Mapping CO_2 emission from commuting in regional Australia: Greater Geelong case study

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Abstract

Commuting to work is one of the most important and regular routines of urban transportation. From a geographic perspective, the length of people's commute is influenced, to some degree, by the spatial separation of their home and workplace and the transport infrastructure. The rise of car ownership in Australia has been accompanied by a considerable decrease of public transport use. Increased personal mobility has fuelled the trend of decentralised housing development, mostly without a clear planning for local employment, or alternative means of transportation. As a result, the urban patterns of regional Australia is formed by a complex network of a multitude of small towns, scattered in relatively large areas, which are totally dependent and polarized by few medium and large cities. Such hierarchical and dispersed geographical structure implies significant carbon dioxide emissions from transportation. Transport sector accounts for 14% of Australia's net greenhouse gas emissions, and without further policy action, they are projected to continue to increase.

The aim of this paper is to demonstrate the importance of incorporating urban climate understanding and knowledge into urban planning processes in order to develop cities that are more sustainable. A GIS-based gravity model is employed to examine the travel patterns related to hierarchical and geographical urban region networks, and the derived total carbon emissions, using the Greater Geelong region as a case study. The new challenges presented by climate change bring with them opportunities. In order to fully reach the very challenging targets of carbon reduction in Australia an integrated and strategic vision for urban and regional planning is necessary.

Keywords

Carbon emission; Regional growth; Transport; GIS; and Computer simulation.

1. Introduction

The regional structure of urban Australia is formed by a complex network of a multitude of small towns which are dependent and polarized by few medium and large cities, all dispersed along the coast. According to ABS (2006a), 60% of the Australian population live in only 5 cities with population between 1,200,000 to 5,000,000 inhabitants. On the other hand, there are more than 700 small towns with population between 1,000 to 20,000 inhabitants, where 15% of the Australia's population live.

Over the past 30 years, and more intensely in the last decade, there has been a distinct movement from inland centres and capital cities to attractive non-metropolitan coastal areas, mainly for lifestyle reasons (ABS, 2006b). This process has been coined as *amenity migration* (Gurran et al., 2007). Places likely to attract amenity migrants commonly have high natural and rural scenery values, recreational amenities, a mild climate, and affordable residential land. For some migrants, particularly those who need to retain job connections to a major centre, proximity to metropolitan areas remain an important criterion.

The number of private cars in Australia has risen dramatically. In 1920 there was an average of 71 persons per car in Australia. In 1950, the amount of registered cars increased at a rate above population growth, and this average has declined to 11 persons per car. In 2003 Australia reached an alarming average of 2 persons per car (ABS, 2005). Private vehicles are a dominant force in Australia, result of the higher valuation of freedom and comfort, despite the economical and environmental cost involved, when compared to public transport. For example, over the period 1977-1996, although car prices have increased 2.25 fold and fuel prices have increased 5 fold, the amount of cars per capita has still increased 1.3 fold, with vehicle kilometres per car per annum almost unchanged (Hensher, 1998; Iftekhar and Tapsuwan, 2010). The rise of car ownership in Australia was accompanied by a considerable decrease of public transport use: 50% in the 1950s to 10% from late 1970s (BTRE, 2007).

Such hierarchical and geographical structure, associated with the low density development, housing/jobs imbalance in small towns, and private car mobility characteristics of Australia, implies significant carbon dioxide emissions from transportation.

Australia is one of the many global regions experiencing significant climate change as a result of global emissions of greenhouse gases from human activities. According to EPA, Environment Protection Authority (2011), the transport sector is the second main source of CO_2, which accounts for 14% to 16% net greenhouse gas emissions in Australia. Between 1990 and 2009, CO_2 from the transport sector grew by 35% (DCCEE, 2011). Without further policy action, Australia's emissions are projected to continue to increase.

The Australian Federal Government has released a set of maps showing how sea level rise will affect part of the Australian coast. This was based on a study developed in 2010 by CSIRO, Commonwealth Scientific and Industrial Research Organisation. They developed three scenarios for sea level rise between 2030-2100, considering 0.5, 0.8 and 1.1 metres, relative to the levels in 1990 (AoCI, 2010). The low scenario (0.5 m) considers sea level rise in the context of a global agreement which brings dramatic reductions in global emissions and represents what is likely to be unavoidable. The medium scenario (0.8 m) represents the application of projections suggested by the IPCC's (Intergovernmental Panel on Climate Change) 4th Assessment Report. The high-end scenario (1.1 m) consider the high end risk identified by the IPCC's 4th Assessment Report and also reflects the impacts of recent warming trends beyond those already included in the IPCC's projections. Even in the context of the low scenario, rising seas would submerge large parts of Victoria coastal region.

As a response to this situation, the Government has set targets of 5, 15 or 25% below 2000 levels of greenhouse emissions by 2020. Projections suggest that Australia would need to reduce greenhouse emissions by 160 million tonnes of greenhouse gases per year by 2020 to achieve the minimum target of 5% less emissions than 2000 levels, or by 270 million tonnes of greenhouse gases per year to reduce emissions by 25% less than 2000 levels (DCCEE, 2010).

One of the main actions taken by the Australian Federal Government towards carbon emission reduction is the carbon price policy, which is detailed in the report *Working Together for a Clean Energy Future* (Australian Government, 2011). Starting on 1 July 2012, it will initially affect around 500 of the biggest polluters in Australia, which account for around 60% of Australia's carbon pollution (including electricity generation). Households, smaller businesses and farmers will have no direct obligations under the carbon price. Indeed, petrol is exempt from tax, and households will be compensated financially to cover potential increases in cost of living resulting from the carbon taxation.

The *Low Carbon Growth Plan for Australia* (ClimateWorks, 2010) identified a range of greenhouse abatement opportunities that can be achieved with the carbon price package currently under planning and implementation in Australia. This plan reports estimates of size and costs of emissions reductions opportunities for a range of sectors (power, forestry, industry, building, agriculture, and transport). Carbon price will capture opportunities for which technology and economics are well understood, but not profitable to undertake at the moment. By imposing a cost on emissions, estimates indicated that a quarter of these opportunities can generate a positive economic return for businesses, and another third could be achieved at a low cost.

The same methodology has been applied to the Greater Geelong, identifying the opportunities of emission reduction (ClimateWorks, 2011b). Compared to the national plan, there is a higher proportion of opportunities in the Greater Geelong Region which are profitable (almost half) or low cost (a third), when compared to the national scenario. However, in absolute figures, opportunities for emission abatement in Geelong are more limited, being able to achieve only 14% of the emission reduction by 2020 from 2000 levels. This means that complementary targeted actions are necessary in the Greater Geelong Region to achieve the challenging targets of emission reduction in Australia.

