PREDICTIONS OF AIR QUALITY IMPACTS IN VICTORIA UNDER THREE FUTURE EMISSION SCENARIOS

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Abstract

Significant trends exist in urban air quality in Australia. Total exhaust emissions from motor vehicles are improving in major urban areas, despite strong growth in traffic. At the same time, the population of major cities is growing, which is likely to increase emissions from a range of domestic and commercial activity. Industrial emissions are also likely to change, especially from energy generation. Looking further into the future, climate change is likely to be a significant influence on many air pollutants, especially ozone.

This project reports on the findings of a study into air quality in Victoria, taking into account climate change, population change, and emission trends. A key feature of this work was the simulation of multiple pollutants ($PM_{2.5}$, O_3, NO_2, SO_2, CO and four air toxics) under three realistic future emission scenarios. The focus of the study is the Port Phillip Region (covering Melbourne and Geelong) in the year 2030, however some results are also presented for the state of Victoria.

A detailed gridded, time-dependent emissions inventory was prepared for a baseline scenario (2006), and three future emission scenarios in 2030 (E1, E2 and E3). These inventories were subject to extensive QA, and were used with the TAPM-CTM regional air quality model, driven by dynamically downscaled climate projections. Each simulation covered a ten-year period to ensure that year-to-year variability was adequately assessed.

Results are expressed in a number of impact metrics, including regional population exposure, maps of temporally averaged concentrations, time series charts and compliance with current air quality standards. The study found that ozone and particles are the key pollutants of concern in 2030, and that domestic, commercial and industrial sources are likely to overtake motor vehicle exhaust emissions of many pollutants in the near future, which has important implications for future policy development.

Keywords: climate change, air quality impacts, future scenarios.

1. Introduction

Air quality has been measured in Melbourne and other Australian cities for a number of decades. Substantial improvements in air quality have been observed over this time (DECW 2010, DERM 2011, Barnett 2012). However, many issues remain, and there are continuing pressures on the air environment from population growth, economic growth and climate change. Balancing these pressures are progressive improvements in technology, fuels, and air quality standards.

The main purpose of the *Future Air Quality* study was to make quantitative predictions of air pollution for the year 2030, accounting for known trends. The focus was on urban air quality in the Port Phillip Region, which includes Victoria's major population centres (Melbourne and Geelong).

The study also included a number of other objectives, not discussed in detail here, including simulations of the effect of climate change only on air quality in 2030 and 2070 (Lee *et al*. 2012a), and simulations of Victorian-scale dust and fire events (Lee *et al*., 2012b; Meyer *et al*. 2012).

A key feature of this work is the modelling of urban $PM_{2.5}$, including organic and inorganic secondary particle formation, and sea salt generation. Insights and data from this study are being used to support research into future human health outcomes (Sujaritpong et al., 2011) and policy development under the Australian National Plan for Clean Air.

2. Methodology

2.1 Overview

The work was organised into a number of stages:

- Development of baseline and future scenarios,
- Development of emissions inventories,
- Downscaling of global climate model data,
- Development of hourly population data,
- Choice of impact metrics,
- Air quality model development and testing, and
- Air quality simulation for each scenario.

Model output was summarised to show the effect of climate change only, and also the combined effect of climate, emission and population changes.

Papers have been published describing the climate and air quality modelling systems (Cope *et al.* 2011b, Lee *et al*. 2012a), the emissions inventory (Bannister *et al*. 2011, Delaney *et al.* 2011), model and emissions verification (Cope *et al.* 2011a, Marshall *et al.* 2011), and population modelling (Walsh *et al*. 2011). Impact metrics and future scenarios are described in EPA (2013). A brief summary of the methodology, especially where recent extensions have been made, is provided here.

