Estimating Greenhouse Emissions from Australian Capital Territory Travel Modes

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The current version of this paper can be downloaded at http://grapevine.net.au/~mccluskeyarundell/leon_pubs.html

Contents

Abstract

Life cycle analysis of greenhouse emissions from travel modes shows that tailpipe emissions are the dominant emissions from vehicles with internal combustion engines. Significant indirect emissions arise from production of the food that fuels walking and cycling. Most emissions caused by electric light rail are from the power stations that provide its electricity.

Urban car travel is estimated to cause 367 grams CO_2-e of emissions per passenger-kilometre. Walking, bus or light rail cause about the same emissions as a car with a driver and a passenger. Motorcycling causes about the same emissions as a car with a driver and two passengers. Cycling causes about the same emissions as a car with a driver and three passengers.

For intercity travel, a car is estimated to cause 240 grams CO_2-e of emissions per passenger-kilometre. Rail and air cause about 70% of the emissions of driving, and motorcycling and coach travel one half.

International air travel is estimated to cause 77 grams of CO_2-e emissions per kilometre.

Acknowledgements

I wish to thank Drs Richard Jones (dec.) and John Todd of the University of Tasmania, who introduced me to the idea of looking beyond the primary contributions to energy use (and emissions), and Benoit Blondel of the European Cyclists Federation for his advice on how to avoid double-counting of emissions.

Notes on version 1.5

This version corrects some estimates in version 1.4 that did not include emissions from secondary travel, and uses independent data to re-estimate the daily distance walked.

Background

This paper estimates the total net greenhouse emissions attributable to various travel modes. It aims to include the best available estimates for all emissions for which estimates are available. As such, it is a work in progress.

Some estimates, such as those in the Australian Greenhouse Office's “Global Warming – Cool It” brochure, consider only tailpipe emissions.

The estimates in the European Cyclists' Federation's (ECF) “*Cycle More Often 2 Cool Down the Planet!” report* are based on a partial life cycle assessment that includes emissions from vehicle production, operation (including fuel production and utilisation) and maintenance, but excludes emissions from road accidents and from the construction, operation and maintenance of infrastructure such as roads.

This paper considers the following emissions:

- Tailpipe emissions: direct emissions from the combustion of vehicle fuels.
- Emissions from production of electricity used to power electric transport such as light rail.
- Fuel refining: Further work will be required to quantify emissions from fuel extraction and transport.
- Exhalation: metabolic activity produces exhaled carbon dioxide. Exhaled carbon dioxide is estimated, but is excluded from totals on the ground that it has previously been removed from the atmosphere by plants that were either consumed directly, or used as feed for animals that have subsequently been consumed to fuel the metabolic activity that occured during travel.
- Food production: emissions from production of the food that is metabolised during travel.
- Vehicle manufacture: emissions from manufacturing vehicles and from producing the materials used in vehicles.
- Vehicle maintenance: emissions from vehicle maintenance and from producing the materials that are consumed in maintenance.
- Physical Infrastructure: emissions from the production and maintenance of physical infrastructure such as roads, and from producing the materials that are used in that infrastructure.

- Travel by secondary modes: A car trip includes a walk to and from the car. An aeroplane trip requires travel to and from airports. Every component of the trip causes greenhouse emissions.

Emissions resulting from road accidents and organisational infrastructure (such as government transport departments) are not included.

There is little readily available information about emissions embodied in infrastructure. The main reference used for these emissions is Dave (2010) which does not appear to have been subject to peer review. Embodied emissions of 54 g CO_2-e/passenger-km (for the “Green Line” light rail system) have been applied to light rail and also to intercity rail. More accurate estimates of embodied emissions for these modes may substantially change their estimated total emissions.

Summary

Life cycle analysis of greenhouse emissions from travel modes shows that tailpipe emissions are the dominant emissions caused by vehicles with internal combustion engines, that indirect emissions arise from production of the food that fuels walking and cycling, and that the main source of emissions due to electric light rail is from the power stations that provide its electricity.

Canberrans travel a daily mean of 73 km that includes 36 km by cars and light commercial vehicles, 26 km by air, 6 km on foot, 2.3 km by bus, 1 km by bicycle and 0.3 km by motorcycle (Fig. 1 and Table 1).

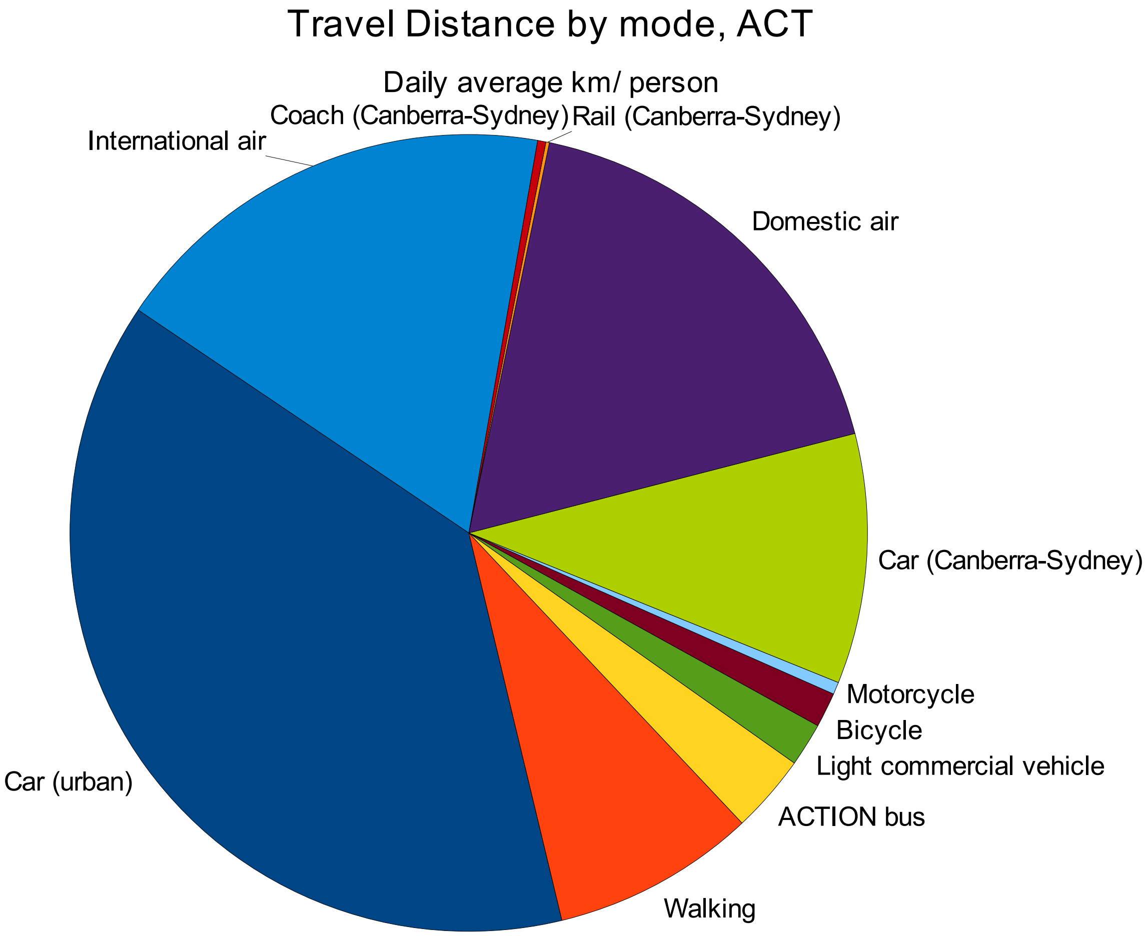


Figure 1: Distance travelled, by mode

The average Canberran's annual travel causes almost six tonnes of greenhouse gas emissions. More than four of these tonnes are due to car travel, and one tonne is due to aviation (Fig. 2).

