AV / ZEV Environmental & Health Impact Assessment

Final Report

Infrastructure Victoria

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Executive Summary

Infrastructure Victoria engaged Aurecon and Environmental Resources Management (ERM) to provide advice on the population health and environmental impacts of Zero Emission Vehicles (ZEV) and Autonomous Vehicles (AV) in Victoria. This engagement is part of a portfolio of work commissioned by Infrastructure Victoria to obtain expert advice on the range of impacts that the uptake of ZEVs and AVs will have on the Victorian population, the environment and the Victorian economy.

The uptake of ZEVs and AVs will have major impacts on a wide range of infrastructure sectors. The penetration of ZEVs and AVs will transform the transport network, the economy, the energy sector, Information and Communication Technology (ICT), and land-use. Each work package considers the impact of a number of selected scenarios on a specific aspect of Victorian infrastructure, the Victorian Government, or the population. Each scenario considers a unique mix of technology, vehicle ownership model, level of automation and speed of uptake (refer to Table E-1).

Table E-1 – Scenario definitions

Scenario	Year	Driving Mode	Power Source	Ownership / market model	Occupancy level
Electric avenue	2046	Non-driverless	Electric	Private Ownership	Single occupancy
Private drive	2046	Driverless	Electric	Private ownership	Single occupancy
Fleet street	2046	Driverless	Electric	Shared, on-demand services	Multiple occupancy
Hydrogen highway	2046	Driverless	Hydrogen	Private ownership	Single occupancy
Slow lane	2046	Non-driverless and driverless	Electric and petrol / diesel	Shared, on-demand services and private ownership	Multiple occupancy and Single occupancy
High speed	2031	Driverless	Electric	Shared, on-demand services	Multiple occupancy
Dead end	2046	Non-driverless	Petrol / diesel	Shared, on-demand services and private ownership	Multiple occupancy and Single occupancy

Source: Infrastructure Victoria Advice on Automated and Zero Emissions Vehicles Infrastructure: Future Scenarios Report (2018)

This report outlines the projected impacts of the selected ZEV / AV scenarios on population health and the environment. The report considers four main types of impact:

1. Improvements in population health from reduced exhaust emissions (population impact).
2. Other health and non-health population impacts (population impact).
3. Environmental impacts from manufacture (environmental impact).
4. The impact on waste infrastructure (environmental impact).

The first two impacts (population impacts) were analysed by comparing the vehicle mix and operation in each ZEV / AV scenario, prepared by KPMG Consulting as part of a separate work package, to the hypothetical ‘Dead end’ scenario, which includes only petrol and diesel vehicles. The results of this assessment include the net reduction in air emissions, the consequent net improvements in population health from reduced exposure to air pollutants, and potential changes in noise levels, active transport use and greenhouse gas (GHG) emissions.

The analysis of population health and non-health impacts has found that:

- A fleet comprising of ZEVs and AVs is expected to substantially reduce adverse health outcomes from exposure to pollutants harmful to human health. The estimated net reduction for the ZEV / AV scenarios, relative to the Dead end scenario, ranges from 1,343 Disability Adjusted Life Years (DALYs) to 3,737 DALYs, which is an aggregate measure of the reduced premature mortality and reduced morbidity, including the incidence of cardiovascular and respiratory illnesses.
- There is potential for significant benefits from a reduction in human error related crashes with the uptake of AVs, albeit the scale of these benefits will be less certain until AVs have established a measurable track-record.
- Some of these health benefits may be offset by an increase in health risk from a reduction in active transport use, and these risks are higher in the scenarios with privately owned driverless vehicles (the Private drive and Hydrogen highway scenarios).
- The potential reduction in GHG exhaust emissions, estimated to be up to 27 Mt CO_2-e, would make a large contribution towards meeting Victoria's GHG emission reduction targets. However, the net reduction depends on the GHG emissions-intensity of the electricity used to power electric vehicles.
- There are potentially large benefits from a reduction in noise emissions, such as increased flexibility for freight transport at night, but equally some risks, such as an increased safety risk for hearing impaired pedestrians. However, there is insufficient data to make strong conclusions on the benefits and risks associated with noise reductions.

The manufacturing and disposal impacts (environmental impacts) were analysed by considering the fleet mix and the turnover rate. The manufacturing impacts were analysed by comparing the environmental footprint of manufacturing vehicles in the ZEV / AV scenario to the environmental footprint in the Dead end scenario. The disposal impacts were analysed by considering the differences in the quantity and composition of waste production in the ZEV / AV scenarios, relative to the Dead end scenario.

The analysis of environmental (manufacturing and disposal) impacts has found that:

- Current methods for manufacturing electric and hydrogen powered vehicles may have larger environmental footprints than the manufacture of vehicles with internal combustion engines (ICE), due to higher energy requirements and the need to use rarer materials. However, the resource intensity of manufacturing is likely to reduce over time as manufacturing processes improve and become more efficient.
- The projected amount of lithium battery waste assessed for electric vehicle scenarios are of a magnitude that is much higher than current industry forecasts.
- Similarly, the projected generation of electronic waste (e-waste) will increase rapidly in the autonomous vehicle scenarios. This growth has not been considered in key waste policies and strategies.
- If the transition happens much more rapidly, the waste challenges are amplified because, as assumed in the High speed scenario, there are strong financial incentives to abandon privately owned non-autonomous vehicles. These incentives result in earlier abandonment of these vehicles, depressing their market value, and creating a feedback loop of stronger incentives to dispose the vehicles and transition to the shared model. This is likely to heighten the risks of illegal dumping, waste stock-piling and illegal exports.

Against this backdrop, policymakers should manage the transition by developing strategies to mitigate risks and capitalise on opportunities.

The implications for policymakers are that:

- The near elimination of harmful vehicle emissions, except for particulate matter (PM) from non-exhaust sources, will require a 'recalibration' of air quality policy to target the right sectors and the sources. This may require a shift in emphasis from reducing exhaust emissions to reducing exposure from non-exhaust sources through road and / or vehicle design, and through the use of vegetation barriers.
- Health agencies should monitor health risks arising from the reduced use of active transport under the shared ownership model.
- Victorians will need to be aware of the environmental footprint of manufacturing, whether the manufacturing takes place in Victoria or elsewhere. Considering the trends in global environment policy, the environmental impacts of manufacture may be 'internalised' in the price of imports.
- The impacts on the waste sector present both opportunities and challenges for the economy.
- On the one hand, there is the potential to develop local industries to process, recover and recycle valuable materials and components.
- On the other, the rapid change in waste generation could overwhelm the waste infrastructure, leading to risks of illegal dumping, waste stockpiling and / or illegal exports. An extended producer responsibility (EPR) scheme may be a suitable policy measure to manage the end-of-life impacts of the new waste.
- The heightened risks under a more rapid transition than anticipated, as in the High speed scenario, could be managed through a range of measures including increasing surveillance of potential illegal dumping sites, stronger oversight of the waste sector and greater penalties for illegal waste handling.

A key conclusion arising from this work is that there are very large health benefits associated with the transition to a ZEV / AV fleet. The analysis estimates a potential health benefit from a ZEV and AV fleet in 2046 of up to 3,781 DALYs. This is equivalent to $735 million (in 2018 prices) in economic terms using an estimate of the Value of a Statistical Life Year (VSLY). Given the magnitude of the health benefits and the significant opportunities associated with a transformation to a ZEV / AV fleet, Aurecon and ERM recommend that the Victorian Government consider the economic viability of policy measures to incentivise the uptake of ZEV and AV vehicles, and develop strategies to monitor and manage adverse impacts from manufacturing and waste disposal.

1 Introduction

1.1 Context and Background

Infrastructure Victoria is preparing advice for the Victorian Government on the infrastructure requirements to support autonomous vehicles (AV) and zero emission vehicles (ZEV) in Victoria. The adoption of these technologies will have major impacts on a range of infrastructure sectors, and on the population and environment of Victoria.

To support the preparation of the advice, Infrastructure Victoria has engaged experts to provide evidence on the potential impacts of AVs and ZEVs on:

- the transport network
- population and land-use
- energy systems
- information and communication technology
- the finances of the Victorian state and local governments
- the transport engineering sector
- the environment and population health.

Infrastructure Victoria is also obtaining expert advice on:

- AV and ZEV developments in international markets
- how AVs and ZEVs may change the visual design of streetscapes, transport hubs and freeways
- how the impacts will vary by socioeconomic group.

1.2 Purpose and Scope of this Report

Infrastructure Victoria has engaged Aurecon and Environmental Resources Management (ERM) to provide advice on the population health and environmental impacts of AVs and ZEVs.

Vehicles emit a range of pollutants into the atmosphere that affect human health and ecosystems. These include particulate matter (PM), oxides of nitrogen (NO_X), volatile organic compounds (VOCs) and carbon monoxide (CO), among other pollutants. In particular, there is strong health evidence that PM and NO_X cause adverse effects to human health, including increasing the risk of cardiovascular and respiratory diseases, and in some cases, the risk of premature mortality.

The uptake of AVs and ZEVs will change the emissions of these pollutants, and in turn, change the exposure of the population to pollutant concentrations. This will result in a change in associated health outcomes (e.g. premature mortality, hospital visits for cardiovascular disease and respiratory disease, and emergency department visits for asthma etc.[1]).

Other health and environmental impacts include impacts on:

- safety
- the use of active transport
- noise levels.

The transition to AVs and ZEVs will also have impacts during the manufacture and disposal stages.

[1] These are discussed further in Section 4.3.1

The manufacture of AVs and ZEVs will have different impacts compared to the manufacture of conventional (Internal Combustion Engine) vehicles, by changing the energy requirements, material use, emissions and waste production during the manufacturing process.

The transition to an AV and ZEV fleet will also change the requirements for waste infrastructure, waste policy and waste management practices. This will result in some opportunities for Victoria to develop domestic reprocessing industries. On the other hand, the change to the composition of the fleet will require changes to the waste infrastructure, which could lead to unintended outcomes during the transition such as illegal dumping.

The scope of this report is to provide analysis on the magnitude and nature of these impacts under a range of hypothetical scenarios of technology choice, driving modes, ownership models and occupancy models.

1.3 Limitations of the Study

The study relies heavily on transport modelling of vehicle activity in the selected scenarios. No verification of the results of the transport modelling was performed.

The estimates of population health impacts are based on a simplified ‘impact pathway’ approach for most pollutants and a damage cost approach for others (refer to Section 3). This requires some simplifying assumptions, which are outlined in Section 3.

Limited data were available on the manufacturing impacts of ZEVs and AVs. Therefore, while the results in this study are based on publicly available data, there appears to be a gap in the literature on the characterisation and quantification of the environmental footprint of ZEV and AV manufacture.

The estimates of incremental health benefits should not be considered projections of the future but are based on hypothetical ‘extreme’ scenarios of the uptake, or non-uptake, of ZEVs and AVs in Victoria (refer to Section 2).

1.4 Report Structure

The remainder of the report is structured as follows:

- Section 2 summarises the scenarios that have been considered.
- Section 3 outlines the methodology used to estimate population health and environmental impacts.
- Section 4 presents the results of the population health impact assessment, including selected non-health population impacts.
- Section 5 presents the results of disposal and manufacturing impacts.
- Section 6 discusses key considerations for government.
- Section 7 concludes.

2 Scenarios

Table 2-1 summarises the scenarios.

Table 2-1 – Scenario definitions

Scenario	Year	Driving Mode	Power Source	Ownership / market model	Occupancy level
Electric avenue	2046	Non-driverless	Electric	Private Ownership	Single occupancy
Private drive	2046	Driverless	Electric	Private ownership	Single occupancy
Fleet street	2046	Driverless	Electric	Shared, on-demand services	Multiple occupancy
Hydrogen highway	2046	Driverless	Hydrogen	Private ownership	Single occupancy
Slow lane	2046	Non-driverless and driverless	Electric and petrol / diesel	Shared, on-demand services and private ownership	Multiple occupancy and Single occupancy
High speed	2031	Driverless	Electric	Shared, on-demand services	Multiple occupancy
Dead end	2046	Non-driverless	Petrol / diesel	Shared, on-demand services and private ownership	Multiple occupancy and Single occupancy

Source: Infrastructure Victoria Advice on Automated and Zero Emissions Vehicles Infrastructure: Future Scenarios Report (2018)

The scenarios are not necessarily forecasts of the likely Victorian fleet in 2046 (or 2031 for the 'High speed' scenario). Rather, they are hypothetical 'extreme' outcomes for fleet transformations to particular technologies (electric, hydrogen, petrol / diesel, or electric and petrol / diesel), driving modes (driverless, non-driverless or a combination), ownership models (private ownership, shared ownership, on-demand services, or a combination) and occupancy models (single occupancy, multiple occupancy or a combination).

The results for each of the scenarios represents the corresponding impacts under these extreme outcomes. The results can be combined to construct plausible forecasts of the impacts of the likely uptake of AVs and ZEVs in Victoria.

3 Methodology

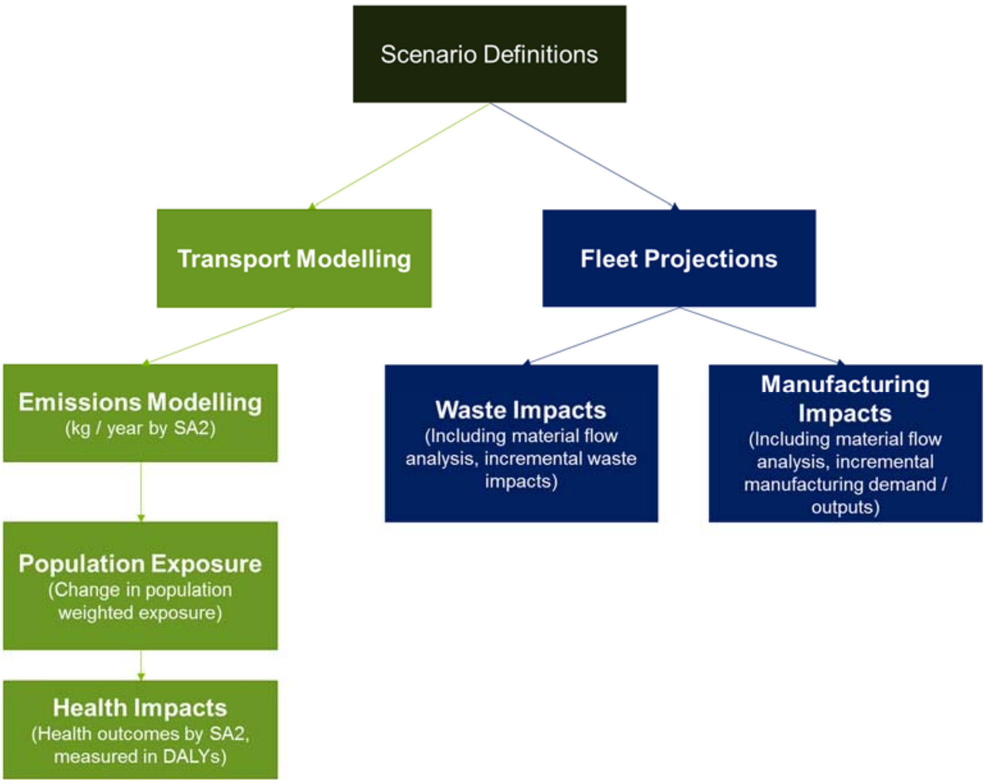
3.1 Analytical Framework

The population health and environmental impacts analysis is driven by the scenario definitions outlined in Section 2. The scenarios define the technologies that make up the vehicle fleet in 2046 (or 2031 in the 'High speed' scenario). The assumed fleet composition in each scenario affects:

- transport use and traffic activity in Victoria, which in turn affects the size and distribution of population health benefits from emission reductions (population health impacts)
- demands on the manufacturing and the waste sectors.

These two branches of impacts have been analysed using two different analytical frameworks, which are summarised in sections 3.1.1 and 3.1.2 respectively. Appendix A contains more detail on the assumptions and techniques used to analyse the impacts. Figure 3-1 below provides an overview of the analytical framework used in this report.

Figure 3-1 – Overview of Analytical Framework



3.1.1 Population Health Impacts Methodology

The population health impacts were estimated by using the results of the transport modelling, which included the estimate of vehicle kilometres travelled (VKT) and average speed by:

- scenario
- Australian Standard Geographical System (ASGS) Statistical Area 2 (SA2) regions
- vehicle type.

The estimation of population health impacts (refer to Section 4) uses the 'impact pathway' approach to estimate the impacts of the key pollutants (PM and NO_X), and uses a 'damage cost' approach to estimate the impacts of two other pollutants (VOC and CO).

PM, NO_X, VOC and CO are the pollutants that cause the greatest adverse health effects and therefore have been analysed in relatively greater detail in earlier studies (e.g. see DTI, 2010). Data from previous studies were used to quantify the potential impact of AVs and ZEVs on the population. The impacts are presented in the common unit of Disability Adjusted Life Years (DALY). DALYs measure the aggregate burden of mortality and morbidity experienced by a population. A life year lost due to an external health risk (e.g. pollution) represents one DALY. Years living with a disease are converted to DALYs using a 'disability weight'. This study uses the disability weights provided by Access Economics (2008). Each disability weight represents a scalar used to convert morbidity outcomes into a mortality equivalent (e.g. contracting Rheumatic fever is equivalent to 0.047 DALYs, whereas death is 1 DALY), and can be used to measure cumulative relative effects of changes in health outcomes.

The results have been summarised by scenario, pollutant, socioeconomic group, and remoteness category (metro, regional or remote). Detailed results by SA2 regions are provided in Appendix B.

Impacts from other pollutants (SO_2, benzene, toluene, ethylbenzene and xylenes), noise impacts, safety impacts and other health impacts are discussed qualitatively in Section 4.4, based on a review of relevant literature.

Emissions Estimation

Exhaust emissions for all scenarios were calculated using COPERT Australia software (EMISIA, 2014). The COPERT model is an internationally recognised tool for the estimation of air pollutant and GHG emissions estimation from road sources. COPERT Australia is the Australian specific version of the original model developed in the European Union, and was selected over other models (e.g. PIARC) due to its completeness of inventory and most up to date technologies.

Non-exhaust emissions for all scenarios were calculated in accordance with EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016 (European Environment Agency, 2016). The estimated emissions were then used to calculate total emission reductions per SA2 region for each pollutant and scenario, relative to the base case (Dead end) scenario.

The emission modelling methodology and results are detailed in a separate report, titled *Air Emission Calculation from Road Transport in Melbourne Metropolitan Area* (ERM, 2018). The necessary data for emission estimation were only available for the Melbourne Metropolitan Area. As such, the results for Melbourne were calculated using a detailed approach (described) below, and the results for the rest of Victoria were based on an extrapolation of the Melbourne results using regression analysis (refer to Appendix C).

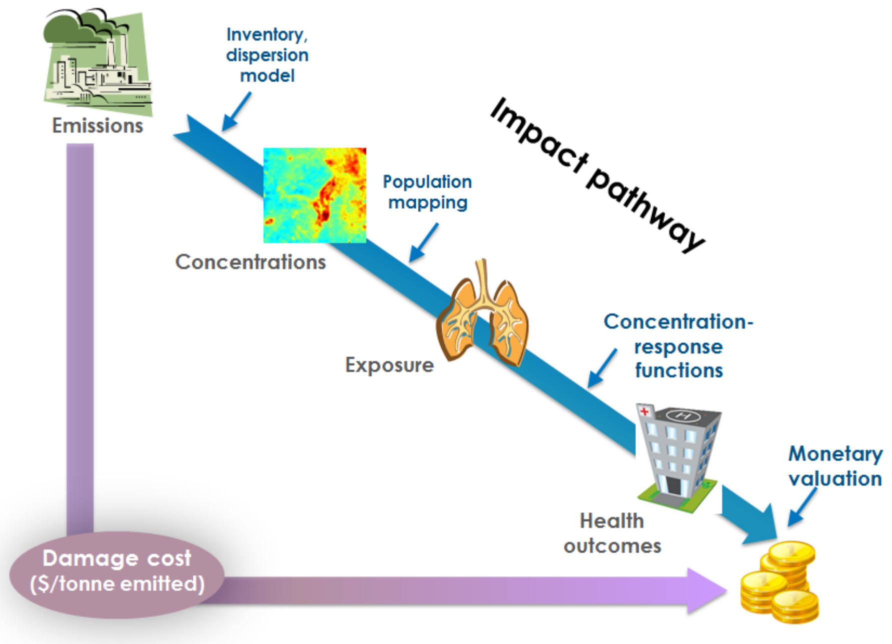
Impact Pathway Approach

The impact pathway approach was applied by estimating:

- changes in emissions of the two key pollutants (PM and NO_X)
- resulting changes in population exposure for selected regions and demographic groups
- changes in health outcomes using 'Concentration Response Functions' (CRFs) from the epidemiological literature
- the aggregate cost expressed as Disability Adjusted Life Years (DALY) and in economic terms.

Figure 3-2 below illustrates a summary of the impact pathway mentioned above.

Figure 3-2 – Impact pathway demonstration by DEFRA (2013)



Source: Extracted from DEFRA (2013)

To estimate population exposure, 'decay functions' were used to estimate the change in ambient concentrations of pollutants associated with the change in emissions. A decay function provides a relationship between the mass of emissions from a source (e.g. kg of $PM_{2.5}$[2]), and the change in ambient concentrations of that pollutant at various distances from the source (e.g. $\mu g/m^3$ of $PM_{2.5}$ at specified distances from the road centreline).

The decay functions from the Design Manual for Roads and Bridges (DMRB) produced by Highways England provides decay curves for $PM_{2.5}$ and NO_X. A geographic information system (ArcGIS) was used to estimate population weighted concentration exposure by:

- starting with a shapefile map of the 2046 road network
- estimating emissions per road link for each scenario
- estimating concentrations of $PM_{2.5}$ and NO_X for 1 x 1 km^2 grid-cells in each SA2, by applying the decay functions from DMRB, and specifying the road links as the source of emissions.

A population weighted mean concentration was calculated for each SA2 using the estimated concentrations for each grid cell, and the corresponding population distribution from the Australian Bureau of Statistics (2017) as the weights. The population weighted mean provides a more meaningful measure of average exposure across an SA2 than an unweighted mean, because it provides greater weight to grid cells with a higher relative population, and therefore greater health impacts.

CRFs for various health outcomes, corresponding disability weights for each outcome, population forecasts and baseline incidence rates were then used to estimate the changes in DALYs for each SA2 under each scenario.

Damage Cost Approach

The damage cost approach expresses the health impacts in monetary terms per unit of emissions (e.g. $ per tonne). The damage cost approach makes many simplifying assumptions, which makes it less accurate than the impact pathway approach, but is suitable to apply in cases where health impacts are expected to be less material and / or more uncertain.

The result of applying damage costs is an estimate of the health impact expressed in monetary terms ($). The monetary results have been converted to DALYs for aggregation and comparison with the impact

[2] PM_{10} and $PM_{2.5}$ are particles with aerodynamic diameters of less than or equal to 10 and 2.5 micrometres respectively

pathway results. This was done by assuming a Value of a Statistical Life Year (VSLY), which provides a conversion factor between DALYs and economic costs ($) (refer to Appendix A).

3.1.2 Manufacturing and Disposal Impacts Methodology

The manufacturing and disposal impacts were estimated by considering the turnover of the fleet in each of the scenarios, and the numbers and types of vehicles reaching end-of-life each year. This allowed the estimation of vehicles of each type requiring:

- disposal of some materials to landfill
- collection of some materials for reprocessing
- the manufacture of new vehicles to replace those reaching end-of-life
- the manufacture of new vehicles to meet the demands of a growing fleet.

Fleet turnover was modelled by estimating the size of the fleet in 2046 by using analysis of ABS data on the ratio of vehicles to population, and estimating the proportion of fleet reaching end-of-life.

Waste infrastructure impacts, opportunities and policy considerations

The impacts, opportunities and policy considerations for the waste sector were assessed by considering the amount of material requiring processing (the demand for waste management services) and the potential capacity of the waste infrastructure in the future (the supply of waste management services).

Demand was disaggregated into key material types and estimated based on assumptions about the composition of vehicles reaching end of life. This provided an estimate of the weight of each material type requiring processing by the waste sector in 2046 compared to the Dead end scenario.

To assess the impact this is likely to have on the waste infrastructure, relevant waste policies and strategies were analysed to understand the forecasted long-term investment in Victorian waste infrastructure, and whether this investment is likely to be sufficient to handle the volumes required by 2046.

The comparison of supply and demand highlights material types and segments of the waste sector with sufficient capacity based on anticipated investments, and material types and segments with an anticipated shortfall of planned investment.

This demand-supply analysis allowed for the identification of risks and opportunities, including:

- potential stranded investment (e.g. overcapacity in infrastructure that may not be required)
- material types that are at risk of being stockpiled and / or illegally dumped (e.g. due to a shortage of landfill or reprocessing capacity in a region)
- opportunities to develop the domestic reprocessing industry for some material types (e.g. lithium batteries).

Policy considerations and potential policy solutions to manage these risks and opportunities are outlined in Section 6.

4 Population Health and Non-Health Impacts

The following sub-sections outline the population health impacts, and selected non-health impacts, of each scenario.

