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PV5 Environmental parameter values

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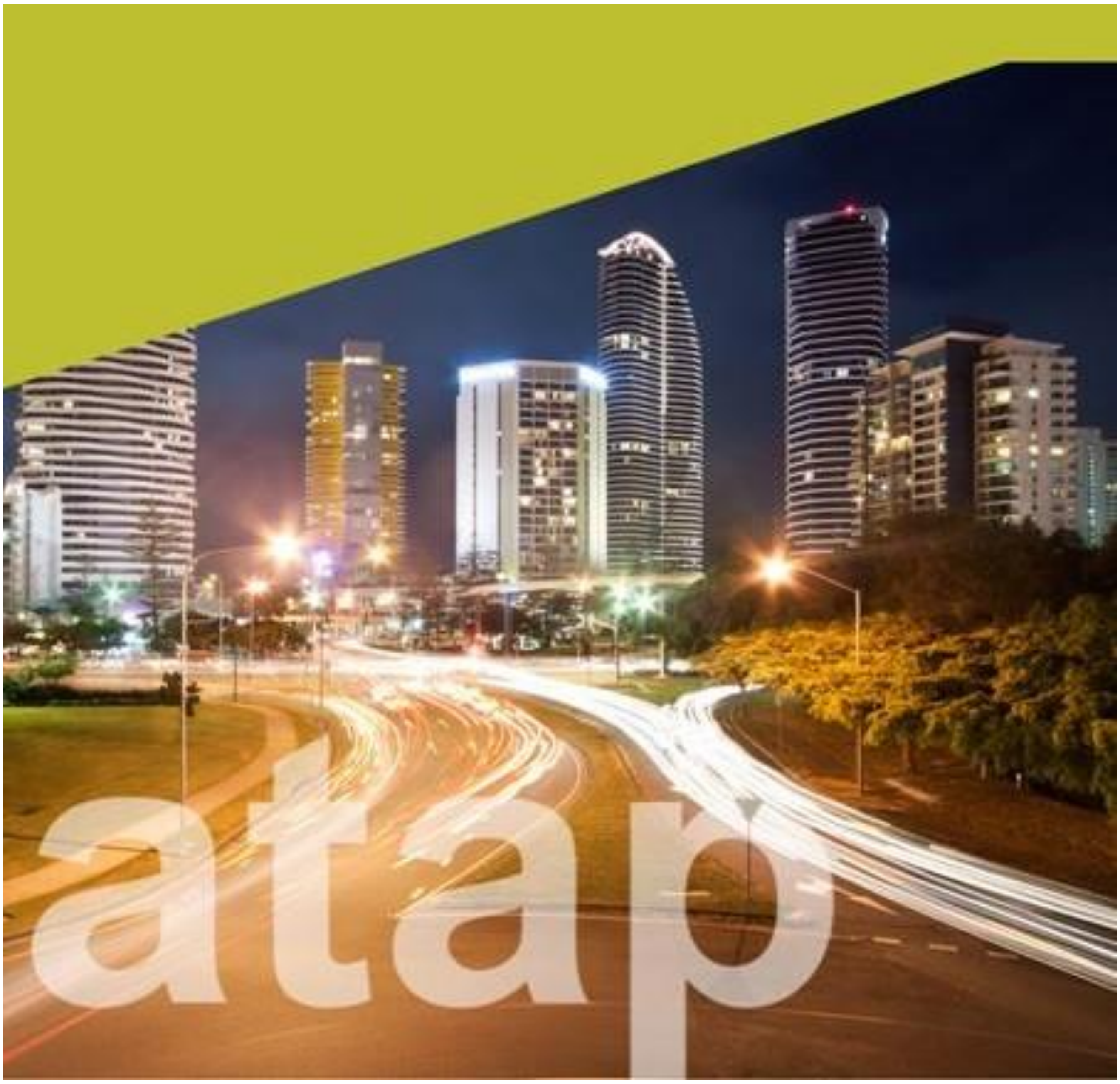

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At a glance

Environmental parameter values in the *Australian Transport Assessment and Planning Guidelines* are an important reference for facilitating a consistent approach towards quantifying the environmental costs of transport projects and initiatives in Australia.

This report provides an update to, and expansion of, existing published environmental parameter values in Australian Transport Assessment and Planning (2020) and Austroads (2014).

The update adapts the latest international values to the Australian context and indexes them to updated dollar values. It includes new parameter values for an extended list of transport modes (vehicle types and sizes) and fuel types where new baseline data is available.

The updated environmental parameter values provide the following level of detail:

- The values cover eight environmental impact categories
  - air pollution
  - greenhouse gas (GHG) emissions
  - noise pollution
  - upstream and downstream costs (with ‘well-to-tank’ emissions being a major quantifiable component)
  - soil and water pollution
  - nature and landscape
  - additional costs in urban areas (barrier effects)
  - biodiversity.
- The values are reported by urban and rural locations.
- The values cover passenger and freight transport modes, including:

  Passenger transport
  - 2-wheelers: e-bikes, scooters/mopeds, motorcycles
  - passenger cars: mini, small, medium, large, 4WD/SUV
  - buses and coaches: minibus (light commercial vehicles), urban small bus (midi bus), urban standard bus, urban articulated bus, busway bus, coach
  - passenger rail: tram, metro single-deck train, metro double-deck train, regional trains, inter-city train
  - aviation: mid-sized aircraft (Airbus, Boeing) by distance
  - water transport: local ferry, large passenger and vehicle ferry

  Freight transport
  - light commercial vehicles (vans, utes)
  - heavy commercial vehicles: rigid by payload, articulated by payload
  - freight rail: short
  - road freight: light commercial vehicles (LCVs), heavy vehicles (HVs), by size
  - freight rail: short container and bulk goods, long container and bulk goods
  - aviation: mid-sized aircraft (Airbus, Boeing) by distance
  - water transport: small vessels by distance, large vessels by distance.

- Values are provided for different energy types (as they apply by mode):
  - petrol
  - diesel
  - liquid petroleum gas (LPG)
  - compressed natural gas (CNG)
  - electricity
  - other (including aircraft and maritime vessel fuels).

Some new values reported in the update may be substantially different to previously reported values due to updated baseline data, new assumptions and updated calculations or the recalibration of the European data. Caveats and assumptions are listed to provide a context for the use of the values.

The reported environmental unit costs should be used with a significant degree of caution, as a reflection of the uncertainties involved in the estimation of environmental unit costs, especially those related to climate change. They should be interpreted as indicative rather than definitive, and their impact on decision-making should be checked through sensitivity testing.

1. Introduction

This Part of the ATAP Guidelines, Part PV5, provides environmental unit costs for use in the assessment of transport policies, plans and initiatives in Australia. The recommended values are set out in Look-Up tables.

In 2020, ATAP published an interim update for PV5 based on the figures reported in Austroads (2012) and Austroads (2014). This 2021 update supersedes each of those earlier reports.

This 2021 update adapts the latest international environmental parameter values to the Australian context and indexes these values to June 2020 dollar terms. It includes new parameter values for an extended list of transport modes (vehicle types and sizes) and fuel types.

Like the previous parameter values, this multi-modal update is based on European data (CE Delft 2019a), which provides a detailed update of European values. Key impact categories covered by the European data and adapted to the Australian context include air pollution, greenhouse gas emissions (climate change), noise pollution, 'well-to-tank' (WTT) emissions (a major quantifiable component of upstream and downstream costs) and the impact on nature and landscape (habitat).

The latest European data did not include updates for other categories previously reported in Austroads (2012 & 2014), namely soil and water pollution, biodiversity, and urban barrier effects. As such, this update provides a mix of detailed values based on the new European data and indexed values based on Austroads (2012 & 2014) and reported in Australian Transport Assessment and Planning (2020) where new baseline data was unavailable. Some new values reported in this update differ substantially from previously reported values. These differences can be accounted for by updated baseline data, new assumptions and updated calculations or the recalibration of the European data. Caveats and assumptions are listed to provide a context for the use on the parameter values.

This work represents a full update of the parameter values and provides a comprehensive set of values to replace those previously published by Australian Transport Assessment and Planning (2020) and Austroads (2014).

1.1 Caveat

It is important to note from the outset that the estimation of environmental unit costs is a complex and challenging activity, involving significant uncertainty. This is especially the case with greenhouse gas emissions, which are influenced by actions not just in Australia but also in other countries. The challenges include:

- The lack of Australian data
- Transferring and calibrating environmental cost valuations from other countries to Australia
- The existence of a number of different methodologies available to produce estimates, including based on damage costs, control/avoidance costs and social cost.

As a result, environmental unit costs, including those presented here, should be used with a significant degree of caution. They should be interpreted as indicative rather than definitive. The use of sensitivity testing to assess the robustness of transport system decisions to the environmental unit costs, especially those that are related to greenhouse gas emissions, is strongly encouraged.

2. Context

2.1 Role of environmental parameter values

Environmental impacts such as air pollution, greenhouse gas (GHG) emissions and noise pollution and biodiversity loss are by-products of transport activities that can harm the wellbeing of the society and the quality of the natural environment. Consequently, these impacts (or externalities) should be accounted for when undertaking economic appraisals, such as cost-benefit analysis (CBA), of transport projects or policies.

Transport-related environmental impacts are not direct costs to individuals or businesses but are borne by broader communities, ecosystems and some impacts, such as GHG emissions, can occur across borders. Costs accrue to either prevent damage by mitigating the impact (determined using the avoidance cost approach), or costs caused by the damage such as health costs (determined using the damage costs approach) (Austroads 2014).

Due to the lack of explicit market prices, monetising the environmental impacts of transport activities for the purpose of economic appraisals is a challenging task and outcomes vary depending on the assumptions made by individual economic appraisal practitioners.

Environmental parameter values in the *Australian Transport Assessment and Planning Guidelines* (the Guidelines) are monetised values for a suite of environmental impacts that should be assigned to a unit of transport activities. The Guidelines provide a consistent set of inputs for economic appraisals of transport projects and initiatives thereby facilitating a consistent approach for economic appraisals following the ATAP framework.

2.2 Purpose of this multi-modal update of environmental parameter values

The purpose of this update is to expand previously reported environmental externality costs. The update consists of:

- An update of values based on more recent data sources, new insights and updated methodologies (reported in CE Delft 2019a)
- Where possible, the provision of more detailed values than reported previously, i.e. for more vehicle types and sizes and fuel types (multi-modal update).

This update captures the latest data provided by CE Delft (2019a) for European countries, using additional sources where appropriate. Earlier European data (CE Delft et al. 2011) were also used as a reference to highlight key changes in the baseline data used for the Australian parameter values update.

2.3 Background

Since 2015, the Guidelines have referred users to the values in two Australian publications:

- NGTSM (2006), Volume 3, Appendix C
- Austroads (2012) — which reports indexed values from an Austroads (2003) study. It also took account of the NGTSM values, eliminating the need for the NGTSM values as a separate source.

In addition, in 2014, Austroads also released a set of environmental parameter values for use by practitioners. The Austroads (2014) work was essentially a review and major updating of Austroads (2012). It involved updated methodologies and data sources.

There have been no further significant updates of environmental parameter values for Australia since 2014, although in 2020 ATAP released an interim update reflecting the combined values provided in Austroads (2012 & 2014).

2.3.1 Austroads (2012)

Austroads (2012) reported indexed values from earlier studies published by Austroads (dating back to 2003). Values were provided for both passenger and freight transport and were reported in vehicle-kilometres (vkt), passenger-kilometres (pkm) and tonne-kilometres (tkm).

Units of measurement used in this study

- Vehicle-kilometres travelled (vkt) is a unit of measurement representing the total distance (in kilometres) travelled by a vehicle. Vkt does not consider who or what is being transported and is a valid measure for both freight and passenger transport.
- Passenger-kilometres (pkm) is a unit of measurement for passenger transport which represents the movement of one person by a given transport mode (road, rail, air, water) over one kilometre. In this study, all occupants (including the driver) of passenger cars, buses and two-wheelers are considered passengers (regardless of whether the trips are for private or commercial purposes). For rail, ferry and air transport, drivers and crew are not included in the passenger assumptions. Passenger-kilometres are calculated by using the total vehicle-kilometres travelled by a vehicle type and the average occupancy of the vehicle type.

Tonne-kilometres (tkm) is a unit of measurement of freight transport which represents the transport of one tonne of goods (including packaging and tare weights of containers) by a given transport mode (road, rail, air, water) over one kilometre. Tonne-kilometres are calculated using the laden distance travelled for work purposes and average load weight.

2.3.2 Austroads (2014)

Values reported in Austroads (2014) were a major update of the Austroads (2012) report and data set. It included a review and update of methodologies and data sources, predominantly based on a major European study (CE Delft et al. 2011). This update led to parameter values which were somewhat different to those reported in Austroads (2012), i.e. often substantially lower, with this ascribed to the different costing methodology applied as well as some changes in the evidence base.

2.3.3 Interim update (Australian Transport Assessment and Planning 2020)

Australian Transport Assessment and Planning (2020) indexed to December 2019 A$ and consolidated the values presented in Austroads (2012 & 2014). The values from the two studies are consolidated given the uncertainty around the estimation of the parameter values and different assumptions, data and methodologies used. Australian Transport Assessment and Planning (2020) lists low, mid and high values, where Austroads (2012) values are adopted as high values and Austroads (2014) values are adopted as low values. Mid values are an average between the low and high values.

2.4 Caveats

As noted in Chapter 1, estimating environmental externality values is a complex and challenging activity involving significant uncertainty. This is because environmental impact costs, such those relating to air pollution, greenhouse gas emissions, noise or electricity generation/fuel production and distribution are not directly quantifiable. These effects can be quantified by measuring the costs of the damage they cause (*damage costs*, e.g. health costs), or by estimating the cost to prevent or reduce them (*avoidance costs*, e.g. GHG mitigation), or the cost for replacing or repairing adverse impacts (*replacement costs*, e.g. repairing habitat damage).

Australian data for estimating externalities is only sporadically available, and does not yet provide adequate coverage of all the relevant environmental impact categories. As such, the previous parameter values were based on European data (CE Delft 2019a) which has used differing methodologies, data sets and new insights over the years. This makes the valuation of externalities and numerical comparison challenging (Austroads 2014). ATAP is currently undertaking work to scope the necessary work to address the lack of comprehensive Australian data.

Converting overseas (European) data into Australian values requires adjustments to be made to account for differences in exchange rates, inflation, consumer price level (or purchasing power), population density and the carbon intensity of power sources.

Although the parameter values presented in this report are based on more recent (European) data and reflect more recent knowledge, developments and methodologies compared to previous studies, the values need to be used with caution. In recognition of this caution, parameter values should be used as indicative values, and sensitivity testing should be performed when used in transport studies. To help account for this uncertainty, some typical value ranges are provided here, expressed as percentages which can be applied to mid values in order to obtain low and high values (Section 5.3).