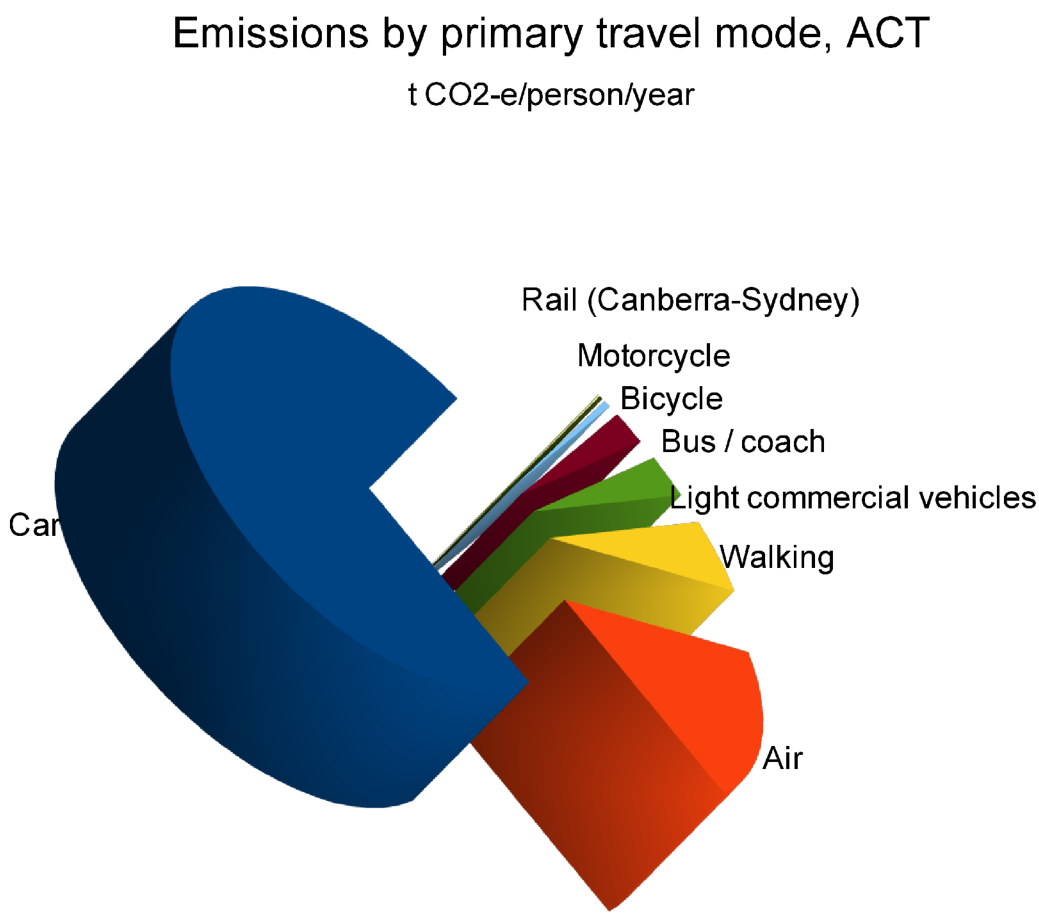


Figure 2: Greenhouse emissions by primary mode of travel

Travel emissions can be reduced by reducing travel, or by replacing driver-only car travel with less greenhouse-intensive forms of transport such as walking or bus (reduction by half), motorcycling (two-thirds), cycling (three-quarters) and car travel with passengers (up to four-fifths).

International aviation causes emissions of about 77 g CO_2-e per passenger-kilometre. It has been postulated that emissions from aviation have greater global warming effect because they are emitted in the upper atmosphere.

Light rail and fast interstate trains are also proposed for Canberra. Their greenhouse emissions in Canberra may be higher than their emissions in other places, just as Canberra's ACTION Bus emissions are higher than those of Sydney Buses.

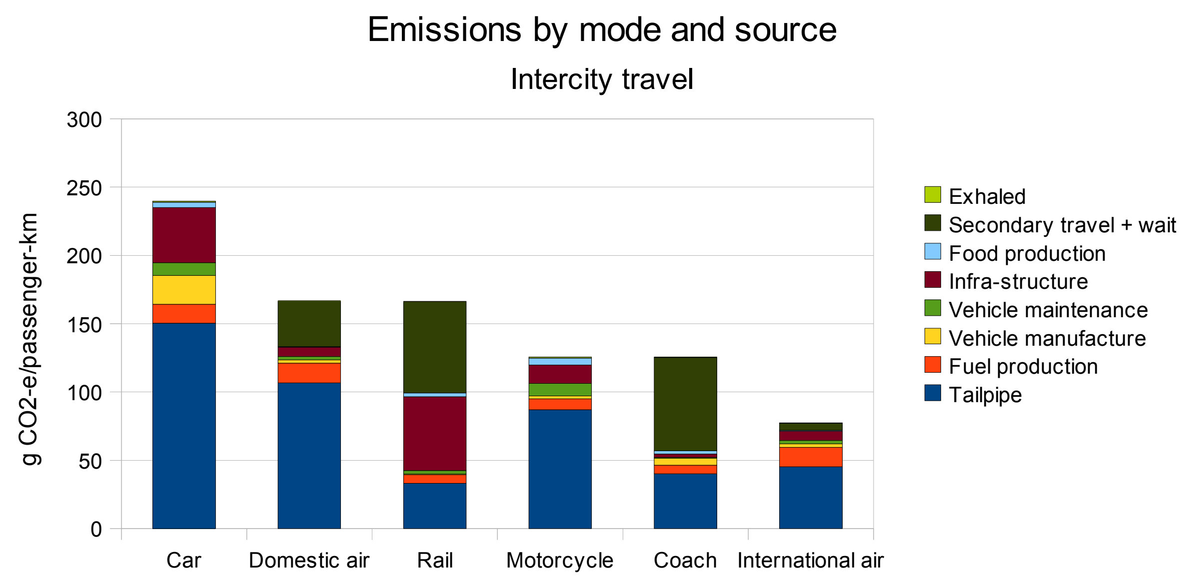
Primary travel mode	g CO_2 e/passenger km inc. secondary travel	Passenger km/person/day	kg CO_2 e/ person/ yr
Urban			
Car (urban)	367	27.78	3,690
Walking	169	6.01	328
ACTION bus	179	2.32	131
Light commercial vehicle	389	1.28	180
Bicycle	83	1.03	28
Pedelec	84	0.01	0.3
Motorcycle (urban)	132	0.32	15
Light rail	200	n.a.	n.a.
Intercity			
Car (Canberra Sydney)	240	7.37	643
Motorcycle (intercity)	126	0.04	n.a.
Domestic air	167	12.91	628
Rail (Canberra Sydney)	166	0.10	4
Coach (Canberra Sydney)	126	0.24	5
International air	77	13.33	350

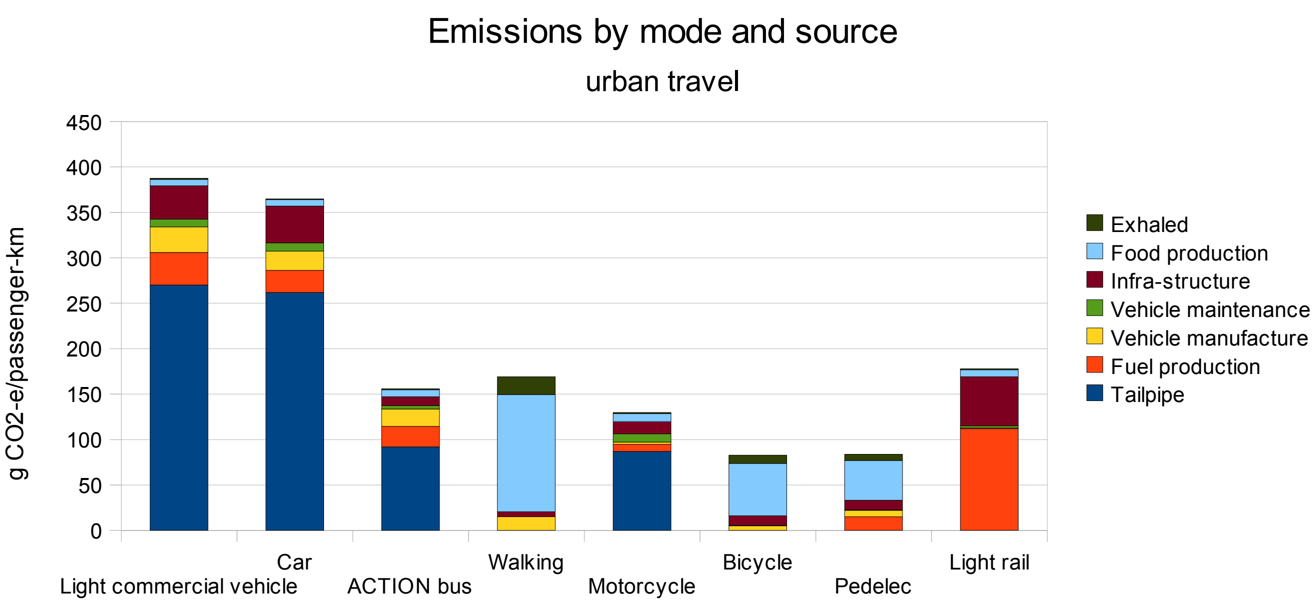
Table 1: Distance travelled, emissions per passenger and annual emissions per person, by transport mode, Canberra.

