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Socio-economic spatial characteristics and household transport greenhouse gas emissions: a Sydney case study

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Abstract

Different population subgroups, described by various spatial, socio-economic, demographic and other personal and household characteristics, produce different levels of greenhouse gas (GHG) emissions from daily travel. We examined the effects of a variety of socioeconomic spatial characteristics on household transport GHG emissions in the Sydney Metropolitan Area.

Descriptive analysis showed that only a small proportion of households accounted for the majority of transport GHG emissions in Sydney. Detailed statistical analysis and multivariate regression models showed that car ownership, number of drivers, household size, number of workers, household income and distance to the central business district (CBD) had statistically significant and positive effects on household travel GHG emissions, while population density and land use mix in the community where households were located both had statistically significant and negative influences on travel emissions.

The results suggest that transport GHG reduction policies should target commuting trips and high income households to effectively achieve policy objectives. In addition, policies targeting households from the highest emission quintile could efficiently reduce transport emissions in Sydney. This study indicated that socio-economic disadvantage should be taken into consideration when making emission reduction transport policies.

1. Introduction

In Australia, the transportation sector is responsible for approximately 14.4% of GHG emissions, with road transport accounting for 89.2%, and its share in overall emissions has been increasing (AGO, 2007). To limit climate change, policy makers are looking for strategies to reduce road transport emissions. Consequently, there is a need to undertake research in Australia to reveal what factors and to what extent these factors impact household travel GHG emissions to provide an evidence base for policy makers.

So far, many studies have been undertaken to investigate the factors that impact urban passenger travel behaviour and the resulting energy consumption and GHG emissions in Australian cities (e.g. Corpuz et al., 2006; Alford et al., 2008; Rickwood, 2009; Ellis et al., 2010; Paez et al., 2010; Raimond et al., 2010; Shin et al., 2010; Silva et al., 2010; Wiblin, 2010; Woodruff et al., 2010; Xu et al., 2010; Burke et al., 2011; Li et al., 2011; Silva et al., 2011; Mckibbin, 2011; Tsang et al., 2011; Hay et al., 2012; Shobeirinejad et al., 2012; Tsai et al., 2012). However, several research gaps still exist. Firstly, most studies have assessed the effect of household or personal socio-economic and spatial characteristics on only a subset of travel behaviours that affect GHG emissions, rather than GHG emissions itself. For instance, some studies have evaluated the effect of household characteristics on the number or type of vehicles owned, while others have evaluated the effect on travel mode choice or on vehicle kilometres travelled (VKT). In terms of travel purposes, most studies have only examined the effect on one travel purpose such as commuting, while few studies have estimated the effect on all travel purposes. Secondly, most studies have conducted analysis at aggregate levels (i.e. whole urban area, Statistical Local Area, Local Government Area and Travel Zone as the smallest unit), with few studies conducting analysis at disaggregated levels (i.e. personal and household). Analysis conducted at aggregate levels can mask important information because households living in the same community may have very different socio-economic attributes and present very different emission patterns. Therefore, much still remains to be known in Australian cities regarding GHG profiles of the population and which segments of the population are contributing most to the problem.

This present research attempted to tackle the above mentioned shortcomings. The main aim of this study was to calculate transport GHG emissions at the household level for a sample of 6541 households in the Sydney Metropolitan Area and investigate the effects of a variety of socio-economic spatial characteristics on household transport GHG emissions. The specific objectives of this paper were to: (1) develop a detailed methodology to calculate GHG emissions using Household Travel Survey data and considering all travel purposes and all travel modes; (2) investigate the relationship between GHG emissions and a variety of socio-economic spatial characteristics using descriptive analysis and multivariate regression model; and, (3) raise some policy implications for reduction of passenger travel GHG emissions in Sydney.

The paper is structured as follows: relevant literature is reviewed in Section 2, data and methods are described in Section 3, results are discussed in Sections 4 and 5, and conclusions and discussions based on the results are found in Section 6.

2. Socio-economic spatial factors that may influence household travel GHG emissions

The literature on travel behaviour points out that household socio-economic characteristics, and locational and land use factors impact household travel behaviour such as travel mode choice and VKT (Cervero et al., 1997; Greening, 1997; Schwanen et al., 2001; Stead, 2001; Stead et al., 2001; Brand et al., 2010; Ewing et al., 2010; Barla et al., 2011; Dieleman et al., 2011; Kamruzzaman et al., 2011; Lindsey et al., 2011; Zahabi et al., 2012).

In a review and evaluation of the relationships between urban form and travel patterns, Stead et al. (2001) discussed nine aspects of urban form, ranging from regional strategic planning level to specific local planning issues at the neighbourhood scale that impacted household travel behaviour. These factors included distance of residence from urban centre, settlement size, mixing of land uses, provision of local facilities, density of development, proximity to transport networks, availability of residential parking, road network type and neighbourhood type.

In a review of the relationships between socio-economic characteristics and travel behaviour, Stead (2001) found that eleven main socio-economic factors may impact travel patterns and the resulting transport GHG emissions, that is, income; car ownership and availability; possession of a driver licence; working status; employment type; gender; age; household size and composition; level of education and attitudes; and personality type.

