on data from NO₂ passive samplers
- emissions-based dispersion modelling for NO₂, and particulate matter (PM₁₀ & PM_{2.5})
- proximity measures (e.g. distance to main road)
- fixed-site monitoring data, and
- personal passive NO₂ monitoring.

The work was conducted in conjunction with an ongoing study investigating respiratory symptoms in residents living in the vicinity of the Lane Cove Tunnel. The best-performing exposure assessment method for predicting individual household exposure will be used in the epidemiological study to test the associations between changes in traffic-related air pollution associated with the tunnel and various measures of respiratory health status.

Principal Findings

Of the models tested, the land use regression (LUR) models were the most reliable in predicting NO₂ exposures and agreed most accurately with the measured passive NO₂ levels. The models were able to explain a high proportion of the spatial variability in NO₂ exposure.

The most complex LUR model (a mixed model incorporating a temporal component using data from fixed-site monitors in the area) demonstrated the greatest ability in predicting NO₂ exposure in the study area. The predictor variables for the LUR models were consistent with those reported internationally and included: traffic density, population density, commercial land use and the fixed site data.

The emissions based models (i.e. LWM, TAPM and TAPM-interpolated) were found to perform reasonably well when compared to the fixed site monitors, but were found to have poorer agreement with the passive NO₂ sampler readings. However, these models can be useful for predicting pollutants not easily measured at multiple locations or predicting pollutants over small time intervals.

Interpolation of data from passive samplers using kriging was unreliable for predicting NO₂ exposure, probably due to the lack of autocorrelation in the data given the small-scale urban environment and the choice of NO₂ as the pollutant. Kriging is likely to be more successful when interpolating data for pollutants that have a more regional influence e.g. ozone.

The proximity measures (e.g. distance from main road), while readily available and easy to apply did not perform as well as the LUR models. This was expected because the LUR models incorporate additional explanatory factors and a more sophisticated measure of traffic exposure than that used in the proximity measures. However, where resources are limited for exposure assessment work, or where exposures need to be assigned retrospectively, use of proximity measures could be used.

Personal sampling of NO₂ was found to be useful for describing the range of NO₂ exposure levels for adults and children and was found to correlate reasonably well with household NO₂ exposure for adults but less so for children. Although we are uncertain, there is anecdotal evidence that the degree of compliance in wearing the samplers is lower for children than for adults given the activities that children engage in. This may affect the readings recorded for some children.

On average personal NO₂ exposure was about 2 ppb lower than for ambient household exposure, which is consistent with overseas study results. After adjusting for outdoor household levels of NO₂, personal exposure was related to indoor sources of NO₂ (cooking with gas stoves and ovens).

Policy Implications and Limitations

This study has examined a number of methods for assigning exposure to traffic-related air pollution in an urban environment. Ultimately, the type of exposure methods used for epidemiological or other studies and policy decisions need to be tailored to the resources available and the study or policy question to be answered. All of the methods tested have their utility as well as advantages and limitations. It is important to recognise these when designing future studies.

These exposure methods provide a toolbox for health researchers for application in future studies and will help to reduce exposure misclassification and hence reduce measurement bias in studies. The associated epidemiological study will provide information for policy makers by better describing the potential for and magnitude of health effects associated with traffic related air pollution in an Australian setting.

This study applied exposure assessment methods to NO₂ (and PM₁₀ & PM_{2.5} for emissions modelling) in a relatively small urban area. It is recommended that LUR models (also incorporating temporal information where possible) and emissions modelling be further tested with other pollutants and in other Australian settings (e.g. across larger urban areas) to determine whether the models perform consistently.

Policy Summary – Theme 2, Project 3

Urban-scale population exposure: does chemical transformation need to be considered?

Martin Cope, Sunhee Lee, Ian Galbally and Rob Gillett

Centre for Australian Weather and Climate Research – A partnership between the Australian Bureau of Meteorology and CSIRO Marine and Atmospheric Research

Introduction

The aim of this project was to investigate the level of chemical detail which is required in air quality dispersion models to accurately and defensibly model the urban concentrations of the reactive air toxics formaldehyde, toluene and the xylenes.

The principal driver for this project was the Air Toxics National Environment Protection Measure (AT NEPM). The goal of the AT NEPM is to collect data on ambient (i.e. outdoor) levels of formaldehyde, toluene, xylene, benzene and PAHs at sites where elevated levels are expected to occur and where there is a likelihood that significant population exposure could occur. The AT NEPM provides guidance on information that can be used for identifying such sites and this information can include data taken from emission inventories and air quality dispersion modelling.

However, the use of dispersion modelling data for site identification is potentially of concern because, overwhelmingly, urban-scale air toxic modelling undertaken to date in Australian cities has treated air toxics as unreactive. This means that the modelled compounds are emitted and dispersed in the atmosphere without taking into account changes in concentration due to chemical reactions. Of the air toxics considered in the AT NEPM, the reactive compounds toluene, xylene and formaldehyde are identified as being of potential concern with respect to this assumption. Formaldehyde is of particular concern because it is both lost through reaction and generated as a product of reaction from other compounds which are commonly present in urban and rural atmospheres.