The low carbon growth plan has been reviewed a year later of its first release and production and abatement of emissions in Australia have been updated (ClimateWorks, 2011a). Results suggested that Australia has gone backwards; emissions have actually increased. The update also found that delaying action on climate change would increase the cost to businesses and households by $5.5 billion in order to reach Australia's 5% reduction in 2020 (minimum target). These costs are due to some opportunities being lost forever and some being hard to catch up.

2. Aim of the study

Transport is one of the sectors addressed in the low carbon growth plan. The report indicates the transport sector has the potential to contribute 6% of the 2020 lowest cost emissions reduction opportunity in the Greater Geelong, and that 97% of the total transport abatement potential will also bring net financial savings to the business or households who capture them. Three strategies are listed in the report to reduce emissions from transportation: (a) improving the fuel efficiency of new petrol and diesel vehicles; (b) changing how vehicles are used (eco-driving); and (c) increasing the use of cleaner vehicle technologies (such as hybrid cars and electric vehicles).

The three strategies above are focused on private transportation. Indeed, the report estimates that between now and 2020, Greater Geelong residents and business, following current trends, will purchase 88,850 new cars and light commercial vehicles, 1,950 medium duty trucks and 1,000 large articulated trucks (ClimateWorks, 2011b). The Low Carbon Growth Plans for Australia and Greater Geelong do not challenge the current reliance on private car, or take into consideration potential for greenhouse abatement by increasing the use of public transportation, or other low emission modes. Better fuel efficiency of buses, adoption of eco-driving behaviour by bus drivers, and also the use of new technologies in bus fleet, will certainly result in reduction of greenhouse emissions in the region. However, this impact is limited if the country keeps the trend of increasing the amount of private cars and reducing the use of public transport.

Travel to work, also called commuting, is one of the most important and regular routines of transportation in towns and cities. In New South Wales, Australia, for example, commute represents 16% of the trips, 28% of the distance travelled, and 25% of the time spent in trips; and other work-related trips add 9% of the total trips, 15% of the distance travelled and 12% of the time (TNSW, 2010).

From a geographic perspective, the length of people's commute is influenced, to some degree, by the spatial separation of their home and workplace and the prevailing urban structure. The spatial configuration and local diversity of residences and workplaces in a city is reflective of development patterns conditioned by planners, policy-makers, and private citizens pursuing their varied interests (Horner, 2004). Within this nexus, job-housing balance is a term used to formally describe the relative locations of jobs with respect to housing in a given area (Giuliano and Small, 1993). According to Cervero (1989), a well designed urban area with integrated residential and workplace locations (e.g., a balance between jobs and housing) should promote less commuting. However, increased personal mobility worldwide has fuelled the trend of decentralised housing development, mostly without a clear planning for local employment (Newman and Kenworthy, 2006).

Reaching the very challenging targets of carbon emissions in Australia would involve major changes in the Australian path for continuing growth and development, and an integrated and strategic vision for urban and regional planning. Currently, the regional spatial structure of urban Australia is a trap for itself. At the same time it contributes to worsen the sea level problem by high carbon emissions, it greatly suffers adverse impacts from the problem. This is because the majority of small towns, which are distant from but dependent of larger urban centres, connected mostly by private cars, are located on the coast.

Therefore, transportation in relation to urban and regional growth will certainly have an important role in addressing the reduction of greenhouse emissions, which are not being captured by the new carbon price package, especially considering the exemption on petrol. The aim of this paper is to investigate the interdependencies between urban clusters, regional networks, transportation modes and patterns, and greenhouse emissions, in the context of regional growth in Australia and climate change policies.

3. Methodology: GIS based spatial interaction model for mapping CO_2 emission from commuting

Spatial interaction is a broad term encompassing any movement over space that results from a human process. It includes journey to work, migration, information and commodity flows, utilisation of public and private facilities, etc. They are mathematical formulations that are used to analyse and forecast spatial interaction patterns.

Gravity models are the most widely used types of interaction models (Haynes and Fortheringham, 1984). The gravity model as a concept is of fundamental importance to modern scientific geography because it makes explicit and operational the idea of relative as opposed to absolute location. It can be seen in the application and refinement of the gravity model over the last fifty years (Niedercorn and Ammari, 1987). Its continued use by city planners, transportation analysts, retail location firms, shopping centres investors, land developers, and urban social theorists is without precedent. The reasons for these strong and continuing interests are easy to understand and stem from both theoretical and practical considerations.

The gravity model, which derives its name from an analogy to the gravitational interaction between planetary bodies, appears to capture and interrelate two basic elements: (a) scale impacts (for example, cities with small or large population); and (b) distance impacts (for example, the farther places, people, or activities are apart, the less they interact) (Haynes and Fortheringham, 1984). Gravity model is based on the principle that trip makers choose the trips which provide the greatest net benefit for them as individuals, and that the trip distribution patterns reflects the overall probability of particular trips being chosen on this basis (Cochrane, 1975).

A GIS based spatial interaction model (gravity model) is employed in this research to examine the travel to work patterns related to hierarchical and geographical urban region networks in coastal Australia, and the derived total carbon emissions. This experience combines traditional travel modelling to the examination of the mechanisms of land-use/transport interactions on carbon emissions.

The spatial interaction model within a GIS environment estimates the spatial distribution of trips to work in the study area. The distribution is a probabilistic result of a doubled constrained gravity model. At the origins the number of resident workers is known a priori. At the destinations, the number of employment is also known. Distance between origins and destinations is determined by the shortest path in the major road network, or by the bus routes in the region.

The model assumes that probability of a worker who lives at i to travel to work at j (P_{ij}) is dependent on the attractiveness of j (A_j), in terms of employment, and the distance between i and j (d_{ij}). The probability grows with the increase of attractiveness of destination, and declines with the increase of the distance between origin and destination. The decay function is regulated by an exponent (β). The higher the exponent, the lower the willingness of workers to commute longer distances. Moreover, P_{ij} for a specific destination j is also dependent of the comparison between all other destination alternatives, considering their attractiveness and relative distances. This is mathematically expressed in Equation 1.

$$P_{ij} = \frac{A_j \times d_{ij}^{-\beta}}{\sum_{j=1}^{n} A_j \times d_{ij}^{-\beta}} \qquad \text{Equation 1}$$

The number of workers who live in i and travel to work at j (W_{ijm}) by transport mode x (private car as a driver; or public transport) is calculated by multiplying the probability of a worker who live in i and travel to work at j (P_{ij}), obtained from the spatial interaction model, to the total number of resident workers in i (w_i), and by the rate of trips to work by mode of transport for the origin i (R_i), where the workers live. This is shown in Equation 2.

$$\left(W_{ij}\right)_x = P_{ij} \times w_i \times (R_i)_x \qquad \text{Equation 2}$$

From this point, there are two different models to distribute workers across space in their trips to work (private transport model, and the public transport model). Workers using private cars will be distributed by a network analysis function based on the shortest distance, using the main road network in the region. For the public transport system, the routes are already defined, as well as the timetable of the trips.