3. Scope

This update of the environmental parameter values for use in transport projects provides updated cost values for the eight categories previously reported by ATAP (Section 0). Where updated values were not available, an indexation of the previously reported values has been undertaken, based on Austroads (2012 & 2014) which are also summarised in Australian Transport Assessment and Planning (2020).

3.1 Update of existing parameter values

The environmental parameter values are updated for the environmental impact categories, transport modes and locations listed below. This structure is the same as in Austroads (2014), i.e. there is no change to the environmental impact categories.

- Eight impact categories
  - air pollution
  - greenhouse gas (GHG) emissions
  - upstream and downstream costs (WTT emissions)
  - noise pollution
  - nature and landscape
  - soil and water pollution
  - additional costs in urban areas (barrier effects)
  - biodiversity
- Two transport modes
  - passenger transport (road, rail, air and maritime)
  - freight transport (road, rail, air and maritime)
- Two locations
  - urban
  - rural.

Table 3-1 provides a brief description of the eight environmental cost elements.

3.2 Additional modes and energy sources (vehicle classes and energy types)

The coverage of the environmental parameter values has also been expanded. More detailed values are provided for a greater number of vehicle types, differentiating between vehicle sizes, fuel types and other categories where applicable (e.g. transport distances).

The breakdown by vehicle and fuel type closely follows the structure of the key data source, CE Delft (2019a). Equivalence tables are provided in Section 4.3 to facilitate the conversion of European values into Australian values. These tables include vehicle sizes and kerb weights, emission classes, carbon intensity of electricity generation and fleet composition.

Table 3-1: Environmental cost elements

Cost element	Description
Air pollution	Health costs, building and material damage, crop losses
Greenhouse gas emissions	Long-term social and economic impacts of greenhouse gas emissions into the atmosphere
Upstream and downstream costs (well-to-tank emissions)	Indirect environmental (air pollution and greenhouse gas emissions) costs of energy generation and distribution
Noise pollution	Health, wellbeing and annoyance impacts
Nature and landscape	Impact of infrastructure on existing habitats
Soil and water pollution	Impact of run-off on water quality and soil quality
Additional costs in urban areas (barrier effects)	The barrier and separation effects of motorised traffic on pedestrians, cyclists, etc.
Biodiversity	Impact of air pollution on natural ecosystems

Source: Adapted from Austroads (2012 & 2014).

Transport modes and energy types are broken down as follows:

- Transport modes

  Passenger transport

  - 2-wheelers: e-bikes, scooters/mopeds, motorcycles
  - passenger cars: mini, small, medium, large, 4WD/SUV
  - buses and coaches: minibus (light commercial vehicles), urban small bus (midi bus), urban standard bus, urban articulated bus, busway bus, coach
  - passenger rail: tram, metro single-deck train, metro double-deck train, regional train, inter-city train
  - aviation: mid-sized aircraft (Airbus, Boeing) by distance
  - water transport: local ferry, large passenger and vehicle (RoPax) ferry

  Freight transport

  - light commercial vehicles (vans, utes)
  - heavy commercial vehicles: rigid by payload, articulated by payload
  - freight rail: short
  - road freight: light commercial vehicles (LCVs), heavy vehicles (HVs), by size
  - freight rail: short container and bulk goods, long container and bulk goods
  - aviation: mid-sized aircraft (Airbus, Boeing) by distance
  - water transport: small vessel by distance, large vessel by distance
- Energy types (as they apply by mode)
  - petrol
  - diesel
  - liquid petroleum gas (LPG)
  - compressed natural gas (CNG)
  - electricity

  - other (including aircraft and maritime vessel fuels).

3.3 Exclusions and scope limits

This update is not a major revision of methodologies or data sources. Updated and expanded analysis is limited by the available baseline European data. For example, hydrogen is an emerging transport energy source but there was no baseline data to support the development of Australian parameter values for hydrogen-powered vehicles.

The foundation for future comprehensive work leading to a major update is being addressed in a separate scoping study being carried out as well as this update.

4. Methodology

The ideal approach for estimating Australian environmental parameter values would be to base them completely on direct Australian environmental impact data — however, such data either does not currently exist or has only limited availability. In this update, Australian estimates have been inferred from data collected in other countries, adjusted appropriately to Australian dollar values.

4.1 High-level methodology

Environmental parameter values published in Austroads (2014) are predominantly based on European data published in CE Delft et al. (2011) which were adjusted to Australian conditions using a set of adjustment factors and methodologies (top-down approach).

This update applied a consistent top-down methodology using the most recent European data (CE Delft 2019a). Minor adjustments were made where required to adapt the methodology to the more detailed outputs.

As in Austroads (2014), the parameter values are provided in vehicle-kilometres as well as person-kilometres (for passenger transport) and tonne-kilometres (for freight transport). Where possible, mid-level estimates as well as plausible minimum and maximum estimates (% of mid values) are provided for sensitivity analyses.

Austroads (2014) provides **average** values in output data tables, separating urban and rural as well as passenger and freight transport. This update maintains a similar structure for the output data tables. However, considering the addition of transport modes and the refinement of the parameter values (e.g. by energy source), additional, more comprehensive tables are provided for all parameters where more detailed data (**marginal** parameter values) are available. For an overview of data availability and the difference between the average and marginal values, refer to Section 4.4 and Appendix A.

4.2 Methodological steps

As noted, a top-down methodology was adopted for this parameter update. The method used **average** and detailed **marginal** parameter values from CE Delft (2019a), using aggregated values for all 28 countries of the European Union (EU28). Values from individual countries are not used as detailed (marginal) values are only provided for EU28. Austroads (2014) also established that there was no single European country that was representative of Australia and EU28 data was a preferred basis to adapt for the Australian context.

Based on average and marginal values, the following steps are taken to adjust values, applying a refined methodology compared to that which was used in Austroads (2014):

1. Aggregation of road types: CE Delft (2019a) provides values for different types of metropolitan, urban and rural roads. These types of roads have been consolidated into urban and rural road types based on the vkt on each road type. This replicates the output structure used in Austroads (2014). Refer to Table 4-1 for details.
2. Conversion to costs per 1000 km: CE Delft (2019a) reports parameter values in Euros per vkt, pkm or tkm. However, previous Australia values were reported in Australian dollars per 1000 vkt, pkm or tkm. For consistency, the European values were converted into Euros per 1000 km as a basis for step 3.

3. Currency conversion: CE Delft (2019a) reports values in 2016 Euros which were converted to 2016 Australian dollars using exchange rates according to RBA (2020). One Australian dollar equals 0.6741 Euros (average 2016).
4. Indexation: CE Delft (2019a) reports values for a 2016 price level (2016 Euros) which were converted into a 2020 price level (June 2020 Australian dollars) to account for inflation, using the CPI factor of 1.0534 according to Australian Bureau of Statistics (2020b).
5. Adjustment for purchasing power: The parameter values were adjusted to reflect purchasing power parity between countries using data according to World Bank (2019). The price level in Australia is 14.7% above the European average (EU28).
6. Adjustment for population density: The population density in European cities is generally much higher compared to Australian cities. Population density data from 92 European cities and Australia's six largest cities (Demographia 2020) was compared and used to adjust for population density. The population density in Australian cities is about 42% compared to European cities. The study acknowledges that the population density differential is likely to be even greater in rural (inhabited) populations, however in the absence of comparable rural population density data, the population density adjustment is assumed to be equal for urban and (inhabited) rural areas.

   Where environmental impacts affect local populations, population density is an important factor in determining environmental costs. For example, more people are exposed to the impacts of air noise pollution in higher population density areas than in less dense areas. As such the environmental impact costs should be higher in more densely populated areas. Conversely, where environmental impacts are dispersed (e.g. greenhouse gases), population density is less important. Austroads (2014) applied a population density adjustment factor to every environmental impact to account for the different population densities of Australian and European cities.

   This update applies the population density adjustment to only those environmental impacts that population density is a driver of environmental costs (i.e. air pollution, the air pollution component of the WTT emissions[1] and noise). For impacts where population density does not drive costs (i.e. climate change, the greenhouse gas emissions component of WTT emissions, nature and landscape), no adjustment was made.

   As noted in Section 1, this update provides updated figures where new European baseline data was available. New baseline data were not available for the soil and water, biodiversity and urban barrier effect impacts as the (average) values presented in this report replicate the mid-point values from Austroads (2012 & 2014) as published in Australian Transport Assessment and Planning (2020). It would be reasonable to remove the population adjustment for soil and water and biodiversity impacts as they are unaffected by the presence or density of human populations. Future updates could consider removing or amending the population density adjustment for urban barrier effects where the impact of population density is uncertain.

   Adjustments for population density significantly reduce the parameter values due to the comparatively low average population density in Australian cities. ATAP continues to investigate whether the population adjustment factors are appropriate.

[1] CE Delft et al. (2019a) reports that 'The costs due to greenhouse gas emissions from WTT contribute to about 60–65% of the WTT costs. For road transport, for example, the share of climate change costs is 62%, the share of air pollution costs 38%'. This update has assumed a 62:38 climate change and air pollution cost split across all modes.

7. Aggregation of emission classes (for road vehicles only): CE Delft (2019a) states (marginal) values by vehicle emission classes (Euro 0 to Euro 6 for light vehicles and 0 to VI for heavy vehicles) for most road vehicle types. This update was unable to identify any data that precisely specified the Australian vehicle population by emissions class. In the absence of specific vehicle population data by emissions class, the age of a vehicle (i.e. when it was first registered) is a reasonable indicator of its emissions class. Marginal values have been grouped using age brackets of Australian vehicles according to Australian Bureau of Statistics (2020a) and by matching vehicle ages to the introduction of the relevant vehicle emissions standards in Australia.
8. Adjustment for vehicle occupancy and payload: As a point of difference to Austroads (2014) where an adjustment for vehicle occupancy was performed, the same vehicle occupancy or average payload was assumed in this update for the different vehicle types and sizes. This approach is considered more suitable due to the more detailed data and the difficulty of matching vehicle occupancy and payload for similar Australian vehicles (for heavy vehicles). An equivalence table is provided matching European and Australian vehicle categories (Table 4-2). Occupancy and payload figures for every vehicle type can be found in Appendix A.

In addition to the above adjustments, the carbon intensity of Australian energy production was accounted for in vehicles using electricity, i.e. electric (road) vehicles and electric trams and trains. This affects the GHG emissions component of the WTT parameter values[2]. On average, emissions from electricity generation and use in Australia are 2.83 times higher than the average of EU28 (Department of Industry, Science, Energy and Resources 2020, European Environment Agency 2020). Refer to Table 4-5 for details. The values provided in this update are adjusted to the Australian average electricity mix. However, values for individual states and territories with lower or higher carbon intensity of electricity production can also be calculated using the other conversion factors listed in Table 4-5.

4.2.1 Unit cost of greenhouse gas emissions

A final step in the methodology was to ensure the values reported here reflect the major uncertainty involved in estimating the costs of greenhouse gas emissions (see discussion on caveats in sections 1.1 and 2.4).

The unit cost of greenhouse gas emissions is expressed internationally in the units of $ per tonne of CO2-e (carbon dioxide equivalent). It is a central variable in estimating the environmental costs of greenhouse gas emissions. The value used in the most recent Australian studies (Austroads 2012 and 2014) was around A$ 60 per tonne of CO2-e (indexed to December 2019 dollars).

ATAP (2020) noted that the most recent Australian and international literature report a wide range of values for the $ per tonne of CO2-e. The range of values reflects differences in a range of factors including: costing methodology (abatement cost, damage cost, social cost); future climate scenarios; technology changes; potential future emission reduction targets. Research and debate continue on the most suitable value, and is likely to continue for years to come. The A$60 per tonne of CO2-e figure used in the most recent Australian studies appears to sit broadly in the middle of the range of values reported in the literature.

[2] CE Delft et al. (2019a) reports that ‘The costs due to greenhouse gas emissions from WTT contribute to about 60–65% of the WTT costs. For road transport, for example, the share of climate change costs is 62%, the share of air pollution costs 38%’. With limited details provided on the background data, this update has assumed a 62:38 climate change and air pollution cost split across all modes. This assumption is made acknowledging that this proportion may not hold for all vehicle or fuel types (especially for electricity generation) and therefore introduces a level of uncertainty into some of the resulting estimates.

This situation of uncertainty has not changed since ATAP (2020) was published, so a continuation of the approach used there has also been adopted here. That is, this ATAP guidance does *not* recommend a single value for practitioners to use, for a number of reasons:

- The complexity involved, given the global nature of greenhouse gas impacts
- The extensive and evolving ongoing research on the matter
- The associated high degree of uncertainty.

Instead, *ATAP recommends that practitioners use a range of values for the $ per tonne of CO2-e via sensitivity testing*. Such testing will allow practitioners to assess whether the value used for the $ per tonne of greenhouse gas emissions is a critical input to any given assessment. That is, are the final results of the assessment sensitive to the value used for the $ per tonne of CO2-e, and hence will use of the assessment results lead to a robust decision.

For illustrative purposes, the figures related to greenhouse gas emissions ('climate change' and 'WTT') reported here in Table 5-1 to Table 5-16 are based on $60 per tonne of CO2-e. This required an adjustment to the CE Delft (2019a) figures that formed the underlying basis of this guidance. With respect to $ per tonne of CO2-e, CE Delft (2019a) used a figure of € 100 per tonne of CO2-e, which equates to around A$160 per tonne of CO2-e. To ensure the values reported here continue to reflect a value of A$60 per tonne of CO2-e, an adjustment was undertaken, consisting of scaling the CE Delft 'climate change' and 'WTT' figures by the ratio 60/160 = 0.375. Given the high levels of uncertainty discussed above, this adjustment is considered suitable at this point in time.

Table 5-1 to Table 5-16 provide illustrative numbers based on A$60 per tonne of CO2-e. In cases where further sensitivity testing is desired, the figures in Table 5-1 to Table 5-16 can be scaled up or down in proportion to lower or higher $/tonne CO2-e figures. Given the high uncertainties around the $ per tonne of CO2-e, sensitivity testing over quite a wide range — say from levels of around $30 per tonne to around $200 per tonne — can often be worthwhile for analyses dealing with possible climate change impacts.

Practitioners that base their assessments on $/tonne CO2-e figures that are different to those discussed here should provide a clear explanation of the source and basis of the alternative figures they have used.

4.3 Equivalence tables

The tables in this section summarise information and data that was used to convert European to Australian parameter values or adjust values to Australian conditions.