Given this background, the main objectives of the project were as follows.

1. To assess the ability of an air quality dispersion model to reproduce the observed concentrations of formaldehyde, toluene and xylene in Melbourne and Sydney.
2. To investigate how the peak modelled concentrations of toluene, xylenes and formaldehyde for Melbourne and Sydney compare to the AT NEPM Monitoring Investigation Levels (MILs) for these pollutants.
3. To determine the degree of error associated with modelling toluene, xylenes and formaldehyde without considering chemical reactions.
4. To provide a recommendation as to the optimal level of model complexity required to achieve a defensible outcome when dispersion modelling is used to identify monitoring sites for AT NEPM purposes.

Principal Findings

A limited comparison of modelled and observed air toxic concentrations (with the modelled compounds treated as reactive) was undertaken for Melbourne and Sydney and it was found that the level of agreement was generally sufficiently good as to justify the use of dispersion modelling to estimate peak concentrations of toluene, xylenes and formaldehyde away from the limited number of locations where air toxics concentrations were quantified through monitoring programs.

The modelling suggested that peak concentrations of toluene and xylenes were relatively small compared to AT NEPM MILs (a result which was also consistent with monitored concentrations). For example, peak

modelled 24-hour toluene and xylenes concentrations comprised less than 4% and 16% of their respective MILs (1000 ppb and 250 ppb) and peak modelled annual average toluene and xylene concentrations comprised less than 15% and 9% of their respective investigation levels (100 ppb and 200 ppb). Peak modelled 24-hour formaldehyde concentrations were considered to be more significant but still relatively small, comprising 25% of the MIL for formaldehyde of 40 ppb.

The omission of chemical reactions when modelling toluene and xylenes was found to be insignificant, leading to errors in the peak 24-hour and annual average concentrations of less than 0.5% of the monitoring investigation levels. Given that the peak concentrations only comprise 16% or lower of the investigation levels anyway, it was concluded that the degree of error associated with treating toluene and xylenes as unreactive is small and that the error in any event leads to a slightly conservative (over estimate) result. In the case of formaldehyde, the omission of chemistry in the dispersion modelling lead to under predictions of up to 13% of the 24-hour monitoring investigation level.

A similar exercise was undertaken for the calculation of urban population exposure to toluene, xylenes and formaldehyde. Population exposure was calculated using annual average concentrations and population density and when coupled with unit risk factors may be used to calculate cancer risk and population health costs. In the case of toluene and xylenes, the omission of chemical reactions in the dispersion modelling caused population exposure to be over estimated by up to 11 and 27% respectively. In the case of formaldehyde, the omission of chemical reactions caused population exposure to be under estimated by up to 63%.

Policy Implications and Limitations

These results presented above indicate that the urban-scale peak concentrations of toluene and xylenes are relatively small compared to their monitoring investigation levels and that the additional accuracy associated with modelling the chemical reaction of these species is not currently justified. In any event, the omission of chemical transformation makes the modelled concentrations slightly conservative.

There is a stronger need to consider the chemical reaction of formaldehyde in urban-scale dispersion modelling because chemical transformation leads to net increases in the concentrations of formaldehyde and because peak 24-hour formaldehyde concentrations are closer to the MIL for formaldehyde. The modelled urban population exposure magnitude is also sensitive to the chemical reaction of formaldehyde. Note that this result is only applicable for urban-scale impacts. Formaldehyde concentrations immediately downwind of significant primary sources of formaldehyde such as airports, roads and some industries will be dominated by the direct emissions of formaldehyde and hence modelled concentrations will be less sensitive to the treatment of chemical reactions in such cases.

Policy Summary – Theme 2, Project 4

Towards the integration of bioanalytical tools for air pollution assessment, regulation and management

Jochen Mueller, Michael Bartkow and Janet Tang, Miroslava Macova and Karen Kennedy

University of Queensland, Research Centre for Environmental Toxicology (EnTox)

Introduction

Air pollution is comprised of a mixture of chemicals of known and unknown toxicities, and identification of the potential risks they pose when acting in combination remains a challenge. The current practice for assessing exposure to air pollution is through monitoring programs based on a subset of presumably representative indicator species. The toxic effects of air pollutants are usually determined for specific individual chemicals. Establishing procedures for realistically assessing population risk for short and long term exposure to mixtures of toxic air pollutants is clearly of strong public interest, and is a national issue.

This study was designed to assess the usefulness of using bioanalytical tools, together with selective chemical analysis, to characterise the toxicity of air samples on living systems (i.e. bacterial cells). Air samples were collected from 12 sites using a filter-adsorbent sampling system (which nominally separate particle and gas phase components). The sampling sites represented different indoor and outdoor exposure scenarios (i.e. outdoor industrial, industrial/urban, traffic corridors, residential and background rural; and indoor industrial, office and domestic). Samples were analysed initially using four different assays with a refinement in the final stage of the project to three toxicity endpoints including:

- i) genotoxicity
- ii) Ah-receptor response (i.e. dioxin-like activity)
- iii) estrogenic/antiestrogenic response.