The analysis of population health and non-health impacts has found that:

- A fleet comprising of ZEVs and AVs is expected to substantially reduce adverse health outcomes from exposure to pollutants harmful to human health. The estimated net reduction for the ZEV / AV scenarios, relative to the Dead end scenario, ranges from 1,343 Disability Adjusted Life Years (DALYs) to 3,737 DALYs, which is an aggregate measure of the reduced premature mortality and reduced morbidity, including the incidence of cardiovascular and respiratory illnesses.
- There is potential for significant benefits from a reduction in human error related crashes with the uptake of AVs, albeit the scale of these benefits will be less certain until AVs have established a measurable track-record.
- Some of these health benefits may be offset by an increase in health risk from a reduction in active transport use, and these risks are higher in the scenarios with privately owned driverless vehicles (the Private drive and Hydrogen highway scenarios).
- The potential reduction in GHG exhaust emissions, estimated to be up to 27 Mt CO_2-e, would make a large contribution towards meeting Victoria's GHG emission reduction targets. However, the net reduction depends on the GHG emissions-intensity of the electricity used to power electric vehicles.
- There are potentially large benefits from a reduction in noise emissions, such as increased flexibility for freight transport at night, but equally some risks, such as an increased safety risk for hearing impaired pedestrians. However, there is insufficient data to make strong conclusions on the benefits and risks associated with noise reductions.

4.1 Emissions Estimation

Table 4-1, Table 4-2 and Table 4-3 summarise estimated emissions and emission reductions by scenario and pollutant. Note, the results relate only to the Melbourne metropolitan region. However, the population health benefits (DALYs) for Melbourne estimated using the Melbourne emissions data were extrapolated state-wide using the methodology described in Appendix C.

The Slow lane scenario achieves the lowest emission reductions for each of the pollutants.

Electric Avenue, Hydrogen Highway, Private Drive and Fleet Street scenarios reduce emissions of $PM_{2.5}$ and PM_{10} in all SA2 regions relative to the Dead end scenario. For the Slow lane scenario, emissions of $PM_{2.5}$ and PM_{10} emissions reduce in the majority of SA2 regions, however an increase in $PM_{2.5}$ and PM_{10} emissions is projected for a number of SA2 regions.

All scenarios, except for the Slow lane scenario, are assumed to reduce emissions of NO_X, CO, VOCs, SO_2, benzene, toluene, ethylbenzene and xylenes vehicle emissions to zero.

For reporting purposes, SA2s were grouped into the following categories using ABS ASGS correspondences:

- **Metro** – All SA2s classed with a remoteness area (RA) name of "Major Cities of Australia".
- **Regional** – All SA2s with an RA name of "Inner Regional Australia".
- **Remote** – All SA2s with an RA name of "Outer Regional Australia", "Remote Australia" or "Very Remote Australia".

Table 4-1 – Dead end and Slow lane scenario emissions for Melbourne by SA2 group (kg / year)

	CO	VOCs	PM_{10}	SO_2	Benzene	Toluene	Ethylbenzene	Xylenes	$PM_{2.5}$	NO_x
Dead End										
Metro	42,249,316	8,076,247	4,511,411	325,441	323,666	621,724	107,533	482,048	2,419,953	11,402,495
Regional	2,193,447	522,793	257,162	16,820	14,761	28,162	4,868	23,943	137,014	780,038
Remote	4,965,928	917,493	508,212	38,023	37,895	72,852	12,602	55,734	272,753	1,249,624
Dead End Total	**49,408,691**	**9,516,533**	**5,276,784**	**380,284**	**376,322**	**722,737**	**125,003**	**561,724**	**2,829,720**	**13,432,156**
Slow Lane										
Metro	20,449,367	3,953,641	3,727,068	188,270	60,305	110,875	19,281	113,172	1,979,043	8,001,779
Regional	1,244,376	310,865	219,132	10,420	3,115	5,617	974	7,187	116,154	591,324
Remote	2,376,777	437,473	416,484	21,142	8,044	14,965	2,600	14,063	220,572	839,352
Slow Lane Total	**24,070,520**	**4,701,979**	**4,362,684**	**219,832**	**71,464**	**131,457**	**22,855**	**134,422**	**2,315,769**	**9,432,455**

Table 4-2 – $PM_{2.5}$ emissions by scenario (kg / year)

	Dead end	Electric Avenue	Fleet Street	High Speed[1]	Hydrogen Highway	Private Drive	Slow lane
Metro	2,419,953	1,366,486	1,260,279	n/a	1,440,412	1,473,552	1,979,043
Regional	137,014	78,404	76,889	n/a	75,759	76,424	116,154
Remote	272,753	152,752	143,099	n/a	159,925	161,369	220,572
Total	**2,829,720**	**1,597,642**	**1,480,268**	**n/a**	**1,676,096**	**1,711,344**	**2,315,769**

Note[1]: No transport modelling and therefore emission modelling was undertaken for this scenario. The health impacts of the High speed scenario have been estimated by scaling the Fleet Street scenario results.

Table 4-3 – NOx emissions by scenario (kg / year)

	Dead end	Slow lane
Metro	11,402,495	8,001,779
Regional	780,038	591,324
Remote	1,249,624	839,352
Total	**13,432,156**	**9,432,455**

4.2 Exposure Assessment

4.3 Health Impacts Due to Exposure

The following sections outline the health impacts (positive or negative) related to the changes in emissions and concentrations in each uptake scenario. Results are presented as the total number of DALYs avoided compared to the Dead end scenario. Population and distribution data for each SA2 were provided by SGS Economics for all the scenarios except for the High speed scenario. For the High speed scenario, population projections from Victoria in the Future (VIF) were used (DELWP, 2017).

4.3.1 Health Outcomes Related to Pollutants

The vehicle emission reductions included in this study, relative to the base case (Dead end) scenario, are $PM_{2.5}$, PM_{10}, SO_2, NO_x, VOCs, CO, Benzene, Toulene, Ethylbenzene and Xylenes.

The impact of exposure to the following emissions has been conducted using the Impact Pathway method outlined in Section 3.1.1:

- **$PM_{2.5}$** – results of various epidemiological studies have indicated that a wide range of health effects are attributable to exposure to particles ($PM_{2.5}$), including increases in mortality, as well as morbidity related to respiratory disease, cardiovascular disease, cardiac disease, pneumonia and bronchitis. Literature has also identified strong links to increases in emergency department visits for asthma (NEPC, 2010; EPHC 2006).
- **NO_x** – There is considerable evidence in literature regarding health outcomes attributable to exposure to NO_x emissions, with short term effects including increases in all cause, cardiovascular and respiratory mortality (WHO, 2013a; NEPC, 2010: USEPA, 2008), particularly in the 65+ age group. No threshold effect has been identified. Other morbidity impacts (hospital admissions and emergency department visits) have also been linked – particularly for children and older adults (65+).

The impact of exposure to the following emissions has been conducted using the Damage Cost method outlined in Section 3.1.1:

- **VOCs** - In a review of the VOC standards in the United States, the USEPA concluded that there was clear, consistent evidence of a causal relationship between short-term exposure to O_3, the formation of which is directly influenced by the emission of VOCs, and respiratory health effects (USEPA, 2006). Long term exposure has been linked with impacts on people with existing diseases such as chronic obstructive pulmonary disease (COPD), diabetes, congestive heart failure etc.
- **CO** – Exposure to CO has been linked to increases in all-cause mortality (all ages), as well as morbidity for cardiac disease (age 65+) and cardiovascular disease (age 65+) (USEPA, 2008).

Changes in the quantities of the following pollutants have been modelled, however due to lack of conclusive data and evidence of health outcomes they have been discussed qualitatively below:

- **SO_2** - Short-term exposure to SO_2 has been linked to daily mortality, respiratory effects and cardiovascular effects in epidemiological literature (WHO, 2013a).
- **$PM_{2.5-10}$** – Similar to $PM_{2.5}$, PM_{10} is associated with increases in daily mortality, as well as morbidity related to respiratory disease, cardiovascular disease, cardiac disease, pneumonia and bronchitis (DTI, 2010). However, there is limited evidence of effects directly attributable to the ‘coarse’ fraction between 2.5 and 10 micrometres in aerodynamic diameter (i.e. $PM_{2.5-10}$).

Health impacts for Benzene, Toulene, Ethylbenzene and Xylenes are not conclusive in the literature, and have not been considered in this report.

4.3.2 Impacts by SA2 Group

Table 4-4 below provides a summary of the total number of DALYs[3] and avoided DALYs calculated for each scenario by SA2 group[4].

Table 4-4 – DALYs by SA2 group and uptake scenario

	Electric avenue (2046)	High speed (2031)	Fleet street (2046)	Hydrogen highway (2046)	Slow lane (2046)	Private drive (2046)	Dead end (2046)[5]
Total DALYs							
Regional	57	46	56	57	122	53	214
Metro	1,731	1,297	1,583	1,933	3,906	2,119	5,196
Remote	5	4	5	5	10	4	14
TOTAL (DALYs)	1,793	1,347	1,644	1,995	4,037	2,175	5,425
Total Change from Dead end scenario (DALYs Avoided)							
Regional	158	130	158	157	93	162	
Metro	3,464	2,961	3,613	3,263	1,290	3,077	
Remote	10	8	10	10	4	10	
TOTAL (DALYs)	3,632	3,099	3,781	3,430	1,388	3,250	
TOTAL ($m)	706	603	735	667	270	632	

Comparing results across scenarios:

- the **Slow lane** scenario has the lowest avoided DALYs of all scenarios, with an estimated 1,388 avoided DALYs
- the **Fleet Street** scenario has the highest avoided DALYs at 3,781[6]
- the **Metro regions** have the highest DALYs in all scenarios.

Consistent with the results of previous studies by EPA Victoria (2012) and the Department of Infrastructure and Transport (2010), the Metro regions of Victoria are likely to receive the greatest benefits of emission reductions in all scenarios.

This is due to the greater absolute population, and the density of population near major roads in the metro areas where pollutant concentrations are higher due to proximity to the source.

Figure 4-1 and Figure 4-2 illustrate the variability of estimated avoided DALYs across Melbourne and the rest of Victoria, respectively, and show that the benefits are concentrated around major population centres.

[3] Includes premature mortality, hospital admissions due to respiratory disease, cardiovascular disease, and emergency department visits for Asthma.
[4] SA2 groups are derived as per the ABS Remoteness Index, summarised as follows: Metro (Major cities), Regional (Inner Regional), Remote (Outer Regional, Remote and Very Remote) (ABS, 2018).
[5] Dead end scenario indicates total DALYs estimated for that scenario. All other columns show avoided DALYs compared to this base scenario.
[6] Estimated at ~$735 million using the Value of a Statistical Life (VSLY) described in Section Section 3.1.1.

Figure 4-1 – Estimated Avoided DALYs Melbourne (Fleet street scenario)

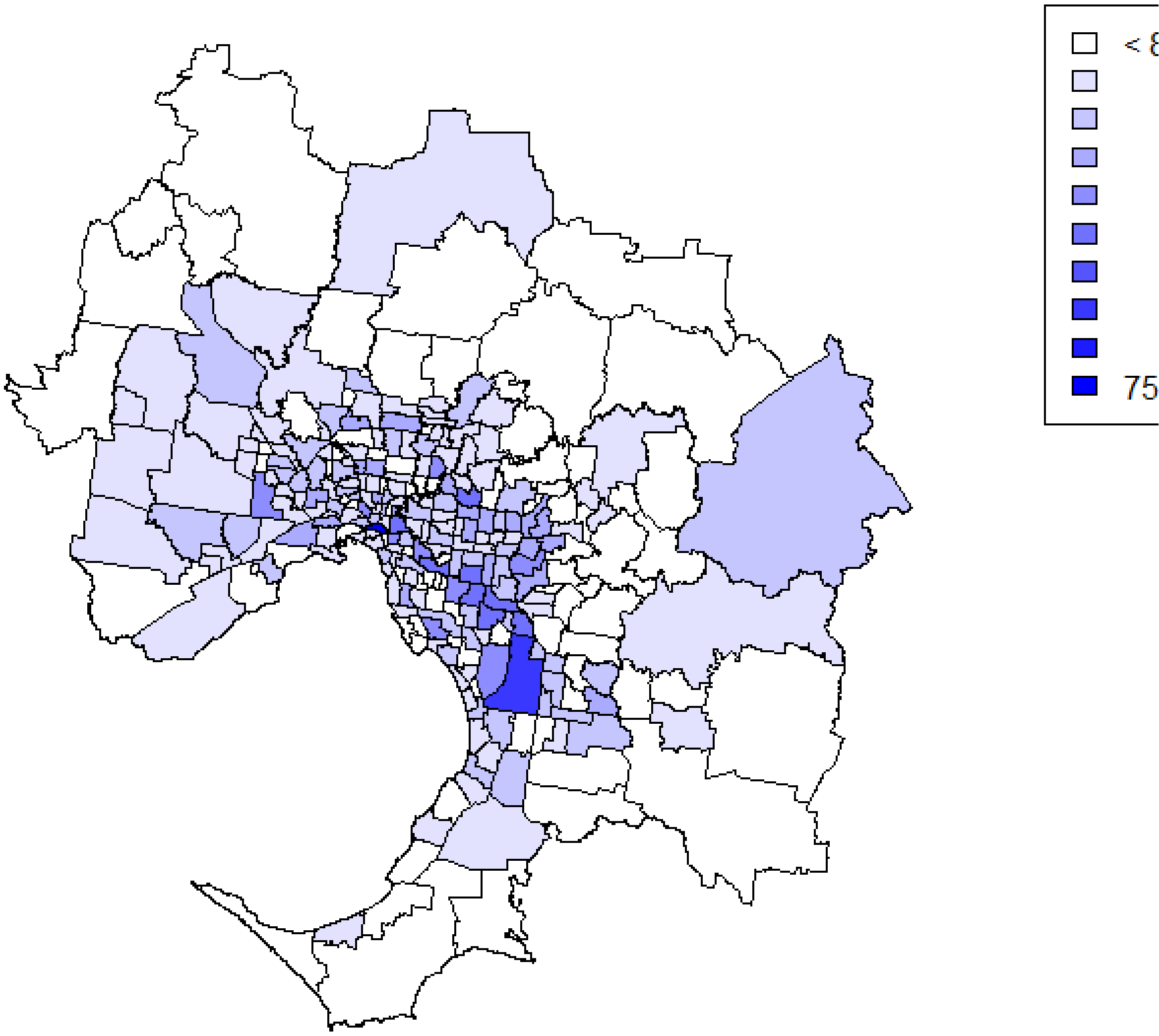
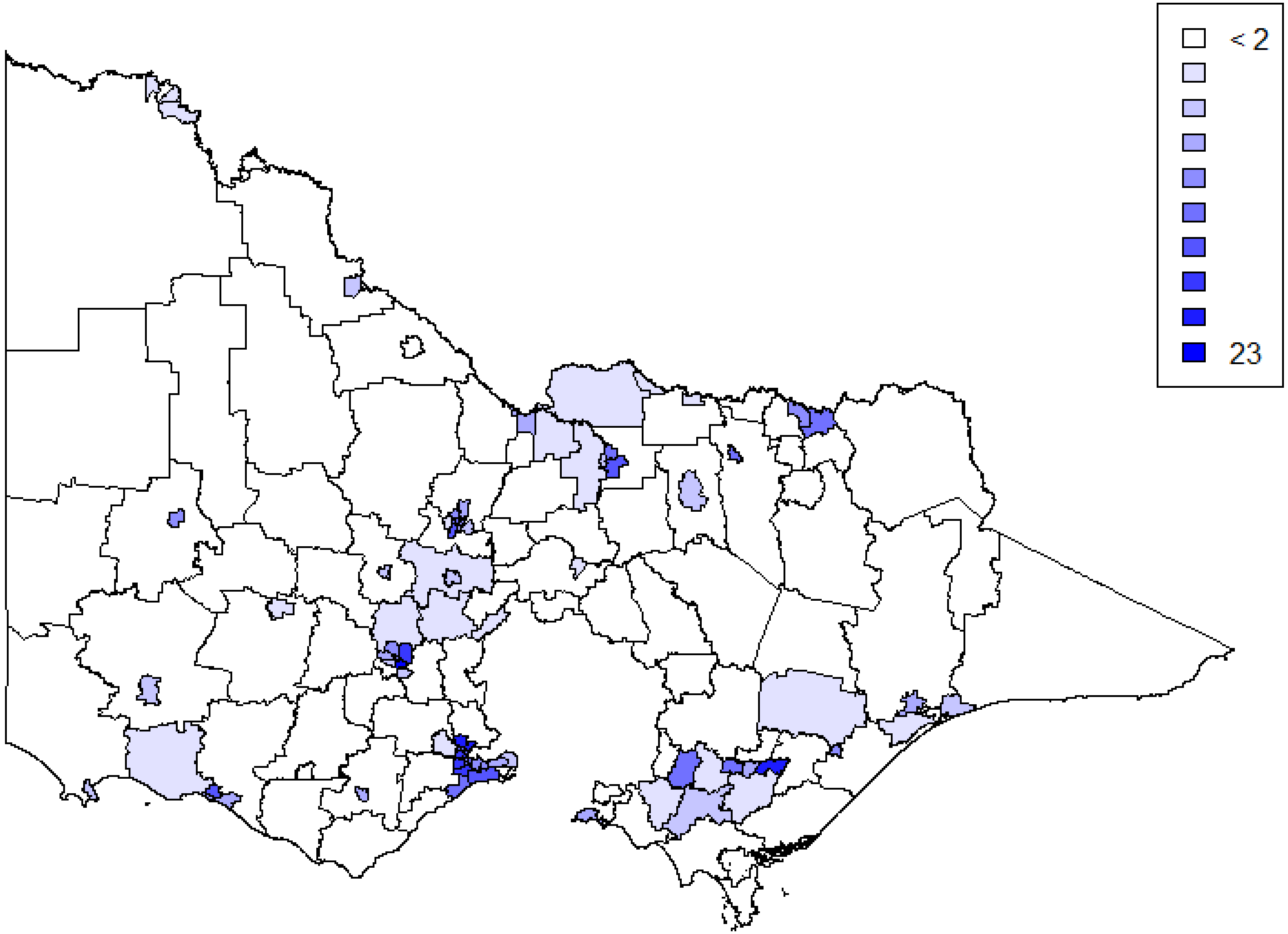


Figure 4-2 – Estimated Avoided DALYs Rest of Victoria (Fleet street scenario)



4.3.3 Impacts by Socioeconomic Group

Each SA2 was grouped into the following socioeconomic status (SES) categories using ABS Socio-Economic Indexes for Areas (SEIFAs):

- **High SES** – Victorian Index of Relative Socioeconomic Advantage and Disadvantage (IRSAD) decile between 8 and 10 inclusive.
- **Medium SES** – Victorian IRSAD decile between 4 and 7 inclusive.
- **Low SES** – Victorian IRSAD between 1 and 3 inclusive.

Table 4-5 below provides a summary of the total number of DALYs and avoided DALYs calculated for each scenario, compared to the Dead end scenario by SES group.

Table 4-5 – DALYs by SEIFA group and uptake scenario

	Electric avenue (2046)	High speed (2031)	Fleet street (2046)	Hydrogen highway (2046)	Slow lane (2046)	Private drive (2046)	Dead end (2046)
Total DALYs							
High SES	685	500	610	788	1,537	898	1,999
Medium SES	700	530	646	768	1,579	818	2,198
Low SES	408	317	387	438	921	460	1,227
TOTAL	**1,793**	**1,347**	**1,644**	**1,995**	**4,037**	**2,175**	**5,425**
Total Change from Dead end scenario (DALYs Avoided)							
High SES	1,314	1,138	1,388	1,211	461	1,101	
Medium SES	1,498	1,272	1,552	1,430	619	1,380	
Low SES	820	689	840	789	306	768	
TOTAL	**3,632**	3,099	**3,781**	**3,430**	**1,388**	**3,250**	
TOTAL ($m)	**706**	**603**	**735**	**667**	**270**	**632**	

Comparing the above results across scenarios:

- **The Medium SES group** is projected to have the highest total avoided DALYs for each uptake scenario followed closely by High and Low SES groups.
- However, in proportion to the population included in each group (i.e. 30%, 40% and 30% in the Low, Medium and High SES group respectively), the **High SES group** is projected to **benefit the most per capita**.

High SES households are projected to have a higher number of avoided DALYs due to the correlation between High SES and high population density, which means High SES groups are likely to receive greater benefits from emissions reductions.

4.3.4 Impacts by Pollutant

Table 4-6 provides the estimated DALYs and Avoided DALYs by each pollutant and scenario.

Table 4-6 – DALYs by Pollutant and uptake scenario

	Electric avenue (2046)	High speed (2031)	Fleet street (2046)	Hydrogen highway (2046)	Slow lane (2046)	Private drive (2046)	Dead end (2046)
Total DALYs							
NO_x	-	-	-	-	1,150	-	1,657
$PM_{2.5}$	1,793	1,347	1,644	1,995	2,663	2,175	3,265
VOCs	-	-	-	-	222	-	455
CO	-	-	-	-	<1	-	4
TOTAL	**1,793**	**1,347**	**1,644**	**1,995**	**4,036**	**2,175**	**5,381**
Total Change from Dead end scenario (DALYs Avoided)							
NO_x	1,657	1,358	1,657	1,657	507	1,657	
$PM_{2.5}$	1,472	1,329	1,621	1,270	601	1,089	
VOCs	499	409	499	499	276	499	
CO	4	3	4	4	4	4	
TOTAL	3,632	3,099	3,781	3,430	1,389	3,249	
TOTAL ($m)	706	602	735	667	270	632	

NO_x and $PM_{2.5}$ results were calculated using an impact pathway approach, while VOCs and CO results were calculated using a damage cost approach (as described in Section 3).

In all full ZEV uptake scenarios[7], emissions of NO_x, VOCs and CO are completely removed. $PM_{2.5}$ emissions for these scenarios vary based on vehicle use (average speed, brake wear, VKTs etc.). Comparing results across scenarios:

- The **Fleet Street scenario** has the **highest $PM_{2.5}$ reduction**, estimated to be 1,621[8] avoided DALYs.
- As the **Slow lane scenario** considers that only 50% of the fleet will be replaced by ZEVs and AVs, and as a result the avoided DALYs for this scenario are **lower by approximately 50%.**

Reductions in NO_x exposure are associated with the highest number of avoided DALYs across all pollutants, with an estimated 1,657 avoided DALYs[9] in the Fleet Street scenario.

Reductions in CO emissions provide minimal health benefits, because exposure to CO is associated with a much lower health response compared to other pollutants.

4.4 Other Health Impacts

The following sections discuss other potential health impacts that have been identified in literature, that are not directly related to changes in air emissions.

4.4.1 Noise

Noise pollution is recognised as an issue by key Australian environmental agencies, and is defined by EPA Victoria (2018) as *"sound at a level which is annoying, distracting or physically harmful"*. Exposure to continuous high levels of noise pollution (85-90 dBA) over a lifetime (particularly in work-related, industrial settings) is linked with progressive loss of hearing and hearing sensitivity thresholds (Stansfeld & Matheson, 2003).

Most urban noise originates from motor vehicles, exacerbated by ever increasing levels of urban density and aviation noise (Fong & Jhonston, 2000). Recent noise impact studies have measured not only the impacts of long / short term industrial level noise exposure, but also the wider effects of long term community noise

[7] Full ZEV uptake scenarios are all scenarios except "Slow lane" and "Dead end".
[8] Estimated at ~$315 million using the Value of a Statistical Life (VSLY) described in Section Section 3.1.1.
[9] Estimated at ~$322 million using VSLY described in Section Section 3.1.1.

pollution. Fong and Johnston (2000) published an extensive review of noise and health for Toronto Public Health, providing insights into health effects including:

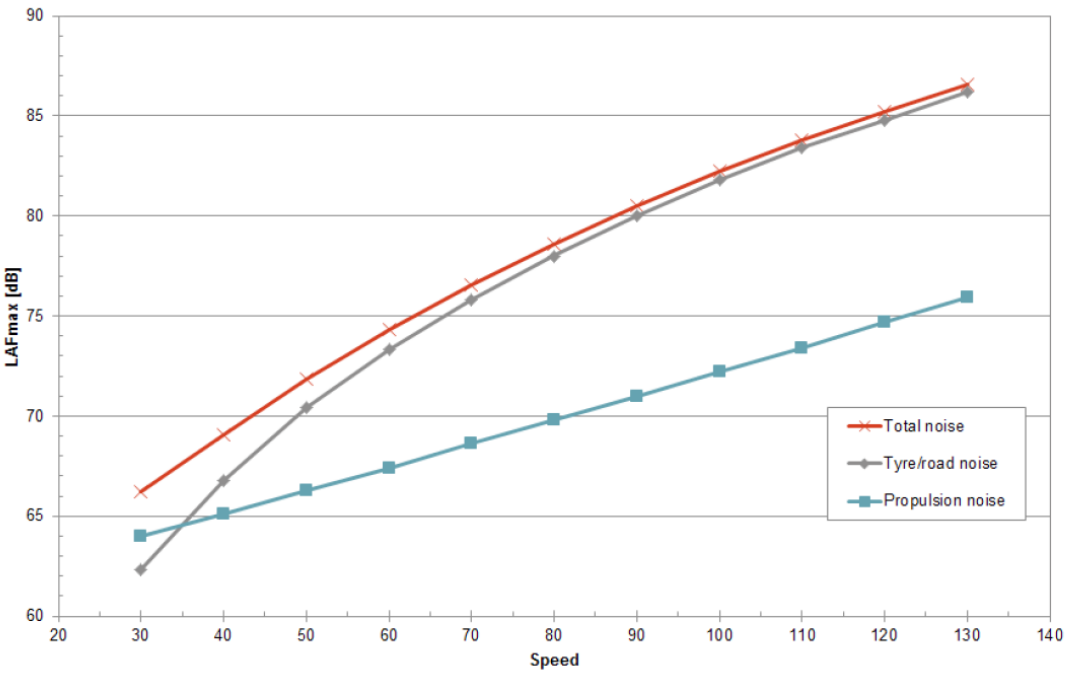
- hearing loss / impairment
- stress induced health outcomes.