4.3.1 Road types

Weighting factors (WFs) based on vkt on different roads in Australia were used to aggregate European road types (motorways, urban/rural roads and other roads) to Australian urban and rural categories only.

Table 4-1: Road types based on vkt

European road types and subcategories			Australian road types			
			Urban		Rural	
			Arterial roads	Local roads	National highways and arterial roads	Local roads
Metropolitan area	Motorway	A	X			
	Urban road	B		X		
	Other road	C		X		
Urban area	Motorway	D	X			
	Urban road	E		X		
Rural area	Motorway	F			X	
	Rural road	G				X
Vkt-based WF (1)			0.72	0.28	0.83	0.17
Calculation for conversion of parameter values for EU road types into parameter values for Australian urban & rural road types			= avg(A, D) * WF(Urban Arterial) + avg(B, C, E) * WF(Urban Local)		= F*WF(Rural Arterial) + G*WF (Rural Local)	

(1) Vkt-based weighting factors (WFs) are calculated based on Austroads (2015), Table C.3.1.

Source: European road types and subcategories according to CE Delft (2019a); Australian road types based on matching of urban and rural categories to roads types reported in Austroads (2015).

4.3.2 European vs Australian vehicle categories

The European vehicle categories reported in CE Delft (2019a) can be matched with Australian vehicle categories according to Table 4-2. Two different Australian classification are reported:

- vehicle classification according to Austroads 12 categories (Austroads 2019a)
- vehicle classification according to the ATAP 20 vehicle categories (Australian Transport Assessment and Planning 2016).

Table 4-2 also shows whether a vehicle type is a light or heavy vehicle and whether its function is for passenger (P) or freight (F) transport.

Table 4-2: Vehicle categories

Vehicle classes and types		Gross vehicle mass	Austroads		ATAP PV2		Vehicle type	Passenger (P) / freight transport (F)
2-wheelers	Moped/ scooter		n/a	n/a	n/a	n/a	Light	P
	Motorcycle		n/a	n/a	n/a	n/a	Light	P
	Mini		n/a	n/a	n/a	n/a	Light	P

Vehicle classes and types		Gross vehicle mass	Austroads		ATAP PV2		Vehicle type	Passenger (P) / freight transport (F)
Passenger cars	Small		1	Short vehicle	01	Small car	Light	P
	Medium		1	Short vehicle	02, 05	Medium car	Light	P
	Large		1	Short vehicle	03	Large car	Light	P
Urban bus	Midi	<15 t	3	Two axle truck	06, 07	Light/medium rigid	Light	P
	Standard	15-18 t	3, 4	Two/three axle truck	08, 09	Medium rigid/heavy bus	Heavy	P
	Artic.	>18 t	6	Three axle articulated vehicle	09	Heavy bus	Heavy	P
Coach	Standard	≤18 t	3, 4	Two/three axle truck	08, 09	Medium rigid/heavy bus	Heavy	P
	Artic.	>18 t	6	Three axle articulated vehicle	09	Heavy bus	Heavy	P
LCV	Van/ute		1, 3	Short vehicle/two axle truck	04, 06	Light/medium rigid	Light	P, F
Heavy vehicles	Rigid	<7.5 t	3	Two axle truck	06	Light rigid	Light/ heavy	F
	Rigid	7.5-12 t	3, 4	Two/three axle truck	07, 08	Medium/heavy rigid	Heavy	F
	Rigid	12-14 t	3, 4	Two/three axle truck	07, 08	Heavy rigid	Heavy	F
	Rigid	14-20 t	4	Three axle truck	08	Heavy rigid	Heavy	F
	Rigid	20-26 t	4	Three axle truck	08	Heavy rigid	Heavy	F
	Rigid	26-28 t	4	Three axle truck	08	Heavy rigid	Heavy	F
	Rigid	28-32 t	4	Three axle truck	08	Heavy rigid	Heavy	F
	Rigid	>32 t	4	Three axle truck	08	Heavy rigid	Heavy	F
	Artic.	14-20 t	7, 8	Four/five axle articulated vehicle	10,11	Four/five axle articulated	Heavy	F
	Artic.	20-28 t	7, 8	Four/five axle articulated vehicle	10,11	Four/five axle articulated	Heavy	F
	Artic.	28-34 t	9, 10	Six axle articulated vehicle/B-double	12,13	Six axle articulated/ rigid + five axle dog	Heavy	F
	Artic.	34-40 t	9, 10	Six axle articulated vehicle/B-double	12,13	Six axle articulated/ rigid + five axle dog	Heavy	F

Vehicle classes and types		Gross vehicle mass	Austroads		ATAP PV2		Vehicle type	Passenger (P) / freight transport (F)
	Artic.	40-50 t	10-12	Double/triple road train	14-20	B-double/twin steer + five axle dog/A-double/B-triple, A-B combination/ A-triple/double B-double	Heavy	F
	Artic.	50-60 t	10-12	Double/triple road train	14-20	B-double/twin steer + five axle dog/A-double/B-triple, A-B combination/ A-triple/double B-double	Heavy	F

Source: Description of vehicle classes, vehicle types and gross vehicle masses (GVMs) according to CE Delft (2019a); Austroads vehicle descriptions according to Austroads (2019a); ATAP PV2 vehicle descriptions according to Australian Transport Assessment and Planning (2016).

4.3.3 Vehicle ages and emission classes

CE Delft (2019a) reports values for European vehicle emission classes Euro 0 to 6 (light vehicles) and Euro 0 to VI (heavy vehicles). This update was unable to identify data that precisely specified the Australian vehicle population by emissions class. In the absence of specific vehicle population data by emissions class, the age of a vehicle (i.e. when it was first registered) is a reasonable indicator of its emissions class.

An approximate matching of Australian vehicles was undertaken based on the timing of the introduction of the relevant vehicle emissions standards in Australia and the age categories and number of vehicles registered in each age category.

Australia has adopted vehicle emissions standards through the Australian Design Rules (ADR79 for light vehicles and ADR80 for heavy vehicles) progressively between 1995 and November 2016. Table 4-3 identifies when the vehicle emissions standards were introduced in Australia.

Table 4-3: Introduction of emission standards in Australia

Standard	Phase-in periods (after which emission standard is mandatory for all new vehicles)[3]		
	Light petrol and LPG vehicles	Light diesel vehicles	Heavy vehicles
Euro (I)	n/a	n/a	1 Jan 1995 to 1 Jan 1996 (ADR70/00)
Euro 2 (II)	1 Jan 2003 to 1 Jan 2004 (ADR79/00)	1 Jan 2002 to 1 Jan 2003 (ADR79/00)	n/a
Euro 3 (III)	1 Jan 2005 to 1 Jan 2006 (ADR79/01)	n/a	1 Jan 2002 to 1 Jan 2003 (ADR80/00)
Euro 4 (IV)	A July 2008 to 1 July 2010 (ADR79/02)	1 Jan 2006 to Jan 2007 (ADR79/02)	1 Jan 2007 to 1 Jan 2008 (ADR80/02)
Euro 5 (V)	1 Nov 2013 to 1 Nov 2016 (ADR79/03)	1 Nov 2013 to 1 Nov 2016 (ADR79/03)	1 Jan 2010 to Jan 2011 (ADR80/03)
Euro 6 (VI)[4]	n/a	n/a	n/a

Source: Department of Infrastructure, Transport, Cities and Regional Development (2020a & 2020b).

Table 4-4 shows the approximate matching of vehicle emission classes to vehicle age brackets and the estimated vehicle populations within each class.

Table 4-4: Emission classes and vehicle age brackets

Vehicle distributions based on ABS data (1)	Light vehicles (2)	Heavy vehicles (2)	2-wheelers	Passenger cars	LCVs	HVs	Buses & coaches
Pre-2004	Euro 1-2	Euro I-II	22.98%	21.27%	24.13%	35.94%	28.75%
2005-2009	Euro 3	Euro III	23.48%	21.82%	20.00%	20.20%	22.35%
2010-2014	Euro 4	Euro IV	25.78%	27.56%	25.36%	19.37%	25.33%
2015-2019	Euro 5	Euro V	27.76%	29.35%	30.50%	24.49%	23.57%
Total			100%	100%	100%	100%	100%

(1) Vehicles on register obtained from Australian Bureau of Statistics (2020a).

(2) Approximate matching

Source: Estimation based on Australian Bureau of Statistics (2020a).

[3] In each case, the first date applies to vehicle models first produced on or after that date, with all new vehicles required to comply by the second date.

[4] The Australian Government's Ministerial Forum on Vehicle Emissions is currently undertaking a review to consider whether Australia should adopt the Euro 6 standards for light vehicles and Euro VI standards for heavy vehicles (https://www.infrastructure.gov.au/vehicles/environment/emission/index.aspx).

It is worth noting that some new imported vehicles sold in Australia may meet and comply with higher emission standards than defined by the applicable Australian standard (beyond-compliant vehicles). For example, some Euro 6 (VI) vehicles are being sold in Australia, despite it not yet being a national standard. Users should note that this could lead to an overestimation of the externality costs in this update, in particular for air pollution, whereas climate change and WTT emissions parameter values are rather similar for the Euro 4 (IV), 5 (V), and 6 (VI) emission classes.

The vehicle matching did not include Euro 0 light and heavy vehicles as these older vehicles represent a very small proportion of the current vehicle fleet (around 1-1.5% by some estimates (Cosgrove, D, 5 November 2020, email, personal communications)) and represent an even smaller proportion of vkt. This omission, while relatively insignificant, would partially offset the potential overestimation of externality costs from beyond-compliant vehicles.

4.3.4 Electricity emissions factors for end users

The carbon intensity of electricity in Australia is higher on average and in most states and territories compared to the EU28 average. This is an important distinction for the conversion of WTT parameter values for electric passenger cars and rail vehicles. Table 4-5 provides conversion factors as ratios between the EU28 and Australian states and territories.

Table 4-5 shows the carbon intensity of electricity in Europe (EU28), Australia and each state and territory. It also provides the Australian average conversion factors and those for each state and territory. The WTT parameter values for electric road and rail vehicles as provided in CE Delft (2019a) are adjusted using the conversion factor ratio between the average Australian vs EU28 ratio (i.e. 2.83, highlighted in red in Table 4-5).

Table 4-5: Carbon intensity of electricity for EU28 and Australia, in $kgCO_2/kWh$ (2020)

State or territory	Scope 2: electricity generation	Scope 3: electricity distribution	Full cycle	Conversion to EU28	Conversion to Australian average
EU28 (1)	0.28	0.03	0.31	1.00	n/a
Australia	0.78	0.09	0.87	2.83	1.00
NSW & ACT	0.81	0.09	0.89	2.89	1.02
Vic	0.98	0.11	1.09	3.54	1.25
Qld	0.81	0.12	0.93	3.02	1.07
SA	0.43	0.09	0.52	1.69	0.60
WA (2)	0.68	0.02	0.70	2.27	0.80
Tas	0.15	0.02	0.17	0.55	0.20
NT	0.62	0.07	0.70	2.27	0.80

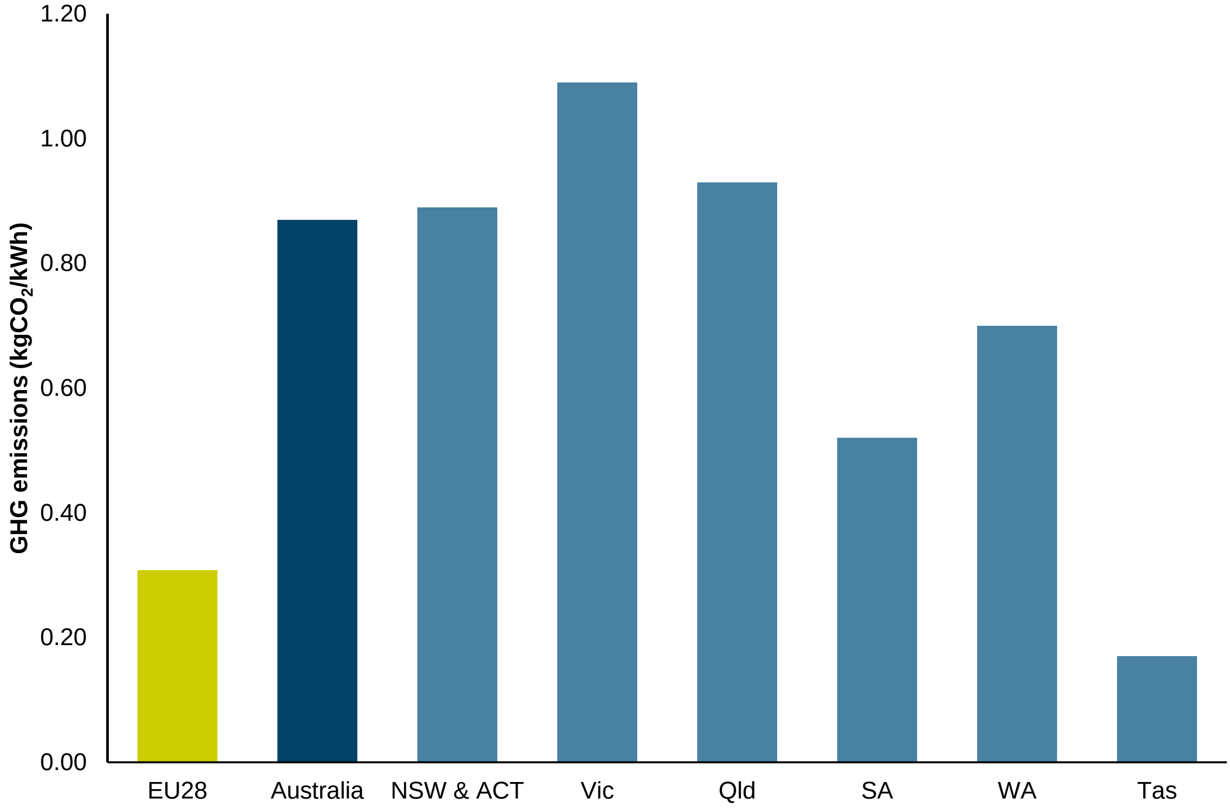
(1) Scope 2 values for 2020 are extrapolated based on 1990 to 2017 values for EU28 electricity generation. The 2017 value is 294.21 gCO_2/kWh. The scope 3 value for Europe is estimated based on the average Australian scope 2/scope 3 ratio.

(2) South-west interconnected system only.

Source: Australian data sourced from the Department of Industry, Science, Energy and Resources (2020), Table 44. EU28 data sourced from European Environment Agency (2020).

In estimating parameter values for individual states and territories, the respective values should be multiplied by the ratio between the Australian average and individual states and territories (i.e. the factor in the right column of Table 4-5). A graphic representation of European and Australian emissions from electricity generation is shown in Figure 4-1.