Emissions per passenger kilometre

Emissions per passenger kilometre, and their source components, are shown in Figures 3 and 4 and in Table 2.

FiFigure 4: Emissions by mode and source - Intercity travel





URBAN TRAVEL emissions (g CO2-e/passenger-km)									
Primary travel mode	Tailpipe	Fuel product-ion	Vehicle manu-facture	Vehicle mainten-ance	Infra-structure	Food product-ion	Secondary travel & Waiting	Exhaled	Total*
Light commercial vehicle	270	36	28	9	37	7	2	1	389
Car	262	24	21	9	40	7	2	1	367
Light rail	0	112	1	3	54	7	23	1	200
ACTION bus	92	22	19	4	10	7	23	1	179
Walking	0	0	15	0	6	129	0	20	169
Motorcycle	87	8	2	9	13	9	2	1	132
Pedelec	0	15	7	1	11	44	0	7	84
Bicycle	0	0	5	1	11	58	0	9	83
INTERCITY TRAVEL emissions (g CO2-e/passenger-km)									
Primary travel mode	Tailpipe	Fuel product-ion	Vehicle manu-facture	Vehicle mainten-ance	Infra-structure	Food product-ion	Secondary travel & Waiting	Exhaled	Total*
Car	150	14	21	9	40	4	0	1	240
Domestic air	107	14	3	3	7	0	34	0	167
Rail	33	6	1	3	54	3	67	0	166
Coach	40	6	5	1	3	2	68	0	126
Motorcycle	87	8	2	9	13	5	0	1	126
INTERNATIONAL air	45	14	3	3	7	1	5	0	77

Table 2: Estimated life cycle emissions (g CO_2-e/passenger-km) by travel mode and source.
**Totals exclude exhaled CO_2.*

Methodology

Methodology overview

This paper considers not only tailpipe emissions, but also emissions due to production of transport fuel (including electricity), vehicle manufacture and maintenance, infrastructure (roads etc), production of the food that is metabolised during travel (whether or not that food contributed to propulsion), secondary modes of travel, waiting periods (for scheduled public transport services) and exhaled carbon dioxide.

Exhaled CO_2 is estimated, but to avoid double counting it is not included in totals. This is because exhaled CO_2 ultimately derives from CO_2 that was previously removed from the atmosphere by plants. Estimates of CO_2 emissions from food production (which are included in totals) do not include an allowance for the CO_2 that is removed by plants from the atmosphere. If they did include such an allowance, then it would be appropriate to include exhaled CO_2 in totals.

Secondary travel is included in totals that are used for comparing the emissions caused by different modes of travel. For example, half of the emissions attributed to coach trips arises from travel (assumed to be by car) to and from bus terminals. Secondary travel is not included when totalling emissions across modes, because that would result in double counting.

Metabolic activity derives its energy from metabolising food. The production of that food causes greenhouse emissions from sources such as tailpipe emissions from farm machinery, or methane emissions from cattle, sheep or rice paddies.

Travelling by active transport such as cycling or walking will cause more emissions per hour from exhalation or food production, compared with passive transport such as being a car, bus or train passenger. Higher speed will increase the rate of emissions from cycling or walking. Speed of cycling or walking does not appear to be a critical consideration when considering emissions per kilometre. This is because activity level is approximately proportional to speed. At a higher activity level and higher speed, a person takes less time to travel a given distance.

Time spent travelling is an integral part of any trip, as is waiting when travelling by scheduled public transport such as buses or aeroplanes. A person will metabolise a given amount of food in an hour as an aeroplane passenger. They will metabolise the same amount during an hour of travelling as a passenger by a slower mode such as car, coach or train. For a given trip they will spend less hours travelling by aeroplane than by a slower mode of transport. So for that trip their emissions due to food production will be lower.

Exhaled CO_2

This paper assumes that CO_2 expiry is directly proportional to activity level. Thus, a 70 kg person exhales 0.48 grams of CO_2 per minute per unit of MET.

A person at rest has an activity level of one MET. This is equivalent to the consumption of 3.5 ml of oxygen per kilogram of body mass per minute[1, 2].

One mole of oxygen (O2) weighs 32 grams and occupies 22.4 litres at standard temperature and pressure. One ml of oxygen is 0.000156 moles. When metabolised, it produces 0.000156 moles of carbon dioxide (molecular weight 44), weighing 0.00688 grams.

A 70 kg person at an activity level of 1 MET exhales 0.48 grams of CO_2 per minute.

Metabolic rates (METS) were obtained from Ainsworth (2003).

Trip distances and driving times were obtained from the NRMA on-line travel planner (http://www.mynrma.com.au/trip-planner.htm) or from Google Earth.

Travel times for walking and cycling were calculated on the basis of a walking speed of 4.8 km/h and an average cycling speed of 13 km/h.

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1 Rockwell fitness, http://rockwellfitness.com/?page_id=1153, accessed 30 May 2011.

2 Dr. Andreacci, 2006, Bloomsburg University of Pennylvania: Assessment of Anaerobic & Aerobic Power, http://facstaff.bloomu.edu/jandreac/Downloads/class_notes/Exercise_Physiology/Lab2b Maximal_WAnT VO2maxPower.pdf, accessed 30 May 2011.

For ACTION bus trips, walking, wait and bus travel times were obtained from the ACTION Google Earth travel planner via the ACTION website at https://www.action.act.gov.au/. Travel, walking and waiting times for light rail were assumed to be the same as for ACTION buses.

Aeroplane, coach and train waiting and travel times were obtained from the websites of QANTAS (www.qantas.com.au), Murray's (http://www.murrays.com.au) and Countrylink (http://www.countrylink.info/).

Tailpipe emissions

Table 3 (below) shows the sources for the tailpipe emissions used in this paper.

Travel mode	**Tailipipe emissions** g CO_2-e/passenger-km	**Source**
URBAN		
Car	262	Derived from SKM MMA, 2011
Walking	0	
ACTION bus	92	Derived from BITRE (2010), TAMS (2010) and SKM MMA, (2011)
Light commercial vehicle	270	Dave (2010, “SUV”)
Bicycle	0	
Pedelec	0	
Motorcycle	87	Derived from SKM MMA, (2011)
Light rail	0	
INTERCITY		
Car	150	See discussion under “Cars & light commercial vehicles”
Rail	33	Derived from SKM MMA, 2011
Aviation	107	Derived from SKM MMA, 2011
Motorcycle	87	Derived from SKM MMA, 2011
Coach	40	assumed to be in the same ratio to Sydney buses as are car emissions from extra-urban car driving, compared with city car driving.
INTERNATIONAL		
Aviation	45	Derived from SKM MMA, 2011

Table 3: Tailpipe emissions

Emissions due to vehicle manufacture

Table 4 (below) shows the sources for the vehicle manufacture emissions used in this paper.