For the case of private cars as driver as a mode of transport, W_{ij} represents the number of private vehicles involved in trips to work between origin i and destination j. Based on the assessment of the shortest routes between origins and destinations in the major road network, the GIS distributes the number of vehicles in each road segment, accumulating the flow. V_k represents the number of private vehicles at road segment k related to trips to work between all origins i and all destinations j (Equation 3).

$$V_k = \left(\sum_{i,j=1}^{i,j=m,n} W_{ij}\right)_k \qquad \text{Equation 3}$$

The quantity of fuel consumption by type of fuel f at road segment k (Q_{fk}) can be estimated by the spatial distribution of private vehicles on the road network (Equation 4). It is the result of the number of vehicles in the road segment *k* (V_k), multiplied by 2, to consider commuting return trips, and multiplied by the proportion of cars which use fuel *f* (T_f). It also includes the average fuel consumption (litre/100 km) of cars with fuel *f* (c_f) and the length of road segment *k* in metres (l_k); *100,000* is the unit adjustment factor to provide a result in litres of fuel.

$$Q_{fk} = (V_k \times 2) \times T_f \times \frac{(c_f \times l_k)}{100{,}000} \qquad \text{Equation 4}$$

From private cars, the emissions of gas *g* from fuel type *f* (PrE_{gf}) can now be estimated based on the fuel consumption and distribution. It is obtained by multiplying the quantity of fuel type *f* consumed, to the energy content factor of fuel type *f* (EC_f) and to the emission factor for the gas *g* for fuel type *f* (EF_{gf}). In the research we focused on carbon dioxide (CO_2), since 72% of the greenhouse emissions are made up of CO_2. This calculation is made for each road segment *k*, and the result is in Kg CO_2. Equation 5 and respective parameters are based on DCCEE's National Greenhouse Account Factors Report (DCCEE, 2010).

$$\left(PrE_{gf}\right)_k = \left(\frac{Q_f \times EC_f \times EF_{gf}}{1{,}000}\right)_k \qquad \text{Equation 5}$$

Table 1 presents these parameters for the Australian context.

Table 1. Australia's national parameters related to motor vehicles/private cars use related to fuel type

Fuel type f	% passenger cars[+]	Average fuel consumption (l/100km)[¤]	Energy Content Factor EC_f (GJ/kL)[*]	Emission factor EF_{gf} for CO_2 (Kg CO_2/GJ)[*]
Gasoline	83	11.4	34.2	66.7
Diesel	11	24.5	38.6	69.2
LPG/other	6	16.7	26.2	59.6

Sources: [+] ABS (2011), [¤] ABS (2008), [*] DCCEE (2011).

In the public transport model, the estimated emissions from the bus fleet related to commuting is obtained by mapping and inventorying all bus routes during commuting time, morning and evening. This provides an account for the total distance travelled by the fleet and also its spatial distribution.

For the public transport system, carbon dioxide emissions from diesel buses (*PuE*) are estimated based on the fuel consumption, distance travelled by bus, and the emission rate for urban buses. Since the distribution of bus routes have been performed in a GIS, different levels of emissions are obtained across the region under study. For each road segment *k*, PuE_k is obtained by multiplying the number of bus routes during commuting hours (*B*), to the length of road segment *k* (*D*), to the fuel consumption rate (*F*, in l/km), to the rate of carbon dioxide emissions (*R*, in Kg CO_2/l). This calculation is made for each road segment *k*, and the result is in Kg CO_2 (Equation 6). Based on Leung (2010), we adopted the following parameters: type of fuel diesel; fuel consumption of 0.465 l/km; and rate of emissions of 2.639 Kg CO_2/l.

$$(PuE)_k = (B\ x\ D\ x\ F\ x\ R)_k \qquad \text{Equation 6}$$

The total amount of CO_2 emissions for each road segment k related to commuting was obtained by summing the emissions from private cars involved in trips to work and public transport during commuting hours, as expressed in Equation 7.

$$(TE)_k = (PrE + PuE)_k \qquad \text{Equation 7}$$

4. Case Study

4.1 Description of the context

The area under study includes Greater Geelong Region, Bellarine Peninsula, and a small part of the Surf Coast, which we named here as the Extended Greater Geelong Region (Figure 1). This is the second most populated region of Victoria in Australia. This area is a good example of the typical Australian scattered pattern of regional development along the coast. According to the demographic census of 2006, Geelong is the central city, with 161,000 inhabitants, and there are another twelve urban settlements in the surroundings with population varying from a minimum of 589 inhabitants to a maximum of 11,274 inhabitants (ABS, 2006a).

The whole region has a total population of 223,785, being the total labour force in the region formed by 91,909 workers, and 86,105 of them are currently employed workers. Total employment in the region is 80,154. There is a deficit of employment opportunities in the region. Jobs are not only unevenly distributed across the towns, and concentrated in parts of Geelong, but also almost 6,000 workers need to travel out of the region to access work opportunities.

This situation is highly concerning, since the Greater Geelong region is seen by the State and Federal Governments as one of the major areas for accommodating population growth in Victoria in the next decades. There are estimates that the population will double by 2050 (G21, 2007), and the almost 100,000 new vehicles will be purchased by 2020 in the region (ClimateWorks, 2011b). A new development for 50,000 new residents in the Armstrong Creek area, in the south of Geelong, has just been launched in 2010.

Such configuration makes it necessary for the workers to travel longer distances to access jobs. There is an average of 24 km separating the towns of the region, which would totalise almost 50 km in a return-based commuting trip.