Stress induced health outcomes are related to annoyance, as well as other effects that can be induced or exacerbated by exposure to excessive noise such as: cardiovascular disease, sleep disturbance, immune effects, biochemical effects and other performance related issues (Fong & Johnston, 2000; Stansfeld & Matheson, 2003; Basner, et al., 2013).

The literature suggests that ZEVs have significantly lower propulsion noise during operations than that of comparable ICE vehicles. Most studies, such as Iversen (2015), measure the overall noise reduction of a ZEV compared to an ICE and note that at high speeds, the overall noise reduction is marginal due to the increase in contributions to the sound profile from tire and aerodynamic noise (Iverson, 2015; Jabben, Verheijen, & Potma, 2012; Bernhard & Wayson, 2000).

Figure 4-3 indicates the contributions of highway traffic noise (in decibels) to tyre / road noise and propulsion noise respectively relative to speed (km/hr) using the Nord2000 model. The y-axis is measured in “LAFmax”. This refers to the loudness of sounds as perceived by the human ear (LA), at a Fast (F) exponential time weighting, measuring maximum sound (max) in decibels. This measure is commonly used for correlating perceived loudness at low sound levels, and corresponds to the full audio range (20 Hz to 20 kHz) (Acoustic Glossary, 2018).

Figure 4-3 – Contributions of sub sources of highway traffic noise for an average ICE[10]

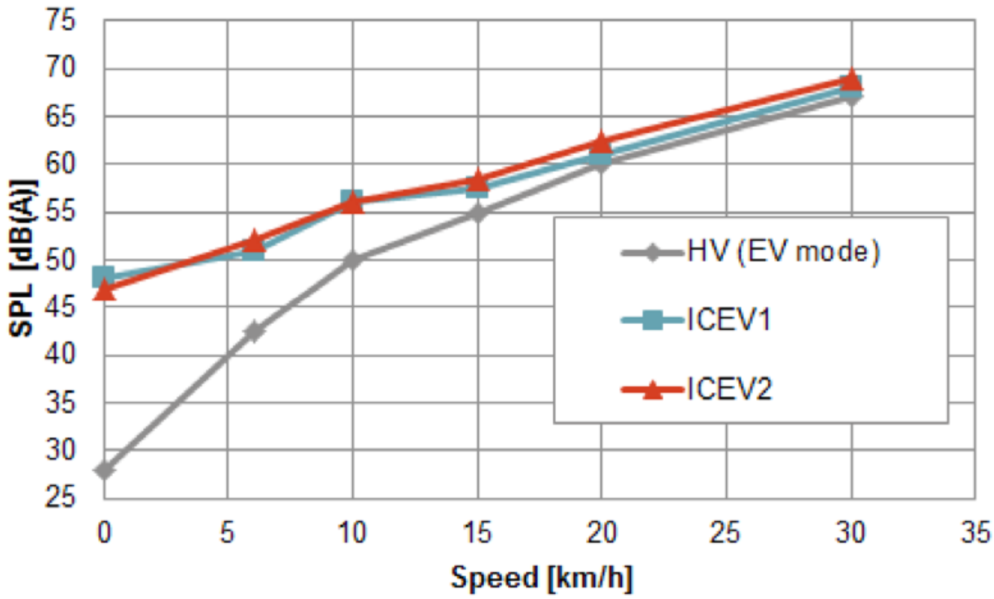


Source: Extracted from Marbjerg (2013)

Figure 4-3 above indicates differences in overall noise sources from an ICE travelling at speeds greater than 30 km /hr. A Japanese study by Sakamoto et al (2010) conducted a low speed range comparison test of 2 mid-range ICEs with a comparable hybrid electric vehicle (HV), which could be tuned to a ‘full electric mode’ for testing. Figure 4-4 depicts the results of this experiment, at a distance of 2 metres from the source while cars were travelling at constant speeds. The HV in electric mode has significantly reduced sound pressure level (SPL) at lower speeds (measured in decibels). However, as predicted by Marbjerg (2013), SPL begins to converge at higher speeds.

[10] Figure extracted from Marbjerg’s (2013) report, “Noise from electric vehicles: a literature survey” (Bernhard & Wayson, 2000), and is referenced in Bernhard & Wayson (2000).

Figure 4-4 – Comparison of a HV to two comparable ICEs in Sound Pressure Level vs. Speed



Source: Extracted from Sakamoto et al (2010)

Overall, ZEVs could significantly reduce traffic noise at low speeds in dense urban areas, or where high quantities of low speed / start-stop driving are common, with some results indicating reductions of approximately 3 – 4 dB in urban areas (Jabben, Verheijen, & Potma, 2012; Marbjerg, 2013). This includes high density areas where there are a number of traffic lights / intersections with high levels of engine breaking and acceleration from stoppage – potentially increasing the attractiveness of residential properties otherwise devalued due to noise pollution.

Reduction in vehicle noise also has the potential to impact road usage patterns. Examples such as road freight operations, which are typically restricted at night, could potentially increase their operating timetable and become more efficient / economic as their noise impact on urban areas is reduced.

However, at higher speeds ZEVs and ICEs noise differences are less distinguishable due to the increase in noise from other sources (aerodynamics and tire noises). Noise reduction in high density, low / medium speed area applications has the potential to provide benefits. Such benefits have been measured using various techniques, including (Narvud, 2002):

- **Impact pathway** – Similar to the approach used in Section 4.3, using noise dispersion modelling, concentration response functions, relevant health outcomes etc. to measure the potential benefit (in avoided DALYs).
- **Willingness to pay (WTP) using hedonic pricing** – measuring the value attributable to urban noise reduction relative to house prices.
- **Stated preference WTP** – using contingent valuation to measure the WTP for reduction in urban noise.

The above methods have been found to be very sensitive to baseline assumptions including population density, house pricing and impacts attributable to aircraft noise (Narvud, 2002).

There are, however, some critics on the benefit of quieter cars at slower speeds. Fender (2011) released a peer reviewed report describing the potential dangers for pedestrians, who are much less likely to hear a ZEV approaching at lower speeds than an ICE vehicle. The report describes basic experimental analysis to determine changes in vehicle detection distance of blindfolded pedestrians for ICEs and ZEV.

Sources in the report from the National High Transportation Safety Administration (NHSTA, 2010) provide more conclusive evidence on the potential impacts of quieter cars to blind / sight impaired pedestrians. The NHSTA (2010) measured how well electric vehicles were detected by blind / visually impaired pedestrians, and noted a significant change in detection distance.

The literature is less conclusive on how AVs affect noise (other than coupling them with a ZEV propulsion system) and AV technology is unlikely to materially affect the noise originating from motor vehicles.

4.4.2 Accidents

The leading cause of vehicle accidents in Australia is human error, which may contribute up to 94% of the crash related fatalities based on international estimates[11]. AV technology has the potential to reduce, if not remove, this portion of vehicle accidents in Australia depending on the level of automation introduced[12] (ADVI, 2018; Fagnant & Kockelman, 2013). While there is a potential for large benefits (as estimated below), the actual number of reduced fatal and serious incidents may not be wholly reduced and is therefore an uncertain assumption. The following results should be interpreted considering the heavy reliance on crash reduction assumptions and crash data.

To estimate the potential economic benefit from a reduction in vehicle accidents due to the implementation of AVs, the following has been assumed:

- crash costs are derived from the Australian Transport Assessment and Planning (ATAP) PV2 Guidelines for Road Transport, Road Parameter Values (TIC, 2016) at $2.4M AUD (2018) per fatal crash, $549K per serious injury accident and $21K per "Other" accident
- percentage of crashes in Victoria attributable to human error is 94% (NHTSA, 2015)
- Victoria averaged 276 road deaths in 2016 which was 0.004% of the population, which when applied to population projections for 2046 and 2031 equates to an annual average road toll of 409 and 336 respectively[13] (Data.vic, 2017)
- similarly, Victoria is projected to have 15,611 and 6,003 "Other" and "Serious" vehicle accidents in 2046, and 12,837 and 4,936 "Other" and "Serious" vehicle accidents in 2031
- only scenarios with full driverless uptake are assumed to reduce crashes, and the assumed technology is Level 5 SAE compliant (full automation, no human interaction).

Using the above assumptions, the reduced crash fatality benefit for each AV scenario is estimated at $982,684,051 in 2046 or $808,016,368 in 2031. Potential benefits for non-fatal crashes were estimated at $3,417M and $2,810M in 2046 and 2031 respectively. These estimates are much less certain than those of the pollutant exposure related benefits in Section 4.3.

Note that the above results only include the potential benefits of a reduction in accidents. However, the costs or 'dis-benefits' have not been quantified, as well as other potential qualitative benefits. These could include:

- Decrease in the number of available organ donors. In 2011, car accidents accounted for more than 11% of organ donations (ANZ Organ Donation Registry, 2011)
- Changes to deaths of wildlife in Australia – depending on the AV technology adopted, AVs could increase or decrease the likelihood of wildlife fatalities on Australian roads (Bland, 2015).

The implementation of Autonomous Vehicles is likely to provide a benefit to the Victorian community via a reduction in occurrences in crashes, however, more research should be conducted to consider the full breadth of costs and benefits related to traffic safety and AVs.

4.4.3 Active Transport

The mass adoption of AVs (regardless of power source) has the potential to reshape the way humans move between destinations. As the technology evolves, so too will the infrastructure to support it and the layout of cities and transport nodes (Eno, 2013).

Changes in the trends of active transport use by the population of Victoria will depend heavily on the transport, infrastructure planning and automation levels, as described by the Victoria Transport Policy Institute (2018). For example, spaces that become increasingly redundant (e.g. mass car parks) could be converted to active transport infrastructure or recreational green spaces. This potential could also extend to

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[11] Sourced from U.S. National Highway Traffic Safety Administration (NHTSA), as directed by IV in comments on Revision 1a of this report. Online: **https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115**
[12] AVs may not reduce all human error related crashes, depending on the assumed AV technology levels of either SAE level 4 vs. level. The Society of Automated Engineers (SAE) developed standardised terminology for automation levels in vehicles. SAE Level 4 is "High Automation" and Level 5 is "Full Automation" (SAE, 2016).
[13] 2016 and 2046 population data provided by SGS Economics and 2031 projections sourced from Victoria in the Future (VIF)(2018) data.

the use of on street parking in dense urban areas, where the need for a personal car begins to diminish and streetscapes have the opportunity to be converted into active transport highways (Stace, 2016).

Potential increases in the incremental costs for short trips also have the potential to drive some pedestrians to consider a walk / cycle to their local supermarket to avoid short trip fees (as an example).

While there is potential for widespread benefits, international literature has also recognised the potential for rapid AV uptake to reduce the attractiveness of active transport (ADVI, 2016). If, for instance, AVs are privately owned (e.g. the "Private drive" scenario), owners could become heavily incentivised to increase time on the road: calling their car to pick them up from work, pick up groceries, drop off / pick up after a night out or at a restaurant etc. Incremental exercise (e.g. walking to the bus, walking home from work) could reduce dramatically, with little incentive to do otherwise (Spinoulas & Davidson, 2015; Stace, 2016).

Considering the above, there are two main scenarios could be considered when estimating the impacts of AVs on active transport: private vs. shared ownership. Assuming:

- active transport values in Australia sourced from the Australian Transport Assessment and Planning Guidelines (ATAP) (TIC, 2016) and value of benefits provided by Garrard (2009)
- the shared and private ownership models increase and reduce active transport by 10% respectively
- Victorian active travel statistics and impacts provided by Garrard (2009)
- health costs per km travelled at $0.376 (2009) per km (Brown et al, 2012; Garrard, 2009), escalated using Australian historical CPI[14]
- population projections provided by SGS for 2046 (SGS, 2018).

In the above scenario, changing active transport behaviours has a value equivalent to 164 / 133 DALYs in 2046 / 2031 respectively and could either be a benefit (avoided DALYs) or a cost (increased DALYs) depending on the uptake scenario. In "Private Ownership" scenarios, this value is considered a cost due to expected reductions in active transport. In "Shared Ownership" scenarios, the value is considered a benefit attributable to an uptake in incremental active transport, as travellers are incentivised to reduce the number of paid trips they make in a day.

Modelling specific impacts of active transport requires a wide range of assumptions, and the potential impacts on active transport are uncertain. From a public health and safety point of view, changing the incremental active transport behaviours of the Victorian public could have significant impacts and should be strongly considered throughout the future development of AV technologies and infrastructure.

4.5 Summary of Population Health Impacts

4.5.1 Summary of Findings

The analysis of potential health benefits shows that a very large reduction in the health impacts from vehicle emissions is possible in the ZEV / AV scenarios. In these scenarios, health impacts reduce to approximately 25-30% of the impacts in the Dead end scenario. This includes a full reduction in the emission of non-PM pollutants, and an approximate halving of emissions of $PM_{2.5}$.

The magnitude of the health benefits is projected to vary according to the scenario, and the distribution of impacts will vary by population group:

- The **Fleet street** scenario has the highest total avoided DALYs (compared to the Dead end scenario) at 3,737.
- The **Slow lane** scenario has the lowest total avoided DALYs at 1,343.
- High SES population and Metro regions of Victoria are likely to receive the greatest health benefits (in total avoided DALYs) due to increased population densities and proximities to roads.

[14] Source: RateInflation.com - https://www.rateinflation.com/consumer-price-index/australia-historical-cpi

- In all full ZEV uptake scenarios[15], emissions of NO_x, VOC and CO are completely removed. $PM_{2.5}$ emissions for these scenarios vary based on vehicle use (average speed, brake wear, VKTs etc.).
- There are likely to also be benefits in noise reduction for ZEVs (at low speeds), reductions in car accidents for AVs and potential health impacts related to reductions / increases in Active travel based on ownership models.

4.5.2 Comparison with previous work

Marsden Jacob (2016) conducted a review of the Fuel Quality Standards Act 2000, which estimated a baseline health cost from vehicle emissions for Australia of $3,588 million in 2015. Assuming that the impacts for each state or territory scale according to the proportion of vehicle numbers in that state or territory, which is approximately 27% for Victoria (Marsden Jacob, 2016, p.45), the estimated baseline impact for Victoria in 2015 is approximately $770 million.

Comparatively, the analysis in this report estimated a baseline health cost in 2046 (Dead end scenario) of $1,046 million. Assuming no uptake of ZEV (e.g. a 'Dead End' situation) the impacts in 2046 will be higher than 2015. This is due to be population growth, offset partly by the increase in improvements in ICE vehicle emissions as the fleet turns over to the cleaner ICE technologies (e.g. Euro 5 or 6).

In an earlier study, The Centre for International Economics projected that by 2020, if transport infrastructure and policy was maintained at 'business as usual' levels, the air pollution costs from road transport in Sydney would be $1.2 billion in 2005 prices (CIE, 2005).

In summary, the results of this study reconcile strongly with the results of previous work.

4.5.3 Implications of the findings

The almost complete elimination of harmful vehicle emissions, except for PM, by using ZEV / AV has significant implications for environmental policymakers. Vehicle emissions have been a major focus of policies and measures to improve air quality. With a large proportion of the vehicle emissions reduced, the focus may need to shift to other sources, and to measures that address the residual PM emissions that cannot be addressed by reducing exhaust emissions. The implications for policy are discussed in Section 6.

4.6 Greenhouse Gas Emissions

In the full ZEV scenarios, CO_2 **exhaust emissions** from vehicles are expected to be completely removed. To understand the magnitude of this reduction, projected CO_2 emissions for the Dead end scenario were estimated by:

- using *Road Transport Emission Factors: 2010 NAEI* (NAEI, 2012)[16]
- applying CO_2 'equivalent' emission factors (grams of CO_2-e per km of vehicle travel) to the transport modelling results from metropolitan Melbourne
- extrapolating this result to provide a whole-of-Victoria estimate.

Based on this approach:

- 23 Mt of CO_2-e / year of GHG emissions are projected from road vehicles in metropolitan Melbourne in the Dead end scenario
- 27 Mt of CO_2-e / year of GHG emissions are projected from road vehicles in Victoria in the Dead end scenario.

As such, the full ZEV scenarios are expected to reduce CO_2-e **vehicle exhaust emissions** in Victoria by approximately 27 Mt. However, some of this reduction is likely to be offset by an increase in electricity sector

[15] Full ZEV uptake scenarios are all scenarios except "Slow lane" and "Dead end".
[16] These NAEI emission factors are based on the analysis of emission test data for in-service vehicles in the UK for a range of drive cycles. There are emission factors based on vehicle type, fuel used and mode of transport.

emissions, depending on the emissions intensity of the electricity grid. Notwithstanding this offsetting effect, the magnitude of the vehicle emissions reduction would equate to:

- approximately 25% of Victoria's GHG emissions in 2015[17]
- or approximately the amount of emission reduction required (Mt CO_2-e) to meet Victoria's 2020 Emissions Reduction Target (Victorian Government, 2015).

Lower emission reductions are expected in the Slow lane scenario. For the Slow lane scenario:

- 17 Mt of CO_2-e / year of GHG emissions are projected from road vehicles in metropolitan Melbourne
- 21 Mt of CO_2-e / year of GHG emissions are projected from road vehicles in Victoria.

Relative to the Dead end scenario, for which 27 Mt of CO_2-e / year of GHG emissions are projected, the Slow lane scenario is estimated to reduce vehicle exhaust GHG emissions by 6 Mt CO_2-e. The scenario is projected to achieve lower GHG emission reductions compared to the full ZEV scenarios because less of the fleet is assumed to be replaced with ZEVs and, in particular, heavy duty vehicles are assumed to remain as petrol or diesel.

The High speed scenario, which is modelled for the year 2031, is projected to reduce vehicle exhaust GHG emissions by a lower amount than the 2046 scenarios, because the baseline emissions for 2031 are lower (i.e. emissions are being reduced from a lower base). Using the ratio of vehicle kilometres travelled in 2031 vs 2046 from the transport modelling data, the High speed scenario is projected to:

- reduce 24 Mt of CO_2-e / year of GHG emissions from road vehicles in Victoria.

That is, the High speed scenario also reduces a significant amount of vehicle exhaust CO_2-e emissions, albeit from a lower base.

Table 4-7 – Vehicle Exhaust CO2-e emission reductions (Mt reduction from Dead end)

	Full ZEV scenarios (2046)	Slow lane (2046)	High speed (2031)
Melbourne	23	5	20
Rest of Victoria	4	1	4
Total	**27**	**6**	**24**

4.7 Other Impacts

There are potentially other impacts that have not been quantified / discussed in this report. However, some additional issues (and potential areas of opportunity if adequately prepared for) are discussed qualitatively below.

Autonomous Vehicle rely on advanced technology: including telecommunications between cars, to satellites, and other internal componentry, software to manage these systems and hardware to house them. All of this data will contain sensitive personal information that will need to be protected for its users, and controlled to ensure correct use. Navigational systems will also be subject to malicious interference, and will need to be safeguarded for public protection (Anderson, et al., 2016; Fleetwood, 2017).

Hardware and software will also need to be designed and tested to ensure they are adequate for use, ensuring the health and safety of their passengers is not exposed due to faulty coding or artificial decision making (Fleetwood, 2017).

Technologies such as polymer electrolyte membrane hydrogen fuel cell vehicles (PEMHFCV) and battery electric vehicles (BEV) contain potentially harmful chemicals and electrical power – ensuring these substances and energies are safely managed during maintenance, general use and accidents should be considered (ADVI, 2016).

[17] Victoria was estimated to have produced a total 119 Mt CO2e in 2015. Source: https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0021/55254/DELWPClimateChange_Framework.pdf

5 Manufacturing and Disposal Impacts

The following sub-sections outline the manufacturing and disposal impacts (environmental impacts) of each scenario. Autonomous vehicles have not been extensively assessed in Section 5 due to the lack of available literature relating to manufacture / disposal environmental impacts. However, potential issues have been briefly discussed in Sections 5.1.3 (manufacture) and 5.2.3 (disposal).

Manufacturing and disposal impacts have been modelled based on the expected vehicle ownership in 2046 / 2031. While intervening periods have not been modelled, the trajectory of change between now (2018) and the end-dates is assumed to be linear. Therefore, the manufacturing and disposal impacts will gradually increase over time. The issues that stakeholders should be monitoring during the transition are outlined in section 6.1.3.

For ‘Shared Use’ ownership model scenarios, the total fleet is assumed to reduce which also means the total amount of vehicle waste into the waste system will change – this has been discussed briefly in Section 5.2.4. For detailed technical assumptions, refer to Appendix A.

To model each scenario, the following assumptions were used:

- 10% of the fleet is turned over each year
- shared, on demand services scenarios were assumed to reduce the fleet size by 40% compared to the Dead end scenario (based on a U.S. paper by Martin et al (2010))
- fleet projections are based the ratio of vehicles per person (per vehicle type), and population projections produced by SGS Economics (for 2046), and DELWP (for 2031).

The analysis of environmental (manufacturing and disposal) impacts has found that:

- Current methods for manufacturing electric and hydrogen powered vehicles may have larger environmental footprints than the manufacture of vehicles with internal combustion engines (ICE), due to higher energy requirements and the need to use rarer materials. However, the resource intensity of manufacturing is likely to reduce over time as manufacturing processes improve and become more efficient.
- The projected amount of lithium battery waste assessed for electric vehicle scenarios are of a magnitude that is much higher than current industry forecasts.
- Similarly, the projected generation of electronic waste (e-waste) will increase rapidly in the autonomous vehicle scenarios. This growth has not been considered in key waste policies and strategies.
- If the transition happens much more rapidly, the waste challenges are amplified because, as assumed in the High speed scenario, there are strong financial incentives to abandon privately owned non-autonomous vehicles. These incentives result in earlier abandonment of these vehicles, depressing their market value, and creating a feedback loop of stronger incentives to dispose the vehicles and transition to the shared model. This is likely to heighten the risks of illegal dumping, waste stock-piling and illegal exports.

5.1 Manufacturing

The key impacts during manufacturing depend on the technology and power source of those vehicles, which are:

- electric Vehicles
- hydrogen Vehicles

The impacts also depend on changes in the ratio of vehicles to population. That is, impacts would be lower if there were fewer vehicles per person.

The impacts for each technology in terms of embodied emissions, direct emissions and other environmental impacts, are summarised in the subsections 5.1, 5.2 and 5.3.

The difference in impacts between an internal combustion engine (ICE) and a ZEV is due to the propulsion system and its ancillary components (particularly the power source). For the purposes of this assessment, all other key components not specified in the following sections are assumed to remain the same across all scenarios (e.g. body, doors, brakes, exterior / interior decorations, tyres etc.).

This assessment does not estimate the proportion of manufacturing impacts occurring within Victoria, which no longer has a significant domestic vehicle manufacturing industry. There may be the potential to manufacture some of the components of ZEVs or AVs in Victoria in the future. Whether Victoria does develop such industries or not, Victorians will need to be aware of the environmental footprint of the production of these vehicles, both from an environmental stewardship standpoint, and potentially even from an economic standpoint.

Aside from purely environmental considerations, the externalities of vehicle manufacture may become ‘internalised’ (i.e. incorporated) into the price of vehicles and vehicle components during import. Many countries are putting in place policies to internalise environmental impacts, such as carbon markets and taxes, which will reflect in the price of goods being imported. Some jurisdictions, such as the European Union (EU), are even progressing measures such as the carbon taxing of imports from countries that do not have adequate policies to address climate change.

As such, whether the vehicles and vehicle components are produced in Victoria or elsewhere, Victorians need to be aware of the environmental impacts associated with their manufacture.

5.1.1 Battery Electric Vehicles

Lithium-ion batteries are the most common and expected power source for battery powered electric vehicles, including various Lithium compounds for the cathode ($LiCoO_2$, $LiNiO_2$, $LiMnO_2$ and $LiFePO_4$), electrolyte and anode (Hawkins et al, 2012; Un-Noor et al, 2017; Ramoni & Zhang, 2013). There is also promising research into advanced technologies such as solid-state lithium batteries: solid-state batteries (i.e. no liquid electrolyte) offer higher energy density, longevity and adaptability than current battery technologies (MEV, 2018). However, due to a lack of available literature, these future technologies have not been modelled.

The manufacturing phase of a battery EV life cycle is considered the most environmentally intensive based on various international life cycle assessments (LCAs)[18], predominantly attributable to the manufacture of the lithium-ion batteries (Egede, 2017). While there could potentially be some high-level differences in overall manufacture of an electric vehicle, the material change in manufacturing impacts is assumed to be associated with the production of lithium-ion batteries. There are expected to be increases in the manufacture of components containing rare earth materials and copper (for the drivetrain, including electric motors etc.). Rare earth minerals needed for EV manufacture include neodymium, terbium and dysprosium, which allow the electromagnetic components to operate at high temperatures. However, due to lack of availability of specific literature, these have been discussed qualitatively.