2.2 Emission scenarios

The census year 2006 was chosen to form a baseline scenario. The future year 2030 was chosen as a number of state and national government projections were available for this year. Three emission scenarios for 2030 were developed:

E1: A low impact scenario

E2: A medium impact scenario (most likely future)

E3: A high impact scenario

These scenarios are intended to represent plausible emission futures for Victoria (see Appendix A).

2.3 Emissions inventories

Emissions data were estimated for each scenario using existing methods (Ng, Joynt & Yan 2005, Delaney *et al.* 2011) and future projections of emission factors and fuel use where available. A refinement was made for above-ground shipping and aviation exhausts, which were represented as a series of elevated point sources at various heights (Unal *et al.* 2005).

Emissions were estimated for a Victorian grid (5 km resolution) and a finer grid covering the Port Phillip Region (1km resolution). Figure 1 illustrates the spatial extent of the two emission grids.

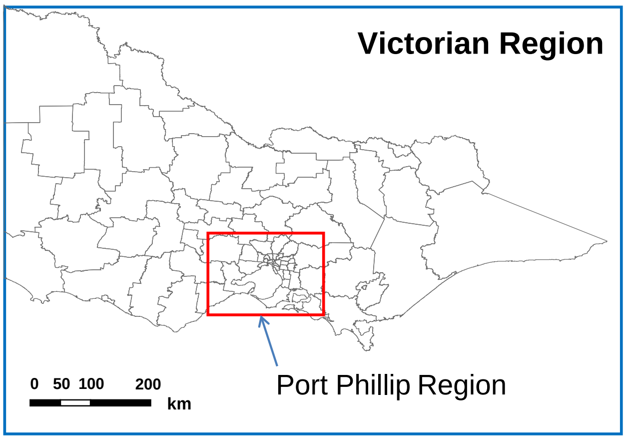

Figure 1: Spatial extent of emission inventories (with local government boundaries shown)

Emissions of all major pollutants were estimated including CO, NO_X, SO_X, NH_3, particles and VOCs. Particle emissions were broken down by chemical component (including sulphate, elemental carbon, organic carbon and metals) and by size fraction. VOCs were treated as lumped species under the Carbon Bond IV scheme, plus explicit tracking of benzene, toluene, xylenes and formaldehyde.

Re-entrained road dust emissions were estimated, and adjusted according to traffic levels (Ng, Joynt & Yan 2005). Wind-blown dust emissions were not included in this study, which means that $PM_{10-2.5,}$ and therefore total PM_{10}, could not be assessed at this stage; this will be examined in future research. Emissions from bushfires and planned burns were not included due to the difficulty of reliably predicting future bushfire and burning activity.

Each pollutant source was given its own temporal profile, with variation by month of year, day of week and hour of day. A full year of hourly emissions data (including spatial and chemical breakdown) was prepared for 2006 and for each of the three 2030 scenarios. Point sources were also assigned values for stack height and diameter, and exit velocity and temperature. The final emissions data (see Appendix B) were subject to extensive quality assurance (Marshall *et al*. 2011).

2.4 Meteorology

In order to reliably assess the frequency of high pollutant concentration events, more than one year of meteorology needs to be used. In this study 10 years of meteorological data were used for each scenario run (Cope *et al.* 2011b).

Meteorological data were obtained by dynamic downscaling of Global Climate Models, based on IPCC A2 greenhouse emissions. Initially four GCMs were used to assess the likely inter-GCM uncertainty in air quality predictions driven by changing climatology (Cope et al 2011b).

A single GCM (CSIRO MK3.5) was then chosen for running simulations with the baseline and E1-E3 future scenarios; this GCM gave exposure results close to the average of the four-GCM ensemble.

Three decadal periods were selected from the GCM data (1996-2005, 2025-2034, and 2065-2074). The first decade was used with 2006 emissions; the second decade was used with both 2006 emissions (to assess the effect of climate change alone) and 2030 emissions (to assess the combined effect of climate and emission changes). The third decade was only used for the initial multi-GCM study.