Travel mode	**Emissions from vehicle manufacture** g CO_2-e/passenger-km	**Source**
URBAN		
Car	21.1	Dave, 2010 (Sedan)*
Walking	15	See Note 1 below
ACTION bus	19.3	Dave, 2010 (Bus – average)
Light commercial vehicle	28.0	Dave, 2010 (SUV)*
Bicycle	5.0	Dave, 2010 (Bicycling)* and European Cyclists' Federation, 2011.
Pedelec	6.5	Bicycle+10% (est.)
Motorcycle	7.0	See Note 2 below
Light rail	0.6	Dave, 2010 (Green Line)*
INTERCITY		
Car*	21.1	Dave, 2010 (Sedan)*
Rail*	0.6	Dave, 2010 (Green Line)*
Aviation	2.5	Dave, 2010 (Boeing 737)*
Motorcycle	7.0	Dave, 2010 ()*
Coach*	5.0	Dave, 2010 (Bus – on peak)*
INTERNATIONAL		
Aviation	2.5	Dave, 2010 (Boeing 737)*

Table 4: Greenhouse gas emissions from vehicle manufacture.

* Converted from emissions per passenger mile.

Note 1: In 1999 Steve Fugate walked about 26,000 miles and wore out 33 pairs of shoes, and in 2010 Jonathon Stalls walked 3,030 miles while destroying 7 pairs of shoes[3]. These two walkers together averaged 1,168 km per pair of shoes.

> Nike reports that “an average pair of Nike running shoes ... results in the use of a total of … 18 kg of CO_2 throughout its life”[4].
>
> On the basis that the production of a pair of shoes results in 18 kg of CO_2 and that they travel an average of 1,168 km, this equates to 15 grams of CO_2 per kilometre.

Note 2: For motorcycles, we use Dave's “Sedan” figure of 21.1 grams per passenger-kilometre, adjusted in proportion to motorcycle tailpipe emissions (87 g per passenger-kilometre) relative to those estimated for cars (262 g/passenger km), giving an estimate of 7.0 g per passenger-kilometre for fuel production.

3 http://en.wikipedia.org/wiki/List_of_people_who_have_walked_across_the_United_States, accessed 25 November 2011.

4 http://www.nikebiz.com/crreport/content/environment/4-3-2-highlights-of-our-work.php?cat=climate-and-energy, accessed 25 November 2011

Emissions due to fuel production

Table 5 (below) shows the sources for the fuel production emissions used in this paper.

Travel mode	**Emissions from fuel production** g CO_2-e/passenger-km	**Source**
URBAN		
Car	24.2	Dave, 2010 (Sedan)*
Walking	0	See under “Food Production”
ACTION bus	22.4	Dave, 2010 (Bus – average)
Light commercial vehicle	36	Dave, 2010 (SUV)*
Bicycle	0	See under “Food Production”
Pedelec	15	Estimated emissions from electricity production. See discussion under “Pedelecs.”
Motorcycle	8	See Note below
Light rail	112	Estimated emissions from electricity production. See discussion under “Light Rail.”
INTERCITY		
Car	24.2	Dave, 2010 (Sedan)*
Rail	6.2	Dave, 2010 (Bus – on peak)*
Aviation	14.3	Dave, 2010 (Boeing 737)*
Motorcycle	8	See Note below
Coach	6.2	Dave, 2010 (Bus – on peak)*
INTERNATIONAL		
Aviation	14.3	Dave, 2010 (Boeing 737)*

Table 5: Greenhouse gas emissions from fuel production.

* Converted from emissions per passenger mile.

<u>Note</u>: For motorcycles, we use Dave's “Sedan” figure of 24 grams per passenger-kilometre, adjusted in proportion to motorcycle tailpipe emissions (87 g per passenger-kilometre) relative to those estimated for cars (262 g/passenger km), giving an estimate of 8.0 g per passenger-kilometre for fuel production.

Vehicle maintenance

Table 6 (below) shows the sources for the vehicle maintenance emissions used in this paper.

Travel mode	**Emissions from vehicle maintenance** g CO_2-e/passenger-km	**Source**
URBAN		
Car	9.3	Dave, 2010 (Sedan)*
Walking	0	Assumed
ACTION bus	3.7	Dave, 2010 (Bus – average)
Light commercial vehicle	8.7	Dave, 2010 (SUV)*
Bicycle	0.6	Dave, 2010 (Bicycling)*
Motorcycle	9.3	See Note below
Light rail	2.5	Dave, 2010 ("Green Line")*
INTERCITY		
Car	9.3	Dave, 2010 (Sedan)*
Rail	2.5	Dave, 2010 (Green Line)*
Aviation	2.5	Dave, 2010 (Boeing 737)*
Motorcycle	9.3	See Note below
Coach*	0.6	Dave, 2010 (Bus – on peak)*
INTERNATIONAL		
Aviation	2.5	Dave, 2010 (Boeing 737)*

Table 6: Greenhouse gas emissions from vehicle maintenance.

* Converted from emissions per passenger mile.

Note: Motorcycles may have lower service costs than cars per service, but tend to have shorter maintenance intervals. We assume that motorcycles have the same maintenance emissions as "Sedans".

Infrastructure

Table 7 (below) shows the sources for the infrastructure emissions used in this paper.

Travel mode	Emissions from infrastructure g CO_2-e/passenger-km	Source
URBAN		
Car	40.4	Dave, 2010 (Sedan)*
Walking	5.6	Dave, 2010 (Walking)*
ACTION bus	9.9	Dave, 2010 (Bus – average)*
Light commercial vehicle	36.6	Dave, 2010 (SUV)*
Bicycle	10.6	Dave, 2010 (Bicycling)*
Motorcycle	20.2	See Note below
Light rail	54.0	Dave, 2010 ("Green Line")*
INTERCITY		
Car	40.4	Dave, 2010 (Sedan)*
Rail*	54.0	Dave, 2010 (Green Line)*
Aviation	6.8	Dave, 2010 (Boeing 737)*
Motorcycle	20.2	See Note below
Coach	2.5	Dave, 2010 (Bus – on peak)*
INTERNATIONAL		
Aviation	6.8	Dave, 2010 (Boeing 737)*

Table 7: Greenhouse gas emissions from infrastructure.

* Converted from emissions per passenger mile.

Note: We assume motorcycling infrastructure emission to be half those of a "sedan" - I.e. 20.2 g CO_2 per kilometre.

Emissions from food production

This paper assumes that food consumption is directly proportional to activity level.

In 2009 Australia's annual agricultural production was worth $41,849 million (ABS 7106.0 - Australian Farming in Brief, 2010) and the agriculture sector produced 86 million tonnes (81,000 million kg) of CO_2-e emissions (Department of Climate Change and Energy Efficiency 2010, Australia's emissions projections 2010, DCCEE, Canberra, ACT). This is an average emissions intensity of 2.06 kg per dollar of production.

In 2009 Australia imported $10,883 million worth of food, and exported $24,647 million worth of food (ABS 5368 and 5349). So Australia's net consumption of food was $28,035 million.

AT 2.06 kg of greenhouse emissions per dollar, Australia's annual consumption of $28,035 million worth of food represents 58 million tonnes of greenhouse emissions, or 2.63 tonnes for each of Australia's 22 million people.

2.63 tonnes of emissions per year is equivalent to 4.99 g per minute, per person.

The average activity level of a normally active person is 1.5 – 1.7 times resting energy expenditure (ACSM, ADA and DoC, 2000) – that is, 1.5 to 1.7 METs.

At a typical activity level of 1.6 METs, the food consumed by the average Australian is responsible for greenhouse emissions of 4.99 grams CO_2-e per minute. That is a rate of 3.12 grams per MET-minute.

Secondary travel

Walking is the only primary mode of travel that provides a complete trip, from origin to destination.

Other travel modes require the use of secondary travel modes.

Cars, light commercial vehicles and motorcycles

Driving and motorcycling require a walk to the vehicle, plus a walk from the parked vehicle to the final destination. For a single car, commercial vehicle or motorcycle trip, these walks are assumed to total 200 metres.