Figure 4-1: Carbon intensity of electricity for EU28 and Australia



Source: Australian data sourced from the Department of Industry, Science, Energy and Resources (2020), Table 44. EU28 data sourced from European Environment Agency (2020).

A note of caution on the WTT parameter values for electric vehicles

Upstream (WTT) parameter values for electric vehicles, derived by direct scaling of the values provided in CE Delft (2019a), using the average conversion factor in Table 4-5, are higher than expected (based on what is known regarding average modal efficiencies for Australia) – for both electric passenger road vehicles and electric passenger trains. Some reasons for this discrepancy could include the CE Delft 2019a results possibly having:

- European power stations generally sited relatively close to population centres meaning higher air pollution costs
- different sources and methods used to calculate the baseline rail and road vehicle emission factors, and upstream emission costs, that are key inputs to the WTT parameter values
- differences in rail vehicle types – there is insufficient information available to fully explore the underlying data used to generate electric rail vehicle emission factors
- somewhat overestimated WTT air pollution costs even for the more highly populated European conditions, let alone the more sparsely populated Australian situation.

This, combined with further approximations introduced by the carbon cost scaling discussed in section 4.2.1, makes the baseline WTT parameter values (as presented in Tables 5-5 to 5-16) very approximate and likely to be generally less reliable than the Climate Change parameter values (e.g. will tend to overestimate Australian WTT impacts for electric vehicles). For reference, some alternative WTT parameter evaluations are provided (based on Australian data) in Tables 5-21 and 5-22.

A vehicle’s well-to-wheel (WTW) GHG emissions are a combination of upstream (WTT) and exhaust emissions or tank-to-wheel (TTW) emissions as captured by the climate change impact parameter value.

For example, for a medium-sized petrol-power passenger car, the resulting WTW parameter values for aggregate emission output (across the air pollution, climate change and WTT emissions categories based on CE Delft 2019a) would be:

$12.07/1000 km (from the TTW climate change parameter estimate, see Table 5-2), plus

$3.54/1000 km (from the WTT parameter estimate), plus $2.54/1000 km (for the air pollution parameter value); giving a total of

$18.15/1000 km (with $15.61/1000 km for the climate change plus WTT parameters).

For an electric vehicle (based on CE Delft 2019a, again referring to Table 5-2), the total for aggregate emission output would be $17.72/1000 km (with $17.03/1000 km from the WTT cost parameter only) . As there are no exhaust emissions from electric vehicles the ‘climate change’ category costs (from direct energy use) are zero.

In this example from Table 5-2, the WTW aggregate emissions parameter values are similar for the electric vehicle when compared with the petrol vehicle.

Research conducted by the University of Queensland suggested that electric vehicles should generate around 40% fewer lifecycle emissions compared with a similar size internal-combustion-engine vehicle (based on the Australian average emissions intensity of electricity generation) (Whitehead 2019). It should therefore be expected that the relevant unit costs would be of a similar relative magnitude to this.

Further complicating the situation is that CE Delft (2019a) bases its electric vehicle unit costs on a very efficient vehicle type (i.e. using 11.4 kWh/100 km according to CE Delft 2019b). This is below most electric vehicles available for sale in Australia (which tend to range from around 12 to 22 kWh/100 km according to Electric Vehicle Council 2020). If unit values were based on an electric vehicle within this range, the CE Delft 2019a methodology would generate even higher WTT unit costs for electric vehicles.

While electric vehicles only currently represent a very small proportion of Australia’s road passenger vehicle fleet, this is likely to grow over time, and since most urban passenger rail is already electric, this WTT anomaly could cause some externality estimation issues.

For comparison, using the Table 5-22 values (derived from Australia data) for a medium-sized passenger car, the resulting WTW parameter estimate for aggregate emission output from the petrol-powered vehicle totals $33.1/1000 km (with $20.7/1000 km for the climate change plus WTT parameters).

When compared with the electric car estimates therein (Table 5-22), the WTW total is 15.2/1000 km (with $14.2/1000 km for the climate change plus WTT parameters). These values (with the EV at around 30% lower than the petrol-powered result for climate change plus WTT parameters, and over 50% lower for aggregate emission output) are more consistent with the Australian results of Whitehead 2019 and Smit 2020).

The ATAP Steering Committee will further consider options to re-adjust the WTT parameter values for electric road and rail vehicles.

4.4 Overview of latest European data sets

Detailed EU28 data that can be used to estimate Australian values to the new level of detail (i.e. for different vehicles types, sizes and fuel types) are only available for a selection of impact categories as shown in Table 4-6. Specifically, detailed values for air pollution, greenhouse gas emissions, and WTT emissions were available. Noise pollution is also available but to a more detailed level. Updated values for the nature and landscape category were also available, although only at a high (average) level. Other values were not updated. This level of detail is reflected in the new Australian values in this update.

Detailed values were only available as marginal values opposed to average values (which were reported in Austroads 2014). Marginal costs represent the external costs caused by an additional transport activity (CE Delft 2019a), such as the noise costs of adding an additional vehicle to an already busy road. A fuller discussion of average vs marginal costs is provided in Appendix A.

For air pollution, greenhouse gas emissions and WTT emissions, marginal and average values are usually fairly equivalent, which means that the new (detailed) marginal values can be used in exchange for average ones. However, for noise emissions, the marginal values are often different compared to the average values, with this depending on the population density, density of traffic flow and time of day (CE Delft 2019a). Some studies suggest that marginal noise costs are only about 30-60% of the average costs. For details about the differences between average and marginal costs, see Appendix A or refer to CE Delft (2019a, Section 2).

Table 4-6: Level of detail of the parameter value update by impact category

Impact category	Update based on detailed marginal parameter values	Update based on average values	Simple update based on previous Austroads values	Marginal vs. average values comparability	Comments
Air pollution	X	X		Same	Update based on CE Delft (2019a) data
Greenhouse gases (climate change)	X	X		Same	Update based on CE Delft (2019a) data
Noise	X	X		Different	Update based on CE Delft (2019a) data; marginal difference from average ones
WTT emissions	X	X		Same	Update based on CE Delft (2019a) data
Soil and water			X	Not applicable (no marginal values available)-	No CE Delft (2019a) data; simple update based on Australian Transport Assessment and Planning (2020)
Nature and landscape		X		Not applicable (no marginal values available)-	CE Delft (2019a) data only available for broader categories like the current set of parameter values
Urban barrier effects			X	Not applicable (no marginal values available)-	No CE Delft (2019a) data; simple update based on Australian Transport Assessment and Planning (2020)
Biodiversity			X	Not applicable (no marginal values available)-	No CE Delft (2019a) data; simple update based on Australian Transport Assessment and Planning (2020)

Note: Data from other jurisdictions such as North America (e.g. Victoria Transport Policy Institute 2016) are available, but is not as comprehensive as the data in CE Delft (2019a), and is relatively outdated. Using an alternative data source was therefore not considered suitable.

5. Parameter values unit cost tables

This section provides the results of this multi-modal environmental parameter values update. Sections 5.1 and 5.2 produce the updated average and marginal environmental parameter cost values for passenger and freight transport and all eight impact categories that can be used by practitioners.

Transport projects and initiatives will not necessarily have impacts across all environmental impact categories. Practitioners should refer to the *Australian Transport Assessment and Planning (ATAP) T2 Cost Benefit Analysis Guidelines* (ATAP 2018) for guidance on identifying the benefits and costs of a transport project or initiative. This guidance will help practitioners apply appropriate judgement to identify the right environmental parameters in the context of specific projects or initiatives being assessed. In a CBA, environmental externalities can be expressed as positive or negative benefits of project or initiative options as compared with their base case.

Except for noise impacts, average and marginal cost values are assumed to be the same.

Section 5.3 provides guidance and tools to account for a level of uncertainty in the values provided and Section 5.4 describes how or why the updated values differ from previous sets of parameter values. It is recommended that practitioners undertake sensitivity testing to assess the robustness of their assessment results, and subsequent decisions, for variations in the environmental unit costs reflected by this range.

It is recommended that practitioners use the unit cost values presented in Sections 5.1 and 5.2 as the mid-point values for the primary central analysis of project assessments and CBAs. Section 5.3 provides some guidance on possible low and high adjustment percentages to be used for sensitivity testing.

5.1 Passenger transport

5.1.1 Passenger transport – urban

Table 5-1: Average parameter values in A$ per 1000 vkt/pkm – passenger transport – urban (June 2020 dollars)

Passenger transport – urban	2-wheelers		Passenger cars		Buses & coaches				Rail	
	Motorcycle		Car		Mini-bus		Bus		Passenger train	
	vkt	pkm	vkt	pkm	vkt	pkm	vkt	pkm	vkt	pkm
Air pollution	8.74	8.32	8.48	5.27	24.15	4.83	106.36	5.55	8.49	0.06
Climate change	6.3	6	12.74	7.92	18.52	3.71	58.82	3.07	0	0
WTT emissions	2.78	2.64	3.24	2.01	4.15	0.83	15.61	0.82	1368	10.33
Noise	70.19	66.85	6.65	4.13	8.48	1.7	47.11	2.48	606.7	10.3
Soil and water	2.86	2.72	2.86	1.87	3.84	0.77	33.47	3.54	46.47	0.79
Nature and landscape	0.59	0.56	1.51	0.94	1.53	0.31	3.49	0.18	84.09	1.43
Urban effects	5.02	4.78	5.02	3.15	4.43	0.89	14.77	1.58	46.47	0.79
Biodiversity	0.69	0.66	0.69	0.39	0.3	0.06	5.51	0.59	0.58	0.01

Notes:

For the impact categories of air pollution, climate change, WTT emissions, noise: all values are based on data from CE Delft (2019a), following the methodology described in Section 4.

For the impact category of nature and landscape: following Austroads (2014), urban values are 10% of rural values, whereby rural values are based on data from CE Delft (2019a), following the methodology described in Section 4.

For the impact categories of soil and water, urban effects, biodiversity: values are indexed based on Australian Transport Assessment and Planning (2020); vehicle occupancy rates and payloads according to CE Delft (2019a) were used where applicable (refer to Appendix C).

Table 5-2: Marginal parameter values for air pollution, climate change and WTT emissions in A$ per 1000 vkt/pkm – passenger transport – urban (June 2020 dollars)

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	pkm	vkt	pkm	vkt	pkm	
2-wheelers	e-bike	Electric	0.03	0.03	0.00	0.00	0.42	0.40	Assumed to be 20% of electric motorcycle[5]
	Scooter/moped	Petrol	6.32	6.02	4.14	3.95	1.22	1.16	4-stroke only[6]
		Electric	0.17	0.16	0.00	0.00	2.10	2.00	Equals motorcycle
	Motorcycle	Petrol	8.11	7.73	7.85	7.48	2.30	2.19	4-stroke only
		Electric	0.17	0.16	0.00	0.00	2.10	2.00	
Passenger cars	Mini	Petrol	0.62	0.39	9.14	5.80	2.68	1.70	Euro 4-6 only, hence low value
		LPG	0.54	0.35	8.77	5.57	1.46	0.93	Based on small petrol vs. LPG ratio
		Diesel	13.53	8.6	8.01	5.09	1.45	0.92	
		Hybrid	0.92	0.58	5.64	3.59	1.55	0.98	
		Electric	0.69	0.44	0.00	0.00	17.03	10.82	
	Small	Petrol	2.49	1.58	10.34	6.57	3.03	1.93	
		LPG	2.18	1.38	9.93	6.31	1.66	1.05	
		Diesel	18.6	11.82	10.85	6.89	1.97	1.25	
		Hybrid	0.92	0.59	5.63	3.58	1.54	0.98	
		Electric	0.69	0.44	0.00	0.00	17.03	10.82	
	Medium	Petrol	2.54	1.61	12.07	7.67	3.54	2.25	

[5] Baseline dataset did not provide unique values for e-bikes. The update had not identified an alternative reference for e-bike emissions values. In recognition that e-bike emissions would be small, the values were assumed to be 20% of those generated by an electric motorbike.

[6] Scooter/moped refers to on-road registered vehicles (e.g. Vespas) and emissions values are assumed to be equivalent to motorbikes. Practitioners should use the e-bike values for micro-mobility small scooters (e.g. electric-powered kick scooters such as Lime scooters).

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	pkm	vkt	pkm	vkt	pkm	
		LPG	2.22	1.41	11.59	7.36	1.94	1.23	Based on small petrol vs. LPG ratio
		Diesel	18.71	11.88	12.96	8.24	2.35	1.49	
		Hybrid	0.92	0.59	5.63	3.58	1.54	0.98	Equals small & large
		Electric	0.69	0.44	0.00	0.00	17.03	10.82	
	Large	Petrol	2.56	1.63	15.04	9.56	4.41	2.80	
		LPG	2.24	1.42	14.45	9.18	2.41	1.53	Based on small petrol vs. LPG ratio
		Diesel	18.82	11.95	15.08	9.58	2.73	1.74	
		Hybrid	0.92	0.59	5.63	3.58	1.54	0.98	
		Electric	0.69	0.44	0.00	0.00	17.03	10.82	
	SUV/4WD	Petrol	2.55	1.62	13.55	8.61	3.98	2.52	Average medium & large
		LPG	2.23	1.42	13.02	8.27	2.17	1.38	Based on small petrol vs. LPG ratio
		Diesel	18.76	11.92	14.02	8.91	2.54	1.61	Average medium & large
		Hybrid	0.92	0.59	5.63	3.58	1.54	0.98	Equals small & large
		Electric	0.69	0.44	0.00	0.00	17.03	10.82	Equals electric
Buses and coaches	Mini-bus	Petrol	3.02	0.6	15.69	3.14	4.60	0.92	Estimation based on goods LCVs; assumed avg. occupancy of 5 passengers per vehicle
		Diesel	33.08	6.62	17.64	3.53	3.54	0.71	Estimation based on goods LCVs; assumed avg. occupancy of 5 passengers per vehicle
		Electric	0.69	0.14	0.00	0.00	48.95	9.79	Estimation based on goods LCVs; assumed avg. occupancy of 5 passengers per vehicle
	Small urban bus <15 t	Diesel	82.86	6.14	39.98	2.96	7.25	0.54	Midi bus
		Electric	2.07	0.15	0.00	0.00	94.09	6.97	Midi bus
		Diesel	107.22	6.35	51.16	3.03	9.27	0.55	Standard bus

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	pkm	vkt	pkm	vkt	pkm	
	Medium urban bus 15-18 t	CNG	237.01	14.04	103.33	6.12	16.51	0.98	Standard bus; Euro I, II, III, IV only, hence high value
		Electric	2.07	0.12	0.00	0.00	135.90	8.05	Standard bus
	Large urban bus >18 t	Diesel	130.88	6.46	63.95	3.16	11.59	0.57	Articulated bus
		Electric	2.07	0.1	0.00	0.00	167.27	8.26	Articulated bus
	Busway	Diesel	130.88	6.46	63.95	3.16	11.59	0.57	Equals articulated urban bus
		Electric	2.07	0.1	0.00	0.00	167.27	8.26	Equals articulated urban bus
	Coach	Diesel	115.6	7.66	52.13	3.45	9.45	0.63	Standard coach
Rail	Tram	Electric	6.5	0.13	0.00	0.00	628.76	12.57	Urban only
	Metro single-decker	Electric	13	0.05	0.00	0.00	1257.53	5.03	Urban only
	Metro double-decker	Electric	13	0.03	0.00	0.00	1257.53	2.79	Urban only
	Inter-city	Diesel	446.35	5.13	117.59	1.35	84.17	0.97	Without exhaust gas recirculation (EGR), or selective catalytic reduction (SCR)
	Regional	Diesel	472.93	15.26	153.31	4.95	42.09	1.36	Without exhaust gas recirculation (EGR), or selective catalytic reduction (SCR)

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4. In some cases, additional sources were used as noted in the comments column.