Global meteorology was initially downscaled using CCAM (McGregor & Dix 2008) to a 60 km cubic-conformal grid covering all of Australia. CCAM output was then used as input for further downscaling within TAPM-CTM, providing hourly meteorology at 9km resolution over Victoria, and 3km resolution over the Port Phillip Region.

2.5 Population

Travel surveys have been used in Victoria to map the typical daily movements of people, allowing improved approaches to modelling of air pollution exposure (Marquez *et al.* 2001, Walsh *et al*. 2011).

In this study, hourly population maps for typical weekdays and weekends in the Port Phillip Region were prepared for 2006 and for the 2030 scenarios, based on a 2007 travel survey (DOT 2009). To do this for a future year required an extension to the method described in Walsh *et al.* (2011).

Firstly, local government area (LGA) population projections (DPCD, 2009) were applied to a detailed mesh-block 2006 census map, to obtain a map of 'residential' population in 2030. Dynamic movement of people in future scenarios was modelled by assuming that the spatial and temporal pattern of people movements would remain the same in the future, simply scaled up by population growth. The same method was applied to 2006 to ensure comparability of the two population datasets.

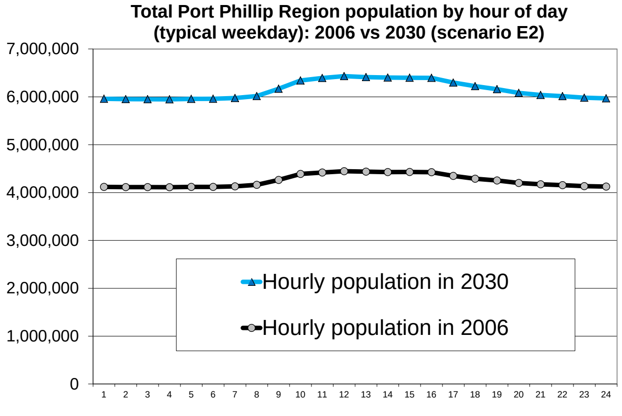

Figure 2: Hourly population pattern on weekdays

A key benefit of this approach is that it captures not only the daily influx of workers from suburbs to the CBD, but also from beyond the urban boundary. This is shown in Figure 2, which plots the hourly total population of the Port Phillip Region, demonstrating a significant increase in the total urban population during working hours.

2.6 Impact metrics

Air pollution causes many undesirable effects, but the most economically and socially significant are those on human health. In this study, various metrics have been developed to provide surrogate indicators for human health impact. The calculation of human health outcomes (morbidity, mortality and costs) will be the subject of a future study.

The challenge of designing impact metrics is to summarise a very large amount of spatial, temporal and chemical detail in terms that can be understood by policy makers and other stakeholders. The approach taken here is to use a number of different ways of presenting the data, each of which conveys a different aspect. The impact metrics chosen are[1]:

- Concentration time series plots (decadal scale)
- Maps of long-term average concentration
- Regional population exposure (regional sum of (population density x concentration)
- Number of breaches of air quality standards

The first two are self-explanatory. Regional population exposure was calculated using hourly concentration maps and hourly population maps, following the 'dynamic population exposure' formula in Walsh *et al.* (2011).

The number of breaches of standards is sensitive to variations at the tail end of the modelled distribution. Following Australian regulatory modelling practice, a 99.9th percentile approach was used. This involved calculating the daily maximum, spatial maximum predicted concentration, then discarding the top four days in each decade, prior to counting breaches of air quality standards.

2.7 Air quality model

TAPM-CTM was chosen as the air quality model (Cope *et al.* 2009). Biogenic emissions were calculated dynamically within the model according to sunlight and temperature (Bannister *et al.* 2011). Domestic wood heater emissions were dynamically adjusted according to temperature, as more wood is burnt on cold nights (Ng & Minchin 2000). Tailpipe and evaporative emissions from petrol vehicles were also adjusted for temperature (Cope *et al.* 2009).