Principal Findings

The results of the study showed that:

- extracts of both the gas and particle phase samples exhibit a genotoxic response and differences were observable between the sites
- samples collected from most sites elicited an Ah-receptor response, with the highest responses associated with the particle phase of samples, and
- most air samples showed a response for estrogenicity and in all cases the gas phase was more estrogenic than the particle phase.

Highlights of the study included:

- the gas phase samples from office sites and samples collected from what would be considered as relatively 'polluted sites' such as high traffic areas, produced similar genotoxic responses
- the gas phase of air samples was often more genotoxic than the corresponding particle phase
- chemical analysis could only account for a very low percentage of genotoxic response
- the Ah-receptor response in the sample collected at the high density residential site was greater than expected for the concentrations measured in samples from both high traffic sites
- further testing of two samples indicated that the Ah-response was probably due to chemicals other than dioxins and dioxin-like PCBs, and
- samples from indoors exhibited the highest estrogenicity of all samples.

Policy Implications and Limitations

This study demonstrates that we are exposed to pollutants that have a range of potential health effects at diverse sites, including in our offices, where we usually expect exposure to be low. The results challenge the traditional view that particles represent the greatest exposure risk compared to the gas phase, and that exposure to pollutants at high traffic and industrial sites exceeds exposure indoors and in residential areas. While industrial and vehicular related sources were associated with the release of genotoxic pollutants and chemicals capable of causing Ah-receptor responses, the sources of genotoxic chemicals in indoor air, particularly in offices, needs further investigation as does the sources of chemicals causing an Ah-receptor response in high-density residential areas.

These results also highlight limitations associated with current approaches to managing air quality. For example current air quality standards in Australia are limited to several criteria outdoor air pollutants. More monitoring is proposed under the Air Toxics NEPM, targeting a few volatile organic chemicals (e.g. benzene) and one indicator for PAH (benzo[a]pyrene). However the testing in this project showed that effects are occurring after the loss of the volatile chemicals from samples during processing. Furthermore, the measured chemical concentrations of benzo[a]pyrene and 14 other PAHs could not account for the genotoxic response measured in the assay. These results show that the traditional approach to air quality management which targets specific chemicals may underestimate the potential risk of exposure at certain sites including indoor locations where humans spend a significant amount of time.

Taking into consideration the limited number of sites, this study demonstrated that the applied techniques can provide very useful information for assessing potential health effects resulting from exposure to air pollutants and identify specific chemicals that should be targeted. The study has expanded the toolbox available for characterising air quality. Importantly this project also shows that the results from the bioanalytical assessment of air samples can be communicated in terms that are meaningful for air quality managers using specific toxic equivalencies for comparison to guideline values. This approach has the added advantage of accounting for significantly more of the chemical constituents in a sample.

While this project has delivered a range of useful outcomes, it is acknowledged that the number of sites and samples collected was limited and further work is required at more sites in the future. It has also identified areas that require further work to improve the applicability of these techniques to air quality management including:

- incorporating, where available, in-vitro tests based on human cell lines as replacements for tests such as the umu assay which use a bacterial cell line
- investigating which chemicals may be causing the genotoxic response
- sampling for other classes of air pollutants such as the volatile organic chemicals
- collecting different particle size fractions for testing in bioassays
- investigating opportunities to close the gap between in-vitro and in-vivo testing and increasing the relevance of in-vitro toxicity testing for both acute and chronic end points

Policy Summary – Theme 3, Project 1

Particles, ozone and air toxic levels in rural communities during prescribed burning seasons

Mick Meyer, Fabienne Reisen, Ashok Luhar, Jenny Powell, Sunhee Lee, Martin Cope, Melita Keyword, Ian Galbally (CAWCR, Aspendale, Vic), Kevin Tolhurst (UoM, Creswick, Vic), Lachie McCaw (DEC, Manjimup, WA), Simone Linfoot (DECC, Sydney, NSW), David Parry (CDU, Casuarina, NT)

Introduction

Information on rural air quality in Australia is sparse. While smoke from biomass burning, such as the prescribed burning of forests, wildfires and stubble burning, is often blamed as the major source of air pollution in rural centres, there is little data on the significance of these impacts. This study monitored air pollutants at four sites in rural Australia between 2006 and 2008. Fine particles (PM_{2.5}), ozone (O₃) and BTEX (benzene, toluene, ethylbenzene and xylene) were monitored for 12 months at Manjimup WA, Ovens VIC, and Casuarina NT. PM₁₀ was monitored at Wagga Wagga, NSW. The specific issues addressed in the study were:

1. The seasonal exposure of rural population centres (defined as centres outside the State capital cities with more than 1000 residents) to priority air pollutants resulting from prescribed burning or agricultural waste burning activities.
2. The contribution of emissions from prescribed burning to ambient ozone concentrations experienced by these communities; and
3. The extent to which ambient pollutants from prescribed burning penetrate into houses and, hence, the potential impact of smoke on the total (ambient and indoor) exposure levels of the resident population.