Bicycles

The walk to a bicycle, and from the parked bicycle to the final destination, is assumed to be 125 metres.

Aviation

Domestic air travel typically involves a drive to the departure airport, plus a drive from the destination airport to the final destination.

The average driving distance to the Canberra airport, from five randomly selected Canberra addresses, was found to be 18.3 km. The average driving distance from Sydney airport to five randomly selected Sydney addresses was found to be 40.2 km.

The total amount of secondary driving for air travel is thus estimated as 58 km.

The walking component of secondary travel is included implicitly, by using car travel emissions factors that include an allowance for walking, as is described above.

International air travel from Canberra typically involves a flight from Canberra to Sydney – nominally 281 km. As is described above, domestic flight emissions include an allowance for car travel and car travel emissions include an allowance for walking.

Bus and coach

Bus trips require walking to and from bus stops, and between buses. The Transit Trip Planner on the ACTION bus website (https://www.action.act.gov.au/) indicates these walking times. A sample of ten bus trips from and to randomly selected Canberra addresses, indicated an average trip distance of 16.2 km, and an average walking duration of 20.8 minutes (equivalent to 1.66 km of walking).

An intercity bus trip involves a drive to the departure terminal, plus a drive from the destination terminal to the final destination. The average driving distance to Canberra's Jolimont Centre interstate bus terminal, from five randomly selected Canberra addresses, was found to be 16.6 km, with an average driving time of 19.2 minutes. The average driving distance from Sydney's interstate bus terminal in Eddy Avenue (adjacent to Sydney's Central Railway Station) to five randomly selected Sydney addresses was found to be 35.6 km, with an average driving time of 34.2 minutes. The total amount of secondary driving for intercity coach travel is thus estimated as 52 km.

Rail

A rail trip from Canberra to Sydney involves a drive to Kingston railway station, plus a drive from the Sydney's Central Station to the final destination.

The average driving distance to Kingston railway station, from five randomly selected Canberra addresses, was found to be 15.1 km. The average driving distance from Sydney's Central Railway Station to five randomly selected Sydney addresses was found to be 35.6 km. The total amount of secondary driving for intercity rail travel is thus estimated as 51 km.

Cars & light commercial vehicles

Distance travelled

343,000 Canberrans[5] travelled 4.4 billion passenger kilometres by car in 2007-08 (BITRE 2009b, Table 5.3h). This is a per capita average of 12,828 km per year, or 35.15 km per day.

Canberrans' main intercity driving destination is Sydney. In 2007-08 there were 6.545 million passenger movements between Canberra and Sydney (road distance 281 km)[6]. Assuming that half of these were by Canberrans, this is a per capita equivalent of 9.6 trips, 2,689 km per year, or 7.37 km per day.

Subtracting 7.37 km per day of intercity driving from the total of 35.15 km per day leaves 27.78 of urban driving per day.

343,000 Canberrans[7] travelled 0.16 billion passenger kilometres in light commercial vehicles in 2007-08 (BITRE 2010, Table 5.3h). This is a per capita average of 466 km per year, or 1.28 km per day.

Secondary travel

A walk distance of 200 metres is assumed, for a representative trip distance of 16.2 km.

Exhaled CO2-e and Emissions from food production

Exhaled emissions are estimated at 0.482 grams CO_2-e per MET-minute, and food production emissions are estimated at 3.12 g per MET-minute.

At an urban speed of 54 km/h, it takes 1.12 minutes to drive a kilometre. At 2 METs and 3.12 g CO2-e per MET-minute, this equates to 1.07 g/km exhaled CO_2-e and 6.93 g CO_2-e/km from food production.

5 ABS 3101

6 BITRE 2009b

7 ABS 3101

At an intercity speed of 94 km/h, it takes 0.64 minutes to drive a kilometre. At 2 METs and 3.12 g CO_2-e per MET-minute, this equates to 0.62 g/km exhaled CO_2-e and 3.98 g CO_2-e/km from food production.

Emissions due to vehicle manufacture

Emissions from manufacturing are estimated at 21.1 and 28.0 g CO_2-e/passenger-km for cars and light commercial vehicles respectively (Dave, 2010, “Sedan”.)

Tailpipe emissions

Australian Passenger cars emitted 43.5 MT CO_2-e in 2008, and provided 165.9 billion passenger kilometres of transport[8]. On this basis passenger cars on average emit 262 g CO_2-e per passenger-kilometre.

Highway fuel consumptions (and therefore emissions) of cars are typically lower than their urban equivalents. For Australia's most popular car, the Mazda3, urban fuel consumption is 10.8 l/100 km, extra-urban 6.2 and combined 7.9. Most Australian driving is urban and fuel consumption test drivers drive more economically than normal drivers; so Australian the urban fuel consumption figure of 10.8 l/100 km corresponds approximately to average driving.

On the basis that the average figure of 262 g/passenger km represents urban driving, then for intercity driving this would proportionately reduce to 150.41 g CO_2-e per passenger-kilometre.

According to Dave (2010), SUVs (used here as a proxy for light commercial vehicles) emit 270 g CO_2-e per passenger-kilometre.

Other sources of emissions

We use Dave's “Sedan” figure of 24 grams per passenger-kilometre for fuel production cars, and her “SUV” figure of 36.0 for light commercial vehicles.

For intercity car driving, the fuel production figure is reduced in the same proportion as the tailpipe emissions, to 13.78 g CO_2-e per passenger-kilometre.

Emissions from vehicle maintenance are estimated at 9.3 g CO_2-e/passenger-km for cars and 8.70 for light commercial vehicles (Dave, 2010, “Sedan” and “SUV” respectively).

Emissions from infrastructure are estimated at 40.4 and 36.65 g CO_2-e/passenger-km for cars and light commercial vehicles respectively (Dave, 2010, “Sedan” and “SUV”).

Walking

Distance travelled

The average Australian takes 9,695 steps per day[9]. Assuming the author's stride length of 0.62 metres, this equates to 6.01 kilometres per day or 2,194 kilometres per year.

8 SKM MMA, 2011

9 Bassett, D R. JR.; Wyatt, H R.2; Thompson, H; Peters, J C.; Hill, J O., Pedometer Measured Physical Activity and Health Behaviors in U.S. Adults, as cited by Tom Vanderbilt in *The*

Walking includes both "trips" and shorter walks such as walking at home, at school or at work.

The average Canberra resident reports spending 26 minutes a day on 1.89 walking "trips"[10]. Assuming an average speed of 4.8 km/hr, this equates to an average walking trip length of 1.10 km, and a total of 2.08 km per day travelled in walking "trips."

Pedometer programs[11] typically recommend 10,000 steps per day for general health and fitness. The author typically walks 4 km per day (6,000 steps) and cycles about 5 km.

Exhaled CO_2-e

Walking at 4.8 km/h corresponds to an activity level of 3.3 METs. At this speed it takes 12.5 minutes to travel a kilometre. So exhalation adds 19.80 grams of CO_2 per kilometre of walking.

Other emission sources

At 4.8 km/h it takes 12.5 minutes to walk a kilometre, resulting in 129 grams of CO_2-e emissions from food production.

In 1999 Steve Fugate walked about 26,000 miles and wore out 33 pairs of shoes, and in 2010 Jonathon Stalls walked 3,030 miles while destroying 7 pairs of shoes[12]. These two walkers together averaged 1,168 km per pair of shoes.

Nike reports that "an average pair of Nike running shoes ... results in the use of a total of … 18 kg of CO_2 throughout its life"[13].

On the basis that the production of a pair of shoes results in 18 kg of CO_2 and that they travel an average of 1,168 km, this equates to 15 grams of CO_2 per kilometre.Emissions due to vehicle manufacture.

No emissions are attributed to vehicle maintenance for walking.

Dave (2010) attributes 5.6 g CO_2-e/passenger-km to infrastructure for walking.

ACTION buses

Distance travelled

343,000 Canberrans[14] travelled 0.29 billion passenger kilometres by bus in 2007-08[15]. This is a per capita average of 845 km per year, or 2.32 km per day.