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[1] A further metric (the number of people exposed above various concentration thresholds) is presented in EPA (2013).

The inventory-model system was subject to testing against measured concentrations in Melbourne (Cope *et al.* 2011a, Marshall *et al.* 2011), giving reasonably good agreement.

2.8 Air quality simulations

Simulations for the years 1996-2005 and 2025-2034 were run on the NEC supercomputer cluster at the Australian National Computing Infrastructure (NCI).

These results enabled further checks on model performance. An example is shown in Figure 3, which plots the predicted 1996-2005 average NO_2 concentration against measurements at monitoring locations around the Port Phillip Region; showing good performance in predicting spatial variations.

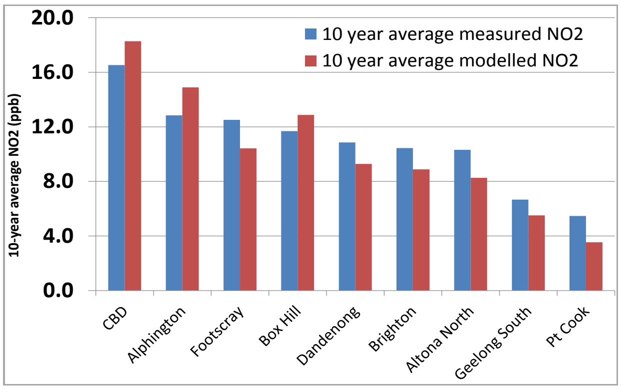

Figure 3: Spatial performance of the model for NO_2

3. Results

3.1 Time series plots

Figure 4 shows how daily maximum concentrations of ozone are expected to change between 2006 and 2030 (E2 scenario). A small reduction is indicated in peak ozone levels. In contrast, a significant increase is expected in average ozone levels – this is due to reduced nitric oxide (NO) emissions, the major component of NO_X, leading to less titration of ozone on days of typical meteorology.

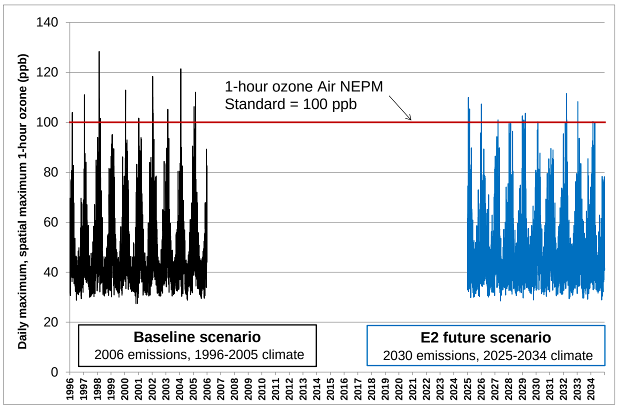

Figure 4: Highest predicted daily 1-hour ozone (O_3) concentrations in the study region: 2006 vs 2030 (E2)

3.2 Concentration maps

Figure 5 shows the predicted 10-year average concentration of $PM_{2.5}$ for the baseline (2006) and E2 future (2030) scenarios. The model predicts a moderate reduction in $PM_{2.5}$ in the CBD and inner suburbs and little change elsewhere. This is primarily due to the expected improvements in diesel vehicle standards.