Principal Findings

Monitoring data indicates that biomass burning has a substantial impact on rural population centres in Australia, with the main pollutant of concern being PM_{2.5}. Emissions from prescribed burning contributed to PM_{2.5} levels in rural centres that were comparable to, or significantly higher than, levels measured in Australia's urban centres. The Ambient Air Quality National Environment Protection Measure (AAQ NEPM) ozone standard was exceeded only during protracted forest wildfires. BTEX concentrations did not approach the Air Toxics NEPM (AT NEPM) monitoring investigation levels (MIL) at any rural site.

At Manjimup, the four exceedences of the AAQ NEPM PM_{2.5} Advisory Reporting Standard were caused by plume strikes, mostly from spring burns with one event in autumn from an unidentified source. During these days PM_{2.5} exceeded the Standard for around 20% of the time. The site at Ovens in NE Victoria was similarly affected during the autumn prescribed burning season; during this month-long period, smoke impacted the town on 12 days of which seven exceeded the PM_{2.5} Standard. The impact of the 2006/7 wildfires had a substantial impact on Ovens causing exceedence of the PM_{2.5} Standard on 13 of the 31 days monitored during the event. Darwin air quality was most affected by savannah fires throughout the dry season, with 3 exceedences of the PM_{2.5} Standard during June and July.

The emissions of two woody biomass smoke tracers, laevoglucosan and non sea salt potassium (nss-K⁺) were characterised for forest fuels in Southern Australia. Analysis of particle samples from Ovens and Manjimup confirmed that more than 80% of the PM_{2.5} recorded during the periods of wildfire and prescribed fire impact were from woody biomass combustion. Preliminary analysis of particle samples from Darwin also indicate that biomass combustion was the main source. Wagga Wagga was more seriously affected by fine particle pollution than the other three sites. During autumn, particle levels at the Wagga monitoring station are among the highest in the NSW network. The correlation between the seasonal and diurnal timing of the exceedences and stubble burning activity within the regions strongly suggests that stubble burning is the cause.

Ozone is formed in smoke plumes by photochemical reactions involving NO_x and VOCs produced during combustion. Elevated ozone concentrations were only observed in plumes exposed to sunlight for several hours prior to impact. These conditions occurred during the wildfire season at Ovens, the spring burning season at Manjimup and in Darwin, but not during autumn prescribed burning periods in Ovens or Manjimup.

In Darwin, average concentrations of benzene, toluene, ethyl benzene and xylene between July and September (mid to late dry season) were 0.13, 0.68, 0.36 and 0.89 ppb, respectively. Although these are low relative to the AAT NEPM MILs for the relevant air toxics, the low benzene to toluene ratio suggests that much of these VOCs were emitted from vehicles rather than biomass combustion sources.

Detailed modelling of smoke transport in the Northern Territory produced predictions of Darwin PM_{2.5} surface concentrations that were consistent with the observations. Predictions of the spatial distribution of PM_{2.5} air quality across the northern region of the Northern Territory showed that most of the region was seriously impacted each year. Hot spots of poor PM_{2.5} air quality, with up to 10 exceedences per month of the Standard, were predicted in an extensive region around Darwin in the early dry season, and up to 5 exceedences per month in central and SE Arnhem Land in the late dry season. There was little interannual variation in the pattern of smoke impact for the modelled period, 2003 to 2007.

The impact of prescribed burning on the indoor air quality of residences depended on the duration of the smoke event and the ventilation rate of the houses. During events that persisted for several days, which occurred at Booralite, VIC, during wildfires in January 2007, indoor air quality was determined by external conditions coupled with management of household ventilation rate.

Policy Implications and Limitations

In regions of high fire activity dispersion modelling shows that impacts are protracted and extremely widespread. Therefore, it can not be assumed as is currently the case, that rural air quality is always good and that regional air quality monitoring and regulation is mostly unnecessary in these areas. For criteria pollutants other than particles, the impacts are dependent on season, and the duration of plume strike. Options to minimise impact from prescribed burning include:

- Limiting burning to months of lower solar radiation and minimising its duration. This would include scheduling ignition times to minimise both photochemical ozone formation and the risk of trapping smoke in town airsheds under a nocturnal inversion;
- Planning burns to optimise smoke dispersion away from towns and valleys.

Areas of the current study that could usefully be strengthened or extended include:

- Characterising the emission properties of the smoke tracers laevoglucosan and nss-K⁺ in order to quantify the proportion of PM_{2.5} concentration attributable to biomass burning in the tropical savannah woodlands, grassland and cropping regions;
- Extending the smoke dispersion modelling to both prescribed fires and wildfires in Southern Australia. Due to time constraints this was not completed in the current study;
- A more comprehensive measurement programme to explicitly target smoke infiltration rates and indoor exposure during the autumn, spring and wildfire seasons; and
- Extending annual or longer-term monitoring for particles and other criteria pollutants to other regions and towns in rural Australia.