Summary: the environmental impacts of manufactured components for BEV technologies could be reduced if effective methods for remanufacturing / re-use / recycling are developed. Results scale with fleet size, so any reduction in the number of cars per population will have positive flow on effects to manufacturing environmental impacts.

McManus (2012) conducted a cradle-to-gate study on the environmental impacts of battery electric vehicles, building on previous LCA studies on battery EVs including Goedkpp et al (2008), Nouri (2002), Samaras & Meisterling (2008), and Rydh & Sanden (2005). McManus (2012) concluded that lithium-ion batteries contribute significantly to greenhouse gas emissions and metal depletion (refer to Table 5-1). Note that these impacts also include the impacts of toxic waste from manufacture.

[18] The International Standards Organisation (ISO, 2006) defines an Environmental LCA as “the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle, i.e., from cradle-to-grave”

Table 5-1 – Lithium-ion battery production environmental Impacts per MJ of capacity[19]

Impact Category	Units	ICE	BEV	Total Change between ICE and BEV production[20]
Climate change	t CO2 eq	5-7	17-27	**16**
Ozone depletion	t CFC-11 eq	(2.24-3.35)E-07	(3.34-5.23)E-04	**1.49**
Human toxicity	t 1,4-DB eq	6-8	3-5	**-3**
Photochemical oxidant formation	t NMVOC	0.03-0.04	0.03-0.05	**0.005**
Particulate matter formation	t PM10 eq	0.02-0.03	0.03-0.04	**0.01**
Ionising radiation	t U235 eq	1.1-1.5	2.7-4.1	**2.1**
Agricultural land occupation	km2	0.12-0.17	0.15-0.23	**0.045**
Urban land occupation	km2	0.08-0.12	0.22-0.34	**-0.0973**
Natural land transformation	km2	0.0011-0.0015	0.0021-0.0033	**0.0014**
Water depletion	ML	0.07-0.1	0.121-0.191	**0.071**
Metal depletion	t Fe eq	2-3	28-44	**33.5**
Fossil depletion	t oil eq	1.8-2.6	2.2-3.4	**0.6**
Energy Consumption	GJ	17	88	**71**
Embodied Emissions	t CO2 eq / GJ			**0.14**

The values from the above table were used to estimate the potential environmental impacts per battery produced in each scenario shown in Section 2, assuming a battery capacity of 23kWh[21] (86 MJ) and using the mid-point of the ranges shown in Table 5-1.

Table 5-2 below summarises the results of the electric vehicle battery production environmental impact analysis.

[19] Table derived from data presented in the McManus M.C (2012) report, *Environmental consequences of the use of batteries in low carbon systems: The impact of battery production*. For explanations on units, see Appendix A.
[20] Calculated delta between the mid points of all ranges between ICE and BEV battery production.
[21] Average car capacity. This has been multiplied by 1, 2 and 4 for LCVs, buses and trucks respectively. Derived from Hawkins and colleagues (2013). This is considered a mid-range vehicle, some ZEVs (e.g. Tesla Model-S) are more powerful (Battery University, 2018).

Table 5-2 – Incremental environmental impacts of battery production for each scenario (relative to Dead end)

Impact Category	Units	Electric Avenue	Private Drive	Fleet Street	Slow lane	High speed (2031)
Climate change	t CO_2 eq	1,098,083	1,098,083	658,850	549,042	539,489
Ozone depletion	t CFC-11 eq	102,259	102,259	61,355	51,130	50,240
Human toxicity	t 1,4-DB eq	-205,891	-205,891	-123,534	-102,945	-101,154
Photochemical oxidant formation	t NMVOC	343	343	206	172	169
Particulate matter formation	t PM_{10} eq	686	686	412	343	337
Ionising radiation	t U_{235} eq	144,123	144,123	86,474	72,062	70,808
Agricultural land occupation	km^2	3	3	2	2	2
Urban land occupation	km^2	12	12	7	6	6
Natural land transformation	km^2	0	0	0	0	0
Water depletion	ML	4,873	4,873	2,924	2,436	2,394
Metal depletion	t Fe eq	2,299,112	2,299,112	1,379,467	1,149,556	1,129,554
Fossil depletion	t oil eq	41,178	41,178	24,707	20,589	20,231
Energy consumption	GJ	18,927,574	18,927,574	11,356,544	9,463,787	9,299,119
Embodied emissions	t CO_2 eq	2,576,253	2,576,253	1,545,752	1,288,127	1,265,713

From the above results, there is a clear increase in the outcomes – specifically in climate change, ozone depletion, metal depletion and energy consumption – for the scenarios with Electric Vehicles. The highest order of magnitude is seen in the full private ownership scenarios (Electric Avenue and Private Drive) due to the assumed higher relative fleet size. In these scenarios, manufacturing could contribute to the equivalent of more than 1% of Victoria's CO_2 equivalent emissions in 2015[22].

Compared to the production of lead-acid batteries, the impacts of battery production on human toxicity (t 1,4-DB eq) is expected to reduce, mainly because of the ethical sourcing of the lithium-ion batteries compared to lead-acid batteries. However, there are still significant issues related to sourcing of rare earth metals in terms of impact on human welfare[23], so the order of magnitude of reduction is debateable (McManus, 2011). The analysis in Table 5-2 also excludes the potential impact of manufacture of other components that will be rare-earth material intensive (particularly for electromagnetic components), which will also need to be monitored as BEV technology uptake ramps up. In terms of energy intensity, results are also subject to the Learning Curve Effect[24] – as the ZEV propulsion market reaches large scale productions, efficiencies are likely to be made equivalent to the improvements seen in historical development of ICE propulsion systems (Ally, 2008), as technology advances throughout uptake. Similar to the technological advances in Solar Photovoltaics technology, rapid uptake of a new technology has the potential to significantly reduce the cost and resource intensity of manufacture.

5.1.2 Hydrogen Fuel Cell Electric Vehicles (HFCEV)

Hydrogen fuel cell vehicles, as with battery EVs, differ to ICEs predominantly in their propulsion systems. A hydrogen fuel cell car relies on the electricity generated from an electrochemical reaction combining Hydrogen gas (H_2) and Oxygen gas (O_2) into water (H_2O) – thus, the only "emission" from operation being water[25].

The manufacturing phase of a HFCEV life cycle is considered the most environmentally intensive based on various international Life Cycle Assessments (LCAs), predominantly due to the manufacture of fuel cell technologies (Sorensen, 2004; Ally, 2008). While there could potentially be some high-level differences in overall manufacture of an HFCEV, the material change in manufacturing impacts is assumed to be associated with the production of the fuel and fuel cell technology (including hydrogen tanks, battery, electric motors etc.).

Specifically, several components of the fuel cell stack are sourced from similar materials to that of a comparable ICE engine (e.g. metals, carbon, plastics, typical materials). The more notable exceptions are in the manufacture of the polymer membrane including perfluorinated ionomers, hydrocarbon-based or using organic materials (Barbi et al, 2003; Kreuer, 2003; Evans et al, 2003). These components also include rare earth materials such as Platinum (Pt) and Palladium (Pd) which are expensive, environmentally damaging and highly sought after. Other electromagnetic components (e.g. electric motor) are likely to increase copper consumption compared to that of existing small-scale electronics in existing ICEs. Reducing the environmental impact on the manufacture of HFCEV (and ZEVs in general) relies heavily on the recycling of precious and environmentally damaging materials at end of life.

Manufacturing impacts will be heavily reliant on development of technologies, and as such there are expected to be:

- more complex methods of hydrogen fuel storage (e.g. polymer lined carbon composites used in some buses, storage in cryogenic liquids, storage in a metal absorber)
- electricity storage (e.g. lithium-ion vs lead acid)
- use of copper in electric components (e.g. electric motor/s) etc.

These technology developments will need to be heavily considered in future strategy as uptake of HFCEVs ramps up. This is particularly important for hydrogen storage, as storage is difficult due to requirements for complex combinations of phase (liquid / gas) and storage materials / methodologies (e.g. hydrogen adsorption, metal hydride storage, alanates and other light hydrides etc.) (Schlapbach & Züttel, 2001). Policy makers will need to constantly monitor the development of these technologies and uptake scenarios to

[22] Victoria was estimated to have produced a total 119 Mt CO2e in 2015. Source: https://www.climatechange.vic.gov.au/__data/assets/pdf_file/0021/55254/DELWPClimateChange_Framework.pdf
[23] Including human health risks and ethical employment conditions
[24] The Learning Curve Effect is the gains in efficiency through improvements in processes over time
[25] This is an ideal environment, assuming no contamination during the process.

ensure manufacturing and waste streams are adequately prepared. Such implications are discussed further in Section 6.

Summary: the environmental impacts of HFCEV technologies could be reduced if effective methods of precious metal extraction are applied / developed. Results scale with fleet size, so any reduction in the number of cars per population will have positive flow on effects to manufacturing environmental impacts.

Sorensen (2004) conducted a life cycle analysis of Proton Exchange Membrane (PEM) fuel cell vehicles, progressing previous work that had otherwise focussed on single environmental issues and other narrower focusses. The study compares a European Volkswagen VW Lupo 3L common rail diesel vehicle with a Daimer Chrysler Fuel Cell vehicle, and their respective components. The following summary is based on data derived from Sorensen (2004), with sources for individual environmental factors shown for each variable. Note that these impacts also include the impacts of toxic waste from manufacture.

Table 5-3 – Environmental impacts of PEM fuel cell vehicle manufacture vs. ICE vehicle manufacture[26]

Impact Category	Unit	Common Rail Diesel	H_2 Vehicle	Total change between ICE and H_2 vehicle	Sources
Energy use	GJ	88	93	**5**	(Weiss et al, 2003; Schweimer & Levin, 2001; Pehnt, 2003)
Greenhouse gas emissions	t CO_2 eq	1	1.7	**0.7**	(Weiss et al, 2003; Schweimer & Levin, 2001; Pehnt, 2003)
SO2 emissions	kg	11.6	36	**24.4**	(Schweimer & Levin, 2001; Pehnt, 2001)
CO emissions	kg		1.7	**1.7**	(Pehnt, 2001)
NOx emissions	kg	6.4	14.5	**8.1**	(Schweimer & Levin, 2001; Pehnt, 2001)
non-methane volatile organic compounds	kg	3.3	1.7	**-1.6**	(Schweimer & Levin, 2001; Pehnt, 2001)
Particulate matter emissions	kg	4.3	2.6	**-1.7**	(Schweimer & Levin, 2001; Pehnt, 2001)
Benzene	g		2.3	**2.3**	(Pehnt, 2001)
Benz(a)pyrine	g		0.034	**0.034**	(Pehnt, 2001)
Embodied Emissions	t CO_2 eq / GJ			**0.14**	(DoEE, 2017)

The variables from the above table were used to estimate the potential environmental impacts per HFCEV car produced in each scenario shown in Section 2. Table 5-4 below summarises the results of the electric vehicle battery production environmental impact analysis.

[26] Table derived from the Sorenson (2004) report, *Total life-cycle analysis of PEM fuel cell car*.

Table 5-4 – Incremental environmental impacts of HFCEV production (relative to Dead end)

Impact Category	Unit	Hydrogen Highway Equivalent (compared to the Dead end scenario)
Energy use	GJ	3,990,129
Greenhouse gas emissions	tCeq	558,618
SO2 emissions	t	19,472
CO emissions	t	1,357
NOx emissions	t	6,464
non-methane volatile organic compounds	t	-1,277
Particulate matter emissions	t	-1,357
Benzene	kg	1,835
Benz(a)pyrine	kg	27
Embodied emissions	t CO_2 eq / GJ	543,101

The above impacts could be significantly reduced if specific materials that have large environmental impacts are recycled (Pt / Pd), the process of manufacture becomes more efficient, or technology advancements allow more environmentally friendly products to be used in the manufacture.

5.1.3 Autonomous Vehicle Manufacture

Limited literature was found regarding AV manufacturing impacts, given the relative age of the technology. This is considered a significant gap in research, and should be considered in detail to mitigate environmental and economic risks associated with rapid uptake scenarios. Policy implications associated with the potential increase in electronic waste (e-waste) are discussed further in Section 6.

5.2 Disposal

Similar to the findings in Section 5.1, the key differences in the disposal of ZEVs will be in the disposal of their propulsion systems, as well as changes in the total fleet (proportionate to the population). This is due to the assumption that the bulk of vehicle technology is already being managed by the waste system, and included in future waste system projections.

Disposal requirements will change over time, and by 2046 there will need to be infrastructure and policies in place to manage the waste of AVs and ZEVs. The differences between each scenario from a disposal perspective are summarised below:

- Driving mode determines whether AV technology waste needs to be included (e.g. driverless vs. non-driverless).
- Power source (e.g. hydrogen, electric, ICE) determines the waste materials.
- The ownership model and occupancy level determines changes in the overall fleet numbers in 2046 (or 2031 for High Speed).

The following sections outline the potential impacts on the waste system, summarised by propulsion type. For detailed assumptions and methodology refer to Appendix A.

5.2.1 Battery Electric Vehicles

Disposal requirements for BEVs are predominantly dependant on the expected operational life of a typical BEV vehicle battery, and the proportion of materials sent to either recycling or landfill / waste.

LCA studies of BEV batteries (as discussed in Section 5.1.1) indicate that emissions from the production of these batteries represent the most significant portion of lifetime vehicle emissions, and reuse of battery material will significantly reduce the need to manufacture the components that cause this environmental harm. The above issues have prompted research and discussions into the need to prepare for the number of potentially reusable EOL lithium-ion batteries, or adequate recycling to recover and reuse precious materials (Ramoni & Zhang, 2013).

In the Australian (and more specifically, the Victorian) context, the Australian Renewable Energy Agency (ARENA) and Clean Energy Finance Corporation (CEFC) have provided funding support to a Melbourne start-up business called Relectrify[27]. Relectricfy are proposing to use their technology to repurpose used batteries from electric vehicles (EV) for use as behind-the-meter household energy storage. In many cases, when a BEV battery is deemed ‘unfit for service’ as a BEV battery, they still contain a majority of their original capacity (~80%[28]). Re-use / recycling of the “EOL” ZEV batteries with technology like Relectrify will be key to reducing the waste / recycling load and managing the potentially harmful environmental impacts of battery disposal.

However, battery recycling at the EOL of a BEV battery effectively discards the remaining capacity and the remaining unrecyclable and / or potentially reusable[29] materials. Economic constraints have been discussed in literature (e.g. Romani & Zhang, 2013; Jungst, 2001), including the ability of the market to absorb large quantities of recycled materials, and the market demand for such materials (if not recycled directly into new batteries). Studies by Kesler et al (2012) and Gruber and Medina (2010) suggest that due to current and projected international lithium deposits, availability of lithium is not likely to constrain uptake of EVs. BEV lithium-ion batteries are typically 1% lithium by weight, reducing the economic value of reclaiming the lithium, especially given the high cost (Kesler et al, 2012; Gruber & Medina, 2010).

Recycling viability also depends on the material used for the cathode, if for instance a cobalt cathode ($LiCoO_2$) is used (similar to the cathodes in some smart phones), the recovery value is significantly increased. Other material properties also influence recycling viability, such as the operating vs. reduction

[27] ARENA and the CEFC have provided $750,000 in early stage equity funding from their joint fund called the “Clean Energy Innovation Fund”
[28] Once BEV batteries are unfit for service as an engine power source, they still contain more than 80% of their original storage capacity which could be reused for less intensive purposes (e.g. home electricity storage)
[29] The difference between “recycle” and “reuse” here relates to: whether the battery is decommissioned and harvested for reusable materials at end of life (recycle) or the battery is removed from the vehicle, and the remaining 80% capacity is reused in a different, less demanding application.

temperatures of the materials and subsequent particle sizes: reduced particle size increases the efficiency and performance of the battery, while subsequently creating difficulties in the recycling processes due to the unusual melting behaviours of these nanoparticles (Ramoni & Zhang, 2013).

Other non-battery components, such as the drive train and additional ancillaries are likely to increase the overall consumption of copper and rare-earth materials. Predominantly ferrous ICE engines will be replaced with electromagnetic systems, which will add increased quantities of rare-earth materials (e.g. neodymium in magnets) to existing waste streams.

No LCAs that directly compare consumption of the more common and rare-earth materials were found, so these effects are discussed qualitatively here. Of particular importance for policy makers, is ensuring there are effective triggers in place to identify increasing burdens on waste systems from increases in the more common materials (policy implications and triggers are discussed further in Section 6.

Given the above-mentioned difficulties in current recycling processes for EVs, there are likely to be challenges associated with the disposal and treatment of BEV batteries. This, however, depends entirely on technology assumptions. If new technologies or processes are discovered, which can extract pure materials at low cost, it is expected that recycling of batteries will become increasingly feasible over time. Remanufacturing[30] and reuse is likely to become a more sustainable option for BEV battery EOL management. Important considerations for the remanufacture of BEV batteries include:

- ensuring adequate research is completed to determine the most cost-effective means of remanufacture
- developing a detailed understanding of battery technologies and when a battery is not fit for use.

Summary: management of lithium-ion battery waste is expected to be difficult, and should be included in waste strategies as early as possible to mitigate risk. To ensure sustainable use of BEVs, development of battery technology should also ensure adequate design considerations for remanufacturing, re-use or recycling of components at EOL.

Table 5-5 below provides a material breakdown of a typical $LiFePO_4$ BEV battery.

[30] Remanufacturing of a BEV battery is equivalent to "repairing" an EOL battery to restore its capacity back to near 100%, ready for reuse as a BEV battery.

Table 5-5 – Component breakdown of a typical BEV $LiFePO_4$ battery[31]

Component	Material	Material Classification	Weight (kg)
Cathode	$LiFePO_4$ (Lithium Iron Phosphate)	Metal	120
Cathode	Aluminium foil	Metal	5
Cathode	Carbon black	Metal	8
Cathode	Styrene acrylate latex	Plastic	10
Electrolyte	Ethylene glycol dimethyl ether	Plastic	44
Electrolyte	Lithium salt (Lithium chloride)	Metal	8
Separator	Polypropylene	Plastic	3
Separator	Polyethylene	Plastic	3
Electronics	Transistor	Metal / Plastic	3
Electronics	Resistor	Metal / Plastic	3
Anode	Graphite	Metal	48
Anode	Carbon black	Composite	1
Anode	Copper	Metal	13
Anode	Styrene butadiene latex	Plastic	2
Packaging	Polypropylene	Plastic	1
Packaging	Aluminium foil	Metal	2
Total			**274**

Table 5-6 below indicates the potential quantity of BEV batteries that will need to be processed p.a. for each scenario, based on similar projections used in Section 5.1.

[31] Table derived from the Zackrisson and colleagues (2010) report, *End-of-life (EOL) issues and options for electric vehicle batteries*. Battery assumed to be designed for existing Volvo PHEV, 10kWh battery consisting of 100 cells providing 370V. Also assumed that a water based solvent, as opposed to a N-methyl-2-pyrrolidon (NMP) solvent. This has been scaled to appropriate sizes for different portions of the fleet requiring higher power.

Table 5-6 – Material quantities for disposal across each scenario (t)

Component	Material	Material Class	Electric Avenue	Private Drive	Fleet Street	Slow lane	High speed
Cathode	$LiFePO_4$ (Lithium Iron Phosphate)	Metal	95,371	95,371	57,222	47,685	46,856
Cathode	Aluminium foil	Metal	4,294	4,294	2,576	2,147	2,110
Cathode	Carbon black	Metal	6,102	6,102	3,661	3,051	2,998
Cathode	Styrene acrylate latex	Plastic	7,910	7,910	4,746	3,955	3,886
Electrolyte	Ethylene glycol dimethyl ether	Plastic	35,482	35,482	21,289	17,741	17,432
Electrolyte	Lithium salt (Lithium chloride)	Metal	6,328	6,328	3,797	3,164	3,109
Separator	Polypropylene	Plastic	2,034	2,034	1,220	1,017	999
Separator	Polyethylene	Plastic	2,034	2,034	1,220	1,017	999
Electronics	Transistor	Metal / Plastic	2,260	2,260	1,356	1,130	1,110
Electronics	Resistor	Metal / Plastic	2,260	2,260	1,356	1,130	1,110
Anode	Graphite	Metal	38,193	38,193	22,916	19,097	18,764
Anode	Carbon black	Composite	1,130	1,130	678	565	555
Anode	Copper	Metal	10,396	10,396	6,238	5,198	5,107
Anode	Styrene butadiene latex	Plastic	1,356	1,356	814	678	666
Packaging	Polypropylene	Plastic	1,130	1,130	678	565	555
Packaging	Aluminium foil	Metal	1,582	1,582	949	791	777
TOTAL (t)			**217,861**	**217,861**	**130,717**	**108,931**	**107,035**

The highest estimated annual BEV waste generated is in the Electric Avenue / Private Drive scenarios. Waste generation is proportional to the fleet size, therefore results scale with fleet size assumptions. The Electric Avenue / Private Drive result is **more than double** recent Australian Department of Environment (DoE) projections for EV lithium-ion battery waste *for the whole of Australia* in 2036 in the “High” (i.e. upper bound project) (Randell, 2016). If BEV waste is not managed carefully, and effective government intervention is not introduced, EV waste could significantly overwhelm projections for the future waste system. This includes the management of recyclable metals (e.g. copper, steel) used in electric motors and other ancillary equipment. The materials recovery rate from recycling BEV battery components is heavily influenced by technology and production, and should also be considered for future policy / research purposes. The expected future recovery rate of these battery components is uncertain, however, it is expected that most metal materials would be recovered for recycling.

5.2.2 Hydrogen Fuel Cell Electric Vehicles

Electrical energy supply equipment (assumed to be a PEM fuel cell) is the main consideration for disposal issues of the future HFCEV fleet (Sorensen, 2004). PEM fuel cells have various complex and expensive to produce components, as well as some key standard materials outlined in Section 5.1.2. As discussed in Section 5.2.1, electric propulsion vehicles are likely to increase the consumption and disposal of rare earth materials (as well as copper) due to electromagnetic componentry (e.g. electric motor). Additional to these, particularly in a HFCEV, are the hydrogen fuel tank and battery. While there are a range of potential materials and technologies for these (e.g. lithium ion batteries, carbon fibre composite fuel tanks - refer Section 5.1.2) the literature is lacking in comparable ICE vs HFCEV LCAs for all of these technologies.

As such, this analysis focuses on the waste management of the PEM fuel stack, and qualitatively discusses the management of other potential waste. Overall, policy makers should be acutely aware of changes in the waste stream, as well as future trending technologies, to ensure the appropriate management of waste, recycling and reuse.

The Naifon-type membrane frequently used in PEM fuel cell (PEMFC) production is associated with high production and environmental costs, thus providing an impetus for recycle / reproduction. Reuse is difficult, due to membrane dehydration and contamination making the stacks prone to brittle failure during removal, as well as reducing their efficiency (Handley et al, 2002). Membrane recycling is expected to be a more likely solution, by dissolving the membrane and recasting it into a useful form, although this is also potentially wrought with contamination and cost issues.

Platinum is more likely to be viable to recover during PEM recycling than other materials, given its value and scarcity. In some cases, ruthenium is also present and has similar benefits in terms of recovery. A well-established chemical recovery process exists to extract these precious metals (a detailed review of the solvent extraction process is provided by Barnes and Edwards (2000), and this recycling process is considered by many studies as critical to the sustainable development and operation a future PEMFC fleet.

EOL recovery for the bipolar plates depends entirely on the material used, and are products of the developing PEMFC technologies. Steel options represent low cost and high recyclability, but are susceptible to corrosion. Other graphite related options are more likely to be reused, and have a higher cost and less recyclability in the event of a change of design. Given the high weight percentage (wt %) of the bipolar plates, it is likely that the design will need to favour a highly recyclable design to improve the sustainability of PEMFC vehicles. Other ancillary components make up approximately 16% of the total weight, and are largely non-recyclable materials (except for the aluminium and steel components).

Technology choice for hydrogen storage will be important from a recyclability / re-use perspective, particularly if complex technologies and materials are used in place of the more common high-pressure cylinders.

Except for the power generation and associated components, the analysis considers that the production of the remainder of the HFCEV (e.g. chassis, fuel, lead-acid batteries etc.) have a similar order of magnitude of environmental footprint as that of ICE production.

Summary: Effective EOL management of HFCEV technologies will likely depend on effective recycling of rare earth metals (e.g. Pd and Pt), as well as advancements in membrane and fuel storage technologies to ensure high levels of recovery and / or remanufacturing.

Table 5-7 below provides a component breakdown of a typical 70kW PEMFC stack (Karakoussis, et al., 2000), and the potential volume of materials that would need to be processed in the Hydrogen Highway scenario.