Crisis in American Walking *How we got off the pedestrian path*. http://www.slate.com/articles/life/walking/2012/04/why_don_t_americans_walk_more_the_crisis_of_pedestrianism_.html, accessed 1 June 2012

10 Wedderburn, M, 2011, "Making Walking Count" Canberra, http://www.transport.act.gov.au/references docs/Making%20Walking%20Count.pdf

11 e.g. http://www.10000steps.org.au

12 http://en.wikipedia.org/wiki/List_of_people_who_have_walked_across_the_United_States, accessed 25 November 2011.

13 http://www.nikebiz.com/crreport/content/environment/4-3-2-highlights-of-our-work.php?cat=climate-and-energy, accessed 25 November 2011

Secondary travel

For ten weekday Canberra bus trips, between randomly selected addresses, the average walking time (according to the trip planner at www.action.act.gov.au) was 20.8 minutes, which at 4.8 km/h is 1.664 km.

Waiting time

Waiting time for bus services can include (1) a wait from the time a person is ready to travel until the next scheduled bus arrives, (2) a wait at the bus stop because it is wise to arrive early in case the bus is ahead of schedule, (3) a further wait at the bus stop if the bus is behind schedule, (4) waiting between connecting services and (5) waiting at the destination, if the bus arrives earlier than necessary (e.g. if the next bus would have arrived too late for a specific appointment).

It would be inappropriate to include both waits (1) and (5), because in that case the waiting would be due to factors other than the travel itself. These waits are approximately equal, because they depend primarily on the time between services.

This paper estimates urban bus waiting time as (1) plus (4). Waits (2) and (3) are ignored, because they are difficult to estimate and are relatively short.

For ten weekday Canberra bus trips, between randomly selected addresses, starting at randomly selected times from 7 am and being completed by 7 pm, the average effective distance (car driving distance) was 16.23 km, the average wait time for the first available scheduled service was 24.7 minutes and the average wait time between connecting services was 11.8 minutes, giving a total wait time of 36.5 minutes.

Exhaled CO_2

For ten randomly selected bus trips, the average trip distance was 16.23 km and the average duration of bus travel (excluding walking and waiting) was 73.6 minutes, for an average effective on-road speed of 25 km/h.

At 25 km/h it takes 2.4 minutes to travel 1 km. A 70 kg bus passenger at an activity level of 1 MET exhales 0.48 grams of CO_2 per minute. This results in exhalation of 1.15 grams of CO_2 per km.

Tailpipe emissions

In 2009-10 ACTION buses used 7.227 million litres of diesel fuel and 2.554 million litres of compressed natural gas (CNG) to carry 16.94 million passengers (TAMS, 2010).

Diesel fuel has an energy content of 38.6 GJ per kl and produces 69.9 kg CO_2-e per GJ. CNG has an energy content of 39.3 GJ/cubic metre and produces 57 kg of CO_2-e per GJ[16].

On this basis ACTION's fuel use produces 25.22 million kg CO_2-e and carries 16.94 million passengers – an average of 1.49 kg CO_2-e per passenger.

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14 ABS 3101

15 BITRE 2010, Table 5.3h

16 SKM MMA, 2011

By way of comparison, in 2008-09 the NSW State Transit Authority of NSW carried 207.851 million passengers and emitted 146,878 tonnes of CO_2-e (STA, 2009 and 2010). This is equivalent to 0.71 kg CO_2-e per passenger.

For ten weekday Canberra bus trips, between randomly selected addresses, the average car driving distance between locations was 16.23 km.

Assuming an average passenger journey of 16.23 km, an ACTION bus emits 91.81 grams of CO_2-e per passenger kilometre.

Other emission sources

According to Dave (2010) average bus emissions due to fuel production are 22.4 g CO_2-e/km.

Travelling by bus corresponds to an activity level of 1 MET. At an average urban speed of 25 km/h, a bus takes 2.4 minutes to travel one kilometre. This corresponds to 7.49 grams of CO_2-e emissions from food production, per kilometre. kilometre.

According to Dave (2010), emissions from bus manufacture average 19.3 g CO_2-e/passenger-km, emissions from bus maintenance average 3.7 g CO_2-e/passenger-km and emissions from bus infrastructure average 9.9 g CO_2-e/passenger-km.

Bicycles

Distance travelled

Arundell (2007) estimated that the average Australian adult cycles 197 km per year, and the average Australian adult cyclist cycles 1,907 km per year.

52,300 Canberran adults (19% of Canberra adults) cycled in 2010.[17] This equates to a total of 99,736,100 km of adult cycling per year.

26,500 Canberra children aged under 15 cycled in 2009, and the average time spent by Australian children cycling was 4.7 hours per fortnight.[18] Assuming an average child cycling speed of 10 km/h, this equates to 1,225 km per year per child, and a total of 32,462,500 km of child cycling per year.

On the basis of the above, Canberra's adults and children cycle collectively 132,198,600 km per year. Averaged over Canberra's 2009 population of 352,189[19], this equates to 375 km per person per year, or 1.03 km per person per day.

Travel speed

The author's previous 8.5 km daily commute along shared off-road paths took at least 23 minutes (average 22 km/h or less). The on-road route was 6.5 km, and so the author's effective average speed was 17 km/h or less.

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17 Australian Sports Commission, 2011

18 *ABS 4901.0*

19 ABS 3218.0

Given that the author was at the time an adult riding ten times per week, compared with 60% of Australian adult cyclists who ride less than once per week[20], it seems reasonable to assume that the overall average cycling speed of Australian children and adults is lower than was the author's commuting speed.

A cycling pace of less than 16 km/h (estimated in this paper as 13 km/h) corresponds to an activity level of 4 METs (Ainsworth, Corbin, Pangrazi and Franks, 2003).

Secondary travel

A 5km cycle trip is assumed to include 125 metres of walking to and from the bicycle.

Exhaled CO_2-e

At 4 METs a 70 kg person exhales 1.92 grams of CO_2 per minute, and at takes 4.62 minutes to travel one kilometre. This results in exhalation of 8.86 grams of CO_2 per kilometre.

Emissions due to food production

Production of the food that is metabolised in one minute by a person at 4 METs causes emissions of 3.12 grams of CO_2-e. At 13 km/h it takes 4.62 minutes to travel one kilometre. This causes food production emissions of 57.6 grams of CO_2-e per kilometre.

Other emission sources

According to Dave (2010) and the European Cyclists' Federation (2011), bicycle manufacture is responsible for 5.0 g CO_2-e/passenger-km.

According to Dave (2010) bicycle maintenance is responsible for 0.6 g CO_2-e/passenger-km and bicycle infrastructure is responsible for 10.6 g CO_2-e/passenger-km.

Pedelecs

There are no statistics available on pedelecs (electric-assisted bicycles) in Canberra.

Pedelecs cover on average 22% more kilometres than normal bicycles[21]., and the author estimates that pedelec numbers are 1% of bicycle numbers. On that basis, the average Canberran would travel 4.58 km per year, or 0.01 km per day, by pedelec.

Based on the author's experience with the Australian Greenhouse Office bicycle fleet, pedelec speed is estimated at 15 km/h, which is approximately 10% greater than the estimated speed of bicycle travel.

Secondary travel is assumed to be a 10 metre walk, for a representative 5 km trip.

Exhaled CO_2-e and emissions due to food production are proportional to metabolic activity. The metabolic rate for pedelec travel is assumed to be 3.5 METs, which is higher than the metabolic rate for motorcycling (2.5 METs) and slightly less than the metabolic rate for

20 Australian Sports Commission, Exercise, Recreation and Sport Survey.

21 TNO, Elektrisch fietsen, Marktonderzoek en verkenning toekomstmogelijkheden, 2008, cited in ECF (2011)

cycling (4 METs). Exhaled CO_2-e is estimated at 6.7 g CO_2-e/km, and emissions from food production at 44 gCO_2 -e/km.