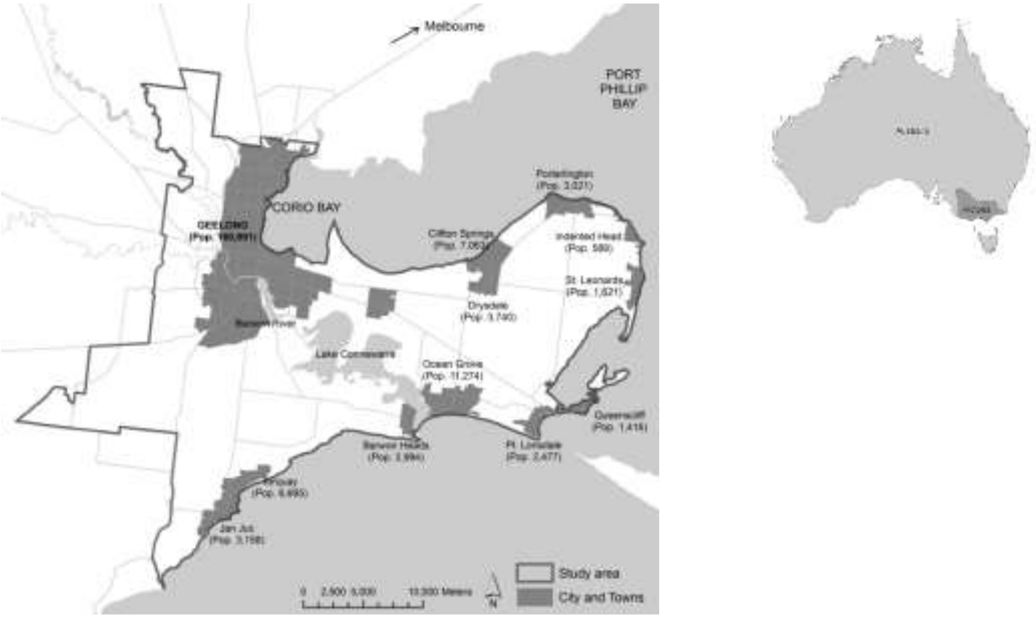


Figure 1. Study area: Extended Greater Geelong Region

There is high reliance on private transportation as the preferred means of transportation for work in the region (Table 2). In average, 65.2% of the employed workers in the region use private car as a driver to go to work; 4.3% go by private car as a passenger; only 1% uses public transport; and 3.8% walk or cycle to work. This is the result of the combination of the region income (57% of population has a weekly income of $1,000 or higher), and vehicle ownership (only 5.3% of the households have no cars; 34.8% have one car; 40.7% have 2 cars; 16.1% have 3 or more cars). Considering that 46% of the households are composed by couples with no children, there is an average of 1.35 persons by car in the region (ABS, 2006a).

Table 2. Mode of travel to work in the extended Greater Geelong Region

Town/City	Population	Employed resident workers	Jobs	Mode of travel to work (%)				
				Car as driver	Car as passenger	Public transport +	Bicycle or walk	Other private ++
Barwon Heads	2,994	1,364	720	64.0	4.4	1.0	4.8	1.6
Clifton Springs	7,063	3,029	1,310	72.0	5.2	0.9	0.9	2.0
Drysdale	3,740	1,294	502	65.4	4.5	1.3	3.2	1.9
Indented Head	589	191	94	70.1	2.1	1.5	1.5	0.0
Jan Juc	3,158	1,646	1,298	66.0	4.9	1.1	2.6	0.8
Leopold	8,746	3,873	5,653	71.3	4.7	1.5	1.6	1.1
Ocean Grove	11,274	5,303	5,654	65.4	5.1	1.1	3.3	1.3
Point Lonsdale	2,477	910	863	59.6	5.2	0.7	6.1	2.0
Portarlington	3,021	858	401	61.5	4.0	0.7	4.6	1.6
Queenscliff	1,1416	548	444	54.4	2.9	0.0	13.0	2.0
St. Leonards	1,621	448	212	67.7	4.6	1.3	3.3	2.4
Torquay	6,695	3,174	2,120	68.4	4.3	0.8	4.5	0.6
Geelong Region:	160,991	63,467		65.9	5.7	2.7	4.9	1.1
Geelong 1/Newtown			3,722					
Geelong 2/Newcomb			24,147					
Geelong 3/Man. Heights			4,865					
Geelong 4/Corio			17,597					
Geelong 5/Grovedale			10,552					
Region Average	223,785	86,105	80,154	65.2	4.3	1.0	3.8	1.7

+ Bus, train, tram, etc.; ++ Truck, motorbike, etc. (Source: ABS, 2006a)

4.2 Spatial interaction model: Estimating the number of trips to work

Based on data from the 2006 Demographic Census, we located the amount of resident employed workers by Census District (CD) in the study area, and the number of people employed in each Statistical Local Area (SLA), as a measurement of existing employment opportunities (Figure 2).

This information was processed by a spatial interaction model within a GIS, in order to estimate the trips-to-work distribution across the region (Equation 1). Taking into account the current lack of surveying data on real journeys-to-work in the region to calibrate de model, different power exponent (β) were tested for the distance decay function ($\beta = -2, -1.5, -1$).

When $\beta = -2$ and $\beta = -1.5$ were used, the model simulation could not reach a solution, overestimating short trips and underestimating long trips. This was caused by the fact these exponents reflected on higher 'friction' for commuting, estimating a number of local workers working close to home larger than the existing employment opportunities. $\beta = -1$ resulted in a good fit. It estimated a number of workers arriving at each job destination compatible with the existing employment opportunities in the destination zones. The lower the exponent, the lower is the "friction" between locations. In this case, for lower exponents, long trips become more probable to occur. It means that for the regional configuration of Extended Greater Geelong, workers are less resistant to commute long distances.

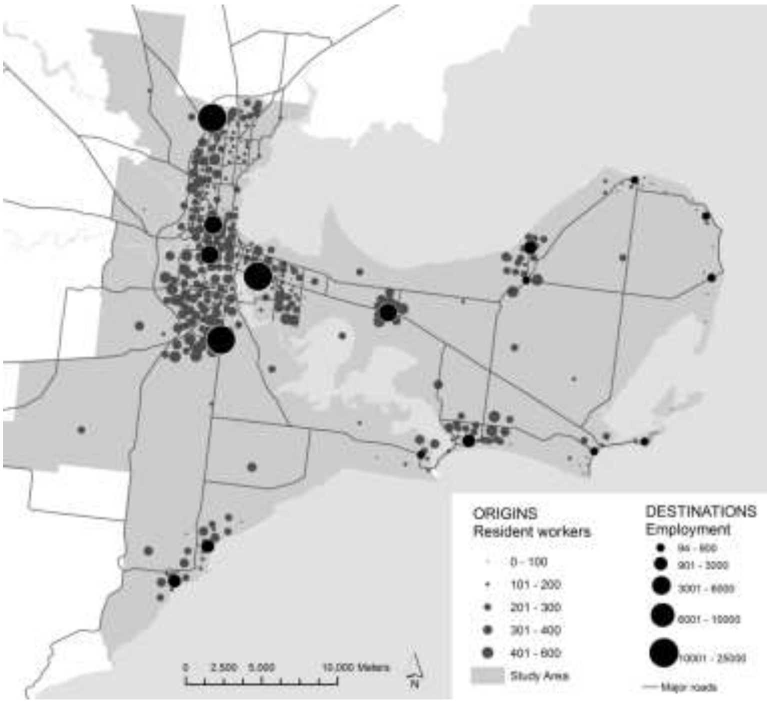


Figure 2. Origins and destinations for journeys to work in the extended Greater Geelong Region