Table 5-7 – Component breakdown of a typical PEM fuel stack and hydrogen storage[32]

Component	Material	Material Class	Wt (kg)	Hydrogen Highway scenario (2046) (t)
Electrode	Platinum	Metal	0.06	54
Electrode	Ruthenium	Metal	0.01	9
Electrode	Carbon paper	Metal	4.37	3,935
Membrane	Nafion membrane	Other organic material	5.64	5,078
Bipolar plate	Polypropylene	Plastic	16.14	14,533
Bipolar plate	Carbon fibres	Composite	16.14	14,533
Bipolar plate	Carbon powder	Composite	21.52	19,377
End-plate	Aluminium alloy	Metal	2.8	2,521
Current collectors	Aluminium alloy	Metal	1.14	1,027
Tie-rod	Steel	Metal	2.05	1,846
Total			**69.87**	**62,914 (t)**

The handling of PEM fuel cell waste in the Australian context does not seem to have been extensively considered, based on a review of existing waste policies and strategies. As such, government intervention and strategies should consider these impacts, and develop approaches to handle the PEM fuel cell waste if the uptake of hydrogen technologies is anticipated to increase. These impacts are discussed further in Section 6. The recovery rate from the recycling of PEMFC components is heavily influenced by technology and production, and should also be considered for future policy / research purposes. The recovery rate is uncertain, however, it is expected that most metal materials would be recycled.

5.2.3 Autonomous Vehicles Disposal

Given the electronics technology centric design of AVs, higher AV uptake is likely significantly contribute to e-waste generation. This includes onboard computers, additional wiring, sensors, radars etc., all of which will need to be processed and either repurposed or disposed of. Detailed studies into the potential waste impacts of AVs appears to be a significant gap in the literature, considering the potential ramifications and widespread uptake of the technology.

To provide some perspective, if an AV is assumed to increase the weight of electronic waste ('e-waste') of a typical car by 10kg, by 2046 the Private Drive scenario could produce more than 79,800 tonnes of e-waste a year. To demonstrate the scale of the challenge that may be associated with handling this waste:

- Victoria's estimated e-waste in 2016 was approximately 130,000 tonnes (DELWP, 2017)
- if e-waste was assumed to grow only in line with projected population growth, this would equate to approximately 70,000 tonnes of additional waste and therefore additional capacity needed in Victoria by 2046
- the addition of e-waste from AVs to this incremental 'business as usual' demand contributed by population growth results in more than a doubling of the incremental demand, and therefore more than a doubling of the required incremental capacity to handle that demand.

Not only are there potential recycling benefits, there are also significant risks to the waste / recycling system if AV waste is not carefully considered. Further risks and opportunities are discussed in Section 6.

[32] Table derived from Karakoussis and colleagues (2000) report, *Environmental Emissions of SOFC and PEMFC System Manufacture and Disposal*. For results, these materials have been scaled to appropriate sizes for different portions of the fleet requiring higher power.

5.2.4 Reduction in Fleet Size

In the 'Fleet Street' scenario, where there is likely to be a shared, on demand service type ownership market, there are also expected to be reductions in fleet numbers (relative to the population). Using the assumptions in the scenarios analysed above, there could be a reduction in the order of 4 million tonnes of vehicle waste being processed by the system. Assuming 75% of a typical vehicle is recyclable (EuroStat, 2015), this removes more than 3.3 million tonnes of product from the recycling system and avoids 700,000 tonnes of additional landfill being produced. This has wide ranging impacts (e.g. considering the current tyre disposal issues in Victoria[33]), and is discussed further in Section 6.

5.2.5 Capacity of Victorian Waste Infrastructure to Handle the Waste

The Victorian waste and resource recovery system handled approximately 13 million tonnes of material in 2015-16 and is projected to need capacity to handle approximately 20 million tonnes by 2046, which is approximately in line with population growth (Sustainability Victoria, 2018). Car bodies contribute to 4% of the metals recovered for reprocessing in Victoria[34].

The *Victorian Statewide Waste and Resource Recovery Infrastructure Plan (SWRRIP)* acknowledges that Victoria's waste infrastructure will need to handle a wider range of materials (Sustainability Victoria, 2018). The SWRRIP notes that e-waste will be a particular challenge due to the Victorian Government's proposed landfill ban and because volumes of **e-waste** are growing **three times faster** than general municipal waste in Australia. As such, the Government has committed $16.5 million to augment collection infrastructure to allow the safe disposal of e-waste by Victorians.

However, the analysis in the preceding sections shows that the volumes of lithium battery waste and other e-waste from EVs / AVs may be of a scale that has not been anticipated by current projections and infrastructure plans (e.g. Randell, 2016; DELWP, 2017, Sustainability Victoria, 2018). There also appears to be a gap in these projections and plans with respect to handling waste from the disposal of hydrogen vehicles.

Volumes of some waste streams have the potential to:

- exceed the capacity of the waste infrastructure, exacerbating the problems of illegal dumping, stockpiling or illegal exporting without a permit, which are already issues of concern for e-waste (Sustainability Victoria, 2018)
- overwhelm environmental regulators, which need to closely monitor the waste industry given the risks that these types of waste carry, such as the combustibility of lithium and lithium-ion batteries (EPA Victoria, 2017).

The problems of waste stock piling, illegal dumping and exports are likely to become even more acute given moves by the Chinese Government, previously one of Australia's key waste export markets, to limit the import of waste from countries only to waste that complies with very strict quality and contamination standards.

Equally, if the volumes are not adequately anticipated, there is also the potential to miss opportunities to develop local industry that would have been able to handle and reprocess the waste in a more economically and socially viable manner.

Given these challenges and potentially missed opportunities, the Victorian Government should continue to support local business that aim to handle and process these waste streams. Examples include Relectrify, as previously mentioned, and Envirostream, which has recently opened a facility at New Gisborne to process lithium batteries and other electronic waste[35].

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[33] As discussed by EPA Victoria: **https://www.epa.vic.gov.au/business-and-industry/guidelines/waste-guidance/storage-of-waste-tyres-in-victoria**
[34] Source: http://www.sustainability.vic.gov.au/Government/Victorian-Waste-data-portal/Victorian-Recycling-Industry-Annual-Report/Metal-recovery
[35] Source: http://www.sustainability.vic.gov.au/About-Us/Latest-News/2018/04/26/04/57/Australias-first-lithium-battery-recycling-plant-opens

Waste Challenges will be Greater in the High Speed Scenario

In the High speed scenario, there is a much more rapid transition to shared electric vehicles, relative to the Fleet street scenario, because it is assumed that the technologies and business models are so cost effective that vehicle owners more rapidly abandon conventional private vehicle ownership. As more of the population transitions to the shared ownership model, there is likely to be a very large supply of second hand private vehicles entering the used car market and the waste system. Consequently, the value of used cars will be significantly reduced, thus increasing the demand on the waste system for used cars and also heightening the risks of illegal dumping.

As such, these risks and the potential for missed opportunities will be even more marked in the High speed scenario because:

- not only will the infrastructure have less time to adjust to these significant changes, relative to the Fleet Street scenario
- but there is likely to be an even greater shortfall of capacity in the High speed scenario because some vehicle owners will be disposing their vehicles much earlier than they would have otherwise
- and because the large ‘spike’ in used cars needing disposal is likely to be temporary, the waste infrastructure sector has a dampened incentive to invest in long term capacity.

As a result, investment in waste capacity will not only be much more urgent, but is likely to be much more costly.

5.3 Summary of manufacturing and disposal impacts

From the analysis and review conducted in Section 5:

- more research is required to understand the potential impacts of AV waste and manufacture in the future
- the sustainability of both BEV and HFCEV technologies will rely heavily on the production of recyclable materials / components, and products that are either able to be re-used or remanufactured at “end of life”
- disposal / manufacturing impacts scale with fleet size, so the greatest impacts are seen in the Electric avenue and Private drive scenarios (in terms of absolute magnitude of change)
- the Hydrogen highway scenario has less environmentally intensive manufacturing than that of the other BEV scenarios
- the BEV scenarios are likely to have an increased amount of new materials entering the waste / recycling system compared to that of HFCEV scenarios.

The analysis of the amounts of projected lithium battery and other electronic waste entering the Victorian waste system in 2046 shows that the significance of the changes does not appear to have been considered by key Victorian waste policies and projections. If not adequately catered for, these new waste streams have the potential to be stockpiled, and illegally dumped or exported, and may also cause health risks while in the Victorian waste system. Equally, opportunities to develop local industry to handle the waste could be overlooked.

These problems are likely to be heightened in the High speed scenario due to:

- the shorter time period for transition
- the population disposing private used cars much earlier than they would have otherwise
- the large ‘spike’ in disposal demand is likely to be temporary.

The challenges of this scenario for policymakers is discussed in Section 6.

6 Key Considerations for Government

Considering the topics discussed in Section 5, there is the potential for significant impacts during the use, manufacturing and disposal stages of the future fleet. Changes of this magnitude give rise to a raft of potential benefits, as well as significant risks, for the population and the environment of Victoria.

6.1.1 Comparison of the Environmental Impacts of Scenarios

Table 6-1 below compares technology type (non-ICE vs ICE), ownership model (shared, private), autonomy (driverless vs non-driverless) and occupancy (multiple vs single) to the following criteria:

- Health: which is preferable from a emissions health impact perspective.
- Manufacturing: which is preferable in terms of manufacturing environmental and health impacts.
- Disposal: which is preferable in terms of recyclability, additions to the waste stream and environmental / health impacts.

Non-ICE's had the best performing health outcomes. The **Shared Ownership** model is considered superior to Private Ownership from a health outcomes perspective, due to its reduction in total fleet size and potential for active travel benefits. Driverless cars where assumed to have higher health benefits than non-driverless, assuming driverless cars would drive more efficiently and reduce accidents. Multiple occupancy is associated with greater health benefits from emission reductions, due to an assumed reduction in fleet size and potential for increases in active travel.

As discussed in Section 5, specific manufacturing and disposal impacts are uncertain from a technology, autonomy and occupancy perspective. However, the Shared Ownership model is preferred from a manufacturing / disposal perspective, due to the smaller fleet size.

Table 6-1 – Preferred Technology, Ownership, Automation and Occupancy Models

	Health	Manufacturing	Disposal
Technology	Non-ICE	Uncertain	Uncertain
Ownership Model	Shared	Shared	Shared
Driver / No Driver	Driverless	Uncertain	Uncertain
Occupancy	Multiple	N/A	N/A

6.1.2 Policy Implications

Based on analysis of the population health, manufacturing and disposal impacts, the results show that:

- There are likely to be substantial reductions in harmful emissions, and substantial improvements in population health, from the adoption of ZEV technology. The high value of the health outcomes to society should prompt policymakers to consider whether measures can be implemented to encourage a more rapid transition to ZEV technology than would otherwise occur under business as usual. The reduction in emissions will also require policymakers to recalibrate air quality policy, and will ease the stress on the Victorian healthcare system.
- The uptake of the future technology will have major impacts on the waste system, not all of which have been extensively considered in existing waste policies and strategies. There are likely to be increases in the amount of waste being generated (e.g. due to the weight of battery technology and due to incremental e-waste production), and new environmental challenges (e.g. the handling of battery waste).
- As such, there is the need to develop new industries and processes to support the reuse and recycling of waste streams, and battery waste in particular.

Each one of these issues is discussed in turn.

Substantial Improvements in Population Health

The projected value of the improvements in health outcomes to society is largest in the Fleet Street scenario, and is estimated to be $735 million in 2046 (in 2018 prices). This should prompt policymakers to explore the economic viability of measures to incentivise the uptake of ZEV technology, and encourage a transition more rapidly than what would have occurred under business as usual settings. The grounds for policy intervention include both a clear market failure, which is the externality cost imposed by vehicle missions, and a large potential social benefit if emissions could be reduced in a cost-effective manner. There is also potential for significant benefits from reduction in human error related crashes with the uptake of AVs. Benefits could potentially exceed $3 billion in 2046 (in 2018 prices) due to the reduction of human error related vehicle accidents by 94%[36]. Policy makers should ensure they maintain (and improve) crash statistics to measure the potential benefits and reap the rewards of a reduction in vehicle accidents.

The almost complete elimination of harmful vehicle emissions, except for PM, by using ZEV / AV has significant implications for the environmental policymakers. Vehicle emissions have been a major focus of policies and measures to improve air quality. With a large proportion of the vehicle emissions reduced, the focus may need to shift to other sources, and to measures that address the residual PM emissions that cannot be addressed by reducing exhaust emissions.

For example, the use of roadside vegetation barriers can be an effective method to reduce concentrations of, and exposure to, airborne particles and other pollutants emitted from road sources (Boulter and Kulkarni, 2013). With the adoption of AVs, there is the potential to reduce existing road widths to allow room for the planting of trees, which can be used to a method to reduce exposure to non-exhaust emissions. There may also be opportunities to reduce the generation of non-exhaust emissions, which include particles formed from road abrasion and resuspension of deposited road dust, through road and / or tyre design.

Impacts from Manufacturing and Disposal and Need to Develop New Industry

As highlighted in Section 5.1 and 5.2, there is potential for significant impacts on the manufacturing and waste streams for each scenario (particularly in the Electric Avenue / Private Drive scenarios). Mitigating risks of exacerbating the production / waste streams and identifying opportunities for economic gain will depend on how the fleet size is managed, and subsequently the technology used to manufacture and dispose of the fleet. Research will need to be prioritised in minimising the environmental impact of manufacture, and ensuring adequate re-use and recycling is established for otherwise harmful products.

Issues such as illegal dumping, hazardous waste to landfill, and emissions release may arise and will need to be managed effectively. A range of policy measures could be used to manage a high volume of new waste streams entering the Victorian waste system. Examples include:

- extended producer responsibility (EPR) schemes, which place the responsibility of managing the recovery and recycling of the product at the end-of-life on the supplier that brings that product to market, by requiring the industry to invest in collection and recycling capacity
- deposit-refund schemes, which are a form of EPR that involves the consumer paying a deposit on the purchase of the product, which is returned to the consumer on returning the product to an approved collector
- product stewardship, which is a collaborative approach to managing products at end-of-life and involves all parts of the supply chain, consumers and governments to contribute to the recovery of products.

Of the above, an EPR model may be suitable for managing battery and other waste products from ZEVs. This could involve the payment of a levy by vehicle dealers on the import or purchase of ZEV, proportion to the waste impacts of the components included in the ERP scheme. The proceeds of the levy would then be used by the industry to pay for the collection, recycling, safe disposal of ZEV components, as well as research and development into recycling process or reducing the environmental footprint of manufacturing.

There are risks associated with uncertainties on the management of e-waste likely to enter the waste stream in Victoria with a high AV uptake. Considering the recent ban on e-waste to landfill in Victoria[37], there is a need to effectively forecast, prioritise and implement e-waste mitigation. There is already an EPR model for

[36] See Section 4.4.2 for detail and references on assumptions
[37] Reference

managing e-waste in Australia, which is the National Television and Computer Recycling Scheme (NTCRS). The scheme could be expanded to include AV e-waste.

More research should be conducted to stress test current forecasts, and project high uptake scenarios of AV e-waste into the future to ensure risks are mitigated.

The disposal challenges are likely to be heightened in the High speed scenario due to:

- the shorter time period for transition
- the population disposing private used cars much earlier than they would have otherwise
- the large ‘spike’ in disposal demand is likely to be temporary.

The Victorian Government will need to manage this through appropriate policy measures such as heightened surveillance of potential illegal dumping sites, provision of temporary waste infrastructure to make disposal accessible and convenient during the spike, and greater penalties for improper waste handling.

Any decision to support investment in waste infrastructure (e.g. through grants or other fiscal support) should only be made in situations where the support would have a demonstrable public benefit (i.e. when the risks and potential social losses of improper waste handling are outweighed by the costs of incentivising the development of the capacity to handle the waste).

6.1.3 Trigger Points to Monitor During Transition

The analysis of population health and environmental impacts highlights that there are likely to be key risks and opportunities arising from the transition to ZEV and AV technology. Relevant agencies should monitor progress during the transition to mitigate key risks that might arise, and equally, exploit opportunities that might arise. Table 6-2 provides a summary of high level **trigger points** / **transition indicators** that agencies should monitor to ensure that risks are mitigated and opportunities are capitalised upon. More quantitative measures of trigger points (e.g. specific population health measures which indicate rising sedentary behaviour, specific pollutant concentrations that indicate that a shift in air quality policy is required etc.) should be developed based on more detailed and quantitative analysis of risks and opportunities.

Table 6-2 – Trigger points & transition indicators summary

Risk / Opportunity	Trigger Point / Transition Indicator	Description
Substantial health benefits through an effective transition	This study indicates an opportunity to realise health benefits with a very large value to the community. Measures that demonstrate positive net benefits to the community, through robust economic appraisal, should prompt Government to consider implementing them.	The large health benefit indicated by this study should be used as a basis for detailed economic appraisal of the potential costs and benefits of measures to incentivise the uptake of ZEV technology more rapidly than would occur under business as usual settings.
Recalibration of air quality policy	Significantly reduced concentrations of air pollutants in Victoria.	If the concentrations of key air pollutions such as PM and NO_X are reduced to such an extent that addressing exhaust emissions further is likely to provide diminishing returns, air quality policy should be recalibrated to target other sectors or other sources of vehicle emissions (e.g. non-exhaust emissions).
Growth in population obesity and other sedentary behaviour related health issues	Transitioning to a driverless / private ownership model could reduce active transport use (walking, cycling etc.)	Monitoring of the changes in the transport landscape and public transport use, to maintain the incentive for the public to use active transport. There is a potential for significant health costs with incremental reductions in active transport, which could be exacerbated by private / driverless uptake scenarios. A reduction in active transport also has the potential to offset the benefits of ZEVs emissions reductions (if coupled with AV / private ownership scenarios). Key agencies such as the Victorian Department of Health & Human Services should consider such risks when forming preventative health and wellbeing plans.
Increased resource consumption	Rising trends of new technology manufacturing in Victoria	There are risks related to the environmental impacts of manufacturing of the proposed technologies. As manufacturing grows, policy makers will need to ensure adequate support / mechanisms are established to manage the impacts of that manufacturing. This also includes energy consumption (energy intensity of manufacture) and embodied CO_2 emissions management. Economic opportunities also arise, for the development of new manufacturing, import and export markets.
PEM / Battery & E-waste volumes	Increased growth in the ownership / use of new vehicle technologies	Similar to the above, management of the new and complex waste streams will need to be effective to mitigate risks to the government and the public. There are also similar opportunities for new recycling / re-use business and research and development into technologies and processes.

Monitoring the above trigger points, using key indicators of change, will allow the Victorian Government to respond to emerging risks and capitalise upon opportunities effectively.

7 Conclusion

7.1.1 Key Population Health Benefits Findings

The analysis has found that the ZEV and AV scenarios, except for the Slow lane, are projected to provide incremental health benefits relative to a ‘Dead end’ scenario of approximately 3,000 to 3,500 DALYs in 2046. The Fleet street scenario achieves the greatest health benefits due to a zero emissions fleet, and due to the fleet efficiencies provided by automation. In this scenario, 3,781 DALYs avoided are projected for the year 2046, which is equivalent to $735 million (in 2018 prices). The Slow lane scenario assumes that the fleet consists of approximately 50% ZEVs and therefore the projected health benefits in this scenario are approximately 50% of the scenarios that assume a full ZEV fleet in 2046.

The near elimination of harmful vehicle emissions, except for particulate matter (PM) from non-exhaust sources, will require a ‘recalibration’ of air quality policy to target the right sectors and the sources. This may require a shift in emphasis from reducing exhaust emissions to reducing exposure from non-exhaust sources through road and / or vehicle design, and through the use of vegetation barriers. Notwithstanding the substantial health benefits from lower emissions, the shared ownership model could also reduce the use of active transport, which would offset some of the population health benefits.

There is also the potential for significant benefits from reduction in human error related crashes with the uptake of AVs, albeit the scale of these benefits will be less certain until AVs have established measurable track-record.

7.1.2 Key Manufacturing and Disposal Impacts Findings

The analysis of the environmental footprint from the manufacture of ZEV has found that the manufacturing of EVs and hydrogen powered vehicles may have larger environmental footprints than the manufacture of vehicles with ICE. However, the resource intensity of manufacturing is likely to reduce over time as the manufacturing process progresses down the ‘learning curve’.

Victorians will need to be aware of the environmental footprint of manufacturing, whether the manufacturing takes place in Victoria or elsewhere. Considering the trends in global environment policy, the environmental impacts of manufacture may be ‘internalised’ in the price of imports.

Projections of waste generation in the scenarios show that the quantities and composition of waste during the transition, and once the fleet has been transformed, are of a scale that does not appear to have been anticipated by existing waste polices and plans.

This will present both opportunities and challenges for the economy. On the one hand, there is the potential to develop local industries to process, recover and recycle valuable materials and components. On the other, the rapid change in waste generation could overwhelm the waste infrastructure, leading to the risk of illegal dumping, waste stockpiling and / or illegal exports. An extended producer responsibility (EPR) scheme may be a suitable policy measure to manage the end of life impacts of the new waste.

If the transition happens at a greater speed than anticipated, as per the ‘High Speed’ scenario, the risks to the waste system are heightened because of the likely early abandonment of used ICE vehicles in favour of the shared ZEV model.

7.1.3 Recommendations

Given the magnitude of the health benefits and the significant opportunities and risks associated with a transformation to a ZEV / AV fleet, Aurecon and ERM recommend that the Victorian Government should consider the economic viability of policy measures to incentivise the uptake of ZEV and AV vehicles, and develop plans to manage the waste impacts.

This could include cost benefit analysis of infrastructure, tax or industry development policies and investments, and of waste policy measures to manage the impacts from a growing quantity of ZEV and AV components entering the waste stream.

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Appendix A
Detailed Assumptions for Methodology

Health Outcome Assumptions

The table below provides the health outcome assumptions for each pollutant used to estimate DALYs through the Impact Pathway Methodology.

Table A-1 – Health outcome assumptions for each pollutant

Pollutant	Health Outcomes	Period	Relative Risk (% increase per µg / m³)	Total Incidence (2016)	Baseline Incidence (Total Pop 2016)	Total Pop at Age for Condition	Disability Weight	Duration of Hospital Admission (Days)		Relative Risk - Source
								Low	High	
$PM_{2.5}$	Annual all-cause mortality (non-accidental) 30+ years	Annual Average	0.006	38,875	0.0063	3,730,300	1.00			(WHO, 2013)
$PM_{2.5}$	Hospital Admissions respiratory disease 65+ years	24 hours	0.004	105,546	0.0048	929,214	0.16	0.005	0.022	(NEPC, 2010)
$PM_{2.5}$	Hospital Admissions cardiovascular disease 65+ years	24 hours	0.003	124,131	0.0108	929,214	0.34	0.005	0.022	(NEPC, 2010)
$PM_{2.5}$	Hospital Admissions respiratory disease 15-64 years	24 hours	0.003	124,131	0.0045	4,109,752	0.16	0.005	0.022	(NEPC, 2010)
$PM_{2.5}$	ED Visits Asthma 1-14 years	24 hours	0.0015	18,692	0.0015	1,140,283	0.13	0.001	0.005	(NEPC, 2010)
NO_2	Annual all-cause mortality (non-accidental)	Annual Average	0.00054	39,450	0.0064	6,179,249	1.00			(WHO, 2013)
NO_2	Hospital Admissions respiratory disease 65+ years	24 –hour average	0.003	105,546	0.0048	929,214	0.16	0.005	0.022	(NEPC, 2010)
NO_2	Hospital Admissions cardiovascular disease 65+ years	24 –hour average	0.0014	124,131	0.0108	929,214	0.34	0.005	0.022	(NEPC, 2010)
NO_2	Hospital Admissions respiratory disease 15-64 years	24 –hour average	0.001	105,546	0.0045	4,109,752	0.16	0.005	0.022	(NEPC, 2010)
NO_2	ED Visits Asthma 1-14 years	24 –hour average	0.0006	18,692	0.0015	1,140,283	0.13	0.001	0.005	(NEPC, 2010)

Separations Data

The tables below indicate the separations data used to measure the baseline incidence of the health outcomes attributable to NO_X and $PM_{2.5}$.