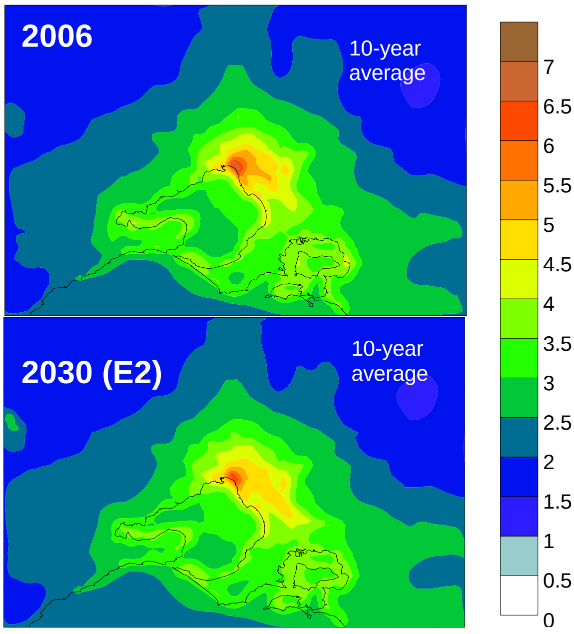

Figure 5: Predicted change in $PM_{2.5}$ ($\mu g/m^3$)

Figure 6 shows a similar analysis for carbon monoxide. The model predicts a strong reduction everywhere in the region, due to improvements in petrol vehicle exhaust (the dominant source of CO).

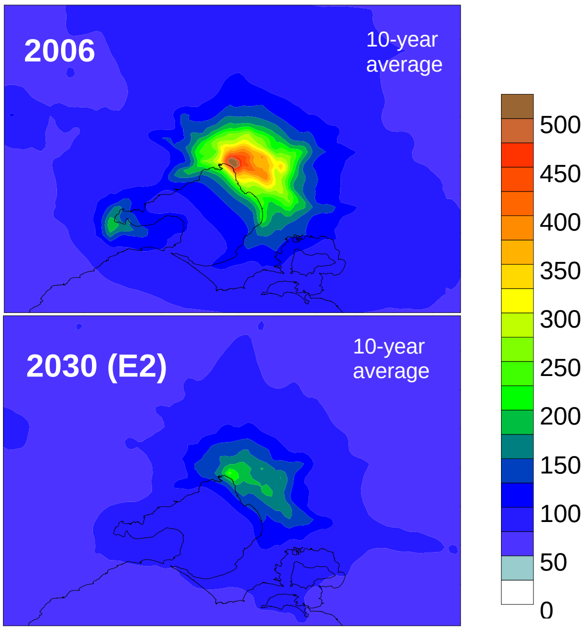

Figure 6: Predicted change in CO (ppb)

3.3 Regional population exposure

Figure 7 shows the regional population exposure predictions for NO_2. From left to right, there is a progression from baseline scenario, to simulations of the effects of climate change only, then including changes to the receiving population, and finally to the full E2 scenario (changes to climate, population and emissions).

For NO_2, the model predicts that climate change will only have a small effect by 2030. Population growth is predicted to drive a strong increase in regional exposure, but this is outweighed by an even stronger reduction in NO_X emissions. A similar effect is found for other pollutants dominated by vehicle exhaust (e.g. CO and benzene).

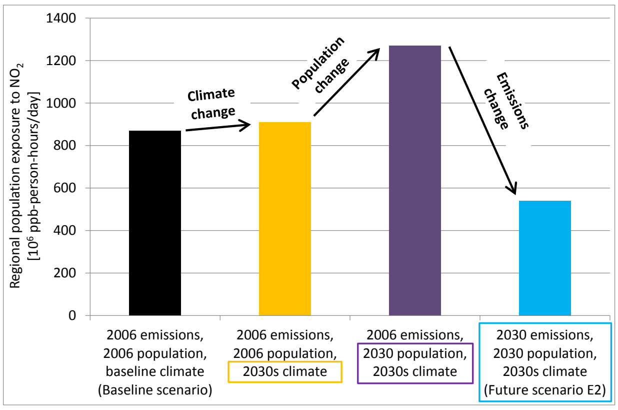

Figure 7: Drivers of change in NO_2 population exposure

Note that this metric is deliberately not a *per-capita* measure of exposure, in order to capture the effect of increasing population on total health impacts and therefore health costs to the community.