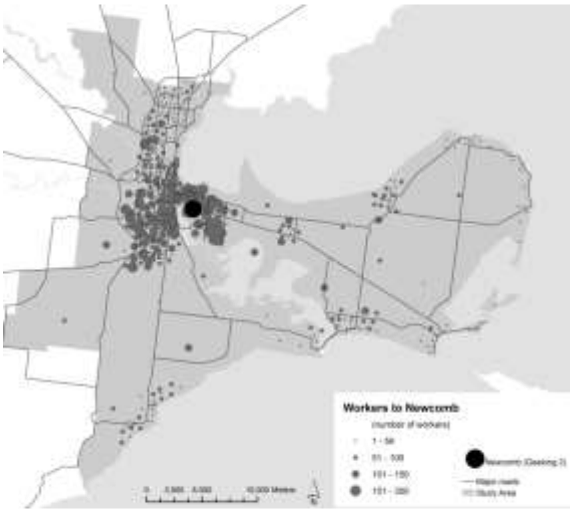
Appendix 1 presents the shortest distance between cities and towns in the extended Greater Geelong region, and Appendix 2 presents the Origin-Destination Matrix estimated in this study for all modes of transportation in the area. The model allocated 93% of the workers of the region among job opportunities in the region. This is consistent with the fact that 7% of the employed population need to access jobs out of the region. The difference between estimated population commuting to jobs within the region and the total amount of resident workers in the region, for each town, has been stores in the “other” area in Appendix 1, which represents job opportunities out of the study area.

4.3 Private Transport Model:

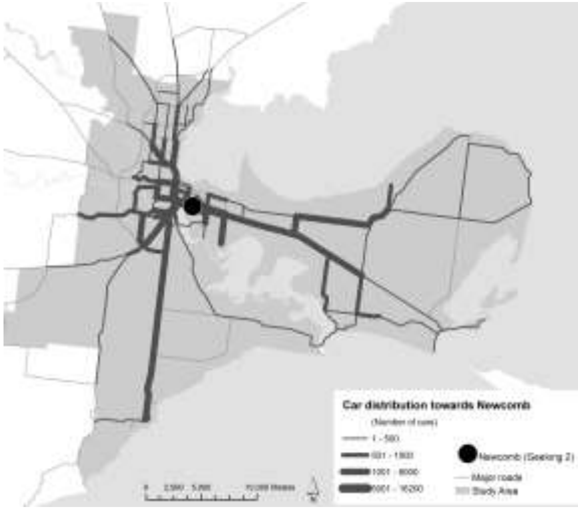
4.3.1 Spatial distribution of trips to work by private car

Based on the estimated flow of workers between origins and destinations obtained from the spatial interaction model, and the rate of private car as a mode of transportation to work for each CD, we estimated the total amount of workers arriving at each job destination (Equation 2).

Using network analysis in a GIS environment, the trips to work were distributed in the major road network. For each pair of origin-destination alternative, the shortest route is identified, and the road segments contained in the route receive the attribute of the number of vehicles. This attribution is accumulated, when the road segment is used for more than one origin and more than one destination (Equation 3). Figure 3 illustrates the results for the destination *Geelong 2/Newcomb*, which is the main employment centre in Geelong area (30% of the total jobs of the region). Figure 3 (a) shows the distribution of the place of residence of workers in the region who travel to Geelong2/Newcomb for work. It is possible to see that most of the workers come from nearby; however, there are also a significant amount of workers from very distant locations. This is due to many factors. First, the power of attraction of Geelong 2/Newcomb is high. Moreover, Geelong 2/Newcomb is located in a central position within the region. And finally, there are not enough jobs for the workers who live in the small distant towns. Therefore, the radius of influence of this job destination spreads over long distance. Figure 3 (b) presents the distribution of private vehicles on the road network towards Geelong 2/Newcomb for work.



(a) Place of residency of people who works in Geelong 2 (Newcomb)



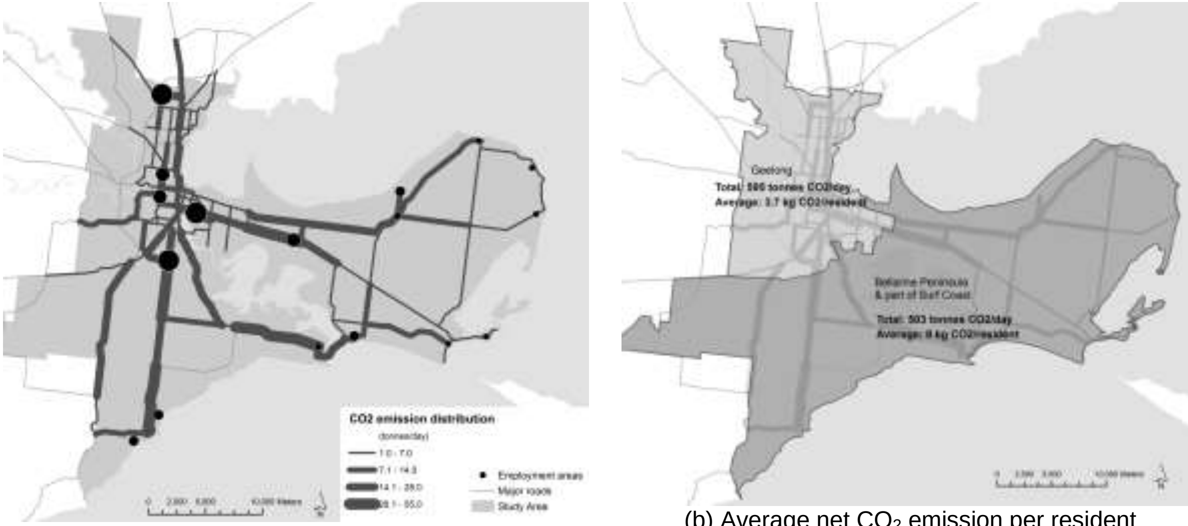
(b) Private vehicles commuting to Geelong 2 (Newcomb)

Figure 3. Trips to work towards Geelong 2/Newcomb

4.3.2 Fuel consumption and CO_2 emissions from work trips by private car

Applying Equation 4 in the GIS, we converted the quantity of vehicles by road segment to the amount of fuel consumption. The model estimated that in the extended Greater Geelong region a total of 1,780,635 km are travelled daily by workers commuting to their jobs by private car, an average of 30.7 km/private vehicle. The model also indicated that there is a daily total consumption of 168 KL of gasoline, 48 KL of diesel and 18 KL of LPG or other fuel in the region related to these commuting trips. Based on spatial distribution of vehicles, fuel consumption, and other technical parameters, Equation 5 estimated a total of 1,097 tonnes of CO_2 discharged daily in the region as a result of the commuting to work trips by private car.