Climate change parameter values equal zero for (battery) electric vehicles as they do not produce tailpipe emissions, but their emissions are accounted for in upstream electricity generation activities.

CE Delft (2019a) provides a single unit cost value for (battery) electric vehicles, regardless of the size. Logically, different vehicle sizes would provide different WTT emission values. However, a lack of more detailed data means that the WTT emission values are the same for all passenger cars regardless of size. Due to the small number of electric vehicles in today's fleets, the impact of using a single parameter value for all electric passenger cars is negligible.

Table 5-3: Marginal parameter values for noise pollution in A$ per 1000 vkt/pkm – passenger transport – urban (June 2020 dollars)

Vehicle category	Vehicle type	Time of day	Traffic density	Noise	
				vkt	pkm
2-wheelers	Motorcycle	Day	Dense	44.45	40.41
			Thin	108.13	98.30
		Night	Dense	80.97	73.60
			Thin	196.94	179.03
Passenger cars		Day	Dense	4.09	2.55
			Thin	9.93	6.21
		Night	Dense	7.44	4.65
			Thin	18.10	11.31
Buses and coaches	Mini-bus	Day	Dense	9.13	1.83
			Thin	22.20	4.44
		Night	Dense	16.62	3.32
			Thin	40.43	8.09
	Bus	Day	Dense	49.21	2.91
			Thin	119.70	7.09
		Night	Dense	89.63	5.31
			Thin	218.02	12.91
	Coach	Day	Dense	28.75	1.52
			Thin	69.94	3.71
		Night	Dense	52.37	2.78
			Thin	127.38	6.75

Vehicle category	Vehicle type	Time of day	Traffic density	Noise	
				vkt	pkm
Rail	Inter-regional passenger train	Day	Dense	374.15	2.82
			Thin	614.01	4.64
		Night	Dense	681.31	5.14
			Thin	1118.10	8.44

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4.

Marginal noise parameter values for air and water transport are not available.

Dense and thin traffic density refers to heavy and light traffic conditions. Users should interpret this broadly in terms of typical road and rail traffic conditions in Australia. As a guide, the Guide to Pavement Technology Part 2: Pavement Structural Design (Austroads 2019b) *classified roads with high traffic volumes as those with greater than 2000 vehicle per lane per day.*

5.1.2 Passenger transport – rural

Table 5-4: Average parameter values in A$ per 1000 vkt/pkm – passenger transport – rural (June 2020 dollars)

Passenger transport – rural	2-wheelers		Passenger car		Buses & coaches				Rail	
	Motorcycle		Car		Mini-bus		Bus		Passenger train	
	vkt	pkm	vkt	pkm	vkt	pkm	vkt	pkm	vkt	pkm
Air pollution	0.09	0.08	0.08	0.05	0	0	0	0	3.5	0.06
Climate change	6.30	6.00	12.74	7.92	18.52	3.71	58.82	3.07	135.32	2.30
WTT emissions	2.78	2.64	3.24	2.01	4.15	0.83	15.61	0.82	35.13	0.60
Noise	0.7	0.67	0.07	0.04	0.08	0.02	0.47	0.02	60.67	1.03
Soil and water	0.3	0.28	0.3	0.2	0.01	0	0.39	0.04	0.58	0.01
Nature and landscape	5.89	5.61	15.06	9.35	15.25	3.05	34.95	1.82	840.9	14.28
Urban effects	-	-	-	-	-	-	-	-	-	-
Biodiversity	0	0	0	0	0	0	0	0	0	0

Notes:

For the impact categories of air pollution, climate change, WTT emissions, noise, nature and landscape: all values are based on data from CE Delft (2019a), following the methodology described in Section 4.

Rural air pollution values are estimated based on urban air pollution values, applying the following factors based on Austroads (2014): 0% for buses and coaches, 1% for 2-wheelers, passenger cars, and rail.

Rural climate change and WTT emission values are the same as urban ones.

Rural noise values are estimated based on urban noise values, applying the following factors: 1% for 2-wheelers, passenger cars, buses and coaches, and 10% for rail.

For the impact categories of soil and water, biodiversity: the values are indexed based on Australian Transport Assessment and Planning (2020); vehicle occupancy rates and payloads according to CE Delft (2019a) were used where applicable (refer to Appendix C).

The impact category of urban effect is not applicable. Urban values can be used for rural towns.

Table 5-5: Marginal parameter values for air pollution, climate change and WTT emissions in A$ per 1000 vkt/pkm – passenger transport – rural (June 2020 dollars)

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	pkm	vkt	pkm	vkt	pkm	
2-Wheelers	e-Bike	Electric	0.03	0.03	0.00	0.00	0.42	0.40	Assumed to be 20% of electric motorcycle[7]
	Scooter/ moped	Petrol	3.17	3.02	4.14	3.95	1.22	1.16	4-stroke only[8]
		Electric	0.17	0.17	0.00	0.00	2.10	2.00	Equals motorcycle
	Motorcycle	Petrol	4.84	4.61	6.29	5.99	1.85	1.76	4-stroke only
		Electric	0.17	0.17	0.00	0.00	2.10	2.00	
Passenger Cars	Mini	Petrol	0.23	0.15	7.60	4.83	2.23	1.42	Euro 4-6 only, hence low value
		LPG	0.2	0.13	7.18	4.56	1.20	0.76	Based on small petrol vs. LPG ratio
		Diesel	7.17	4.55	6.96	4.43	1.26	0.80	
		Hybrid	0.86	0.54	4.64	2.94	1.27	0.81	
		Electric	0.7	0.45	0.00	0.00	17.03	10.82	
	Small	Petrol	1.66	1.06	8.82	5.60	2.59	1.64	
		LPG	1.44	0.91	8.34	5.30	1.39	0.89	
		Diesel	8.94	5.68	9.33	5.93	1.69	1.07	
		Hybrid	0.86	0.54	4.65	2.96	1.28	0.81	
		Electric	0.7	0.45	0.00	0.00	17.03	10.82	
	Medium	Petrol	1.7	1.08	10.48	6.66	3.07	1.95	

[7] The baseline dataset did not provide unique values for e-bikes. The study had not identified an alternative reference for e-bike emission values. In recognition that e-bike emissions would be small, the values were assumed to be 20% of those generated by an electric motorbike.

[8] Scooter/moped refers to on-road registered vehicles (e.g. Vespa) and emission values are assumed to be equivalent to motorbikes. Practitioners should use the e-bike values for micro-mobility small scooters (e.g. electric-powered kick scooters such as Lime scooters).

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	pkm	vkt	pkm	vkt	pkm	
		LPG	1.47	0.93	9.90	6.29	1.65	1.05	Based on small petrol vs. LPG ratio
		Diesel	9	5.72	10.91	6.93	1.98	1.26	
		Hybrid	0.86	0.54	4.65	2.96	1.28	0.81	Equals small & large
		Electric	0.7	0.45	0.00	0.00	17.03	10.82	
	Large	Petrol	1.71	1.08	13.22	8.40	3.88	2.46	
		LPG	1.48	0.94	12.50	7.94	2.09	1.32	Based on small petrol vs. LPG ratio
		Diesel	9.06	5.76	12.50	7.94	2.27	1.44	
		Hybrid	0.86	0.54	4.65	2.96	1.28	0.81	
		Electric	0.7	0.45	0.00	0.00	17.03	10.82	
	SUV/4WD	Petrol	1.7	1.08	11.85	7.53	3.48	2.21	Average medium & large
		LPG	1.47	0.94	11.20	7.11	1.87	1.19	Based on small petrol vs. LPG ratio
		Diesel	9.03	5.74	11.70	7.44	2.12	1.35	Average medium & large
		Hybrid	0.86	0.54	4.65	2.96	1.28	0.81	Equals small & large
		Electric	0.7	0.45	0.00	0.00	17.03	10.82	Equals electric
Buses and Coaches	Mini-Bus	Petrol	1.97	0.39	12.54	2.51	3.68	0.74	Estimation based on goods LCVs; assumed avg. 5 pax. vehicle occupancy
		Diesel	16.02	3.2	12.96	2.59	2.60	0.52	Estimation based on goods LCVs; assumed avg. 5 pax. vehicle occupancy
		Electric	0.7	0.14	0.00	0.00	48.95	9.79	Estimation based on goods LCVs; assumed avg. 5 pax. vehicle occupancy
	Small Urban Bus <15t	Diesel	36.7	2.72	35.43	2.63	6.42	0.48	Midi bus
		Electric	1.5	0.11	0.00	0.00	94.09	6.97	Midi bus
		Diesel	47.29	2.8	45.69	2.71	8.28	0.49	Standard bus

<table>
<tr><th rowspan="2">Vehicle category</th><th rowspan="2">Vehicle type</th><th rowspan="2">Fuel type</th><th colspan="2">Air pollution</th><th colspan="2">Climate change</th><th colspan="2">WTT emissions</th><th rowspan="2">Comments or clarifications based on CE Delft (2019a)</th></tr>
<tr><th>vkt</th><th>pkm</th><th>vkt</th><th>pkm</th><th>vkt</th><th>pkm</th></tr>
<tr><td rowspan="7"></td><td rowspan="2">Medium Urban Bus 15-18t</td><td>CNG</td><td>135.39</td><td>8.02</td><td>102.58</td><td>6.08</td><td>16.47</td><td>0.98</td><td>Standard bus; Euro I, II, III, IV only, hence high value</td></tr>
<tr><td>Electric</td><td>1.5</td><td>0.09</td><td>0.00</td><td>0.00</td><td>135.90</td><td>8.05</td><td>Standard bus</td></tr>
<tr><td rowspan="2">Large Urban Bus >18t</td><td>Diesel</td><td>57.65</td><td>2.85</td><td>58.65</td><td>2.90</td><td>10.63</td><td>0.53</td><td>Articulated bus</td></tr>
<tr><td>Electric</td><td>1.5</td><td>0.07</td><td>0.00</td><td>0.00</td><td>167.27</td><td>8.26</td><td>Articulated bus</td></tr>
<tr><td rowspan="2">Busway</td><td>Diesel</td><td>57.65</td><td>2.85</td><td>58.65</td><td>2.90</td><td>10.63</td><td>0.53</td><td>Equals articulated urban bus</td></tr>
<tr><td>Electric</td><td>1.5</td><td>0.07</td><td>0.00</td><td>0.00</td><td>167.27</td><td>8.26</td><td>Equals articulated urban bus</td></tr>
<tr><td>Coach</td><td>Diesel</td><td>48.46</td><td>3.21</td><td>45.03</td><td>2.99</td><td>8.16</td><td>0.54</td><td>Standard coach</td></tr>
<tr><td rowspan="5">Rail</td><td>Tram</td><td>Electric</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Not applicable, urban only</td></tr>
<tr><td>Metro Single-Decker</td><td>Electric</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Not applicable, urban only</td></tr>
<tr><td>Metro Double-Decker</td><td>Electric</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>Not applicable, urban only</td></tr>
<tr><td>Inter-City</td><td>Diesel</td><td>262.09</td><td>3.01</td><td>117.59</td><td>1.35</td><td>84.17</td><td>0.97</td><td>Without exhaust gas recirculation (EGR), or selective catalytic reduction (SCR)</td></tr>
<tr><td>Regional</td><td>Diesel</td><td>277.24</td><td>8.94</td><td>153.31</td><td>4.95</td><td>42.09</td><td>1.36</td><td>Without exhaust gas recirculation (EGR), or selective catalytic reduction (SCR)</td></tr>
</table>

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4. In some cases, additional sources were used as noted in the comments column.

Climate change parameter values equal zero for (battery) electric vehicles as they do not produce tailpipe emissions, but their emissions are accounted for in upstream electricity generation activities.

CE Delft (2019a) provides a single unit cost value for (battery) electric vehicles, regardless of the size. Logically, different vehicle sizes would provide different WTT emission values. However, a lack of more detailed data means that the WTT emission values are the same for all passenger cars regardless of size. Due to the small number of electric vehicles in today's fleets, the impact of using a single parameter value for all electric passenger cars is negligible.

Table 5-6: Marginal parameter values for noise pollution in A$ per 1000 vkt/pkm – passenger transport – rural (June 2020 dollars)

Vehicle category	Vehicle type	Time of day	Traffic density	Noise	
				vkt	pkm
2-wheelers	Motorcycle	Day	Dense	0.52	0.47
			Thin	1.12	1.01
		Night	Dense	0.92	0.83
			Thin	1.99	1.81
Passenger car		Day	Dense	0.04	0.03
			Thin	0.10	0.06
		Night	Dense	0.09	0.05
			Thin	0.18	0.11
Bus	Mini-bus	Day	Dense	0.10	0.02
			Thin	0.23	0.05
		Night	Dense	0.19	0.04
			Thin	0.41	0.08
	Bus	Day	Dense	0.56	0.03
			Thin	1.22	0.07
		Night	Dense	1.02	0.06
			Thin	2.22	0.13
	Coach	Day	Dense	0.33	0.02
			Thin	0.71	0.04
		Night	Dense	0.60	0.03
			Thin	1.30	0.07

Vehicle category	Vehicle type	Time of day	Traffic density	Noise	
				vkt	pkm
Rail	Inter-regional passenger train	Day	Dense	28.17	0.21
			Thin	46.62	0.35
		Night	Dense	51.48	0.39
			Thin	84.83	0.64

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4.

Marginal noise parameter values for air and water transport are not available.