Pedelecs have no tailpipe emissions. However there are emssions associated with production of the electricity that they consume. A study by TNO[22] estimates CO_2 -e emissions of pedelecs to include 10 grams linked to the production of the electricity that is needed to assist the cyclist, at the Netherlands carbon intensity of 0.42949 kg CO_2 per kWh[23]. At the 0.765 kg CO_2/kWh carbon intensity of Australian electricity production, the emissions due to electricity production for pedelecs would therefore be 17.81 g/km.

Specifications of four electric bicycles reviewed by the author show a range of 4 to 14 Wh (measured as charger output) per km travelled. Allowing for 75% charger efficiency and an electricity generation intensity of 0.765 kg CO_2/kWh, these range from 6 to 19 g CO_2-e/km.

On the basis of the above estimates, the greenhouse intensity of pedelecs is estimated at 15 g CO_2-e/km.

Pedelecs have greater mass, power and complexity than bicycles. Their emissions due to vehicle manufacture, vehicle maintenance and infrastructure are each assumed to be 10% greater than those for bicycles – namely 6.5, 0.66 and 11.7 g CO_2-e/km respectively.

Motorcycles

Distance travelled

343,000 Canberrans[24] collectively travelled 0.04 billion passenger kilometres by motorcycle in 2007-08 (BITRE 2010, Table 5.3h). This is a per capita average of 117 km per year, or 0.32 km per day.

Secondary travel

As for cars, secondary travel is assumed to be a 200 metre walk, for a representative trip distance of 16.2 km.

Exhaled CO_2-e and Emissions due to food production

Travelling by motorcycle corresponds to an activity level of 2.5 METs.

At an average urban speed of 54 km/h a motorcycle takes 1.11 minutes to travel a kilometre. At 2.5 METs and 3.12 g CO_2-e for food production per MET-minute, this means 8.66 grams of CO_2 per kilometre.

At an average interurban speed of 94 km/h a motorcycle takes 0.64 minutes to travel a kilometre. At 2.5 METs and 3.12 g CO_2-e for food production per MET-minute, this means 4.99 grams of CO_2 per kilometre.

At an average urban speed of 54 km/h, a motorcycle takes 1.11 minutes to travel one kilometre. This corresponds to expiration of 1.33 grams of CO_2 per kilometre.

22 TNO, 2010

23 Hendriksen I, Engbers L, Schrijver J, Gijlswijk R van, Weltevreden J, Wilting J., Elektrisch Fietsen – Marktonderzoek en verkenning toekomstmogelijkheden, 2008

24 ABS 3101

At an average interurban speed of 94 km/h, a motorcycle takes 0.64 minutes to travel one kilometre. This corresponds to expiration of 0.77 grams of CO_2 per kilometre.

Tailpipe emissions

Australian motorcycles emitted 0.2 MT CO_2-e in 2008, and provided 2.3 billion passenger kilometres of transport[25]. On this basis motorcycles on average emit 0.2/2.3 g CO_2-e (86.96 g) per passenger-kilometre.

Motorcycle tailpipe emissions can be expected to be greater for large capacity motorcycles, and much lower for small capacity motorcycles. In the author's experience, the motorcycle fuel consumption that generates emissions is about 2.5 l/100km for a 110cc “postie” bike, while the 1800cc Honda Gold Wing has a stated fuel consumption of 35 mpg (US), corresponding to 6.7 l/100 km.

Highway fuel consumption is similar to urban fuel consumption. Motorcycles differ in this respect from cars, which consume less fuel on highways speeds than in urban areas. This is in part because the motorcycle's lower weight reduces its fuel consumption in stop-start traffic, while its relatively higher wind resistance increases its high speed fuel consumption.

Other emission sources

For motorcycles we use Dave's “Sedan” figure of 21.1 grams per passenger-kilometre, adjusted in proportion to motorcycle tailpipe emissions (87 g per passenger-kilometre) relative to those estimated for cars (262 g/passenger km), giving an estimate of 7.0 g per passenger-kilometre for fuel production.

The emissions caused in manufacturing a motorcycle are assumed to be 2.1 g CO_2-e/km, which is 10% of those caused in manufacturing a car. Embodied emissions for similar goods are approximately proportional to weight. A motorcycle weighs about a tenth as much as a car.

We estimate motorcycling infrastructure emissions at 13.47 g CO_2 per kilometre, which is one third that of a “Sedan.”

Motorcycle maintenance emissions are assumed to be 9.3 g CO_2-e/km – the same as for cars. An individual motorcycle service may cause lower emissions than a car service, but motorcycles require more frequent servicing.

Light rail

There is currently no light rail in Canberra.

On the assumption that light rail would be integrated with Canberra's bus network, the following ACTION bus factors are applied to light rail:

- secondary travel: 1.7 km walk
- Exhaled CO_2-e: 1.2 g CO_2-e per passenger km
- Emissions due to food production: 7.5

There are no tailpipe emissions from electric-powered light rail.

25 SKM MMA, 2011

Power for light rail would come from the Australian electricity grid, which has a greenhouse intensity of 765 grams CO_2-e per kWh. In the year to December 2010 Australia produced 196 Mt CO_2-e of emissions[26] from the generation of 256,195,000,000 kWh of electricity[27]. This is an emissions intensity of 765 grams per kWh.

In 2006 Australian light rail provided 0.55 billion passenger km and consumed 0.29 PJ of electricity[28]. This is 0.29x10^9 MJ per 0.55 x 10^9 passenger km, 0.527 MJ per passenger km, or 0.14 kWh per passenger km. This equates to 112 grams CO_2-e of emissions per passenger kilometre.

Most of Australia's light rail is in cities larger than Canberra. Canberra buses consume more than twice as much fuel per passenger as Sydney buses. It is conceivable that passenger loadings in Canberra would be lower than those in larger cities, with consequent higher emissions per passenger kilometre.

Emissions from vehicle manufacture are estimated at 0.6 g CO_2-e/passenger-km and from vehicle maintenance at 2.5 g CO_2-e/passenger-km.

Emissions from infrastructure

Emissions from infrastructure are estimated at 54.0 g CO_2-e/passenger-km (Dave, 2010, “Green Line,” Converted from emissions per passenger mile).

The accuracy of this estimate is uncertain, given that it comes from an apparently un-refereed research paper that provides few details of how the estimate was obtained.

As this figure represents a quarter of the total estimated emissions from light rail, a more reliable estimate of infrastructure emissions may result in a significant revision of the total emissions estimate.

Aviation

Distance travelled

In 2008 Australian domestic air transport provided 49.279 million passengers with 56.2 billion passenger km[29] of travel – an average trip length of 1,140 km. 2.853 million air passengers passed through Canberra airport In 2007-08. Assuming that the 345,000 Canberrans[30] made up half of these passengers, and that their average trip length was 1,140 km, this comes to an average of 4,714 km per year, or 12.91 km per day.

In 2007-08 Australia had 23,264,573 international airline passengers and in 2007 total Australian international travel was 205 billion passenger km[31]. Assuming that half of this

26 Department of Climate Change & Energy Efficiency, National Greenhouse Gas Inventory Accounting for the Kyoto Target December Quarter 2010

27 http://www.tradingeconomics.com/australia/electricity_production_kwh_wb_data.html, accessed 2 Feb 2012.

28 SKM MMA, 2011

29 SKM MMA, 2011

30 ABS 3101

31 BITRE 2009b

travel was done by 21.07 million Australians[32], this is a per capita average of 4,865 km per year, or 13.33 km per day. The average trip length was 8,800 km.

Secondary travel

The main secondary mode of travel for domestic flights is car from home to the departure airport, and from the arrival airport to the final destination.

The main mode of secondary travel for international flights is by air to Sydney.

The average driving distance to the Canberra airport, from five randomly selected Canberra addresses, was found to be 18.3 km. From Sydney airport it was found to be 40.2 km. The total amount of secondary travel for air travel is thus estimated as 58.5 km of driving. At an emissions intensity of 367 g CO_2-e/passenger km, this causes 21,470 g CO_2-e. averaged over 646 km, this equates to 33 g CO_2-e/passenger km.

International air travel from Canberra typically involves a flight from Canberra to Sydney – nominally 281 km.