Table A-2 – Separations data used to measure the baseline incidence of the health outcomes

Same-day acute separations, by principal diagnosis in ICD-10-AM chapters, public hospitals, states and territories, 2015–16

Principal diagnosis		NSW	Vic	Qld	WA	SA	Tas	ACT	NT	Total
A00–B99	Certain infectious and parasitic diseases	9,340	11,456	12,549	2,935	2,253	471	632	742	40,378
C00–D48	Neoplasms	32,660	44,812	28,411	15,132	10,986	3,768	1,245	1,226	138,240
D50–D89	Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	15,420	31,436	15,969	9,099	4,149	1,263	1,043	561	78,940
E00–E89	Endocrine, nutritional and metabolic diseases	7,720	15,174	7,777	5,282	1,633	1,552	560	1,103	40,801
F00–F99	Mental and behavioural disorders	8,055	11,896	8,056	2,591	2,718	351	444	1,445	35,556
G00–G99	Diseases of the nervous system	17,982	32,555	19,465	6,561	5,253	2,283	1,508	802	86,409
H00–H59	Diseases of the eye and adnexa	26,297	28,175	12,883	14,056	8,300	2,784	1,391	944	94,830
H60–H95	Diseases of the ear and mastoid process	4,226	4,991	5,702	1,865	1,705	289	320	331	19,429
I00–I99	Diseases of the circulatory system	22,285	22,216	18,423	7,125	6,792	1,680	1,709	790	81,020
J00–J99	Diseases of the respiratory system	16,638	20,161	22,911	3,800	4,411	1,382	695	1,185	71,183
K00–K93	Diseases of the digestive system	56,786	63,277	41,320	23,117	11,603	5,310	4,250	3,206	208,869
L00–L99	Diseases of the skin and subcutaneous tissue	9,362	10,022	9,474	3,582	4,315	1,379	531	759	39,424
M00–M99	Diseases of the musculoskeletal system and connective tissue	20,284	25,975	18,918	6,890	6,727	2,034	2,410	1,181	84,419
N00–N99	Diseases of the genitourinary system	34,846	38,916	30,779	11,387	9,142	2,751	1,957	1,441	131,219
O00–O99	Pregnancy, childbirth and the puerperium	22,735	16,952	23,127	5,612	7,710	1,096	1,266	2,596	81,094
P00–P96	Certain conditions originating in the perinatal period	880	721	617	220	140	35	61	68	2,742
Q00–Q99	Congenital malformations, deformations and chromosomal abnormalities	4,045	3,701	2,474	1,249	998	305	234	87	13,093

Same-day acute separations, by principal diagnosis in ICD-10-AM chapters, public hospitals, states and territories, 2015–16

R00–R99	Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	72,834	88,207	69,923	26,100	17,372	4,387	5,486	3,877	288,186
S00–T98	Injury, poisoning and certain other consequences of external causes	55,282	49,504	54,661	14,812	13,899	3,010	4,717	4,430	200,315
Z00–Z99	Factors influencing health status and contact with health services	392,908	442,337	280,498	177,798	79,756	26,548	25,005	77,473	1,502,323
	Not reported	180	0	0	0	1	1	1	4	187
Total		**830,765**	**962,484**	**683,937**	**339,213**	**199,863**	**62,679**	**55,465**	**104,251**	**3,238,657**

Same-day acute separations, by principal diagnosis in ICD-10-AM chapters, private hospitals, states and territories, 2015–16

Principal diagnosis		**NSW**	**Vic**	**Qld**	**WA**	**SA**	**Tas**	**ACT**	**NT**	**Total**
A00–B99	Certain infectious and parasitic diseases	3,590	2,653	3,177	1,356	966	n.p.	n.p.	n.p.	12,189
C00–D48	Neoplasms	66,982	55,735	65,867	26,712	24,182	n.p.	n.p.	n.p.	246,351
D50–D89	Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	9,929	12,673	23,322	3,381	4,336	n.p.	n.p.	n.p.	55,249
E00–E89	Endocrine, nutritional and metabolic diseases	5,675	8,673	8,461	4,391	1,767	n.p.	n.p.	n.p.	29,850
F00–F99	Mental and behavioural disorders	10,129	2,404	1,009	30	73	n.p.	n.p.	n.p.	15,611
G00–G99	Diseases of the nervous system	11,399	9,542	14,018	5,996	2,782	n.p.	n.p.	n.p.	45,002
H00–H59	Diseases of the eye and adnexa	90,675	54,062	66,892	30,737	20,944	n.p.	n.p.	n.p.	279,248
H60–H95	Diseases of the ear and mastoid process	7,589	5,515	4,348	2,723	2,252	n.p.	n.p.	n.p.	23,573
I00–I99	Diseases of the circulatory system	16,837	8,478	8,357	5,291	3,564	n.p.	n.p.	n.p.	45,270
J00–J99	Diseases of the respiratory system	8,348	4,798	5,958	1,507	1,695	n.p.	n.p.	n.p.	22,946
K00–K93	Diseases of the digestive system	123,934	131,786	95,669	40,031	30,722	n.p.	n.p.	n.p.	436,017
L00–L99	Diseases of the skin and subcutaneous tissue	7,816	8,425	5,990	3,939	4,796	n.p.	n.p.	n.p.	32,055

Same-day acute separations, by principal diagnosis in ICD-10-AM chapters, private hospitals, states and territories, 2015–16

M00–M99	Diseases of the musculoskeletal system and connective tissue	40,318	33,192	29,692	19,314	15,076	n.p.	n.p.	n.p.	143,218
N00–N99	Diseases of the genitourinary system	37,880	31,516	24,435	13,142	6,968	n.p.	n.p.	n.p.	118,176
O00–O99	Pregnancy, childbirth and the puerperium	9,596	17,045	14,054	7,638	771	n.p.	n.p.	n.p.	49,765
P00–P96	Certain conditions originating in the perinatal period	100	109	37	105	39	n.p.	n.p.	n.p.	407
Q00–Q99	Congenital malformations, deformations and chromosomal abnormalities	2,253	1,658	1,523	874	548	n.p.	n.p.	n.p.	7,065
R00–R99	Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	54,014	54,047	37,652	22,398	10,495	n.p.	n.p.	n.p.	183,835
S00–T98	Injury, poisoning and certain other consequences of external causes	10,457	8,614	7,288	4,186	4,710	n.p.	n.p.	n.p.	36,658
Z00–Z99	Factors influencing health status and contact with health services	187,932	202,457	237,461	155,777	70,710	n.p.	n.p.	n.p.	871,515
	Not reported	0	0	0	0	0	n.p.	n.p.	n.p.	1
Total		**705,453**	**653,382**	**655,210**	**349,528**	**207,396**	n.p.	n.p.	n.p.	**2,654,001**

Overnight acute separations, by principal diagnosis in ICD-10-AM chapters, public hospitals, states and territories, 2015–16

Principal diagnosis		**NSW**	**Vic**	**Qld**	**WA**	**SA**	**Tas**	**ACT**	**NT**	**Total**
A00–B99	Certain infectious and parasitic diseases	34,583	24,680	19,379	9,295	6,617	1,626	1,545	1,992	99,717
C00–D48	Neoplasms	41,599	39,179	27,237	12,437	11,503	2,926	2,347	1,071	138,299
D50–D89	Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	10,908	7,606	5,800	2,387	2,833	572	489	315	30,910

Overnight acute separations, by principal diagnosis in ICD-10-AM chapters, public hospitals, states and territories, 2015–16										
E00–E89	Endocrine, nutritional and metabolic diseases	17,879	14,184	12,648	5,813	5,038	1,169	864	1,680	59,275
F00–F99	Mental and behavioural disorders	25,109	13,048	11,782	8,363	6,930	1,221	1,087	940	68,480
G00–G99	Diseases of the nervous system	23,073	23,836	15,132	6,992	5,523	1,975	1,126	835	78,492
H00–H59	Diseases of the eye and adnexa	4,913	3,272	2,439	1,515	777	143	254	232	13,545
H60–H95	Diseases of the ear and mastoid process	4,893	3,800	3,109	1,741	1,261	280	218	359	15,661
I00–I99	Diseases of the circulatory system	87,771	61,792	53,425	24,711	20,888	5,711	4,644	3,012	261,954
J00–J99	Diseases of the respiratory system	96,861	60,979	55,524	26,443	22,807	5,519	4,535	4,875	277,543
K00–K93	Diseases of the digestive system	92,489	65,841	54,583	28,461	19,720	5,774	4,974	3,460	275,302
L00–L99	Diseases of the skin and subcutaneous tissue	26,703	17,097	18,696	8,836	5,209	1,365	1,247	3,109	82,262
M00–M99	Diseases of the musculoskeletal system and connective tissue	42,116	31,891	24,501	13,847	9,125	2,894	1,954	1,468	127,796
N00–N99	Diseases of the genitourinary system	48,370	34,275	32,689	14,487	11,482	2,796	3,014	2,226	149,339
O00–O99	Pregnancy, childbirth and the puerperium	90,423	70,254	55,285	30,632	18,857	5,499	5,933	4,710	281,593
P00–P96	Certain conditions originating in the perinatal period	18,620	13,730	9,581	5,709	3,823	908	1,340	834	54,545
Q00–Q99	Congenital malformations, deformations and chromosomal abnormalities	5,365	3,544	2,692	1,436	947	200	244	144	14,572
R00–R99	Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	91,950	57,324	49,798	21,420	20,577	4,695	3,609	3,411	252,784
S00–T98	Injury, poisoning and certain other consequences of external causes	117,415	77,747	69,071	36,495	26,223	7,199	6,288	6,411	346,849
Z00–Z99	Factors influencing health status and contact with health services	33,794	13,385	11,073	3,508	6,935	1,055	679	1,049	71,478

Overnight acute separations, by principal diagnosis in ICD-10-AM chapters, public hospitals, states and territories, 2015–16										
	Not reported	659	0	0	0	0	1	2	3	665
Total		**915,493**	**637,464**	**534,444**	**264,528**	**207,075**	**53,528**	**46,393**	**42,136**	**2,701,061**

Overnight acute separations, by principal diagnosis in ICD-10-AM chapters, private hospitals, states and territories, 2015–16										
Principal diagnosis		**NSW**	**Vic**	**Qld**	**WA**	**SA**	**Tas**	**ACT**	**NT**	**Total**
A00–B99	Certain infectious and parasitic diseases	1,752	4,055	4,976	1,296	790	n.p.	n.p.	n.p.	13,361
C00–D48	Neoplasms	27,797	29,937	26,294	11,773	8,473	n.p.	n.p.	n.p.	108,274
D50–D89	Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	1,629	2,983	2,759	1,020	867	n.p.	n.p.	n.p.	9,578
E00–E89	Endocrine, nutritional and metabolic diseases	9,387	7,285	9,172	5,480	1,856	n.p.	n.p.	n.p.	34,299
F00–F99	Mental and behavioural disorders	2,294	1,510	1,574	650	190	n.p.	n.p.	n.p.	6,670
G00–G99	Diseases of the nervous system	18,432	19,103	21,940	9,516	4,728	n.p.	n.p.	n.p.	76,705
H00–H59	Diseases of the eye and adnexa	2,663	1,641	1,505	2,117	856	n.p.	n.p.	n.p.	9,059
H60–H95	Diseases of the ear and mastoid process	2,152	1,518	1,748	798	614	n.p.	n.p.	n.p.	7,133
I00–I99	Diseases of the circulatory system	26,447	31,645	30,524	11,906	7,634	n.p.	n.p.	n.p.	111,437
J00–J99	Diseases of the respiratory system	19,516	19,608	22,917	8,124	6,182	n.p.	n.p.	n.p.	79,737
K00–K93	Diseases of the digestive system	25,865	29,875	31,507	12,072	9,250	n.p.	n.p.	n.p.	113,955
L00–L99	Diseases of the skin and subcutaneous tissue	3,512	4,482	5,117	1,676	1,172	n.p.	n.p.	n.p.	16,644
M00–M99	Diseases of the musculoskeletal system and connective tissue	48,365	49,431	41,566	26,552	16,729	n.p.	n.p.	n.p.	192,630
N00–N99	Diseases of the genitourinary system	22,169	21,980	22,058	9,669	7,014	n.p.	n.p.	n.p.	86,689

Overnight acute separations, by principal diagnosis in ICD-10-AM chapters, private hospitals, states and territories, 2015–16										
O00–O99	Pregnancy, childbirth and the puerperium	25,386	21,469	18,929	11,516	4,652	n.p.	n.p.	n.p.	86,137
P00–P96	Certain conditions originating in the perinatal period	3,674	2,896	2,408	1,666	766	n.p.	n.p.	n.p.	11,900
Q00–Q99	Congenital malformations, deformations and chromosomal abnormalities	1,176	999	854	527	349	n.p.	n.p.	n.p.	4,034
R00–R99	Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere classified	11,767	21,776	21,188	6,164	5,126	n.p.	n.p.	n.p.	68,716
S00–T98	Injury, poisoning and certain other consequences of external causes	18,093	21,153	24,117	10,271	6,975	n.p.	n.p.	n.p.	84,030
Z00–Z99	Factors influencing health status and contact with health services	11,880	6,714	6,103	3,267	2,124	n.p.	n.p.	n.p.	31,653
	Not reported	0	0	0	0	0	n.p.	n.p.	n.p.	3
Total		**283,956**	**300,060**	**297,256**	**136,060**	**86,347**	**n.p.**	**n.p.**	**n.p.**	**1,152,644**

Basic Car Materials – ICEV

Basic material breakdown and weight composition of a typical ICEV used in the analysis. s

Table A-3 – Basic Material Breakdown ICEV

Material	Proportion by weight	Average Weight (kg)
Steel and other ferrous metals	66%	1222
Heavy non-ferrous metals (Zinc, copper, lead)	2%	37
Light non-ferrous metals (Aluminium)	6%	111
Plastics	9%	167
Rubber (tyres)	4%	74
Adhesive, paints	3%	56
Glass	3%	56
Textiles	1%	19
Fluids	1%	19
Other	3%	56

Manufacturing Components and Energy Intensity for ICEV and ZEVs

Manufacturing components derived from a LCA by Hawkins et al. 2012

Table A-4 – Manufacturing components derived from a LCA by Hawkins et al. 2012

Material/ Component	Body-in-white	Body panels	Bumpers	Body hardware	Weld blanks and fasteners	Weld blanks and fasteners (other systems to body)	Doors, including trunk lid	Assembly processes, body shop	Assembly processes, mechanical processing	Assembly processes, press shop	Windscreen glass	Rear screen glass	Side body glass (6)	Material/ Component
Ferrous metals														
Rolled steel	kg	0	19.12	0	0	0	0	0	0	0	0	0	0	0
EAF steel	kg	0	10.32	0	0.367	4.217	4.217	0	0	0	0	0	0	0
galv steel	kg	211.2	4.578	8.433	0	0	0	93	0	0	0	0	0	0
hot rolled steel	kg	0	33.46	0	0	0	0	0	0	0	0	0	0	0
stainless steel	kg	0	0	0	0.08	0	0	0	0	0	0	0	0	0
Cast iron	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Non-ferrous metals														
Wrought Aluminium	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Cast Aluminium	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Copper	kg	0	0	0	0.2	0	0	0	0	0	0	0	0	0
Magnesium	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Zinc	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Platinum	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Lead (Pb)	kg	0	0	0	0	0	0	0	0	0	0	0	0	0
Glass														
Glass	kg	0	0	0	0.06	0	0	0.075	0	0	0	11.6	4.57	12.53
Polymers														
Plastic	kg	0	0	0	6.151	3.425	3.425	12	0	0	0	0	0	0
Rubber	kg	0	0	0	0.23	0	0	0	0	0	0	0	0	0
Scrap														
Scrap, Rolled steel	kg	0	4.017	0	0	0	0	0	0	0	0	0	0	0
Scrap, EAF steel	kg	0	2.168	0	0.077	0.886	0.886	0	0	0	0	0	0	0
Scrap, galv steel	kg	44.38	0.962	1.772	0	0	0	19.54	0	0	0	0	0	0

Material/ Component	Body-in-white	Body panels	Bumpers	Body hardware	Weld blanks and fasteners	Weld blanks and fasteners (other systems to body)	Doors, including trunk lid	Assembly processes, body shop	Assembly processes, mechanical processing	Assembly processes, press shop	Windscreen glass	Rear screen glass	Side body glass (6)	Material/ Component
Scrap, hot rolled steel	kg	0	7.029	0	0	0	0	0	0	0	0	0	0	0
Scrap, stainless steel	kg	0	0	0	0.017	0	0	0	0	0	0	0	0	0
Scrap, glass	kg	0	0	0	0.003	0	0	0.004	0	0	0	0.611	0.241	0.659
Final Assembly														
Oxygen	kg	0	0	0	0	0	0	0	0.038	7E-04	0.022	0	0	0
Acetylene	kg	0	0	0	0	0	0	0	0.003	3E-05	9E-04	0	0	0
Nitrogen	kg	0	0	0	0	0	0	0	0	0.124	0	0	0	0
Carbon dioxide	kg	0	0	0	0	0	0	0	0.258	0.005	0	0	0	0
Natural gas	kg	0	0	0	0	0	0	0	0	1.525	0.272	0	0	0
Drinking water	m^3	0	0	0	0	0	0	0	0.239	0.129	0.102	0	0	0
Operating water	m^3	0	0	0	0	0	0	0	3.052	3.605	8.001	0	0	0
Tech. heat	MJ	0	0	0	0	0	0	0	0	8.491	0	0	0	0
Room heat	MJ	0	0	0	0	0	0	0	553.6	288.7	185.1	0	0	0
Comp. air 6 bar	Nm^3	0	0	0	0	0	0	0	173.2	40.76	205.5	0	0	0
Comp. air 12 bar	Nm^3	0	0	0	0	0	0	0	84.91	0	13.59	0	0	0
Electricity	kWh	0	0	0	0	0	0	0	190.2	139.3	113.8	0	0	0

Manufacturing and Disposal Data & Assumptions

Fleet Model and Base Assumptions

Table A-5 – Fleet Model and Base Assumptions

Assumption / Calculation	Value
Total Vehicles 2016	4,681,337
Population 2016	6,053,353
Ratio	0.77
Fleet turnover per annum	10%
Manufacturing in Victoria	10%
Slow Lane	50%

Assumption / Calculation	Value
Projected Population 2031	7,701,109.37
Projected Baseline Fleet (2031)	5,955,623.14
Projected Population 2046	9,404,975
Projected Baseline Fleet (2046)	7,273,301
Shared - on demand services reduction	40%
Both	20%

Table A-6 – Base Fleet Model

	% of fleet	Outcome multiplier	equivalent capacity (MJ)	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow lane	High speed
Cars	78%	1.00	86.00	5,685,254	5,685,254	3,411,152	5,685,254	2,842,627	2,793,166.04
buses	0.43%	2.00	172.00	31,266	31,266	18,759	31,266	15,633	15,361
LCV	14%	1.00	86.00	1,024,132	1,024,132	614,479	1,024,132	512,066	503,156
Trucks	3%	4.00	344.00	225,229	225,229	135,137	225,229	112,614	110,655
Other	4%	1.00	86.00	307,418	307,418	184,451	307,418	153,709	151,034

Table A-7 – Manufacturing Modelling Results (BEV)

MANUFACTURING		Electric avenue	Private drive	Fleet street	Slow lane	High speed
Climate change	t CO2 eq	109,808	109,808	65,885	54,904	53,949
Ozone depletion	t CFC-11 eq	10,226	10,226	6,136	5,113	5,024
Human toxicity	t 1,4-DB eq	- 20,589	- 20,589	- 12,353	- 10,295	- 10,115
Photochemical oxidant formation	t NMVOC	34	34	21	17	17
Particulate matter formation	t PM10 eq	69	69	41	34	34
Ionising radiation	t U235 eq	14,412	14,412	8,647	7,206	7,081
Agricultural land occupation	km2	0	0	0	0	0
Urban land occupation	km2	1	1	1	1	1
Natural land transformation	km2	0	0	0	0	0
Water depletion	ML	487	487	292	244	239
Metal depletion	t Fe eq	229,911	229,911	137,947	114,956	112,955
Fossil depletion	t oil eq	4,118	4,118	2,471	2,059	2,023
Energy Consumption	GJ	1,892,757	1,892,757	1,135,654	946,379	929,912
Embodied Emissions	t CO2 eq	257,625	257,625	154,575	128,813	126,571

Table A-8 – Waste Modelling Results (BEV)

WASTE		Electric avenue	Private drive	Fleet street	Slow lane	High speed
LiFePO4	120	95,371	95,371	57,222	47,685	46,856
Aluminium foil	5	4,294	4,294	2,576	2,147	2,110
Carbon black	8	6,102	6,102	3,661	3,051	2,998
Styrene acrylate latex	10	7,910	7,910	4,746	3,955	3,886
Ethylene glycol dimethyl ether	44	35,482	35,482	21,289	17,741	17,432
Lithium salt (Lithium chloride)	8	6,328	6,328	3,797	3,164	3,109
Polypropylene	3	2,034	2,034	1,220	1,017	999
Polyethylene	3	2,034	2,034	1,220	1,017	999
Transistor	3	2,260	2,260	1,356	1,130	1,110
Resistor	3	2,260	2,260	1,356	1,130	1,110
Graphite	48	38,193	38,193	22,916	19,097	18,764
Carbon black	1	1,130	1,130	678	565	555
Copper	13	10,396	10,396	6,238	5,198	5,107
Styrene butadiene latex	2	1,356	1,356	814	678	666

WASTE		Electric avenue	Private drive	Fleet street	Slow lane	High speed
Polypropylene	1	1,130	1,130	678	565	555
Aluminium foil	2	1,582	1,582	949	791	777
		217,861	217,861	130,717	108,931	107,035

Table A-9 – Manufacturing Modelling Results (HFCEV)

Factor	Unit	Factor	Hydrogen Highway
Energy use	GJ	5	399,013
Greenhouse gas emissions	tCeq	0.7	55,862
SO2 emissions	t	0.0244	1,947
CO emissions	t	0.0017	136
NOx emissions	t	0.0081	646
non-methane volatile organic compounds	t	-0.0016	- 128
Particulate matter emissions	t	-0.0017	- 136
Benzene	kg	0.0023	184
Benz(a)pyrine	kg	0.000034	3

Table A-10 – Manufacturing Modelling Results (HFCEV)

HFCEV Disposal	Unit	Factor	Hydrogen Highway
Electrode	Platinum	0.06	48
Electrode	Ruthenium	0.01	8
Electrode	Carbon paper	4.37	3,487
Membrane	Nafion membrane	5.64	4,501
Bipolar plate	Polypropylene	16.14	12,880
Bipolar plate	Carbon fibres	16.14	12,880
Bipolar plate	Carbon powder	21.52	17,174
End-plate	Aluminium alloy	2.8	2,234
Current collectors	Aluminium alloy	1.14	910
Tie-rod	Steel	2.05	1,636

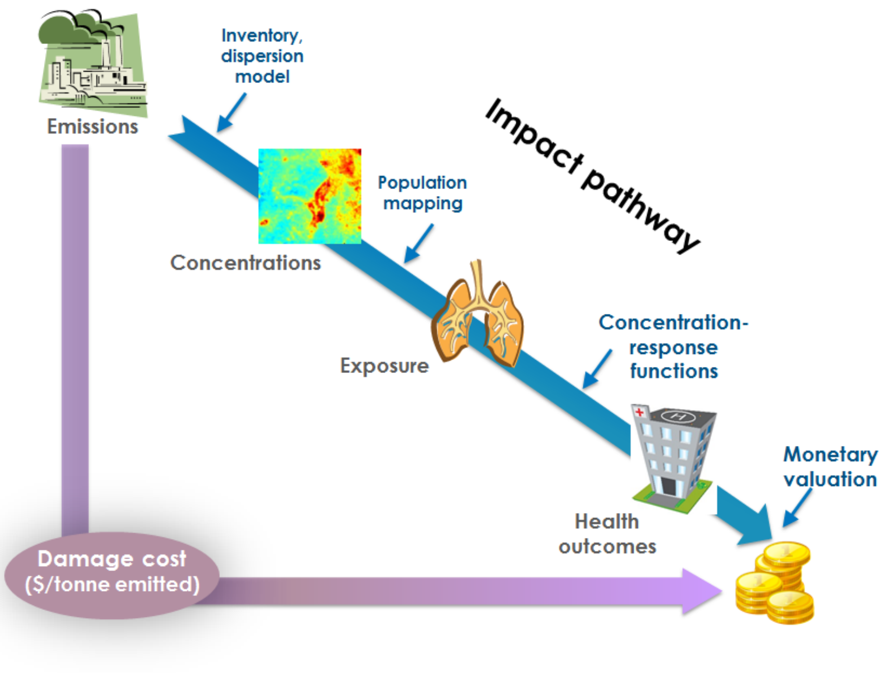
Impact Pathway Methodology

The benefits associated with reductions in NO_2 and $PM_{2.5}$ concentrations were estimated by considering:

- the reduced quantity of emissions (tonnes p.a.)
- the resulting change in concentrations of NO_x and $PM_{2.5}$ in each SA2
- the resulting change in the populations' exposure to the concentrations of these pollutants
- the projected difference in health outcomes associated with that change in exposure
- the value of those health outcomes expressed in monetary terms.

This approach is referred to as the 'impact pathway' (DEFRA, 2013), and is summarised below.

Figure A-1 – Impact Pathway Summary



Estimating changes in health incidence

The final step (changes in health incidence associated with the changes in pollutant concentrations) is estimated using concentration-response functions (CRF). CRFs are expressed as the percentage change in health incidence due to a unit change in concentration levels (refer to Table A-1).

Health outcomes analysed in this study include:

- premature mortality (deaths brought forward)
- hospital admissions related to cardiovascular and respiratory diseases
- emergency department visits.