Dense and thin traffic density refers to heavy and light traffic conditions. Users should interpret this broadly in terms of typical road and rail traffic conditions in Australia. As a guide, the Guide to Pavement Technology Part 2: Pavement Structural Design (Austroads 2019b) *classified roads with high traffic volumes as those with greater than 2000 vehicle per lane per day.*

5.1.3 Passenger transport – other

Table 5-7: Average parameter values in A$ per 1000 vkt/pkm – passenger transport – other (June 2020 dollars)

Passenger transport – other	Aviation		Water transport	
	vkt	pkm	vkt	pkm
Air pollution	303.96	2.29	9488	99.86
Climate change	1650.21	12.41	349.50	3.68
WTT emissions	630.26	4.74	132.00	1.39
Noise	237.85	1.79		
Soil and water				
Nature and landscape	15.57	0.12		
Urban effects				
Biodiversity				

Notes:

There is no differentiation between urban and rural values for aviation and water transport.

For passenger water transport, values are based on Transport for NSW (2016) and represent the average Sydney ferry fleet. The WTT emission value is estimated based on the climate change value as no explicit WTT emission values were available in Transport for NSW (2016).

For the impact categories of air pollution, climate change, WTT emissions, noise, nature and landscape: all values are based on data from CE Delft (2019a), following the methodology described in Section 4.

For the impact categories of soil and water, urban effects, biodiversity: data is not available or not applicable.

Table 5-8: Marginal parameter values for air pollution, climate change and WTT emissions in A$ per 1000 vkt/pkm – passenger transport – other (June 2020 dollars)

Vehicle category	Vehicle type	Fuel type	Distance	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a), and additional sources used
				vkt	pkm	vkt	pkm	vkt	pkm	
Aviation	Small aircraft	Other	500 km	425.14	7.29	1714.43	29.40	725.07	12.44	Estimation based on Qantas (2020a) in relation to data from CE Delft (2019a)
	Medium-small aircraft	Other	1000 km	317.41	4.03	1671.17	21.21	634.32	8.05	Estimation based on Qantas (2020a) in relation to data from CE Delft (2019a)
	Medium aircraft (low emissions)	Other	1500 km	197.76	1.33	1535.40	10.31	512.67	3.44	
		Other	3000 km	130.76	0.88	1434.49	9.63	575.01	3.86	
	Medium aircraft (high emissions)	Other	1500 km	221.59	1.89	1720.44	14.65	574.46	4.89	
		Other	3000 km	146.52	1.25	1607.36	13.69	644.31	5.49	
Water transport	Local ferry	Diesel		9487.93	99.86	349.36	3.68	131.94	1.39	WTT values estimated based on climate change values reported in Transport for NSW (2016); the values represent the average Sydney ferry fleet
	Large (RoPax) ferry[9]	Diesel	100 km	305 801	579.17	38999	73.86	14729	27.90	
		Diesel	500 km	213 400	404.17	19633	37.19	7415	14.04	

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4. In some cases, additional sources were used, as noted in the comments column.

Aircraft types considered: small = Bombardier Dash 8 Q400, medium-small = Fokker 100, medium low emission = Airbus A320, medium high emission = Boeing 737.

[9] Large ferry values based on a RoPax ferry (25 500 gt). RoPax ferries have both passenger and vehicle carrying capacities. The Spirit of Tasmania vessels that service the Melbourne-Devonport route are examples of RoPax used in Australia. Pkm unit values may be overstated where RoPax vessels also carry freight (as the Spirit of Tasmania vessels do).

5.2 Freight Transport

5.2.1 Freight transport – urban

Table 5-9: Average parameter values in A$ per 1000 vkt/tkm – freight transport – urban (June 2020 dollars)

Freight transport – urban	LCV (vans and utes)		HVs		Rail (freight trains)	
	vkt	tkm	vkt	tkm	vkt	tkm
Air pollution	24.15	34.88	69.92	5.67	2276.71	5.06
Climate change	18.52	26.75	43.56	3.53	756.07	1.68
WTT emissions	4.15	6.00	13.06	1.06	320.70	0.71
Noise	8.48	12.24	43.72	8.48	1500.28	3.33
Soil and water	3.84	5.55	30.52	2.76	523.27	0.49
Nature and landscape	1.53	2.22	4.08	0.33	188.27	0.42
Urban effects	4.43	6.4	22.64	1.97	313.96	0.3
Biodiversity	0.3	0.43	10.83	0.98	10.47	0.01

Notes:

For the impact categories of air pollution, climate change, WTT emissions, noise: all values are based on data from CE Delft (2019a), following the methodology described in Section 4.

For the impact category of nature and landscape: following Austroads (2014), urban values are 10% of rural values, whereby rural values are based on data from CE Delft (2019a), following the methodology described in Section 4

For the impact categories of soil and water, urban effects, biodiversity: the values are indexed based on Australian Transport Assessment and Planning (2020); vehicle occupancy rates and payloads according to CE Delft (2019a) were used where applicable (refer to Appendix C).

Table 5-10: Marginal parameter values for air pollution, climate change and WTT emissions in A$ per 1000 vkt/tkm – freight transport – urban (June 2020 dollars)

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	tkm	vkt	tkm	vkt	tkm	
LCV	All: van, ute	Petrol	3.02	4.36	15.69	22.65	4.60	6.65	
		Diesel	33.08	47.78	17.64	25.48	3.54	5.12	
		Electric	0.69	0.99	0.00	0.00	48.95	70.69	
Heavy vehicles	Rigid <7.5 t	Diesel	48.91	59.3	23.49	28.49	4.26	5.16	
		Electric	2.07	2.51	0.00	0.00	94.09	114.08	Estimation based on small electric bus; assumed load of equivalent diesel HV
	Rigid 7.5-12 t	Diesel	69.32	33.06	31.89	15.21	5.78	2.76	
		Electric	2.07	0.99	0.00	0.00	135.90	64.83	Estimation based on medium electric bus; assumed load of equivalent diesel HV
	Rigid 12-14 t	Diesel	74.6	19.24	33.08	8.53	5.99	1.55	
	Rigid 14-20 t	Diesel	91.47	22.26	38.93	9.48	7.05	1.72	
	Rigid 20-26 t	Diesel	112.27	13.22	47.47	5.59	8.60	1.01	
	Rigid 26-28 t	Diesel	114.93	9.67	50.10	4.22	9.08	0.77	
	Rigid 28-32 t	Diesel	130.47	8.92	57.80	3.95	10.47	0.72	
	Rigid >32 t	Diesel	132.79	7.94	57.24	3.42	10.37	0.62	
	Artic. 14 - 20 t	Diesel	84.57	11.89	37.42	5.26	6.78	0.95	
	Artic. 20 - 28 t	Diesel	109	12.56	47.56	5.48	8.62	0.99	
	Artic. 28 - 34 t	Diesel	113.44	7.75	50.51	3.45	9.15	0.63	
	Artic. 34 - 40 t	Diesel	131.43	7.86	57.27	3.43	10.38	0.62	
	Artic. 40 - 50 t	Diesel	143.98	7.38	63.95	3.28	11.59	0.59	
	Artic. 50 - 60 t	Diesel	169.24	7.59	77.31	3.47	14.01	0.63	

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	tkm	vkt	tkm	vkt	tkm	
Rail	Short container	Diesel	2644.42	5.29	794.50	1.06	219.68	0.16	
	Short bulk	Diesel	2647.49	3.53	823.42	0.59	227.68	0.14	
	Long container	Diesel	2655.5	1.9	694.05	0.50	191.91	0.38	
	Long bulk	Diesel	2657.96	1.66	712.31	0.45	196.96	0.26	

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4. In some cases, additional sources were used as noted in the comments column.

Climate change parameter values equal zero for (battery) electric vehicles as they do not produce tailpipe emissions, but their emissions are accounted for in upstream electricity generation activities.

Table 5-11: Marginal parameter values for noise pollution in A$ per 1000 vkt/tkm – freight transport – urban (June 2020 dollars)

Vehicle category	Vehicle type	Time of day	Traffic density	Noise	
				vkt	tkm
LCV		Day	Dense	9.13	13.18
			Thin	22.20	32.06
		Night	Dense	16.62	24.01
			Thin	40.43	58.40
Heavy vehicles	HV 3.5-7.5 t	Day	Dense	29.90	8.05
			Thin	72.73	19.58
		Night	Dense	54.45	14.66
			Thin	132.45	35.66
	HV 7.5-16 t	Day	Dense	42.74	3.97
			Thin	103.98	9.66
		Night	Dense	77.86	7.23
			Thin	189.38	17.59
	HV 16-32 t	Day	Dense	47.98	3.03
			Thin	116.72	7.36
		Night	Dense	87.40	5.51
			Thin	212.58	13.40
	HV >32 t	Day	Dense	53.78	3.22
			Thin	130.83	7.83
		Night	Dense	97.96	5.86
			Thin	238.27	14.25

Vehicle category	Vehicle type	Time of day	Traffic density	Noise	
				vkt	tkm
Rail	Freight train	Day	Dense	418.16	0.80
			Thin	569.19	1.09
		Night	Dense	761.59	1.45
			Thin	1249.62	2.38

Notes:

Marginal noise parameter values for air and water transport are not available.

Dense and thin traffic density refers to heavy and light traffic conditions. Users should interpret this broadly in terms of typical road and rail traffic conditions in Australia. As a guide, the Guide to Pavement Technology Part 2: Pavement Structural Design (Austroads 2019b) *classified roads with high traffic volumes as those with greater than 2000 vehicle per lane per day.*

5.2.2 Freight transport – rural

Table 5-12: Average parameter values in A$ per 1000 vkt/tkm – freight transport – rural (June 2020 dollars)

Freight transport – rural	LCVs (vans and utes)		HVs		Rail (freight trains)	
	vkt	tkm	vkt	tkm	vkt	tkm
Air pollution	0	0	6.99	0.57	22.77	0.05
Climate change	18.52	26.75	43.56	3.53	756.07	1.68
WTT emissions	4.15	6.00	13.06	1.06	320.70	0.71
Noise	0.08	0.12	0.44	0.08	150.03	0.33
Soil and water	0.01	0.01	10.83	0.98	10.47	0.01
Nature and landscape	15.25	22.18	40.8	3.31	1882.73	4.18
Urban effects	-	-	-	-	-	-
Biodiversity	0	0	31.5	2.86	209.31	0.2

Notes:

For the impact categories of air pollution, climate change, WTT emissions, noise, nature and landscape: all values are based on data from CE Delft (2019a), following the methodology described in Section 4.

Rural air pollution values are estimated based on urban air pollution values, applying the following factors based on Austroads (2014): 0% for LCVs, 1% for rail, 10% for HVs.

Rural climate change and WTT emission values are the same as urban ones.

Rural noise values are estimated based on urban noise values, applying the following factors: 1% for 2-wheelers, passenger cars, buses and coaches, and 10% for rail.

For the impact categories of soil and water, biodiversity: the values are indexed based on Australian Transport Assessment and Planning (2020); vehicle occupancy rates and payloads according to CE Delft (2019a) were used where applicable (refer to Appendix C).

The impact category of urban effect is not applicable. Urban values can be used for rural towns.

Table 5-13: Marginal parameter values for air pollution, climate change and WTT emissions in A$ per 1000 vkt/tkm – freight transport – rural (June 2020 dollars)

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	tkm	vkt	tkm	vkt	tkm	
Light	All: van, ute	Petrol	1.97	2.84	12.54	18.11	3.68	5.31	
		Diesel	16.02	23.14	12.96	18.73	2.60	3.76	
		Electric	0.7	1.02	0.00	0.00	48.95	70.69	
Heavy	Rigid <7.5 t	Diesel	25.2	30.55	20.00	24.24	3.62	4.39	
		Electric	1.5	1.81	0.00	0.00	94.09	114.08	Estimation based on small electric bus; assumed load of equivalent diesel HV
	Rigid 7.5-12 t	Diesel	34.03	16.23	28.52	13.60	5.17	2.46	
		Electric	1.5	0.71	0.00	0.00	135.90	64.83	Estimation based on medium electric bus; assumed load of equivalent diesel HV
	Rigid 12-14 t	Diesel	35.85	9.25	30.36	7.83	5.50	1.42	
	Rigid 14-20 t	Diesel	42.6	10.37	35.67	8.68	6.46	1.57	
	Rigid 20-26 t	Diesel	51.66	6.08	43.63	5.14	7.91	0.93	
	Rigid 26-28 t	Diesel	52.49	4.42	46.47	3.91	8.42	0.71	
	Rigid 28-32 t	Diesel	60.06	4.11	53.97	3.69	9.78	0.67	
	Rigid >32 t	Diesel	60.54	3.62	52.82	3.16	9.57	0.57	
	Artic. 14 - 20 t	Diesel	38.49	5.41	34.46	4.85	6.24	0.88	
	Artic. 20 - 28 t	Diesel	49.34	5.69	44.14	5.09	8.00	0.92	
	Artic. 28 - 34 t	Diesel	51.07	3.49	46.78	3.20	8.48	0.58	
	Artic. 34 - 40 t	Diesel	58.96	3.53	52.93	3.17	9.59	0.57	
	Artic. 40 - 50 t	Diesel	64.5	3.31	59.01	3.03	10.69	0.55	
	Artic. 50 - 60 t	Diesel	75.2	3.37	70.38	3.16	12.75	0.57	

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a)
			vkt	tkm	vkt	tkm	vkt	tkm	
Rail	Short container	Diesel	1406.51	2.81	794.50	1.06	219.68	0.16	
	Short bulk	Diesel	1409.59	1.88	823.42	0.59	227.68	0.14	
	Long container	Diesel	1417.59	1.01	694.05	0.50	191.91	0.38	
	Long bulk	Diesel	1420.05	0.89	712.31	0.45	196.96	0.26	

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4. In some cases, additional sources were used as noted in the comments column.

Climate change parameter values equal zero for (battery) electric vehicles as they do not produce tailpipe emissions, but their emissions are accounted for in upstream electricity generation activities.

Table 5-14: Marginal parameter values for noise pollution in A$ per 1000 vkt/tkm –freight transport – rural (June 2020 dollars)

Vehicle category	Vehicle type	Time of day	Traffic density	Noise	
				vkt	tkm
LCV		Day	Dense	0.10	0.15
			Thin	0.23	0.33
		Night	Dense	0.19	0.27
			Thin	0.41	0.60
Heavy vehicles	HV 3.5-7.5 t	Day	Dense	0.34	0.09
			Thin	0.74	0.20
		Night	Dense	0.62	0.17
			Thin	1.35	0.36
	HV 7.5-16 t	Day	Dense	0.48	0.04
			Thin	1.06	0.10
		Night	Dense	0.88	0.08
			Thin	1.92	0.18
	HV 16-32 t	Day	Dense	0.54	0.03
			Thin	1.19	0.07
		Night	Dense	0.99	0.06
			Thin	2.16	0.14
	HV >32 t	Day	Dense	0.61	0.04
			Thin	1.33	0.08
		Night	Dense	1.11	0.07
			Thin	2.42	0.14

Vehicle category	Vehicle type	Time of day	Traffic density	Noise	
				vkt	tkm
Rail	Freight train	Day	Dense	28.81	0.05
			Thin	47.44	0.09
		Night	Dense	52.45	0.10
			Thin	86.42	0.16

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4.