Exhaled CO_2-e and Emissions from food production

An intercity flight from Canberra to Melbourne is equivalent to a 646 km drive and takes 65 minutes. This is equivalent to a driving speed of 596.31 km/h.

A 17,000 km international flight from Sydney to London takes 26 hours, equivalent to a driving speed of 653.85 km/h.

At an activity level of 1 MET (Ainsworth et al, 2000), a 70 kg airline passenger exhales 0.48 grams of CO_2 per minute. Production of the food metabolised in that minute causes emissions of 3.12 g CO_2-e.

At a domestic flight speed of 596.31 km/h it takes 0.101 minutes to travel 1 km. At 1 MET this results in exhalation of 0.048 grams of CO_2 per passenger kilometre and food production emissions of 0.315 grams of CO_2 per passenger kilometre.

At an international flight speed of 654 km/h it takes 0.092 minutes to travel 1 km. At 1 MET this results in exhalation of 0.04 grams of CO_2 per passenger kilometre and food production emissions of 0.29 grams of CO_2 per passenger kilometre.

Scheduled public transport involves waiting time, which at 1 MET causes exhalation of 0.48 g CO_2-e per minute and food production emissions of 3.12 g CO_2-e.

A typical domestic flight requires arrival at the airport 45 minutes before departure, and 30 minutes to disembark, collect checked luggage and leave the airport. Those 75 minutes cause exhalation of 36 g CO_2-e and food production emissions of 234 g CO_2-e. averaged over 646 km, these become 0.06 g CO_2-e/km and food production emissions of 0.36 g CO_2-e/km.

A typical international flight requires arrival at the airport 90 minutes before departure, and an hour to disembark, collect checked luggage and leave the airport. Those 150 minutes cause exhalation of 72 g CO_2-e and food production emissions of 468 g CO_2-e. averaged over 17,000 km, these become 0.0042 g CO_2-e/km and food production emissions of 0.0275 g CO_2-e/km.

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32 ABS 3101

Tailpipe emissions

In 2008 Australian domestic aviation provided 56.2 billion passenger km and emitted 6 Mt CO_2-e[33]. This equates to 106.76 grams CO_2-e per passenger kilometre.

In 2007 Australian international aviation provided 205.5 billion passenger km and emitted 9.3 MT CO_2-e[34]. This equates to 45.26 grams CO_2-e per passenger kilometre.

Other emission sources

The following estimates from Dave (2010), based on a Boeing 737 are used for air travel:

Fuel production: 14.3 g CO_2-e/passenger-km
Vehicle manufacture: 2.5 g CO_2-e/passenger-km
Vehicle maintenance: 2.5 g CO_2-e/passenger-km
Infrastructure: 6.8 g CO_2-e/passenger km.

Intercity rail

Canberra has a direct rail link to Sydney that joins the main Melbourne-Sydney line at Goulburn. Rail trips to to the south normally involve a bus link between Canberra and either Cootamundra or Albury.

Distance travelled

In 2003-04 there were 42,000 rail passenger movements between Canberra and Sydney (Gargett, Hossain and McAuley, 2006), a trip with an equivalent road distance of 281 km. Assuming that half of these trips were made by Canberra's 326,000 residents, then their average rail travel was 36 km per year, or 0.099 km per day.

Secondary travel

The average driving distance to Kingston railway station, from five randomly selected Canberra addresses, was found to be 15.1 km. The average driving distance from Sydney's Central Railway Station to five randomly selected Sydney addresses was found to be 35.6 km. The total amount of secondary travel for intercity rail travel is thus estimated as 50.7 km.

Exhaled CO_2-e and Emissions due to food production

Rail travel corresponds to an activity level of 1 MET.

The Canberra-Sydney trip takes 4 hours and 20 minutes. For the equivalent of a 281 km car trip, this is an effective average speed of 64.85 km/h. At that speed a train takes 0.93 minutes to travel a kilometre. This corresponds to 2.90 grams of CO_2-e emissions from food production, and 0.45 grams of exhaled CO_2 per kilometre.

Rail travel typically involves arriving at the station 30 minutes before departure, to check in baggage.

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33 SKM MMA, 2011

34 SKM MMA, 2011

This 30 minute wait results in the exhalation of 14.4 g CO_2-e and food production emissions of 93.6 g CO_2-e. averaged over 281 km, these become 0.05 g CO_2-e/km exhaled and food production emissions of 0.33 g CO_2-e/km.

Tailpipe emissions

Non-urban passenger rail is forecast to provide 2.54 billion passenger km in 2020, and produce greenhouse emissions of 84.27 kt CO_2-e from a mix of diesel and electric energy sources[35].

On this basis, intercity rail travel produces 84.27/2.54 (33.18) grams CO_2-e of direct emissions per kilometre.

Other emission sources

Emissions due to fuel production are estimated at 6.2 g CO_2-e/passenger-km (Dave, 2010, “Bus – on peak”). This was selected in preference to Dave's “light rail” figure of 5 g CO_2-e/passenger-km because intercity rail and buses use diesel fuel, whereas light rail normally uses electricity.

Based on Dave's (2010) “Green Line” estimates, emissions due to vehicle manufacture are estimated at 0.6 g CO_2-e/passenger-km and emissions from vehicle maintenance are estimated at 2.5 g CO_2-e/passenger-km.

Emissions from infrastructure

Emissions from infrastructure are estimated at 54.0 g CO_2-e/passenger-km (Dave, 2010, “Green Line”).

The accuracy of this estimate is uncertain, given that it relates to light rail rather than heavy rail, and that it comes from an apparently un-refereed research paper that provides few details of how the estimate was obtained.

As this figure represents more than half of the total estimated emissions from intercity rail, a more reliable estimate of infrastructure emissions may result in a significant revision of the total emissions estimate.

Intercity coach

Distance travelled

In 2003-04 there were 207,000 coach passenger movements between Canberra and Sydney (Gargett, Hossain and McAuley 2006), a road distance of 281 km. Assuming that half of these trips were made by 326,000 Canberrans[36], the average Canberran travelled 89 km by intercity coach. This is equivalent to 0.24 km per day of coach travel.

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35 SKM MMA, 2011

36 ABS 3101

Secondary travel

The average driving distance to Canberra's Jolimont Centre interstate bus terminal, from five randomly selected Canberra addresses, was found to be 16.6 km. The average driving distance from Sydney's interstate bus terminal in Eddy Avenue (adjacent to Sydney's Central Railway Station) to five randomly selected Sydney addresses was found to be 35.6 km.

The total amount of supplementary driving for intercity coach travel is thus estimated as 52.2 km.

Exhaled CO_2-e and Emissions due to food production

Travelling by bus corresponds to an activity level of 1 MET.

The 281 km trip between Canberra and Sydney takes 3½ hours, at an average speed of 80.29 km/h. At this speed a coach takes 0.75 minutes to travel one kilometre. This corresponds to exhalation of 0.36 grams of CO_2 per kilometre and 2.34 grams of CO_2-e emissions from food production, per kilometre.

Passengers are expected to check in luggage 15 minutes before departure. This waiting time results in exhalation of 7.2 g CO_2 and food production emissions of 46.8 g CO_2. Averaged over 281 km, these are 0.026 g CO_2 and food production emissions of 0.17 g CO_2.

Tailpipe emissions

For intercity buses, tailpipe emissions are assumed to be in the same ratio to Sydney buses as are car emissions from extra-urban car driving, compared with city car driving . Extra-urban car driving consumption of 6.1 litres per 100 km, is 56% of city consumption of 10.8 litres per 100 km. 56% of 0.71 kg CO_2-e per passenger kilometre is 40.24 g CO_2-e per passenger-kilometre.

Other emission sources

The following estimates are based on Dave's (2010) estimates for “Bus – on peak”:

Fuel production: 6.2 g CO_2-e/passenger-km
Vehicle manufacture: 5.0 g CO_2-e/passenger-km
Vehicle maintenance: 0.6 g CO_2-e/passenger-km
Infrastructure: 2.5 g CO_2-e/passenger-km.

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