Table 1 summarises the “emissions change” effect in relative terms for a number of pollutants; these results are generally consistent with emissions changes (Appendix B). The predicted increase in *ozone* exposure is a side-effect of NO_X reductions (see section 3.1). Measurements show that average Melbourne ozone levels are in fact increasing, but are below natural background (EPA 2013). It is likely that any detrimental effects of increased ozone exposure may be more than balanced by the benefits from reduced CO, NO_2 and air toxics, but this will require further research to confirm.

Table 1: Relative change in regional population exposure due to **changes in emissions** only [2006 → 2030 (E2)]

Pollutant	**Effect of emissions change on regional population exposure**
NO_2	**-57 %**
$PM_{2.5}$	**-6 %**
Ozone	**+16 %**

3.4 Breaches of air quality standards

Table 2 shows the predicted number of breaches of the current Australian (NEPM) air quality standards and advisory standards. Of the pollutants assessed, only ozone and $PM_{2.5}$ were predicted to breach air quality standards under any scenario. The data show the total number of days per decade on which the relevant standard is breached anywhere in the Port Phillip Region.

For ozone, compliance with standards is expected to improve under all three future scenarios. For $PM_{2.5}$, an increase in breaches is expected under the E3 scenario.

Table 2: Predicted # of breaches of AQ standards. (Shading indicates an advisory standard)

Scenario:	**Baseline**	**Future**		
Emissions:	*2006*	*2030*		
Climate:	*1996-2005*	*2025-2034*		
		E1	**E2**	**E3**
1-hr O_3 > 100 ppb	21	2	12	17
4-hr O_3 > 80 ppb	39	19	32	34
24-hr $PM_{2.5}$ > 25 $\mu g/m^3$	12	3	6	15
Annual $PM_{2.5}$ > 8 $\mu g/m^3$	0	0	0	1

4. Discussion & conclusions

A careful account of emission trends (Appendix B) indicates that motor vehicle exhaust emissions are expected to reduce significantly by 2030. This prediction is supported by observed trends in long-term measurements of exhaust-related pollutants such as CO and NO_X in Melbourne (EPA 2013).

In contrast, emissions related to general domestic and commercial activity are expected to increase in line with population growth. Few of these emissions are subject to controls or regulation, and as such they collectively represent a significant threat to air quality in the long term. Between now and 2030, total urban emissions are still expected to reduce.

This study has highlighted *ozone* and $PM_{2.5}$ as the urban pollutants of most concern in the Port Phillip Region in 2030. Concentrations of CO, NO_2, benzene, toluene, xylenes and formaldehyde are expected to reduce significantly. SO_2 levels are generally low with little change expected by 2030.

Model predictions of high-concentration events are very sensitive to slight changes in meteorology, so impact metrics based on peak events (such as the number of policy breaches) are sensitive to various modelling assumptions. Conversely, time-integrated metrics such as regional population exposure tend to be more robust, as they are not skewed by a small number of extreme pollution events.

Despite this, policymakers may still prefer traditional indicators based on the number of high pollution events. In this study a range of metrics were calculated to provide a broad perspective.

This collaborative project has combined a state-of-the art chemical transport model with detailed, local emissions estimates and projections, to provide predictions for several common air pollutants in the Port Philip Region. Some new insights into future air quality trends have been obtained, despite the many uncertainties that are inevitable with a modelling project of this kind (EPA 2013).

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Appendix A: Future emission scenarios

A brief overview of the 2030 emission scenarios is provided here. For more details, including references for sources of data, see EPA (2013).

Scenario E2 (*most likely future*)

Although this scenario has been called the ’most likely future’, it is just one scenario out of a vast number that are possible. To ensure the scenario was realistic, the best available data were obtained, and all assumptions were subject to scrutiny by scientific and policy officers.

Information on future transport links, industrial activity and traffic volumes was obtained by contacting state and commonwealth agencies. Information on future population, energy use, transport technology and emission controls was obtained from published reports.