Although the study was designed to address prescribed burning, wildfires were found to cause major impacts. The study of wildfire emissions requires a network of monitoring stations that can be strategically and rapidly located during wildfire events. The changes in smoke composition with plume ageing are currently poorly understood but potentially significant, particularly when smoke is transported long distances. Secondary pollutants such as ozone are formed during transport and therefore the duration and timing of plume dispersion is likely to affect the toxicity of the smoke that impacts rural towns. Smoke transported into urban airsheds raises background concentrations of pollutant species, adding to the burden from urban pollutant sources and the formation of secondary pollutants. This needs quantification.

Policy Summary – Theme 3, Project 2

New assessments of vehicle air pollution emissions and health effects using advanced on-road remote sensing technology

Jeff Bluett¹, Katie Dey¹, Gavin Fisher²

¹National Institute of Water & Atmospheric Research Ltd, ²Endpoint Limited

Introduction

Detailed information on vehicle fleet emissions is required for air quality modelling and design of emission reduction strategies. Laboratory vehicle emission testing delivers information on a small sample of vehicles. This project provides a large, detailed database of on-road emissions of Australian vehicles using remote sensing technology. The data has been analysed by vehicle type, fuel usage, size and age and has been used to refine estimates of health effects associated with vehicle emissions.

On-road emissions measurements of four key automotive pollutants (carbon Monoxide (CO), hydrocarbons (HC), NO_x (Nitrous Oxides) and smoke (a proxy measure for particulate matter under 10 microns in size (PM₁₀)) were obtained from 53,000 vehicles – 22,000 in Brisbane, 10,000 in Perth and 21,000 in Sydney – using on-road remote sensing technology.

Approximately 89% of the monitored fleet were petrol vehicles, 8% were diesel and the remaining 3% were gas or dual-fuel (gas and petrol). The average age of the vehicles in the sample fleet was 6.9 years old (manufactured in 1998-1999) which is three to four years newer than the average age of all vehicles registered in Australia (10 years).

Principal Findings

Petrol and gas vehicles were found to have higher carbon monoxide (CO) emissions than diesel vehicles, while gas vehicles have higher hydrocarbon emissions (HC) than petrol or light duty diesel vehicles. Diesel vehicles had higher emissions of oxides of nitrogen (NO_x) and particulates (smoke) than petrol and gas vehicles. For petrol vehicles, emissions of all pollutants increase with vehicle age. This trend is also observed for emissions of CO, HC and particulates from diesel vehicle, however in contrast, the emissions of NO_x do not appear to vary significantly with the age of diesel vehicles.

Emissions also varied with vehicle speed and acceleration. Emissions of all four pollutants increased significantly under congested driving conditions.

Emissions for all four pollutants were dominated by a small number of gross emitting vehicles. The ‘most polluting’ 10% of vehicles are responsible for about 70% of CO emissions, 60% of smoke and HC emissions and about 50% of NO_x emissions. The cleanest 60% of the fleet contributes less than 10% of the total emissions for each pollutant. Gross emitting vehicles tended to be older vehicles (ten years plus). Petrol vehicles were more likely to be gross emitters of CO. Diesel vehicles were more likely to be gross emitters of NO and particulate.

Estimates were also made of the air pollution health effects and costs from the tail-pipe emissions from vehicles tested. The health effect results using remote sensing emission factors are up to 175% greater than those using ADR (Australian Design Rules) factors. This is mostly as a result of higher emissions measurements from the in-service fleet compared to the emissions that would be measured from new vehicles under ADR test conditions. The case study demonstrates that the choice of tail-pipe emissions factors is a critical step in health effects assessments.

Policy Implications and Limitations

The project demonstrated that there are a number of ways in which vehicles can potentially be regulated through targeted policy to achieve a reduction in emissions of air pollutants. Transportation and air quality

improvement strategies identified by this project that could help to achieve a reduction in vehicle emissions include:

1. Identifying and removing the 10% of gross emitters from fleet
2. Targeting high emitters with inspection and maintenance schemes
3. Encouraging vehicle tuning through public awareness campaigns
4. Replacing older emissions control technology and/or retrofitting appropriate emissions control technology, and
5. Minimising congested traffic flow.

Data collected in the project can also be used to:

1. Benchmark Australia's fleet emissions for 2006/07, and track future improvements
2. Provide an indication of the proportion of the fleet that could be classed as "gross-emitters" and are unlikely to comply with the emissions standards
3. Quantify the environmental and health benefits of minimising roadway congestion
4. Provide vehicle greenhouse gas emission estimations, along with assessing greenhouse gas reduction strategies
5. Assess the on-road performance of various vehicle models and makes
6. Compare the emissions of Australia's vehicle fleet with other countries/jurisdictions using RSD where policies, fleet profile, emission standards and fuel quality may differ
7. Determine the social implications in terms of equity and access to mobility of any policy or strategy that would result in removing/retiring older (and cheaper) vehicles from the fleet
Undertaking an analysis of this type would require obtaining socio-economic indicators of vehicle owners, and
8. Determine the costs of air pollution discharged from State vehicle fleets on typical roadways and from the various vehicle types within each fleet.