Figure 4 (a) shows the potential distribution of the emissions over the transportation network. It is possible to perceive that high levels of CO_2 emission are spread all over the region, and not only concentrated in the city of Geelong, where most of the population of the region live. Figure 4(b) analyses these emissions separating the main city to the area of the small towns, and relates them to the resident population. There is an average of 3.7 Kg of CO_2/person in Geelong city, when we divide the net emission from commuting estimated by the model in the road network within the boundaries of the city, by the population resident in the city. This rate increases 2.2 fold, to 8 kg of CO_2/person, when the rest of the region, outside the boundaries of Geelong City, is considered. This is because, although only a quarter of the population of the region live in the small towns, many long-journeys by private car are performed daily in order to access jobs in the region, especially in Geelong, which result in 46% of the net emissions from commuting.



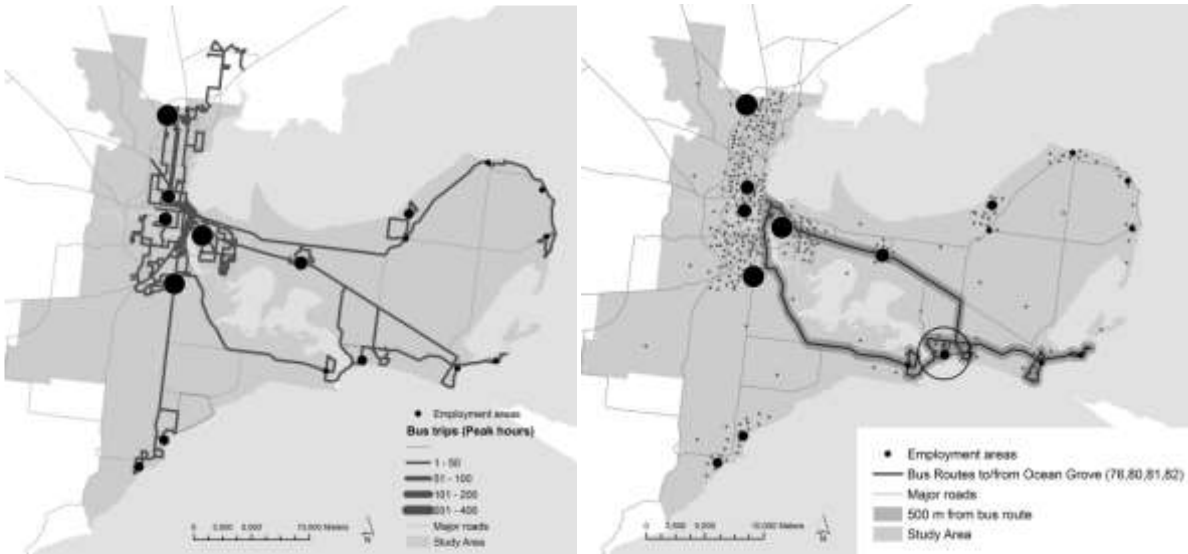
(a) Spatial distribution of CO_2 emission (b) Average net CO_2 emission per resident

Figure 4. CO_2 emissions from commuting trips by private cars in the extended Greater Geelong

4.4 Public Transport Model:

4.4.1 Spatial distribution trips to work by bus

The extended Greater Geelong region is serviced by 28 bus routes, which link different suburbs and towns through 1,088 trips a day and a total of 20,000 km/day, from Monday to Friday. 428 trips a day and a total 8,000 km/day are related to commuting, since they occur during peak hours in the morning (6 to 9 am) and the evening (4 to 7 pm). Existing bus routes vary from a minimum of 8.5 km to a maximum of 48 km. Figure 5(a) presents the connections by bus in the extended Greater Geelong region, indicating the number of bus trips during peak hours. Figure 5(b) provides an example of the bus routes to/from Ocean Grove.



(a) Bus routes and bus trips in peak hours (b) Bus routes to/from Ocean Grove

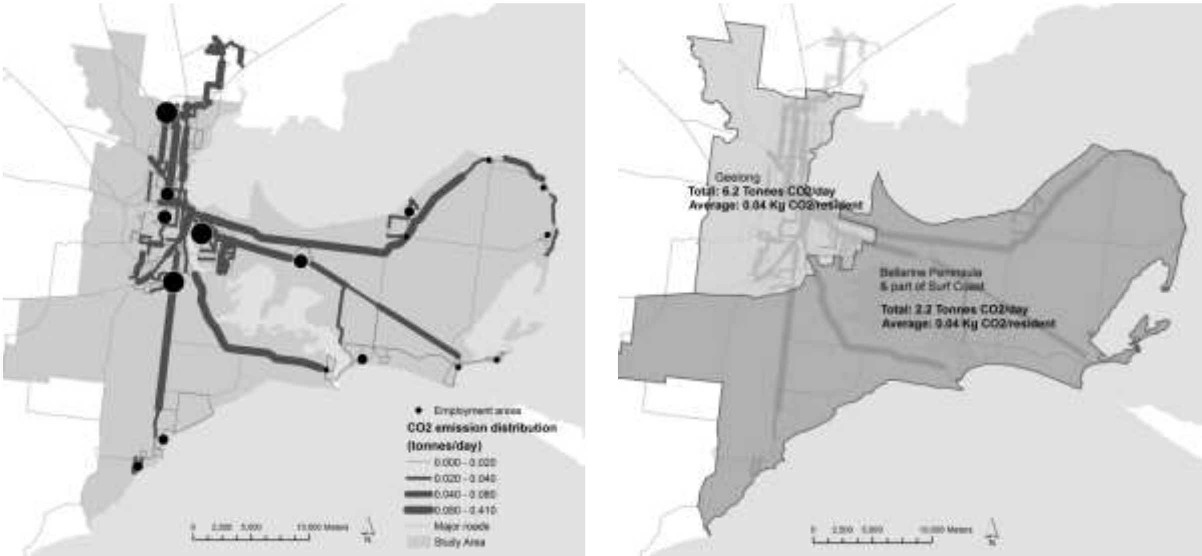
Figure 5. Connections by bus routes in the Extended Greater Geelong Region

4.4.2 Spatial distribution of CO_2 emissions from bus during commuting hours

Figure 6 (a) presents the spatial distribution of CO_2 emissions generated by bus trips in commuting hours in the study area. The estimated emissions were obtained through Equation 6, which considered the bus routes in the study area, the number of trips during commuting hours, and some other parameters, such as type of fuel, fuel consumption and rate of emissions for the vehicles. All the buses in the study area, during the peak hours produce a total of 9,020 Kg of CO2 emissions per day.