Manufacturing component units

Table A-11 – BEV Manufacturing Component Unit Descriptions

Factor	Units	Description
Climate change	t CO2 eq	Tonnes of CO2 equivalent
Ozone depletion	t CFC-11 eq	Tonnes of Trichlorofluoromethane equivalents
Human toxicity	t 1,4-DB eq	Tonnes of dichlorobenzene equivalent
Photochemical oxidant formation	t NMVOC	Tonnes of non-methane volatile organic compounds
Particulate matter formation	t PM10 eq	Tonnes of particulate matter equivalent
Ionising radiation	t U235 eq	Tonnes of Uranium (235) equivalent
Agricultural land occupation	km2	Square Kilometres
Urban land occupation	km2	Square Kilometres
Natural land transformation	km2	Square Kilometres
Water depletion	ML	Mega litre
Metal depletion	t Fe eq	Tonnes of Iron equivalents
Fossil depletion	t oil eq	Tonnes of oil equivalents
Energy Consumption	GJ	Gigajoule
Embodied Emissions	t CO2 eq / GJ	Tonnes of CO2 equivalent

Table A-12 – HFCEV Manufacturing Component Unit Descriptions

Factor	Units	Description
Energy use	GJ	Gigajoule
Greenhouse gas emissions	t CO_2 eq	Tonnes of CO2 equivalent
SO2 emissions	kg	Kilograms
CO emissions	kg	Kilograms
NOx emissions	kg	Kilograms
non-methane volatile organic compounds	kg	Kilograms
Particulate matter emissions	kg	Kilograms
Benzene	g	Grams
Benz(a)pyrine	g	Grams
Embodied Emissions	t CO_2 eq / GJ	Tonnes of CO2 equivalent

Appendix B
Detailed Results by SA2

Total DALYs calculated per SA2 across each scenario

Table B-1 – Total DALYs calculated per SA2 across each scenario

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21001	Alfredton	1.213285	1.109549	1.177499	1.213285	2.492153	1.109549	3.631819
21002	Ballarat	1.060045	0.992955	0.9495	1.060045	2.058303	0.992955	3.096877
21003	Ballarat - North	1.649318	1.483651	1.525199	1.649318	3.192424	1.483651	4.834235
21004	Ballarat - South	1.367661	1.214875	1.263111	1.367661	2.706067	1.214875	4.078795
21005	Buninyong	0.408521	0.360182	0.392468	0.408521	0.83547	0.360182	1.237563
21006	Delacombe	1.301619	1.320033	1.423427	1.301619	2.92666	1.320033	3.952623
21007	Smythes Creek	0.184467	0.15675	0.183564	0.184467	0.398456	0.15675	0.572128
21008	Wendouree - Miners Rest	1.001185	0.887767	0.915845	1.001185	1.952887	0.887767	2.948572
21009	Bacchus Marsh Region	0.005615	0.005789	0.007143	0.005757	0.012173	0.005874	0.015822
21010	Creswick - Clunes	0.281349	0.224324	0.277903	0.281349	0.597688	0.224324	0.869826
21011	Daylesford	0.206002	0.159124	0.203434	0.206002	0.441357	0.159124	0.646195
21012	Gordon (Vic.)	0.515745	0.406266	0.479341	0.515745	1.047347	0.406266	1.558819
21013	Avoca	0.139815	0.101842	0.131383	0.139815	0.292128	0.101842	0.435422
21014	Beaufort	0.233718	0.181377	0.229445	0.233718	0.500675	0.181377	0.721712
21015	Golden Plains - North	0.100148	0.0731	0.097144	0.100148	0.210368	0.0731	0.318573
21016	Maryborough (Vic.)	0.158472	0.14791	0.169838	0.158472	0.360268	0.14791	0.493249
21017	Maryborough Region	0.075508	0.060298	0.081705	0.075508	0.174554	0.060298	0.241132
21018	Bendigo	1.286406	1.226	1.202548	1.286406	2.52869	1.226	3.773655
21019	California Gully - Eaglehawk	0.506499	0.451729	0.492864	0.506499	1.053577	0.451729	1.545225
21020	East Bendigo - Kennington	0.718775	0.660543	0.662485	0.718775	1.407462	0.660543	2.129812
21021	Flora Hill - Spring Gully	0.676018	0.66348	0.655004	0.676018	1.403707	0.66348	2.000346
21022	Kangaroo Flat - Golden Square	1.150501	1.091869	1.116222	1.150501	2.372033	1.091869	3.408688
21023	Maiden Gully	0.719252	0.679789	0.737959	0.719252	1.619127	0.679789	2.190428
21024	Strathfieldsaye	0.741043	0.632989	0.68718	0.741043	1.468093	0.632989	2.236141

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21025	White Hills - Ascot	0.307561	0.277675	0.325577	0.307561	0.685655	0.277675	0.960841
21026	Bendigo Region - South	0.722434	0.621473	0.719106	0.722434	1.521794	0.621473	2.167805
21027	Castlemaine	0.337235	0.304902	0.345356	0.337235	0.729864	0.304902	1.034099
21028	Castlemaine Region	0.642667	0.533814	0.633333	0.642667	1.349362	0.533814	1.933093
21029	Heathcote	0.214965	0.1274	0.155112	0.214965	0.369152	0.1274	0.66122
21030	Kyneton	0.002122	0.00217	0.002709	0.002005	0.003659	0.002166	0.005278
21031	Woodend	0.982922	1.116786	0.976321	1.113246	2.677624	1.123698	2.998107
21032	Bendigo Region - North	0.263826	0.20571	0.267672	0.263826	0.56747	0.20571	0.82334
21033	Loddon	0.199005	0.152868	0.20347	0.199005	0.43728	0.152868	0.618802
21034	Bannockburn	0.938092	0.829245	0.928006	0.938092	1.94156	0.829245	2.811785
21035	Golden Plains - South	0.327743	0.276342	0.354094	0.327743	0.720299	0.276342	1.013854
21036	Winchelsea	0.240051	0.170733	0.203572	0.240051	0.491471	0.170733	0.74002
21037	Belmont	1.232614	1.050496	0.969658	1.232614	2.191937	1.050496	3.575091
21038	Corio - Norlane	2.307323	2.076041	2.091666	2.307323	4.382941	2.076041	6.713841
21039	Geelong	2.144376	1.982316	1.826698	2.144376	3.984999	1.982316	6.165108
21040	Geelong West - Hamlyn Heights	2.699811	2.619691	2.493399	2.699811	5.188072	2.619691	7.759438
21041	Grovedale	4.769426	4.330269	4.283837	4.769426	9.109521	4.330269	13.86911
21042	Highton	1.21783	1.159192	1.149953	1.21783	2.445727	1.159192	3.5783
21043	Lara	0.007669	0.007873	0.009353	0.007871	0.01949	0.007929	0.022153
21044	Leopold	1.472132	1.371216	1.350427	1.472132	2.87844	1.371216	4.303278
21045	Newcomb - Moolap	1.264619	1.159273	1.168168	1.264619	2.486372	1.159273	3.712502
21046	Newtown (Vic.)	1.107362	1.131925	1.071725	1.107362	2.225986	1.131925	3.217467
21047	North Geelong - Bell Park	1.606739	1.512589	1.451414	1.606739	3.100211	1.512589	4.65464
21048	Clifton Springs	1.324462	1.210584	1.257677	1.324462	2.674706	1.210584	3.920397
21049	Lorne - Anglesea	0.216282	0.180986	0.225261	0.216282	0.488369	0.180986	0.676315
21050	Ocean Grove - Barwon Heads	0.838488	0.740225	0.848919	0.838488	1.763352	0.740225	2.561957
21051	Portarlington	0.345927	0.300845	0.341866	0.345927	0.729199	0.300845	1.06305
21052	Queenscliff	0.156721	0.136297	0.158831	0.156721	0.34244	0.136297	0.488284
21053	Torquay	0.513948	0.449518	0.523405	0.513948	1.096633	0.449518	1.585513
21054	Alexandra	0.214441	0.125749	0.165645	0.214441	0.375723	0.125749	0.673046

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21055	Euroa	0.588893	0.442668	0.53447	0.588893	1.162457	0.442668	1.773262
21056	Kilmore - Broadford	0.19827	0.193396	0.210582	0.197092	0.329257	0.198923	0.540122
21057	Mansfield (Vic.)	0.066017	0.032114	0.04795	0.066017	0.114498	0.032114	0.216565
21058	Nagambie	0.487305	0.406087	0.476976	0.487305	1.042704	0.406087	1.461859
21059	Seymour	0.318161	0.293119	0.300368	0.318161	0.650884	0.293119	0.933379
21060	Seymour Region	2.36E-05	2.31E-05	3.33E-05	2.31E-05	4.13E-05	2.31E-05	6E-05
21061	Upper Yarra Valley	0.000555	0.000451	0.000701	0.000555	0.001602	0.000451	0.001917
21062	Yea	0.002461	0.002385	0.00285	0.002416	0.00433	0.002431	0.00675
21063	Benalla	0.640748	0.542439	0.603605	0.640748	1.290911	0.542439	1.912487
21064	Benalla Region	0.154211	0.118386	0.154233	0.154211	0.336737	0.118386	0.481685
21065	Rutherglen	0.052424	0.044251	0.058494	0.052424	0.125679	0.044251	0.168493
21066	Wangaratta	0.722037	0.657601	0.701015	0.722037	1.470786	0.657601	2.164541
21067	Wangaratta Region	0.319764	0.243861	0.314683	0.319764	0.671517	0.243861	0.986624
21068	Beechworth	0.105533	0.089577	0.113086	0.105533	0.243125	0.089577	0.333142
21069	Bright - Mount Beauty	0.055002	0.039254	0.058305	0.055002	0.123125	0.039254	0.180362
21070	Chiltern - Indigo Valley	0.143831	0.118572	0.144189	0.143831	0.316008	0.118572	0.444196
21071	Myrtleford	0.049862	0.040783	0.054155	0.049862	0.116015	0.040783	0.160109
21072	Towong	0.015939	0.01229	0.019807	0.015939	0.041621	0.01229	0.054167
21073	West Wodonga	0.729062	0.633413	0.704036	0.729062	1.487426	0.633413	2.196257
21074	Wodonga	0.627561	0.53743	0.645032	0.627561	1.335882	0.53743	1.941326
21075	Yackandandah	0.081996	0.067824	0.088946	0.081996	0.191044	0.067824	0.261054
21076	Drouin	0.0367	0.036748	0.037278	0.036502	0.08543	0.037296	0.106676
21077	Mount Baw Region	0.114774	0.060706	0.085265	0.114774	0.185451	0.060706	0.365706
21078	Trafalgar (Vic.)	0.641754	0.543024	0.615743	0.641754	1.327113	0.543024	1.923098
21079	Warragul	1.870354	1.654402	1.870741	1.870354	3.89717	1.654402	5.605435
21080	Alps - East	0	0	0	0	0	0	0
21081	Bairnsdale	0.764644	0.671868	0.740473	0.764644	1.564344	0.671868	2.294929
21082	Bruthen - Omeo	0.118525	0.093937	0.135809	0.118525	0.278405	0.093937	0.380526
21083	Lake King	0.001604	0.001373	0.001541	0.001604	0.003311	0.001373	0.004847
21084	Lakes Entrance	0.236044	0.206184	0.249447	0.236044	0.526857	0.206184	0.736093

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21085	Orbost	0.007503	0.005733	0.010062	0.007503	0.020963	0.005733	0.026368
21086	Paynesville	0.154228	0.102372	0.122715	0.154228	0.31777	0.102372	0.48571
21087	Foster	0.058583	0.048139	0.068642	0.058583	0.142651	0.048139	0.191202
21088	French Island	0.001119	0.000957	0.001075	0.001119	0.002309	0.000957	0.00338
21089	Korumburra	0.3464	0.290581	0.356284	0.3464	0.749598	0.290581	1.067482
21090	Leongatha	0.255799	0.20715	0.262817	0.255799	0.561848	0.20715	0.800301
21091	Phillip Island	0.377925	0.34092	0.397726	0.377925	0.83952	0.34092	1.171509
21092	Wilsons Promontory	0.000481	0.000411	0.000462	0.000481	0.000992	0.000411	0.001452
21093	Wonthaggi - Inverloch	0.003102	0.003118	0.002961	0.003094	0.005977	0.003134	0.008703
21094	Churchill	0.25215	0.22037	0.277606	0.25215	0.569767	0.22037	0.78255
21095	Moe - Newborough	1.501116	1.372191	1.418647	1.501116	3.006586	1.372191	4.407196
21096	Morwell	0.786673	0.748737	0.793745	0.786673	1.65686	0.748737	2.338748
21097	Traralgon	1.657334	1.546162	1.644582	1.657334	3.409265	1.546162	4.91734
21098	Yallourn North - Glengarry	0.171873	0.107162	0.131797	0.171873	0.309414	0.107162	0.531239
21099	Alps - West	0.001683	0.00144	0.001617	0.001683	0.003473	0.00144	0.005084
21100	Longford - Loch Sport	0.204111	0.132101	0.169631	0.204111	0.425635	0.132101	0.647225
21101	Maffra	0.273144	0.209836	0.274843	0.273144	0.572798	0.209836	0.850917
21102	Rosedale	0.272948	0.228532	0.276917	0.272948	0.59479	0.228532	0.834389
21103	Sale	0.593212	0.615824	0.668024	0.593212	1.332672	0.615824	1.782693
21104	Yarram	0.033635	0.027033	0.039276	0.033635	0.083306	0.027033	0.110763
21105	Brunswick	6.303676	6.7232	3.956842	7.17817	12.14082	8.762042	17.00212
21106	Brunswick East	2.407501	2.675131	1.421511	2.769465	4.13957	3.146523	6.610929
21107	Brunswick West	3.773797	4.377004	2.853569	4.311545	7.348485	5.212541	10.47382
21108	Coburg	15.44675	18.79763	12.64223	19.26997	31.67093	20.98016	42.69913
21109	Pascoe Vale South	11.75001	13.78737	11.39938	13.20635	25.74011	14.58009	31.15692
21110	Alphington - Fairfield	2.181937	2.816499	2.056172	2.983653	4.780369	3.005039	6.13262
21111	Northcote	3.326651	4.111685	2.46203	4.316777	6.881025	5.211655	9.412192
21112	Thornbury	3.409231	3.69146	2.335758	3.900924	6.386599	4.520476	9.684156
21113	Ascot Vale	7.225564	8.115531	6.190312	7.982937	15.08887	9.626458	19.78407
21114	Essendon - Aberfeldie	9.597432	10.83484	8.815848	10.75368	20.41908	12.29401	25.18127

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21115	Flemington	8.603884	10.65924	8.782558	10.22002	20.1638	12.0049	22.84051
21116	Moonee Ponds	6.769397	7.562647	6.38843	7.17151	14.31304	8.186388	17.4592
21117	Carlton	4.535754	5.967641	3.476508	5.735381	10.32938	7.762725	12.06101
21118	Docklands	14.53526	21.76421	16.0593	22.42614	43.42665	27.41013	43.2058
21119	East Melbourne	5.283987	7.484196	5.012866	7.31332	12.33374	8.304149	14.65712
21120	Flemington Racecourse	2.249003	2.687231	2.158485	2.645836	5.260515	3.033397	3.135509
21121	Kensington	1.968003	2.624301	1.60011	2.646427	4.773048	3.158502	5.834662
21122	Melbourne	13.443	20.6047	11.15689	21.09167	34.37029	31.19626	43.52693
21123	North Melbourne	18.42439	25.99486	18.95684	25.6759	47.48884	30.68712	41.28925
21124	Parkville	3.47199	4.160769	2.561783	4.135796	7.388149	7.001617	8.303225
21125	South Yarra - West	1.839917	2.892469	2.471608	2.319729	6.042885	4.195511	4.916995
21126	Southbank	57.33944	77.29	61.46057	75.38795	140.8462	79.18043	105.2259
21127	West Melbourne	2.426565	2.899391	2.3289	2.854728	5.67584	3.272888	3.383061
21128	Albert Park	6.796884	8.180369	4.896635	8.356813	15.85268	9.127613	20.5659
21129	Elwood	3.961084	4.915393	2.803689	4.857692	9.146484	4.684087	11.93623
21130	Port Melbourne	2.567335	3.199561	2.134	3.272518	6.262491	3.687702	7.759196
21131	Port Melbourne Industrial	6.121899	7.924586	6.451684	7.387718	14.47009	7.748471	16.12984
21132	South Melbourne	11.92288	17.3715	14.24162	15.14077	35.42476	19.47329	33.53576
21133	St Kilda	7.796919	10.93908	8.033036	9.895542	21.76243	16.08971	22.28849
21134	St Kilda East	5.416935	7.13039	5.812593	6.995707	14.26624	12.06022	15.88214
21135	Armadale	2.613911	2.982987	1.39353	2.846606	4.850365	4.330812	7.114173
21136	Prahran - Windsor	4.579282	5.562729	3.043783	5.39078	8.976006	7.55822	12.67182
21137	South Yarra - East	15.21341	19.59786	12.21635	18.84969	34.76272	24.52342	42.08046
21138	Toorak	5.642339	7.237755	4.906435	6.911587	12.67778	8.319812	15.44806
21139	Abbotsford	15.61228	20.08942	13.62135	18.82632	33.47739	22.47429	42.06911
21140	Carlton North - Princes Hill	10.70579	13.02187	10.24584	12.12935	24.62081	15.31824	28.72151
21141	Collingwood	3.015019	4.192382	2.193542	4.107358	6.641998	6.173693	8.276515
21142	Fitzroy	9.452381	12.07471	7.92898	11.27202	21.443	15.33484	25.28585
21143	Fitzroy North	6.838369	8.426207	4.519677	8.489995	13.91742	11.20702	19.00856
21144	Richmond (Vic.)	20.04237	25.68939	15.68799	25.4155	41.21699	31.24045	53.7326

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21145	Yarra - North	5.799744	7.000928	4.577201	6.913247	11.51691	8.763468	15.73369
21146	Ashburton (Vic.)	2.423512	2.761672	2.0468	2.830464	5.03724	3.000796	6.699231
21147	Balwyn	3.751023	3.855939	2.36296	3.908488	6.405977	5.098146	10.43476
21148	Balwyn North	5.854413	6.62912	4.763446	6.407153	11.23487	7.818125	15.70636
21149	Camberwell	7.320013	8.546475	5.542829	8.798696	13.4598	9.614226	20.38878
21150	Glen Iris - East	5.658387	6.76166	4.866286	6.849996	11.66922	7.427658	15.34404
21151	Hawthorn	6.011062	7.771996	3.788189	8.128393	11.8225	9.009789	16.56597
21152	Hawthorn East	5.028769	5.843909	3.100797	6.148106	9.097354	6.604679	13.95891
21153	Kew	9.506596	11.85994	7.225461	11.68437	18.76237	15.42309	25.39086
21154	Kew East	6.31286	7.401255	5.503783	6.405398	12.83681	8.006613	15.32241
21155	Surrey Hills (West) - Canterbury	4.22964	4.528906	2.536164	4.757152	7.270168	5.585575	11.8724
21156	Bulleen	13.07994	14.90656	12.32699	13.78493	27.94665	15.74533	33.41887
21157	Doncaster	20.43772	23.0002	18.50065	21.60066	43.36809	24.66639	54.45915
21158	Doncaster East	2.295232	2.133875	1.958838	2.182387	4.100082	2.241514	6.360426
21159	Templestowe	5.33446	4.839317	3.417419	5.106356	9.475587	5.093523	14.99947
21160	Templestowe Lower	4.179148	3.900453	2.761497	4.176976	7.56001	4.295282	11.68801
21161	Blackburn	11.28359	12.95322	10.30741	12.40973	23.60898	14.02198	30.36657
21162	Blackburn South	2.879935	3.188019	2.348291	3.422923	5.787706	3.408597	8.448303
21163	Box Hill	12.57992	13.16951	8.297958	13.67408	22.96881	14.61856	35.8368
21164	Box Hill North	9.231842	10.762	8.425426	10.06268	19.00388	11.39808	24.55862
21165	Burwood	3.066801	2.804182	1.678901	2.962868	5.089744	3.380065	9.003147
21166	Burwood East	3.187527	3.103409	2.101508	3.28771	5.475517	3.482752	9.070489
21167	Surrey Hills (East) - Mont Albert	5.380466	5.911757	3.629422	5.936854	9.69828	6.493052	15.02792
21168	Beaumaris	1.633601	1.678433	1.683509	1.688258	3.159088	1.738868	4.501606
21169	Brighton (Vic.)	3.65277	4.310079	3.162611	4.254806	7.877075	4.762435	10.60051
21170	Brighton East	8.315293	9.656792	7.598286	9.50741	18.08426	10.47686	24.01163
21171	Cheltenham - Highett (West)	3.007941	3.310705	2.734029	3.33373	5.901057	3.507325	8.500458
21172	Hampton	4.794727	5.192274	4.330017	5.07831	9.172885	5.496642	13.40424
21173	Sandringham - Black Rock	2.306523	2.275938	2.071964	2.271866	4.091509	2.39936	6.324885
21174	Bentleigh - McKinnon	5.256262	6.014318	4.753316	6.054856	10.62725	6.44258	15.07411

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21175	Bentleigh East	5.008013	5.925219	4.444214	5.927872	9.628601	6.321514	14.07427
21176	Carnegie	1.987846	2.42363	1.59572	2.483146	3.925694	2.726345	5.413782
21177	Caulfield - North	11.21197	13.6117	8.248502	12.91007	22.71109	16.4549	30.24733
21178	Caulfield - South	3.806121	4.102705	2.62041	4.114128	6.550416	4.572394	10.42661
21179	Elsternwick	2.115417	2.716353	2.399673	2.586819	5.573552	3.409863	6.102442
21180	Hughesdale	1.602232	1.875594	1.368687	1.842844	3.016517	2.039436	4.465727
21181	Murrumbeena	1.971967	2.539261	1.717271	2.397169	4.261174	2.810146	5.079684
21182	Ormond - Glen Huntly	2.137689	2.66711	1.986266	2.691305	4.163808	2.967691	5.900847
21183	Aspendale Gardens - Waterways	4.21822	4.028055	3.290677	4.020321	8.168053	4.03533	12.01093
21184	Braeside	0.56308	0.480811	0.400816	0.480888	0.999456	0.490506	1.679391
21185	Carrum - Patterson Lakes	6.647493	6.717067	5.272199	6.733209	12.65806	6.719129	17.22241
21186	Chelsea - Bonbeach	3.649905	3.16819	2.400095	3.390457	6.347607	3.745917	10.80444
21187	Chelsea Heights	2.61753	2.779432	2.220857	2.724092	5.334913	2.77934	7.043116
21188	Cheltenham - Highett (East)	15.23224	16.28755	12.496	16.72069	30.73641	17.12744	44.36517
21189	Edithvale - Aspendale	3.408707	3.179581	2.355575	3.370431	6.333743	3.706023	10.38929
21190	Mentone	5.543988	6.155427	5.155053	6.143412	11.31103	6.300709	15.90467
21191	Moorabbin - Heatherton	5.298912	6.033215	5.026646	5.853644	11.45855	5.908326	16.15458
21192	Moorabbin Airport	0.02032	0.023256	0.020025	0.022552	0.043709	0.022657	0.058238
21193	Mordialloc - Parkdale	7.144367	7.286476	5.857433	7.465998	14.19961	7.797002	21.07645
21194	Malvern - Glen Iris	13.7097	17.15403	12.98635	17.12995	29.96138	18.9335	36.16074
21195	Malvern East	24.75002	33.20309	25.84318	32.3911	57.39218	35.84028	65.04075
21196	Bundoora - East	5.203744	5.028531	3.887353	4.790097	9.596131	5.331545	13.32992
21197	Greensborough	6.49727	6.755637	5.728724	6.598765	12.51338	7.045302	16.87778
21198	Heidelberg - Rosanna	15.1768	17.84094	14.92518	16.66294	32.45957	18.95113	38.72636
21199	Heidelberg West	4.531303	5.447792	3.885831	5.556856	9.53305	5.839899	12.78967
21200	Ivanhoe	1.683062	1.931301	1.183669	2.020931	3.159091	2.406826	4.697635
21201	Ivanhoe East - Eaglemont	2.938575	3.545248	2.620685	3.434823	6.098071	3.785437	7.868375
21202	Montmorency - Briar Hill	4.692599	5.150058	3.712717	5.264044	9.302476	5.446797	13.0245
21203	Viewbank - Yallambie	6.268721	7.144278	6.374433	6.60614	13.17216	7.668957	15.86306
21204	Watsonia	6.11851	6.677078	5.949799	6.012037	12.83686	7.038621	14.97046

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21205	Kingsbury	13.33794	12.149	7.207301	12.70302	21.21548	14.00762	37.31208
21206	Preston	9.806783	12.17937	8.302688	12.46149	20.47366	13.22666	27.49196
21207	Reservoir - East	6.088836	7.63954	5.582711	7.777652	13.20171	8.243998	16.95479
21208	Reservoir - West	6.599512	7.694162	5.590559	7.856693	13.22713	8.547076	18.38251
21209	Eltham	4.615225	4.907567	4.372565	5.046859	8.535057	5.051331	12.85967
21210	Hurstbridge	0.397744	0.344856	0.350741	0.354875	0.802126	0.352096	1.166433
21211	Kinglake	0.249627	0.229452	0.259306	0.22671	0.592298	0.237055	0.730556
21212	Panton Hill - St Andrews	0.459639	0.420523	0.430803	0.414967	1.046318	0.427284	1.429452
21213	Plenty - Yarrambat	6.32751	6.637379	6.329557	6.218256	13.08274	6.855499	16.54939
21214	Research - North Warrandyte	0.784415	0.72128	0.619094	0.762808	1.512691	0.733042	2.343173
21215	Wattle Glen - Diamond Creek	2.609645	2.685186	2.608113	2.64124	5.501616	2.766452	7.611206
21216	Bundoora - North	7.569603	7.930621	6.952133	7.539694	15.43016	8.322722	18.90538
21217	Bundoora - West	3.335426	3.226008	2.485989	3.019054	6.156497	3.450789	8.28082
21218	Epping	7.802514	8.796999	8.528792	8.611963	16.01654	9.054782	20.47648
21219	Lalor	6.706806	6.851501	6.058129	6.648971	13.03609	7.24451	17.41692
21220	Mill Park - North	3.385242	3.75627	3.446226	3.75564	7.183584	3.863352	9.308217
21221	Mill Park - South	4.012739	4.407677	4.099178	4.334751	8.443164	4.521838	10.59935
21222	South Morang	1.126717	1.244509	1.162031	1.328226	2.313705	1.295027	3.210761
21223	Thomastown	16.80564	16.86657	14.1842	15.22063	31.73098	17.87127	40.19293
21224	Wallan	14.92128	14.56518	14.46197	14.45855	32.79989	14.88586	41.07693
21225	Whittlesea	10.01269	10.13796	10.33984	10.57321	27.02569	10.18381	33.26387
21226	Airport West	6.983055	7.123565	6.331109	6.698006	13.90628	7.70449	17.00696
21227	Essendon Airport	2.75265	2.929569	2.776891	2.715316	5.921895	3.13662	6.701346
21228	Keilor	8.623904	8.84489	7.938347	8.53384	17.50808	9.501425	21.69341
21229	Keilor East	7.856708	8.144282	6.545051	7.841376	15.22462	8.617539	21.27362
21230	Niddrie - Essendon West	2.649728	2.924917	2.601247	2.876946	5.697498	3.229089	7.033834
21231	Strathmore	6.659666	7.206223	6.070566	6.94329	13.73783	7.783911	17.18623
21232	Gisborne	3.470704	3.25323	3.306096	3.17738	6.776039	3.330079	8.860202
21233	Macedon	0.41026	0.357184	0.392054	0.382779	0.938852	0.36345	1.324532
21234	Riddells Creek	0.379464	0.330172	0.34681	0.328433	0.670927	0.341837	1.10532