Limitations of this work to support policy development include:

1. Pollutants: Only four pollutants are measured, albeit the key ones (CO, NOx and HC and smoke (a proxy for particulates))
2. Comparability to established emissions measurements technologies: A key to further use of RSD is to fully understand how emission measurements made with the RSD correlate with those made with transient dynamometer cycle testing and on-board gas analysers
3. Sample diversity: The nature of the equipment means it is not always possible to sample on every road-type and/or every suburb required to provide a truly representative profile of a city's vehicle fleet emissions. The power of the results could be improved by increasing the range of vehicles and roadways sampled, and
4. Heavy duty vehicles: Heavy duty diesel vehicles which discharge their exhaust gases well above the road level can only be monitored by mounting the RSD source detector unit and mirror on scaffolding (not done for this project).



The project demonstrated a potential public awareness campaign regarding vehicle emissions, their cost and health dis-benefits. Pictured above is a Smart Sign using information from the remote sensing device which provides instantaneous feedback to the drivers on their vehicle's emissions, and thus the state of tune of their vehicles – flashing a bold "Good", "Fair" or "Poor" message.

Policy Summary – Theme 3, Project 3

Measurement of real-world PM₁₀ emission factors from woodheaters by in-situ source monitoring and atmospheric inversion methods

C.P. (Mick) Meyer, Ashok Luhar, Rob Gillett and Melita Keywood

Centre for Australian Weather and Climate Research – A partnership between the Australian Bureau of Meteorology and CSIRO Marine and Atmospheric Research

Introduction

Domestic woodheaters are a major source of particulate matter (PM) pollution in Australia. Most jurisdictions require woodheaters to comply with the Australian Standard for woodheater emissions (AS4013), which includes a particle emissions limit of 4 g per kg of wood burnt. However, there is growing concern that even compliant woodheaters frequently do not meet this limit when operated in homes.

The key issue for policy development for air quality and environmental health is the contribution that woodheaters make to ambient concentrations of particulate and gaseous pollutants. A comprehensive understanding of the factors that influence the contribution of woodheaters to ambient PM levels involves at least three steps: verifying woodheater design characteristics, determining in-service emission factors for woodheaters, and quantifying the contribution of woodheater emissions to the ambient PM levels.

This project was commissioned to investigate the second and third steps by measuring *in situ* the emission rates of woodheaters for a small selection of households in the Launceston air shed in Tasmania. The specific objectives were:

1. To provide an estimate of real-world emission factors for woodheaters in Launceston
2. To provide an estimate of woodheater usage patterns and PM₁₀ emission rates, and
3. To assess whether CSIRO's transport model (TAPM) using in-service emission factors as determined through this study can accurately predict PM concentrations in the Launceston airshed.

Principal Findings

The 24h average emission factors for PM₁₀ (PM₁₀-EF) from the 18 houses successfully tested ranged from 2.6 g to 21.7 g PM₁₀ (kg fuel)⁻¹, with an average of 9.4 g PM₁₀ (kg fuel)⁻¹. These results correspond closely with similar tests conducted in New Zealand. The National Pollutant Inventory (NPI) uses an emission factor of 5.5 g PM₁₀ (kg fuel)⁻¹ to estimate the contribution of woodheaters to the ambient PM₁₀ load.

The main determinant of PM₁₀-EF was combustion efficiency, which in turn was determined by the air supply rate. While some woodheaters were operated mostly with the dampers set fully open, most were operated at significantly reduced air flow leading to higher PM₁₀ emissions.

During week-days, woodheaters in the monitored households were mostly used during the late afternoon and evening. On weekends woodheater use commenced earlier and finished later. Where woodheater operation continued overnight, there was no evidence that overloading occurred. Nor was there any evidence that woodheaters were allowed to smoulder overnight; in contrast they appeared to be refuelled periodically throughout the night. Fuel consumption rates were maximal in the evening hours between 18:00 to 20:00. Two PM₁₀ emission peaks were observed; the first from 17:00 to 18:00 and the second three hours later. PM₁₀ emissions declined rapidly after this second peak and mostly ceased soon after midnight.

The prediction of ambient PM concentrations, using atmospheric transport models combined with an emission factor of 5.5 g PM₁₀ (kg fuel)⁻¹ (as specified in the National Pollutant Inventory), substantially underestimates ambient PM₁₀ concentrations, when compared against measured concentrations. However,

using the mean *in situ* emission factors of $10 \text{ g PM}_{10} (\text{kg fuel})^{-1}$, observed in both this study and in New Zealand studies, coupled with an approximation of the observed daily patterns of heater use leads to good agreement between predicted and measured PM_{10} levels without any model parameter adjustments. This supports the emissions source estimate used and indicates that results from the survey are representative of the Launceston air shed.

Policy Implications and Limitations

The principal conclusion from these findings is that the AS4013 test protocol does not adequately reflect in-service emissions performance. There is, therefore, a strong case for developing a new test cycle that accurately reflects the way in which woodheaters are used in homes.

The current NPI emission factor for PM_{10} from woodheaters, of $5.5 \text{ g PM}_{10} (\text{kg fuel})^{-1}$ significantly underestimates the contribution of woodheaters to the ambient particle load. A revised value of $10 \text{ g PM}_{10} (\text{kg fuel})^{-1}$ should be used, which reflects the true in-service performance of woodheaters, when developing inventories and conducting atmospheric dispersion modelling.