Currently, 1,160 workers use bus as the preferred means for transportation. It results in an average of 7.8 Kg of CO_2/worker-day.

Figure 6(b) analyses these emissions separating the main city to the area of the small towns, and relates them to the resident population. For the public transport system, the concentration of population in Geelong (75% of the residents of the region) was proportional to the CO_2 emissions by bus during commuting hours (74% of the total emission in the region). This is consistent with the fact that public transport outside Geelong is less frequent, with a reduced amount of trips, despite of the long distances of the routes. When the level of emission within the two regions is divided by the respective resident population, the same rate has been found: 0.04 Kg CO_2/resident. This rate is very low compared to the rate from private cars because of the low use of public transport in the region.



(a) Spatial distribution of CO_2 emission (b) Average net CO_2 emission per resident

Figure 6. CO_2 emissions from commuting trips by public transport in the extended Greater Geelong

4.4.3 Effect of increasing the use of existing public transport capacity in the region

Only 1.35% of trips to work are made by public transport in the region, involving a total of 1,160 workers daily. The existing fleet, however, considering only seated passengers (40 passengers/bus) during the peak hours, would allow the transportation of 8,560 workers. Using this higher capacity, the use of bus as a mode of transport could increase from 1.35% to 7.40% and the emissions per worker using public transport could decrease from 7.80 Kg of CO_2/worker-day to 1.05 Kg of CO_2/worker-day. Moreover, this increase in the use of buses could potentially reduce around 8,560 private cars commuting to work daily, and consequently, reduce approximately 170 tonnes of CO_2 emissions/day from them, which represent a reduction of 14%. Table 3 summarises the current situation and the scenario of increased use of the existing public bus infrastructure in the region.

The results presented here indicate that emissions from commuting by public transportation are significantly lower than those from commuting by private car, and emphasise that there are opportunities for large abatement in the CO_2 emissions from the transportation sector related to efforts in increasing the use of existing public transportation system.

Changing the pattern of transport mode, however, from private to public, is not an easy task. Increasing the proportional use of public transport in Australia is in the research agenda, and different aspects have been considered, such as the factors affecting people's decision making on mode of transportation, and also the analysis of performance of existing public transport systems (VIC, 2008).

Table 3. Carbon dioxide emissions from private and public transport, current situation and higher use of existing bus infrastructure in the extended Greater Geelong Region

		Private Vehicles	Public Bus	Total
A. Current situation	Workers	62,611	1,160	63,771
	% Workers	98%	2%	
	Emissions tonnes CO_2/day	1,097	9	1,106
	Emissions Kg CO_2 /worker-day	17.5	7.8	
B. Improved use of existing bus capacity	Workers	54,051	8,560	63,771
	% Workers	87%	13%	
	Emissions tonnes CO_2 /day	935	9	956
	Emissions Kg CO_2 /worker-day	17.3	1.0	
Reduction of emissions (A – B)	(tonnes CO_2 /day)			- 171

Murray (2001) emphasises that the growth of the use of public transport will be achieved only by improving the performance of the system, which would involve reduction in travel time, increased service access, enhanced travel comfort, and more effective price structures. Using a GIS based model to analyse the bus transport system in Brisbane, Australia, Murray (2001) demonstrated that an optimised bus stop placement in the region, with a reduction of a large number of bus stops, could significantly reduce the travel time of the bus routes in the region by requiring less stops, while maintaining the same existing level of accessibility.

5. Discussion and Conclusions

The mutually reinforcing interdependency between urban land and urban transportation is one of the most significant structural relationships for planning and management of regions (Wegener, 2004). The development of urban land creates traffic and increases demand for transportation facility investments. Transportation facility investments encourage urban land development, and so on.

This paper has presented the findings of the first phase of a research focused on analysing the interdependencies between regional growth, networks, transportation modes and patterns, greenhouse emissions and climate change. The current situation of the extended Greater Geelong has been characterised in terms of carbon emissions from commuting by private and public transport as a result of the fragmented regional pattern. Results indicate, in measurable figures, the high level of regional spread of urbanisation, intensive dependence of small town on regional centres in terms of employment, and the consequent significant amount of long-distance commuting trips and CO_2 emissions. Most important, by spatially allocating the emissions from commuting as a result of the current patterns of housing, employment and transportation, it was possible to identify the unfair distribution of pollution. This is due to the fact that the less urbanised and most environmentally sensitive area of the region under analysis is exactly the most affected by CO_2 emissions in a per capita basis. It refers to the population of the Bellarine Peninsula and part of the Surf Coast.

Climate change is of particular concern in Australia, which combines large carbon emissions with high levels of urbanisation on the coast. Currently Australia is the biggest carbon emitter in the world in a per capita basis, over 80% of Australians live in urban settlements, and more than 86% of the population live by the coast.

In terms of policies for climate change in Australia, the recent new Department for Climate Change and Energy Efficiency (DCCEE) has the goal to coordinate the response to climate change nationally, with the involvement of all levels of government. In relation to urban settlements and climate change, there are several relevant DCCEE initiatives: the coastal vulnerability program; the local adaptation pathways program; the integrated assessment of settlements subprogram; the national climate change adaptation research on settlements and infrastructure; and the climate change adaptation skills for professions program, including for urban planning and design professionals.

Integrated urban and regional planning is a key objective expressed in international planning and climate change policy statements. The co-location of housing, transport, employment, education, recreation provides social, economic and environmental benefits. In the context of climate change, reducing the environmental impact of journeys to work and developing a low carbon built environment are important contributions to reducing emissions. Cities are being built and rebuilt every day. The challenge is to identify strategic interventions that can be made to effectively integrate climate change policy in urban and regional planning systems and vice-versa.

The new challenges presented by climate change have significant implications for the future design of cities and towns, and their regional connections. They bring with them opportunities to rethink how we can manage future urban and regional growth. Federal, State and Local governments in Australia are aware of this, and many initiatives, plans and policies are currently under discussion or in early phase of development. Future strategies will involve a mix of mitigation and adaptation measures. Research and skills development in the field of urban climate change, needs to be addressed so that decision makers are supported appropriately. We need new a suite of measures to build more resilient urban settlements and communities, including urban planning and management responses.