Marginal noise parameter values for air and water transport are not available.

Dense and thin traffic density refers to heavy and light traffic conditions. Users should interpret this broadly in terms of typical road and rail traffic conditions in Australia. As a guide, the Guide to Pavement Technology Part 2: Pavement Structural Design (Austroads 2019b) *classified roads with high traffic volumes as those with greater than 2000 vehicle per lane per day.*

5.2.3 Freight transport – other

Table 5-15: Average parameter values in A$ per 1000 vkt/tkm – freight transport – other (June 2020 dollars)

Freight transport – other	Aviation		Water transport	
	vkt	tkm	vkt	tkm
Air pollution	303.96	10.45	510 199	7.94
Climate change	1650.21	56.71	6889.50	1.08
WTT emissions	630.26	21.66	25641.00	0.40
Noise	237.85	8.17		
Soil and water				
Nature and landscape	15.57	0.53		
Urban effects				
Biodiversity				

Notes:

There is no differentiation between urban and rural values for aviation and water transport.

For the impact categories of air pollution, climate change, WTT emissions, noise, nature and landscape: all values are based on data from CE Delft (2019a), following the methodology described in Section 4.

For the impact categories of soil and water, urban effects, biodiversity: data is not available or not applicable.

Table 5-16: Marginal parameter values for air pollution, climate change and WTT emissions in A$ per 1000 vkt/tkm – freight transport – other (June 2020 dollars)

Vehicle category	Vehicle type	Fuel type	Distance	Air pollution		Climate change		WTT emissions		Comments or clarifications based on CE Delft (2019a), and additional sources used
				vkt	tkm	vkt	tkm	vkt	tkm	
Aviation	Small aircraft	Other	1000 km	317.41	31.74	626.69	62.67	237.87	23.79	Estimation based on Qantas Freight (2020) in relation to data from CE Delft (2019a); payloads based on Air Charter Service (2020)
	Medium aircraft	Other	1500 km	221.59	11.5	645.17	33.47	215.42	11.18	Payloads based on Air Charter Service (2020)
		Other	3000 km	146.52	7.6	602.76	31.27	241.62	12.54	Payloads based on Air Charter Service (2020)
Water transport (maritime)	Small container vessel	Other	500 km	436401	18.18	20614.92	0.86	7785.42	0.33	Average tier 0, 1, 2
		Other	3000 km	187890	7.83	11326.78	0.47	4277.67	0.18	Average tier 0, 1, 2
	Small bulk vessel	Other	500 km	151628	10.11	6021.00	0.40	2273.91	0.15	Average tier 0, 1, 2
		Other	3000 km	845677	7.35	4339.97	0.29	1638.99	0.11	Average tier 0, 1, 2
	Large container vessel	Other	500 km	446437	3.88	31165.31	0.27	11769.89	0.10	Average tier 0, 1, 2
		Other	3000 km	373313	3.62	24525.00	0.21	9262.13	0.08	Average tier 0, 1, 2
	Large bulk vessel	Other	500 km	184348	1.79	14671.83	0.14	5541.05	0.05	Average tier 0, 1, 2
		Other	3000 km	317.41	31.74	626.69	62.67	237.87	23.79	Average tier 0, 1, 2

Notes:

All values are based on data from CE Delft (2019a), following the methodology described in Section 4. In some cases, additional sources were used, which are mentioned in the comments column.

Aircraft types considered: small = BAE146-300QT, medium high = Boeing B737-300F.

5.3 Confidence levels

Section 2.4 noted that estimating the costs of environmental externalities is complex and can lead to a significant degree of uncertainty in the values presented. To account for such uncertainty, practitioners are encouraged to use value ranges in their environmental evaluations of transport projects and initiatives.

The *Handbook on the External Costs of Transport* (CE Delft 2019a) does not provide low or high estimates for the parameter values. However, Australian Transport Assessment and Planning (2020) provides value ranges (low and high estimates) based on Austroads (2012 & 2014) values.

In this update, parameter values presented in Sections 5.1 and 5.2 represent a central, or mid-point estimate. Table 5-17 to Table 5-20 provide low and high estimate percentages which can be applied to the central parameter values to obtain low and high parameter values. The low and high percentages refer to the relative difference between low and mid values as well as mid and high values for all eight impact categories as reported in Austroads (2014) and in Australian Transport Assessment and Planning (2020).

Low and high estimates are provided for passenger cars, buses and passenger rail (Table 5-17 and Table 5-18), LCV, HV and freight rail (Table 5-19 and Table 5-20)[10].

Due to the lack of confidence levels for the parameter values, it is recommended to always test the sensitivity of the results when used in individual road or transport projects. This may provide a greater insight into what effect changes in parameter values have in particular circumstances or environments.

Table 5-17: Passenger transport – low estimates (mid-value = 100%)

Passenger transport – low estimates	Urban			Rural		
	Passenger cars	Buses	Rail	Passenger cars	Buses	Rail
Air pollution	97%	71%	71%	67%	67%	67%
Climate change	88%	88%	88%	88%	88%	88%
WTT emissions	70%	55%	55%	100%	55%	55%
Noise	86%	80%	80%	86%	80%	80%
Soil and water	95%	71%	71%	100%	60%	60%
Nature and landscape	100%	100%	100%	100%	100%	100%
Urban effects	59%	62%	62%	100%	100%	100%
Biodiversity	97%	71%	71%	67%	67%	67%

[10] Australian Transport Assessment and Planning (2020) does not provide value ranges for 2-wheelers, air and water transport.

Table 5-18: Passenger transport – high estimates (mid-value = 100%)

Passenger transport – high estimates	Urban			Rural		
	Passenger cars	Buses	Rail	Passenger cars	Buses	Rail
Air pollution	102%	111%	111%	100%	100%	100%
Climate change	112%	112%	112%	112%	112%	112%
WTT emissions	127%	141%	141%	127%	141%	141%
Noise	114%	120%	120%	114%	120%	120%
Soil and water	102%	111%	111%	100%	100%	100%
Nature and landscape	380%	471%	471%	353%	463%	463%
Urban effects	141%	137%	137%	100%	100%	100%
Biodiversity	102%	111%	111%	100%	100%	100%

Table 5-19: Freight transport – low estimates (mid-value = 100%)

Freight transport – low estimates	Urban			Rural		
	LCV	HV	Rail	LCV	HV	Rail
Air pollution	74%	49%	49%	100%	52%	52%
Climate change	93%	50%	50%	93%	50%	50%
WTT emissions	70%	67%	67%	100%	67%	67%
Noise	71%	87%	87%	71%	87%	87%
Soil and water	74%	33%	33%	77%	50%	50%
Nature and landscape	100%	100%	100%	100%	100%	100%
Urban effects	59%	50%	50%	100%	100%	100%
Biodiversity	74%	49%	49%	100%	52%	52%

Table 5-20: Freight transport – high estimates (mid-value = 100%)

Freight transport – high estimates	Urban			Rural		
	LCV	HV	Rail	LCV	HV	Rail
Air pollution	165%	122%	122%	100%	122%	122%
Climate change	105%	175%	175%	105%	175%	175%
WTT emissions	139%	133%	133%	139%	138%	138%
Noise	129%	112%	112%	112%	112%	112%
Soil and water	164%	122%	122%	177%	122%	122%
Nature and landscape	193%	205%	205%	185%	200%	200%
Urban effects	141%	150%	150%	100%	100%	100%
Biodiversity	165%	122%	122%	100%	122%	122%

5.4 Comparison to previous studies

The sections below summarise major differences in parameter values in the underlying data sources, namely CE Delft et al. (2011) and CE Delft (2019a), which translates into differences in previous Australian parameter values (i.e. Austroads 2012 & 2014) compared to this update. The differences noted should be considered as a reminder to use the values with care, considering aspects such as changes of scope, new estimation methodologies and data sources which cause the differences for Australian values between this and previous reports.

5.4.1 Air pollution

The average air pollution costs are slightly higher, but generally on a similar level compared to the air pollution costs reported in CE Delft et al. (2011), which was the basis for the values reported in Austroads (2014). However, air pollution costs for light commercial vehicles have increased in CE Delft (2019a) due to better transport activity data. A direct comparison of data in CE Delft et al. (2011) and CE Delft (2019a) shows that air pollution parameter values for rail and passenger air travel have also increased.

5.4.2 Greenhouse gas emission (climate change)

The average cost for greenhouse gas emissions (climate change) in this update differ from Austroads (2014) due partly to the use of a different unit cost factor for carbon emissions. Austroads (2014) values were based on the low scenario of CE Delft et al. (2011) (25€ per tonne CO_2 equivalent, approx. A$37), whereas CE Delft (2019a) uses a mid-value of 100€ per tonne CO_2 equivalent (approx. A$150-160). As discussed in section 4.2.1, the CE Delft (2019a) values have been adjusted to reflect an indicative central value of A$60 per tonne of CO2-e, compatible with the approach of Australian Transport Assessment and Planning (2020).

5.4.3 Well-to-tank emissions

CE Delft (2019a) states that the data base for the WTT emissions is completely new. For road transport, higher cost factors are compensated by lower emission factors, whereas for rail and aviation, both cost and emission factors are higher. However, overall, average WTT parameter values are on a similar level compared to Austroads (2014).

Like air pollution costs, average costs for WTT emissions in CE Delft (2019a) are on a similar level to CE Delft et al. (2011), although they are slightly higher on average. However, rail WTT emission costs have dropped, which could be due to the increased decarbonisation of electricity (used to power electric trains). As mentioned previously, for electric vehicles the translation of these CE Delft (2019a) European factors to Australian ones is very approximate – and may overestimate WTT impacts (see Table 5-21 for comparison results based on Australian data).

5.4.4 Noise

Average noise costs in CE Delft (2019a) are substantially higher than in CE Delft et al. (2011) (by factors of 2 to 6 times for different vehicle classes, with motorcycle being the highest). This change is reflected in the values in this update. The following factors are considered to play a role:

- higher valuation of the cost of noise, in particular noise annoyance

- updated noise maps, reflecting increased urbanisation, i.e. more people being exposed to higher noise levels
- better correction for incomplete noise maps.

Noise costs for rail and air travel are also higher due to different underlying assumptions and a change of scope.

5.4.5 Nature and Landscape

Comparing CE Delft (2019a) to CE Delft et al. (2011), parameter values for most transport modes are on a similar level. However, the costs for air travel have dropped significantly, which may be due to a change of scope (only 33 European airports are considered in CE Delft (2019a).

5.4.6 Other parameter values

CE Delft (2019a) did not provide updates for the soil and water pollution, urban barrier effects and biodiversity categories. Values provided in this update are therefore based on CE Delft et al. (2011) data, adapted for Australia and indexed to June 2020.

5.5 Comparison with alternative Australian sources

This section provides some alternative numbers, based on Australian studies, as a base against which the numbers in section 5.1 and 5.2 can be broadly compared.

As discussed at several points in this report, the estimation of environmental externality values is a complex and difficult task, with any results generally being very approximate and involving significant levels of uncertainty. The cost values derived for such environmental impacts will tend to vary significantly from study to study. The tables given in Section 5.3 provide an indication of some typical variation levels in the literature values for the various cost categories.

Not only should any central parameter values (such as given in this report) be used with suitable caution (i.e. acknowledging their uncertainty and only generally *indicative* nature), it is also recommended that appropriate sensitivity testing (around those central values) be conducted, especially whenever the results of a project assessment are heavily reliant on the exact level of any particular impact parameters.

This update of the environmental parameter values has been based on a European study (CE Delft 2019a), chosen due to its comprehensive coverage of the relevant impact categories, and generally transparent methodologies. However, this means not only dealing with the uncertainty inherent to the original estimation of these European parameter values, but also extra ambiguity around translating those values into Australian costings, and reservations over how applicable some overseas cost inputs are to Australian conditions.

Since no similarly comprehensive study (as CE Delft 2019a) yet exists for Australian externality costings, ATAP is undertaking a scoping study to investigate further developing environmental parameter values based on Australian data sources. Though no fully comprehensive such data-set is currently available for Australia, a number of recent environmental studies — including Department of Infrastructure, Transport, Regional Development and Communications (2020a, 2020b) *Vehicle Emission Standards for Cleaner Air*, Marsden Jacob Associates & Pacific Environment (2016, 2018), Department of the Environment and Energy (2018) *Better fuel for cleaner air*, and Smit 2020) — provide some Australian-based data, allowing reasonable quantification attempts for at least a few of the impact categories.

As an example of what future work in this area might look like, Table 5-21 and Table 5-22 are presented for urban passenger transport. They provide some interim/provisional estimates, for a sample of the emission-based parameter values, using Australian source data. These values can be contrasted with the adjusted European-sourced values appearing in respective Table 5-1 and Table 5-2.

When choosing suitable value ranges for sensitivity testing, the tables of Section 5.3 can provide some guide, and comparisons between these particular results obtained from two differing methodologies (values in Table 5-21 and Table 5-22 contrasted with Tables 5-1 and 5-2) can give some further indication of the inherent variation underlying such evaluation processes.

The Climate change (and WTT) parameter estimates in Table 5-21 and Table 5-22 are derived using a central estimate for domestic carbon avoidance costs of A$60 per tonne of CO_2-equivalent (for large-scale abatement), the same value used to estimate the equivalent entries in Table 5-1 and Table 5-2.

For the transport modes looked at (urban passenger) here, the provisional estimates based on Australian data (Table 5-21 and Table 5-22) are generally higher than the European-based numbers (Table 5-1 and Table 5-2). The comparative difference is more significant for air pollution than for both Climate change from direct vehicle emissions, and for upstream 'Well-to-tank' emissions due to vehicles' energy use. Overall, however, given the considerable uncertainties discussed earlier, the results from the two sources could be considered to be of a similar comparative order of magnitude.