Industry

The 2009 National Pollutant Inventory was used to identify any new industries not present in 2006. Industry growth rates for each sector were available to 2018; extrapolation was used to obtain 2030 estimates. Changes in the power generation sector are expected, with some major coal-fired power stations likely to close. Co-generation and tri-generation are expected to increase significantly, especially in hospitals, shopping centres, some office buildings and industrial sites, recreation centres, universities and new housing estates.

Transport

Significant changes are expected in the vehicle fleet, fuels used and the level of transport activity (both freight and passenger). The fleet turnover rate was assumed to remain constant. Diesel and petrol will still be widely used, along with less common fuels (natural gas and biofuels). An increasing number of hybrid and electric vehicles are expected, although these will remain a minor component of the fleet. It is assumed that ethanol blends will only be used in a small fraction of petrol vehicles in 2030.

The emission of pollutants from individual vehicles is expected to reduce through new standards (Euro 5 and 6 for light vehicles, and Euro V for heavy vehicles). Overall, the effect of the new standards is expected to outweigh the growth in travel, so total vehicle exhaust emissions should reduce by 2030. However, road dust emissions are expected to grow in line with traffic volumes.

Shipping, railway and aircraft activity are expected to significantly increase, driven by population growth and consumption patterns. In 2030, Melbourne airport is predicted to become the largest source of formaldehyde in Victoria, as road transport VOC emissions will have significantly reduced.

Domestic/commercial

Technological innovation to control air emissions in the domestic and small business sector tends to be slow. Therefore emissions from most domestic and commercial sectors (fuel consumption, surface coatings *etc.*) will be directly affected by increased population. Corresponding growth in housing units is expected to drive increases in emissions from domestic lawn mowing and waste burning.

Domestic wood consumption (in heaters and stoves) is a significant source of pollutants in winter in Victoria. Although the number of housing units is increasing, ABS fuel use projections to 2030 indicate a decrease in per-capita consumption of wood, as people switch to electricity and natural gas for heating. The net effect is little change from 2006 to 2030 in total wood combustion.

Although emissions from the domestic/commercial sector have been compiled using published emission factors and best available estimates of activity, significant uncertainty remains in the estimates for this sector.

Scenario E1 (*low impact future*)

Scenario E1 was derived from E2 by making a number of plausible reductions in emissions. Note that these are hypothetical initiatives and do not represent any state or national policy positions.

- In-service wood heaters compliant with AS/NZS 4013 (PM_{10} emissions less than 4g/(kg of dry fuel)).
- All 2-stroke lawn mowers phased out and replaced with 4-stroke mowers.
- 50 per cent of passenger vehicles replaced with electric vehicles.
- 30 per cent less exhaust and evaporative emissions through better maintenance of light vehicles.
- Briquettes phased out and replaced with natural gas of equivalent energy content.
- 90 per cent reduction in SO_2 emissions from Anglesea power station.

Scenario E3 (*high impact future*)

Similarly the E3 scenario was derived from E2 through plausible increases in emissions, with the addition of a change to population distribution:

- All trucks running on diesel; no hybrids, no CNG.
- Euro 5 and Euro 6 switched off for all light vehicles.
- Additional co-generation within the Port Phillip Region.
- Increased shipping freight at the Port of Hastings and Port of Melbourne.
- 25 per cent more wood burnt in wood heaters.
- 50 per cent of outer Melbourne population growth redistributed to inner Melbourne suburbs.

Appendix B: Predicted emission trends

These charts show the expected change in Port Phillip Region emissions, from 2006 to 2030 (E2).

🟦 Petrol vehicle exhaust
⬛ Diesel vehicle exhaust
🟨 LPG vehicle exhaust
🟪 Petrol vehicle evaporative
🟫 Wood heaters & stoves
🟩 Domestic & commercial activity
⬜ Industrial activity