However, historically, urban and regional planning in Australia has been managed by state and territory, and local governments, without a unified national framework. A fragmented regulation system is formed by an extensive range of urban planning and environmental policies from different government levels to rule the design and structure of Australian cities and regions. Planning and management practices and policies for urban development and climate change have been not properly articulated in the different levels of government. Only recently the Australian Government re-engaged directly with the national urban and city policy. The Council of Australian Governments (COAG) has established in the end of 2009 a set of national criteria for future strategic planning of capital cities, and a statement for national disaster resilience. Another step in the direction of integration is the report *Our Cities, Our Future – A national urban policy for a productive, sustainable and liveable future* (DIT, 2011), which identifies the lack of horizontal and vertical integration of urban policy, between different agencies and non-government bodies and between different levels of government as a barrier to planning for change, and the need to articulate actions.

This study contributes to the climate change research agenda in terms of theme, methodology and scope. For the theme, better understanding of the interdependencies between patterns of urban-regional development and greenhouse emissions is needed in order to devise better planning and design solutions for urban growth and regional development. In terms of methodology, geographical information systems and computer simulation models can be important platforms for developing models to assist professionals and decision-makers to test and assess alternative scenarios prior to development. Such platforms can be used as learning and collaborative environments for planning and design towards sustainability among stakeholders and decision-makers. In terms of scope, this project directly relates scientific development of knowledge and technology with the current political context of urbanisation and climate change. Future research will address some potential improvements, such as the calibration of the gravity model using survey on origin-destination of travels to work. It will also involve the development and assessment of the impacts of scenarios of different configuration of regional growth/transport network/modes of transportation. Finally, such spatial patterns of different scenarios will be related in future research to the ecological mapping of the sensitive areas of the Bellarine Peninsula and Victoria's coastline.

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Appendix 1. Matrix of shortest distance between cities and towns in the extended Greater Geelong Region (km)

Town/City		BH	CS	DR	G1	G2	G3	G4	G5	IH	JJ	LE	OG	PL	PO	QC	SL	TO	Melbourne CBD
Barwon Heads	BH	---																	97.1
Clifton Springs	CS	17.3	---																95.6
Drysdale	DR	16.6	1.3	---															94.2
Geelong 1/Newtown	G1	22.6	23.1	21.7	---														75.4
Geelong 2/Newcomb	G2	21.7	19.1	17.7	5.8	---													78.2
Geelong 3/Manifold Heights	G3	25.6	24.0	22.7	3.0	6.7	---												76.4
Geelong 4/Corio	G4	31.3	29.7	28.4	9.5	12.4	8.6	---											67.3
Geelong 5/Grovedale	G5	20.6	27.7	26.3	7.2	9.1	8.9	22.2	---										85.7
Indented Head	IH	32.4	17.9	17.2	38.9	35.0	39.9	45.6	43.5	---									111.4
Jan Juc	JJ	28.1	45.7	44.4	23.9	25.8	26.4	43.3	19.9	60.4	---								106.9
Leopold	LE	14.7	12.2	11.3	12.7	7.8	14.4	20.1	15.9	28.5	33.1	---							86.0
Ocean Grove	OG	4.0	14.0	13.3	26.3	19.3	27.1	35.0	24.4	33.4	31.9	12.4	---						100.9
Point Lonsdale	PL	14.8	18.7	18.0	30.7	25.7	33.5	39.2	33.9	24.1	42.8	18.8	11.6	---					105.0
Portarlington	PO	26.4	9.4	10.0	31.7	27.8	32.7	38.4	36.4	6.8	54.4	21.3	23.0	21.4	---				104.2
Queenscliff	QC	18.5	20.5	19.8	32.5	27.5	35.3	41.0	35.7	25.9	46.0	20.5	18.6	5.5	23.2	---			106.8
St. Leonards	SL	28.6	14.1	13.5	35.2	31.2	36.2	41.8	39.8	3.7	56.6	24.8	29.7	20.4	10.6	22.2	---		107.7
Torquay	TO	24.4	40.3	39.7	20.2	22.1	22.7	28.9	16.1	56.5	4.2	29.2	28.1	39.0	49.4	42.6	52.8	---	101.6

Appendix 2. Origin-Destination Matrix in the extended Greater Geelong Region, all modes of transportation

Town/City	Dest.	Origins																	SUM (Jobs)
		BH	CS	DR	G1	G2	G3	G4	G5	IH	JJ	LE	OG	PL	PO	QC	SL	TO	
Barwon Heads	BH	217	23	14	21	51	20	21	88	1	11	29	159	12	8	7	5	33	720
Clifton Springs	CS	15	700	121	30	58	33	55	76	6	11	39	70	14	34	11	16	21	1,310
Drysdale	DR	8	151	154	5	18	2	14	39	3	4	16	43	7	14	5	8	11	502
Geelong 1	G1	27	60	28	1,163	527	551	340	716	4	33	64	84	17	20	11	8	69	3,722
Geelong 2	G2	259	550	271	2,754	7,982	2,013	1,580	5,886	37	277	715	794	144	177	33	92	583	24,147
Geelong 3	G3	32	128	38	884	553	1,715	533	593	6	41	80	106	20	28	15	11	82	4,865
Geelong 4	G4	148	413	191	1,116	1,344	1,832	8,680	2,121	31	181	345	496	100	153	27	74	345	17,597
Geelong 5	G5	114	195	97	773	1,224	491	587	5,826	14	148	238	326	59	65	32	33	330	10,552
Indented Head	IH	1	12	8	0	6	0	0	3	34	0	5	6	3	10	1	5	0	94
Jan Juc	JJ	15	21	12	53	64	50	44	134	1	555	19	43	9	8	1	5	264	1,298
Leopold	LE	116	275	151	261	696	277	334	693	15	69	1,995	415	59	68	45	37	147	5,653
Ocean Grove	OG	300	181	101	339	497	331	384	358	14	70	196	2,467	113	54	69	35	145	5,654
Point Lonsdale	PL	29	61	31	18	37	15	22	62	4	11	31	106	301	12	87	10	26	863
Portarlington	PO	6	93	18	2	9	0	4	9	8	7	15	29	4	167	9	14	7	401
Queenscliff	QC	11	25	13	17	28	0	2	31	2	7	13	53	30	11	181	9	11	444
St. Leonards	SL	3	67	18	0	0	0	0	0	8	0	0	16	2	14	6	78	0	212
Torquay	TO	29	40	19	79	153	74	79	242	3	189	36	80	16	15	8	8	1,050	2,120
Other		34	34	9	916	842	1,169	1,478	1,340	0	32	37	10	0	0	0	0	50	5,951
SUM (Workers)		1,364	3,029	1,294	8,431	14,089	8,573	14,157	18,217	191	1,646	3,873	5,303	910	858	548	448	3,174	86,105