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21235	Romsey	0.526358	0.494558	0.597012	0.50351	1.023883	0.511718	1.488363
21236	Coburg North	1.903213	2.28447	1.483356	2.357554	3.831835	2.527518	5.241985
21237	Fawkner	3.974025	4.843585	3.593968	4.864134	8.151849	5.298663	10.87868
21238	Glenroy - Hadfield	4.066063	4.660105	3.2143	4.842165	7.743832	4.964922	11.60527
21239	Pascoe Vale	4.241483	4.824555	3.29296	5.03128	8.162344	5.173996	11.97591
21240	Sunbury	7.62751	8.561063	8.053503	8.873682	19.71475	8.872301	24.6589
21241	Sunbury - South	11.13338	11.31404	10.41374	11.43728	23.50123	11.6559	31.20747
21242	Broadmeadows	16.50177	17.14225	13.52563	15.91148	31.38208	17.69091	39.93648
21243	Campbellfield - Coolaroo	5.329141	5.769184	4.476954	5.754093	10.32578	5.954719	14.41727
21244	Craigieburn - Mickleham	2.227191	2.439812	2.214427	2.530408	4.61864	2.559355	6.558859
21245	Gladstone Park - Westmeadows	6.665053	7.234251	6.710352	7.177131	14.1851	7.461911	18.03085
21246	Greenvale - Bulla	6.642071	7.062571	6.650365	7.128868	15.45481	7.303746	20.45582
21247	Meadow Heights	0.727208	0.75346	0.598743	0.79749	1.370352	0.769462	2.120577
21248	Melbourne Airport	0.503374	0.452217	0.393486	0.430327	0.899614	0.491653	1.293655
21249	Roxburgh Park - Somerton	4.980367	4.76488	4.131334	5.009358	9.762045	4.929676	14.49686
21250	Tullamarine	3.519677	3.390858	2.865981	3.235775	6.591041	3.570656	8.839762
21251	Bayswater	11.10613	13.1628	11.87825	12.80958	23.77826	13.54247	31.85945
21252	Boronia - The Basin	7.113522	7.277733	6.452869	7.622983	13.63774	7.421106	20.67608
21253	Ferntree Gully	3.868945	3.988421	3.506184	4.171446	7.526872	4.070062	11.13845
21254	Knoxfield - Scoresby	10.00312	11.2074	9.628566	12.43927	22.20208	11.57121	30.74635
21255	Lysterfield	1.248459	1.162611	1.061986	1.144495	2.571544	1.154201	3.792777
21256	Rowville - Central	2.713678	2.727966	2.375106	2.830601	5.93193	2.777454	8.252663
21257	Rowville - North	1.368838	1.253857	1.153288	1.243734	2.6253	1.252591	4.149251
21258	Rowville - South	3.701053	3.849244	3.560481	3.750032	8.51107	3.943107	10.78505
21259	Wantirna	10.60015	11.03636	9.720355	9.972226	21.32405	11.66225	28.23017
21260	Wantirna South	14.06897	14.37891	12.47796	13.88684	27.85597	15.02571	38.78636
21261	Donvale - Park Orchards	6.319396	6.651245	5.786225	6.132034	13.17532	6.959691	16.61499
21262	Warrandyte - Wonga Park	1.907429	1.710967	1.574288	1.762354	3.617634	1.751343	5.418036
21263	Bayswater North	2.902449	3.217196	3.03504	3.208293	5.952725	3.316419	8.241705
21264	Croydon	5.234761	5.650538	4.885018	5.761914	9.977859	5.764377	14.76054

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21265	Croydon Hills - Warranwood	2.60345	2.831862	2.868048	2.815207	5.526605	2.90856	7.328043
21266	Ringwood	18.40319	19.93456	17.89976	19.03872	37.96437	20.65947	50.93219
21267	Ringwood East	8.448655	9.155537	7.822973	9.066635	17.1042	9.479319	24.15384
21268	Ringwood North	0.853662	0.848203	0.824272	0.866395	1.734574	0.884683	2.497326
21269	Forest Hill	2.751359	2.932609	2.20995	2.953012	5.822718	3.181372	8.000616
21270	Mitcham (Vic.)	11.86018	13.27219	11.05077	12.32469	24.98387	14.22738	31.02645
21271	Nunawading	8.460416	9.828503	7.593989	9.304444	17.9524	10.56262	23.78702
21272	Vermont	4.426927	4.296159	3.699317	4.141606	8.99346	4.655941	12.37429
21273	Vermont South	4.86575	4.647887	3.191382	4.572169	8.806164	4.993413	13.82854
21274	Belgrave - Selby	1.376942	1.389866	1.260756	1.46335	2.491637	1.417247	3.928138
21275	Chirnside Park	3.215674	3.856748	3.973967	3.638529	7.061848	3.915966	8.869003
21276	Healesville - Yarra Glen	1.603524	1.329636	1.578191	1.325851	3.916417	1.340282	5.067272
21277	Kilsyth	2.736425	2.835011	2.8011	3.00061	5.250851	2.901934	7.637094
21278	Lilydale - Coldstream	5.264159	6.020794	5.755846	5.721823	10.8055	6.038133	14.88747
21279	Monbulk - Silvan	0.464834	0.400623	0.388153	0.408306	0.78763	0.406583	1.356724
21280	Montrose	2.800859	3.240411	2.998428	3.221586	6.086471	3.314295	8.135199
21281	Mooroolbark	5.551696	6.202299	5.875493	6.164724	10.6411	6.313375	15.08592
21282	Mount Dandenong - Olinda	0.838672	0.685832	0.67267	0.687971	1.313387	0.695278	2.389884
21283	Mount Evelyn	2.16374	2.591637	2.281166	2.671264	4.771136	2.653979	6.309362
21284	Upwey - Tecoma	0.76565	0.799552	0.712029	0.843518	1.385882	0.816306	2.174714
21285	Wandin - Seville	1.566566	2.192594	1.833496	2.129125	4.124666	2.205746	4.825732
21286	Yarra Valley	3.922373	4.874047	4.092804	4.858941	11.45466	4.881684	13.49791
21287	Beaconsfield - Officer	6.993326	7.659779	7.166084	7.601198	14.87237	7.95353	19.23423
21288	Bunyip - Garfield	1.416864	1.404233	1.404387	1.407875	3.237933	1.407848	3.96237
21289	Emerald - Cockatoo	2.78269	2.644631	2.611688	2.713824	5.54296	2.687301	8.269097
21290	Koo Wee Rup	0.836015	0.816053	0.815802	0.862443	1.89759	0.825751	2.633952
21291	Pakenham - North	3.561388	3.678362	3.62331	3.789715	7.162909	3.848107	10.39645
21292	Pakenham - South	7.392668	7.658026	7.020588	7.428221	15.09951	7.703919	19.31642
21293	Berwick - North	6.366558	7.21162	6.406248	7.265462	13.45697	7.437143	17.33005
21294	Berwick - South	9.654415	10.60659	9.495843	10.53455	20.33816	10.621	26.62702

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21295	Doveton	7.730381	8.526591	7.879875	8.482092	17.24672	8.926353	20.01448
21296	Endeavour Hills	1.577061	1.517884	1.354048	1.476254	3.214241	1.521367	4.436144
21297	Hallam	7.170704	8.295956	6.937198	8.232476	15.57736	8.547233	19.66263
21298	Narre Warren	6.627054	7.747687	6.527377	7.844614	14.13314	7.927209	18.23891
21299	Narre Warren North	1.637767	1.540737	1.357183	1.488237	3.272644	1.534929	4.634699
21300	Cranbourne	5.19694	6.075485	5.579732	6.198684	11.49535	6.291597	15.12178
21301	Cranbourne East	19.90253	20.66745	18.50272	20.52566	37.43839	21.17305	56.47706
21302	Cranbourne North	6.988043	8.309105	7.383926	8.019255	15.64535	8.516348	19.75254
21303	Cranbourne South	8.132728	7.864803	8.005554	8.03817	17.14551	7.946261	23.30818
21304	Cranbourne West	2.769608	2.88368	2.651044	2.910082	5.552288	2.98192	7.470502
21305	Hampton Park - Lynbrook	6.622238	7.423062	6.713181	7.630352	14.3203	7.695249	18.58071
21306	Lynbrook - Lyndhurst	6.438906	7.992635	7.282459	7.82412	15.36794	8.452657	17.5021
21307	Narre Warren South	1.528116	1.548858	1.31626	1.645367	3.049293	1.535492	4.552596
21308	Pearcedale - Tooradin	1.061714	0.970552	0.988429	0.921491	2.34867	0.979453	3.154066
21309	Clarinda - Oakleigh South	2.112642	2.370118	1.989308	2.361904	4.524944	2.393245	6.275274
21310	Clayton South	10.18393	10.30456	7.735915	10.91083	20.93376	10.49096	31.45663
21311	Dandenong	28.90019	32.64665	26.57643	33.02935	64.35953	33.53861	83.67332
21312	Dandenong North	17.79021	18.97515	17.39599	18.18006	39.11058	19.89045	45.03338
21313	Dingley Village	5.411377	6.059121	5.21001	5.900595	12.19205	6.136168	15.74554
21314	Keysborough	11.83957	12.54344	10.92979	11.81466	26.22646	12.70811	34.64321
21315	Noble Park	6.131978	6.137488	5.31505	5.781753	12.45385	6.331539	16.2422
21316	Noble Park North	7.65662	8.233957	7.661554	7.831763	17.41864	8.646733	19.2795
21317	Springvale	20.8163	24.17938	17.84094	24.26442	47.85983	25.09393	65.02817
21318	Springvale South	2.767817	2.921685	2.219551	2.921098	5.807374	2.952059	8.801481
21319	Ashwood - Chadstone	6.957286	7.640237	5.483972	7.643932	13.6996	8.293828	19.19105
21320	Clayton	21.43834	25.04008	18.06128	25.31817	46.97629	25.45964	63.06077
21321	Glen Waverley - East	5.964426	6.322707	4.57895	6.184227	11.07892	6.600568	17.18719
21322	Glen Waverley - West	11.2411	11.91573	8.444401	11.86725	21.51015	12.46614	31.97433
21323	Mount Waverley - North	5.072247	4.876147	2.79411	5.19735	8.660058	5.250792	14.66609
21324	Mount Waverley - South	15.3171	16.61453	13.26871	16.15208	31.28058	17.29781	40.88001

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21325	Mulgrave	16.63182	18.47442	16.72891	17.82154	37.29041	19.10772	43.29347
21326	Oakleigh - Huntingdale	11.9902	14.74231	10.62749	15.32217	26.39191	15.35774	35.33157
21327	Wheelers Hill	6.106099	7.343039	6.644595	7.901416	14.13486	7.569606	17.88084
21328	Ardeer - Albion	4.422436	4.830094	3.588006	4.55653	9.598078	5.136041	12.72272
21329	Cairnlea	3.018597	3.343153	2.808503	3.05633	6.692638	3.533731	8.189933
21330	Deer Park - Derrimut	10.88546	13.15382	11.93243	12.73936	25.21414	13.45713	31.18777
21331	Delahey	1.684879	1.604499	1.308084	1.713786	3.121402	1.696082	4.686821
21332	Keilor Downs	2.710644	3.164671	2.688504	3.134577	6.165059	3.269352	7.928847
21333	Kings Park (Vic.)	0.571237	0.574835	0.555537	0.58172	1.155793	0.595067	1.649396
21334	St Albans - North	5.008635	5.332932	4.315974	5.49979	10.18961	5.610637	14.37978
21335	St Albans - South	9.487712	9.998898	8.093517	9.347217	19.10868	10.66601	24.39715
21336	Sunshine	4.180453	4.946989	3.596751	4.968151	10.07389	5.389679	12.9877
21337	Sunshine North	9.90438	11.38698	9.302525	10.88861	22.27488	12.09407	27.2439
21338	Sunshine West	5.442412	5.91751	4.77576	5.547678	11.60613	5.986253	14.25198
21339	Sydenham	2.333454	2.355503	2.316848	2.541249	4.586317	2.523071	6.724074
21340	Taylors Lakes	4.302386	4.358093	4.004724	4.474105	8.981922	4.580097	11.93714
21341	Altona	2.03982	2.262249	1.566098	2.237894	4.3671	2.274374	5.878256
21342	Altona Meadows	5.697539	6.446133	5.328799	6.343902	12.85672	6.507903	15.34589
21343	Altona North	12.83776	14.8201	11.56036	14.17552	28.60928	14.45959	34.42117
21344	Newport	4.379551	5.024527	3.248234	5.03787	8.967375	5.261519	12.21342
21345	Seabrook	0.730559	1.179813	1.062597	1.225456	2.088513	1.336447	2.188803
21346	Williamstown	3.632193	4.170681	2.690857	4.07384	6.746388	4.06951	10.08538
21347	Braybrook	9.854555	11.56567	8.243085	11.877	23.90335	12.72915	30.73744
21348	Footscray	10.34121	13.10079	9.244687	13.4162	26.16653	14.65651	31.26445
21349	Maribyrnong	6.794262	7.518027	5.449085	7.876955	14.36602	7.921395	19.76225
21350	Seddon - Kingsville	3.125032	3.43044	2.314803	3.48044	7.019164	4.116904	9.251003
21351	West Footscray - Tottenham	2.86761	2.959841	2.108052	3.087556	6.239284	3.489709	8.67832
21352	Yarraville	10.36492	11.698	8.504281	11.52698	23.08453	12.38234	28.23686
21353	Bacchus Marsh	3.480202	3.472429	3.547473	3.345186	6.154685	3.561269	9.029723
21354	Caroline Springs	0.681961	0.640016	0.559713	0.663617	1.15262	0.646166	1.957689

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21355	Hillside	13.37108	14.40889	14.4233	15.21506	28.5674	15.50755	38.59925
21356	Melton	5.277647	5.421881	5.221784	5.461962	10.82894	5.499051	14.19408
21357	Melton South	10.95451	11.11945	10.66261	11.20287	22.40947	11.27869	29.13999
21358	Melton West	4.305254	4.171538	4.150003	4.13694	8.868911	4.243981	11.15725
21359	Rockbank - Mount Cottrell	100.093	113.5352	101.9898	109.0251	223.281	115.7401	278.6816
21360	Taylors Hill	2.548603	2.401275	2.309182	2.426009	4.519908	2.503646	6.819273
21361	Hoppers Crossing - North	2.723096	2.778662	2.46936	2.846006	5.275672	2.978722	7.552761
21362	Hoppers Crossing - South	3.140257	3.635788	3.12129	3.675132	6.371364	3.789734	9.052297
21363	Laverton	6.513268	7.262802	6.090843	7.041224	14.2152	7.436989	16.98526
21364	Point Cook	2.467122	3.01378	2.797034	3.014066	5.906762	3.270612	7.12412
21365	Tarneit	21.53202	22.62715	20.04359	23.34228	43.9845	24.45246	62.63328
21366	Truganina	10.79195	10.97465	9.469929	11.44356	22.01392	12.21189	30.94192
21367	Werribee	3.490427	3.774199	3.55692	3.919548	7.188114	3.931883	9.784757
21368	Werribee - South	15.8825	16.38054	15.21824	16.21585	33.80509	16.27722	42.70009
21369	Wyndham Vale	10.10416	10.77615	9.119697	10.75747	19.34158	11.05937	28.04903
21370	Carrum Downs	6.775231	6.756725	6.149853	7.092914	13.51032	6.771458	19.34551
21371	Frankston	10.47377	10.76529	10.64662	10.97293	19.65103	11.0867	28.3027
21372	Frankston North	5.074491	4.931418	4.905604	4.806085	9.335078	4.993614	13.03321
21373	Frankston South	4.051682	4.399102	4.650797	4.4715	8.199927	4.475768	11.34403
21374	Langwarrin	7.931456	8.286923	8.185611	8.289256	16.3587	8.395798	22.23989
21375	Seaford (Vic.)	6.611623	6.389226	5.487294	6.386357	11.26091	6.750814	16.73937
21376	Skye - Sandhurst	2.158195	2.267084	2.271914	2.277822	4.746649	2.281284	6.07375
21377	Dromana	3.44768	3.118451	3.071444	3.005678	5.838301	3.218317	8.340774
21378	Flinders	0.633471	0.610837	0.673546	0.611385	1.271142	0.617767	1.844955
21379	Hastings - Somers	3.160806	3.183769	3.349958	3.190342	5.990343	3.234984	8.9129
21380	Mornington	6.230247	6.102734	7.495734	6.201472	11.45442	6.286416	16.71322
21381	Mount Eliza	3.24526	3.173484	3.397541	3.464628	5.747451	3.353436	9.013027
21382	Mount Martha	2.229118	2.308297	2.691022	2.29125	4.20879	2.367185	6.040729
21383	Point Nepean	1.561947	1.561187	1.735089	1.553441	2.998918	1.570039	4.242054
21384	Rosebud - McCrae	5.405011	5.368768	5.506137	4.848254	9.927821	5.492657	13.60366

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21385	Somerville	3.58887	3.43586	3.529144	3.423455	6.64646	3.496226	9.530673
21386	Ararat	0.291199	0.251634	0.286843	0.291199	0.613773	0.251634	0.886897
21387	Ararat Region	0.123685	0.092297	0.125527	0.123685	0.274679	0.092297	0.390731
21388	Horsham	0.371623	0.338939	0.386002	0.371623	0.807158	0.338939	1.142343
21389	Horsham Region	0.103128	0.078225	0.107804	0.103128	0.234491	0.078225	0.327511
21390	Nhill Region	0.007461	0.005674	0.009771	0.007461	0.020359	0.005674	0.025985
21391	St Arnaud	0.098211	0.068346	0.093155	0.098211	0.204848	0.068346	0.310703
21392	Stawell	0.154983	0.119753	0.15978	0.154983	0.341097	0.119753	0.487644
21393	West Wimmera	0.006177	0.004761	0.007877	0.006177	0.016808	0.004761	0.02133
21394	Yarriambiack	0.067371	0.037808	0.055887	0.067371	0.123232	0.037808	0.217289
21395	Irymple	0.684882	0.610727	0.667912	0.684882	1.437791	0.610727	2.065209
21396	Merbein	0.070999	0.064103	0.078596	0.070999	0.168163	0.064103	0.225248
21397	Mildura	0.791091	0.731822	0.813101	0.791091	1.699388	0.731822	2.418768
21398	Mildura Region	0.1733	0.125111	0.177391	0.1733	0.385653	0.125111	0.545048
21399	Red Cliffs	0.284921	0.244274	0.288263	0.284921	0.62022	0.244274	0.876738
21400	Buloke	0.235964	0.177171	0.232595	0.235964	0.503229	0.177171	0.726209
21401	Gannawarra	0.077505	0.058954	0.082204	0.077505	0.17492	0.058954	0.247867
21402	Kerang	0.042716	0.037953	0.047711	0.042716	0.102491	0.037953	0.136411
21403	Robinvale	0.020417	0.018213	0.024651	0.020417	0.052746	0.018213	0.06732
21404	Swan Hill	0.28726	0.241065	0.277912	0.28726	0.612592	0.241065	0.885867
21405	Swan Hill Region	0.063897	0.045604	0.066945	0.063897	0.14542	0.045604	0.207564
21406	Echuca	0.33773	0.297272	0.349284	0.33773	0.732742	0.297272	1.04131
21407	Kyabram	0.144519	0.120574	0.155945	0.144519	0.327881	0.120574	0.456827
21408	Lockington - Gunbower	0.053137	0.035048	0.048549	0.053137	0.109923	0.035048	0.171256
21409	Rochester	0.102565	0.086903	0.107978	0.102565	0.23385	0.086903	0.321718
21410	Rushworth	0.087263	0.053816	0.070811	0.087263	0.170656	0.053816	0.27724
21411	Cobram	0.117276	0.104469	0.126031	0.117276	0.268636	0.104469	0.367858
21412	Moira	0.153201	0.120545	0.156928	0.153201	0.344763	0.120545	0.480941
21413	Numurkah	0.11079	0.089411	0.125011	0.11079	0.260771	0.089411	0.357221
21414	Yarrawonga	0.056879	0.051956	0.065164	0.056879	0.137251	0.051956	0.182493

SA2 Code	SA2 Name	Electric Avenue	Private Drive	Fleet Street	Hydrogen highway	Slow Lane	Private Drive Empty Running	Dead end
21415	Mooroopna	0.306946	0.28136	0.305483	0.306946	0.662324	0.28136	0.939415
21416	Shepparton - North	0.491806	0.456441	0.496445	0.491806	1.081817	0.456441	1.504038
21417	Shepparton - South	1.258541	1.12127	1.237641	1.258541	2.561115	1.12127	3.767876
21418	Shepparton Region - East	0.172146	0.142384	0.180682	0.172146	0.389459	0.142384	0.535255
21419	Shepparton Region - West	0.185667	0.16533	0.208375	0.185667	0.444326	0.16533	0.583851
21420	Glenelg (Vic.)	0.072607	0.055279	0.081139	0.072607	0.170744	0.055279	0.23611
21421	Hamilton (Vic.)	0.142179	0.121592	0.147434	0.142179	0.311826	0.121592	0.44444
21422	Portland	0.15547	0.143525	0.166725	0.15547	0.35093	0.143525	0.484094
21423	Southern Grampians	0.077048	0.057081	0.08178	0.077048	0.17489	0.057081	0.247679
21424	Camperdown	0.151081	0.150722	0.173415	0.151081	0.346597	0.150722	0.460499
21425	Colac	0.362656	0.282484	0.294232	0.362656	0.73213	0.282484	1.102806
21426	Colac Region	0.18032	0.133549	0.168289	0.18032	0.38624	0.133549	0.560453
21427	Corangamite - North	0.18032	0.133549	0.168289	0.18032	0.38624	0.133549	0.560453
21428	Corangamite - South	0.094891	0.055688	0.066396	0.094891	0.197518	0.055688	0.301625
21429	Moyne - East	0.183837	0.143069	0.190749	0.183837	0.405409	0.143069	0.576252
21430	Moyne - West	0.143793	0.116736	0.158604	0.143793	0.333729	0.116736	0.45807
21431	Otway	0.044708	0.036146	0.051733	0.044708	0.110615	0.036146	0.146772
21432	Warrnambool - North	0.785785	0.733873	0.799229	0.785785	1.652065	0.733873	2.371998
21433	Warrnambool - South	0.420082	0.360165	0.408922	0.420082	0.885123	0.360165	1.287771

Appendix C
Regression Analysis for State Wide Results

Statistical analysis of the exposure estimation results for Melbourne SA2s (µg / m^3 per person) showed that exposure for each SA2 was related to:

- the population density of that SA2
- the absolute population of that SA2
- the vehicle kilometres travelled of cars within the SA2.

A double log model form (also known as an 'elasticity' model form) was fitted to the data. The model had the following functional form.

$$\log EXPOSURE = \beta_0 + \beta_1 \log POPULATION\ DENSITY + \beta_2 \log POPULATION + \beta_3 \log VKT + \varepsilon$$

The model had statistically significant coefficients (p-values of less than 1%) and an adjusted R^2 of approximately 50%. While it introduces some multi-collinearity, the inclusion of both population density and population variables significantly improved the fit of the model to the data.

Analysis of standard errors showed that the regression provides a relatively low level of accuracy for use in predictions at the individual SA2 level, with a 95% prediction interval of between 30% to 300%. However, applying this model for predicting exposure across a portfolio of SA2s across Victoria will result in a reduced 95% prediction interval, potentially down to approximately 80% - 120%.

Therefore, while there is some loss of accuracy using a regression approach compared to using emission modelling, the regression approach was considered appropriate for extrapolating the results from metropolitan Melbourne to the rest of Victoria given that:

- the model provides a reasonable fit to the data
- the SA2s from the rest of Victoria contribute less than 5% of the total avoided DALYs from each scenario
- the emission modelling is itself based on many simplifications that result in a moderate level of uncertainty in the results.

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