There are some technical issues in the sampler design that need to be resolved and improved. The most important of these is to refine the primary diluter design to minimise or remove the risk of blockages. It would also be useful to compare the performance of the *in situ* monitoring system against the performance of the AS4013 dilution tunnel. This would provide a direct calibration of the field sampling system against the AS4013 standard, and focus attention on the AS4013 test cycle, rather than the monitoring system.

Additional areas that could be usefully addressed include:

1. Development of surrogate measures of *in situ* heater use or performance. Flue temperature, for example, has proved to be a good indicator of the time-course of heater use, including information on air flow control. Improvements to heater performance in the long term require emissions to be characterised by combustion parameters, such as combustion efficiency, that can be easily measured and controlled. Without this, continued woodheater design is likely to be haphazard and expensive.
2. Development of methods for determining the spatial distribution of woodheater use and emissions in major air sheds such as Launceston. This is required for accurate dispersion modelling and is currently a significant source of uncertainty.

Policy Summary – Theme 4, Project 1

Australian methodology for cost-benefit analysis of ambient air pollution health impacts

Bin Jalaludin^{1,2}, Glenn Salkeld³, Geoff Morgan^{4,5}, Tom Beer⁶, Yasir Bin Nisar¹

¹School of Public Health and Community Medicine, UNSW; ²Centre for Research, Evidence Management and Surveillance, SSWAHS; ³School of Public Health, University of Sydney; ⁴Department of Rural Health (Northern Rivers), University of Sydney; ⁵North Coast Area Health Service; ⁶CSIRO.

Introduction

There is ample evidence to indicate that the health impacts from air pollution represent a major cost to society, with the recent Burden of Disease study estimating that air pollution results in more than 3,000 excess deaths each year in Australia. These and other studies provide justification for allocating community resources to improve air quality.

Cost-benefit analysis (CBA) is a powerful decision-making tool for resource allocation that provides a framework for policy and decision makers to rigorously evaluate the costs and benefits of specific policies and programs. However, there is currently no “standard” methodology for calculating the health costs of ambient air pollution in Australia that specifies which health endpoints to use, which air pollutants to be considered and other major inputs to the CBA process. The application of a consistent, accurate methodology for evaluating such costs will facilitate the design of effective and efficient air quality management strategies that target the major risk factors.

In this project we review eight ambient air pollution CBA studies from Europe, the United States and Australasia. We summarise and evaluate the methods used to assess the economic benefits (i.e. the avoided costs) of health effects of ambient air pollution, as well as the knowledge gaps, contentious issues and uncertainties associated with each CBA.

Principal Findings

The review of national and overseas literature on methods used to conduct CBA for ambient air pollution showed that the assessment of the economic benefits (avoided costs) involves four major steps:

- i. measurement of ambient air pollution
- ii. identification of health effects
- iii. identification of concentration-response function, and
- iv. monetary valuation of the health effects.

On the basis of our review we recommend the following when assessing the health costs of air pollution:

- Limit the number of air pollutants and the number of health effects evaluated in a CBA unless clear evidence emerges of a single health impact from a specific air pollutant.
- The index pollutant approach is valid when the effect of one pollutant (such as PM) dominates. The selection of a few uncorrelated air pollutants may also be a reasonable approach depending on the location and purpose of the analysis. PM₁₀ and preferably PM_{2.5} should continue to be used in the quantification of particulate matter-related health effects as currently the evidence base is not strong on the health effects of finer particles (<PM_{2.5}), numbers of particles or composition of particles.
- The health endpoints should be epidemiologically linked to ambient air pollution and be sufficiently different from each other to avoid double counting. Double counting of health effects will overestimate the benefits.

- Concentration-response functions should be derived from several large well-conducted epidemiological studies and preferably from systematic reviews of epidemiological studies or through published meta-analyses. Local studies should be used wherever possible, provided that the studies are methodologically sound. Concentration-response functions derived from local studies should always be compared with those derived from overseas studies and any meaningful differences investigated before using the local concentration-response functions. If local concentration-response functions are unavailable, then it is appropriate to use concentration-response functions derived from studies conducted overseas.
- The health effects must be able to be expressed in dollar terms. The willingness-to-pay (WTP) approach should be used to monetise the health endpoints. In the case of deaths, it is preferable to both quantify and monetise life years gained rather than simply estimating and monetising the number of deaths averted. Robust published WTP values should be utilised in the monetisation of morbidity and mortality benefits.
- There is a dearth of value of statistical life (VOSL) studies specific to ambient air pollution, and it is strongly recommended that active steps be taken to fund VOSL studies in Australia. A figure of AUD\$6.0 million (range: AUD\$3.7 million to AUD\$8.1 million; 2006 dollar values) for VOSL may be used in Australia until further VOSL studies are undertaken and published.
- Value of life year (VOLY) is preferable to VOSL in monetising the air pollution effects on premature mortality and should be used whenever feasible and practicable. A constant VOLY of AUD\$252,014 (range: \$155,409 to \$340,219; 2006 dollar values) may be used in Australian CBA until further VOLY studies are undertaken and published. Sensitivity analyses should be conducted to determine differences in costs and benefits using VOSL and VOLY.
- Sensitivity analysis should be conducted when there is insufficient information to conduct a robust CBA. Where specific crucial local information is not available to conduct a robust CBA, then targeted studies should be conducted in Australia to obtain the information.