Table 5-21: Alternate average parameter values in A$ per 1000 vkt/pkm – passenger transport – urban (June 2020 dollars)

Passenger transport – urban	2-wheelers		Passenger cars		Buses & coaches				Rail	
	Motorcycle		Car		Mini-bus		Bus		Electric passenger train	
	vkt	pkm	vkt	pkm	vkt	pkm	vkt	pkm	vkt	pkm
Air pollution	18.4	17.5	14.9	9.9	41.7	11.9	121.6	13.5	20.0	0.1
Climate change	8.8	8.4	15.6	10.4	23.4	6.7	54.0	6.0	0	0
WTT emissions	2.8	2.7	5.3	3.6	8.0	2.3	14.3	1.6	1750.0	8.8

Notes:

For the impact category of Air pollution (noxious emissions directly from transport vehicles), estimates are primarily based on Bureau of Infrastructure and Transport Research Economics (BITRE) analysis (pers.com. D Cosgrove) performed for Department of Infrastructure, Transport, Regional Development and Communications (2020a, 2020b) regulation impact statements on the benefits of tighter vehicle emission standards in Australia ('Vehicle Emission Standards for Cleaner Air'); using results from cost of air pollution modelling, performed for Australian capital cities (Marsden Jacob Associates & Pacific Environment 2016, 2018) as part of reviews of Australian fuel quality standards (Department of the Environment and Energy 2018, 'Better fuel for cleaner air'). Values will tend to fall over time whenever stricter vehicle emission standards are enacted in Australia, or under a significant electrification of the Australian vehicle fleet.

For the impact category of Climate change (greenhouse emissions directly from transport vehicles), estimates are primarily based on BITRE values for greenhouse gas emissions from Australian transport, as published in the Bureau of Infrastructure and Transport Research Economics 'Infrastructure Yearbook' (BITRE 2020); using results from the National Greenhouse Gas Inventory (DISER 2020b) and National Greenhouse Accounts Factors (DISER 2020a), average vehicle fuel consumption data from the Australian Bureau of Statistics (2020c) 'Survey of Motor Vehicle Use', and recent analysis of probable life-cycle greenhouse gas emissions from Australian passenger vehicles (Smit 2020).

For the impact category of WTT emissions (well-to-tank emissions, i.e. upstream emissions both noxious and greenhouse – from fuel extraction, processing or supply – due to energy end-use in transport vehicles) estimates use data from the National Greenhouse Gas Inventory (DISER 2020b), National Greenhouse Accounts Factors (DISER 2020a), and National Pollutant Inventory (Department of Agriculture, Water and the Environment 2020); along with the recent analyses of life-cycle emissions for Australian vehicles (Smit 2020).

Estimated occupancy values used reflect actual average operating conditions typical of Australian urban transport systems (across all trip times and purposes, e.g. include off-peak travel for transit vehicles), so are well below vehicle capacity levels (e.g. generally around 20-30 per cent of full loading for most vehicle types).

For the electric train estimates, CO_2 emissions (within the WTT values) reflect the Australian average fuel mix for electricity generation (see National Greenhouse Accounts Factors, DISER 2020a), which still currently relies on substantial levels of coal consumption, but with a growing contribution from renewable sources. Emissions of CO_2 per unit of electricity use vary significantly from state to state (e.g. see Figure 4.1 – where the average emission rate in Tasmania is only about a fifth of the national average, while that of Victoria is about a quarter higher than the national level), and will tend to fall over time if the proportion of generation by renewables continues to climb.

*The air pollution values derived here are generally of a similar magnitude to those estimated by CE Delft (2019a); but the climate change costings are significantly lower, since the CE Delft 2019a results use a central estimate for **global** avoidance costs (for large-scale greenhouse gas emission abatement) of € 100 per tonne of CO_2 equivalent emissions (around A$160/t$CO_2$-equiv), whereas the values in this table use a central value for **domestic** avoidance costs (for large-scale abatement) of A$60/tCO2-equiv (compatible with Australian Transport Assessment and Planning 2020).*

Table 5-22: Alternate parameter values for air pollution, climate change and WTT emissions in A$ per 1000 vkt/pkm – car passenger transport by fuel – urban (June 2020 dollars)

Vehicle category	Vehicle type	Fuel type	Air pollution		Climate change		WTT emissions		Comments or clarifications
			vkt	pkm	vkt	pkm	vkt	pkm	
Passenger cars	Medium	Petrol	12.4	8.3	15.3	10.2	5.4	3.6	
		Diesel	30.2	20.1	18.3	12.2	5.2	3.5	
		Electric	1.0	0.7	0.0	0.0	14.2	9.5	Australian average generation

Notes:

For the impact category of Air pollution (noxious emissions directly from transport vehicles), estimates are primarily based on Bureau of Infrastructure and Transport Research Economics (BITRE) analysis (pers.com. D Cosgrove) performed for Department of Infrastructure, Transport, Regional Development and Communications (2020a, 2020b) regulation impact statements on the benefits of tighter vehicle emission standards in Australia ('Vehicle Emission Standards for Cleaner Air'); using results from cost of air pollution modelling, performed for Australian capital cities (Marsden Jacob Associates & Pacific Environment 2016, 2018) as part of reviews of Australian fuel quality standards (Department of the Environment and Energy 2018, 'Better fuel for cleaner air'). Values will tend to fall over time whenever stricter vehicle emission standards are enacted in Australia.

For the impact category of Climate change (greenhouse emissions directly from transport vehicles), estimates are primarily based on BITRE values for greenhouse gas emissions from Australian transport, as published in the Bureau of Infrastructure and Transport Research Economics 'Infrastructure Yearbook' (BITRE 2020); using results from the National Greenhouse Gas Inventory (DISER 2020b) and National Greenhouse Accounts Factors (DISER 2020a), average vehicle fuel consumption data from the Australian Bureau of Statistics (2020c) 'Survey of Motor Vehicle Use', and recent analysis of probable life-cycle greenhouse gas emissions from Australian passenger vehicles (Smit 2020).

For the impact category of WTT emissions (well-to-tank emissions, i.e. upstream emissions both noxious and greenhouse – from fuel extraction, processing or supply – due to energy end-use in transport vehicles) estimates use data from the National Greenhouse Gas Inventory (DISER 2020b), National Greenhouse Accounts Factors (DISER 2020a), and National Pollutant Inventory (Department of Agriculture, Water and the Environment 2020); along with the recent analyses of life-cycle emissions for Australian vehicles (Smit 2020).

An occupancy value of 1.5 passengers per car is assumed to reflect actual average operating conditions typical of Australian urban driving.

For the battery electric vehicle (EV) estimates, CO_2 emissions (within the WTT values) basically reflect the Australian average fuel mix for electricity generation (see National Greenhouse Accounts Factors, DISER 2020a), which still currently relies on substantial levels of coal consumption, but with a growing contribution from renewable sources. Emissions of CO_2 per unit of electricity use vary significantly from state to state (e.g. see Figure 4.1), and will tend to fall over time if the proportion of generation by renewables continues to climb. The WTT emission rate applying to any particular EV will be highly dependant on the proportion of charging performed on the standard grid (versus renewable sources, such as home solar panels).

*The air pollution values derived here are generally of a similar magnitude to those estimated by CE Delft (2019a); but the climate change costings are significantly lower, since the CE Delft 2019a results use a central estimate for **global** avoidance costs (for large-scale greenhouse gas emission abatement) of € 100 per tonne of CO_2 equivalent emissions (around A$160/t$CO_2$-equiv), whereas the values in this table use a central value for **domestic** avoidance costs (for large-scale abatement) of A$60/tCO2-equiv (compatible with Australian Transport Assessment and Planning 2020).*

6. Conclusion

This environmental parameter value update provides new estimates for external costs to the environment from transport activity. Consistent with previous Australian environmental parameter studies, the estimates are primarily based on European data, which was last updated in 2019, accounting for new developments, insights, data and methodologies. Despite reflecting the latest developments, estimating environmental parameter values remains a challenging task. Consequently, these values should be used with care, and sensitivity testing is recommended to judge the impact on road or transport project outcomes and mitigate the potential negative impacts of mis-estimated values.

ATAP is undertaking a scoping study to investigate the potential to develop environmental parameter values based on Australian data sources. This work would help to overcome the issues associated with converting overseas data to Australian conditions and provide a pathway for a more robust basis for estimating Australian environmental parameter values.

Appendix A Glossary of acronyms and abbreviations

ADR	Australian Design Rules
ATAP	Australian Transport Assessment and Planning
CBA	Cost-benefit analysis
CNG	Compressed natural gas
CO_2	Carbon dioxide
EU	European Union
EU28	28 countries of the European Union
F	Freight vehicle
GHG	Greenhouse gas
HV	Heavy vehicles
km	Kilometre
LCV	Light commercial vehicles
LPG	Liquid petroleum gas
P	Passenger vehicle
pkm	Passenger-kilometres
RoPax	Passenger ferries with roll-on and roll-off features for the carriage of commercial vehicles and private cars
t	Tonne
tkm	Tonne-kilometres
TTW	Tank-to-wheel
vkt	Vehicle-kilometres-travelled
WF	Weighting factors
WTT	Well-to-tank
WTW	Well-to-wheel

Appendix B Total, average and marginal external costs of transport

For some environmental impacts, CE Delft et al. (2011) and CE Delft (2019a) provided separate values for average external and marginal external costs. This appendix provides a short discussion of the various external cost measures for transport.

- Total external costs refer to the total value arising from a specific type of transport externality (e.g. air pollution) within a geographical boundary (e.g. Australia). The total external costs are measured in dollars.
- Average external costs are closely related to total costs as they are the average value of transport external costs per unit of transport activity. Measures of transport activities include vehicle-kilometres-travelled (vkt) for all transport modes, passenger-kilometres (pkm) for passenger transport modes, or tonne-kilometres (tkm) for freight transport modes. Units of average external costs of transport are therefore in dollars or cents per vkt for all transport modes, pkm for passenger transport modes and tkm for freight transport modes. Average external cost is also the basis for environmental parameter values developed in Austroads (2003, 2012 & 2014).
- Marginal external costs of transport are the changes in total external costs due to an additional transport activity being added to the traffic. They are measured in the same units as average marginal costs. The size of marginal costs therefore, however, may depend on the traffic conditions. Marginal external costs can also be further classified as short-run and long-run marginal costs. Their definitions are reproduced from Austroads (2003):
  - Short-run marginal external costs measure the increase in total external costs from an additional vehicle entering the system without considering the fixed costs for running the system or additional costs for network extension. Their estimation covers only variable costs of operation.
  - Long-run marginal costs also cover costs of system variations (e.g. enlargement of the network), since in the long run infrastructure costs are also to be considered as variable. An example for long-run marginal external costs are external costs related to nature and landscape, which are considered as fixed in the short run.

According to CE Delft (2019a), except for noise pollution, average and marginal external costs are approximately equal for all other externalities considered in this update. This is because the intensity of their impact is typically not strongly dependent on the density of the traffic flow. For example, a car entering a dense traffic flow emits a similar (though generally somewhat higher) amount of air pollution as a car entering a thin traffic flow, assuming all other factors are equal.

However, for noise pollution, traffic density matters. The additional noise emitted from a car entering a quiet street with little traffic is much more discernible, and subsequently considered more costly, to the surrounding residents than a car entering a busy street already filled with traffic noise. The marginal noise cost under light traffic conditions is expected to be higher than its average cost but for heavy traffic conditions, the marginal noise cost will be lower.

Appendix C Vehicle occupancy and payload

Table C-1: Vehicle occupancy and payloads – passenger transport

Vehicle category	Vehicle type	Fuel type	Dis-tance	Avg. occupancy or avg. passenger numbers	Source
Moped/scooter/ motorcycle				1.050	CE Delft (2019a)
Passenger car				1.574	CE Delft (2019a)
LCVs (incl. minibuses)				5.000	assumption
Bus/coach	Urban buses midi <15 t			13.505	CE Delft (2019a)
	Urban buses standard 15-18 t			16.882	CE Delft (2019a)
	Urban buses articulated >18 t			20.258	CE Delft (2019a)
	Coaches standard ≤18 t			15.087	CE Delft (2019a)
	Coaches articulated >18 t			22.631	CE Delft (2019a)
Rail	Intercity train	diesel		87	CE Delft (2019a)
	Regional train	diesel		31	CE Delft (2019a)
	Tram	electricity		50	assumption: avg. 50 pax per tram
	Metro single-decker	electricity		250	Action for Public Transport NSW (2013); assumption 50% full on average
	Metro double-decker	electricity		450	Action for Public Transport NSW (2013); assumption 50% full on average
Aviation	Small aircraft		500	58.3	Qantas (2020a)
	Medium-small aircraft		1000	78.8	Qantas (2020b)
	Medium aircraft (low emissions)		1500	148.9	CE Delft (2019a)
	Medium aircraft (high emissions)		1500	117.4	CE Delft (2019a)
Water transport	Urban ferry (Sydney)			95	Transport for NSW (2016)
	Large (RoPax) ferry (25,500 gt)			528	CE Delft (2019a)

Notes:

Aircraft types considered: small = Bombardier Dash 8 Q400, medium-small = Fokker 100, medium low emission = Airbus A320, medium high emission = Boeing 737.

For road transport, average occupancy numbers are listed. For non-road transport (rail, aviation, water transport), average passenger number are used, excluding driver/crew.

Table C-2: Vehicle occupancy and payloads – freight transport

Vehicle category	Vehicle type	Avg. load (tonnes)	Source
LCVs		0.692	CE Delft (2019a)
Heavy vehicles	Rigid <7.5 t	0.825	CE Delft (2019a)
	Rigid 7.5 -2 t	2.096	CE Delft (2019a)
	Rigid 12-14 t	3.877	CE Delft (2019a)
	Rigid 14-20 t	4.109	CE Delft (2019a)
	Rigid 20-26 t	8.490	CE Delft (2019a)
	Rigid 26-28 t	11.886	CE Delft (2019a)
	Rigid 28-32 t	14.628	CE Delft (2019a)
	Rigid >32 t	16.718	CE Delft (2019a)
	Articulated 14-20 t	7.110	CE Delft (2019a)
	Articulated 20-28 t	8.675	CE Delft (2019a)
	Articulated 28-34 t	14.628	CE Delft (2019a)
	Articulated 34-40 t	16.718	CE Delft (2019a)
	Articulated 40-50 t	19.505	CE Delft (2019a)
	Articulated 50-60 t	22.293	CE Delft (2019a)
Rail	Short container	500	CE Delft (2019a)
	Short bulk	750	CE Delft (2019a)
	Long container	1400	CE Delft (2019a)
	Long bulk	1600	CE Delft (2019a)
Aviation	Small aircraft	10	Air Charter Service (2020)
	Medium aircraft	19	Air Charter Service (2020)
Water transport	Small container vessel (28 500 gt)	24 000	CE Delft (2019a)
	Large container vessel (143 000 gt)	115 000	CE Delft (2019a)
	Small bulk vessel (18 000 gt)	15 000	CE Delft (2019a)
	Large bulk vessel (105 000 gt)	103 000	CE Delft (2019a)

Note:

Aircraft types considered: small = BAE146-300QT, medium = Boeing B737-300F.

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