Policy Implications and Limitations

Application of CBA to the study of the health impacts of air pollution is increasingly being recognised as a legitimate approach to policy development and prioritisation. While currently there is no standard methodology for calculating the health costs of ambient air pollution in Australia, this study provides policy makers and researchers with insight and guidance into selecting the relevant air pollutant(s) (e.g. particulates and ozone) and health endpoints (e.g. morbidity and mortality), calculating the number of events for each health endpoint, assigning monetary values to each health endpoint, and calculating the total benefits (in dollar terms). The study also makes recommendations on how to address the uncertainties, contentious issues and knowledge gaps associated with CBA methodologies.

In any cost-benefit analyses, there are gaps in our knowledge or information that may limit its usefulness. CBA for outdoor air pollution can be constrained by the availability of good quality local information, particularly in the area of exposure assessment, to conduct a robust analysis. Therefore, CBA relies on assumptions and on sensitivity analyses to provide a range for the costs and benefits. Such costs and benefits estimates may not be precise enough for the policy development process. Further, CBA necessarily brings together information from a number of disciplines and areas of research, including air quality science, health and epidemiological research, and economics, and can be very resource intensive, both in terms of time and dollar costs. This can be a major limitation in the use of CBA in policy development.

Policy Summary – Theme 4, Project 2

Community based participatory research for air quality management

Peter Musk

Environmental Protection Authority of Western Australia

Introduction

Community concern has influenced jurisdictional policies and programs on a range of air quality issues, particularly when there is a perception of significant community impacts from existing or proposed developments. A range of community consultation and engagement methods have been used, with varying levels of success.

The Community Based Participatory Research (CBPR) Guide and resources provide a mechanism for the community to be proactively involved in air quality management issues. Through actively engaging the community in the collection and interpretation of air quality data, the community, researchers and government develop a better understanding of air quality issues as well as joint ownership of the air quality management processes.

Principal Findings

CBPR was adapted for application in air quality management through the development of a CBPR Guide and a major trial was undertaken with key stakeholders and students from Perth Modern School. Testing of the CBPR materials will continue through the new *Air Quality Management Community Grants Program* where applicants are required to utilise the CBPR approach.

Feedback from key community stakeholders has been positive, with Joel Levin, WA State Coordinator for the International Association of Public Participation saying “CBPR is an exciting example of how engagement between agencies and community can improve relationships and the quality of the outcome. This guide and your willingness to engage in a manner that is consistent with the principles and values of community engagement can be a powerful tool in generating shared understanding of the issues and progressing a way forward.”

Generally the response from Government agencies has also been positive. This included the unsolicited suggestion to utilise the CBPR approach as a mechanism to resolve difficulties engaging community in existing and ongoing air quality problems. However there was some feedback expressing apprehension about involving outspoken community members on a coordination group in the early stages of a study. This was based on previous negative encounters with certain individuals rather than concerns with the CBPR approach itself.

The trial showed the materials developed can easily be adapted for a school environment and provide valuable learning experiences for students and meet the needs of the school curriculum, specifically in the learning areas of Society and Environment and Science.

Policy Implications and Limitations

Air quality management continues to be a key issue for community stakeholders throughout Australia. At present there are limited opportunities for the community to be proactively involved in air quality management issues. The CBPR resources provide an approach to do so and consequently is likely to be received positively by stakeholders. The *Air Quality Management Community Grants Program* provides an example of how the CBPR approach can be supported to engage community in air quality investigations and management actions.

Support for new or existing groups, such as natural resource management, community and resident groups, environment groups and school institutions is an excellent way of engaging the community and encouraging them to take an active role in confronting the issues that directly affect them.

Preliminary discussions with a key stakeholder indicate there may be applicability of the CBPR approach to environmental impact assessment. It may be an effective way to engage local communities in the process particularly as it applies to establishing an understanding of the compliance and monitoring requirements for regulated sites. This includes proponents and the regulator working together with community to build understanding and, through community engaged in the approach, set real and achievable targets.

The lessons learnt in the development of CBPR Program are significant. An attempt to undertake a test of the CBPR Guide by imposing a trial on a community selected by DEC was unrealistic, as such constructs do not necessarily succeed in fostering community engagement, as substantiated by the lack of community response.

Development of the materials and conducting community training activities, such as workshops for existing or interested groups and individuals and waiting for applications to utilise the approach would have provided a more authentic trial.

The trial has also highlighted the importance of engaging stakeholders in the approach. Their understanding of the issues is important to provide community participants with the necessary support. Additionally when arguing to implement often contentious projects the support of other groups is often the difference between success or otherwise. The development and implementation of agreed communication plans is also of critical importance. Where this is not the case, misunderstandings may arise and competing priorities may overtake project objectives.