3. Methodology

The Sydney Household Travel Survey (HTS) was used in this study. The HTS was first established in 1997/98 and has been conducted continuously since then. Approximately 8,500 people in 3,500 households in the Sydney Greater Metropolitan Area (including the Sydney and Illawarra Statistical Divisions and the Newcastle Statistical Subdivision) participate in the survey annually. Each member of the household is asked to fill in a travel diary for one day. The data includes trip information such as origin, destination, purpose, mode, time, costs, personal information such as age, gender, employment status and income, household information such as household and family type, dwelling structure, number of vehicles, and vehicle information such as make, model, fuel type, and vehicle ownership. For the analysis presented here, the HTS 2006-2010 surveys were used. The selected households were households surveyed on a typical workday (i.e. survey day was a weekday in school term and not a public holiday). In total, 6541 households were selected in our study.

Our method of analysis consisted of the following steps:

Transport GHG emissions for each household were calculated: firstly, the emissions for each trip were calculated, and then trip level emissions were aggregated to personal and household levels.

The main household locational characteristics were defined and calculated: these included distance to CBD, population and employment densities, and land use mix.

The relationships between household travel emissions and various socio-economic spatial characteristics were investigated: firstly, the impacts of each individual factor on emissions were explored, and a multivariate linear regression model was then developed to quantitatively reveal the detailed effect of household socio-economic spatial characteristics on transport GHG emissions.

3.1. Calculation of household transport GHG emissions

Seven different travel modes that emit CO_2 were considered in this research, that is, private motor vehicle (including car and motorcycle), taxi, bus, train, monorail, light rail and ferry.

3.1.1. GHG emissions from car trips

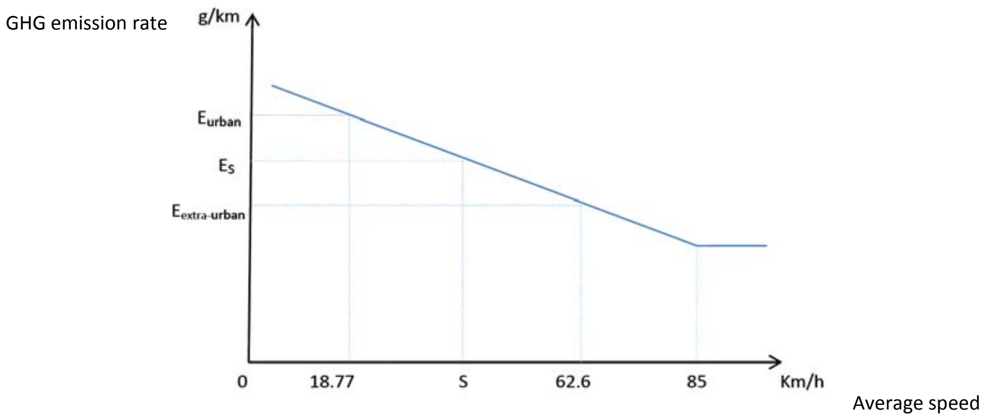
Firstly, the HTS survey vehicle database was matched with the Australian Government Green Vehicle database in terms of vehicle make, model, year, engine size, and fuel type. The Green Vehicle data provides information on the environmental performance for more than 10,000 vehicle types sold in Australia between 1986 and 2003, and manufactured after 2004. The data provides standard vehicle fuel consumption (L/100km) for vehicles sold during and before 2003, and standard vehicle fuel consumption (L/100km) and standard CO_2 emissions (g/km) for vehicles made during and after 2004. The main issue with matching records between these two databases was the large number of vehicle types in the HTS survey database that were not found in the Green Vehicle database. Therefore, if a vehicle type was not found in the Green Vehicle database, information for the closest vehicle match was allocated. For example, if the fuel consumption rate for the Alfa Romeo 156 was not available, the fuel consumption rate for Alfa Romeo 159 (closest match in terms of vehicle make and model) in the Green Vehicle database was used (Li et al., 2011).

Two figures for fuel consumption and CO_2 emissions are given in the Green Vehicle database, expressed as urban, extra urban and combined, and measured according to the New European driving cycle. The average speed for the urban and extra urban driving cycles were 18.77 km/h and 62.6 km/h, respectively.

For those vehicles sold before 2004, only standard fuel consumption rates (L/km) were given by the Green Vehicle data, so we first translated this into CO_2 emissions by multiplying the standard fuel consumption rates by 2.34 kg/L for gasoline and 2.68kg/L for diesel, respectively. According to the Australian Greenhouse Office from the Department of the Environment and Water Resources (2007), the CO_2 emissions from the road transport sector accounts for 97.4% of overall GHG emissions expressed as CO_2 Equivalents (CO_2-e) of the road transport sector. Thus, the standard GHG emissions rates were derived by dividing standard CO_2 emissions by 97.4%.

The GHG emission rates for intermediate speeds were calculated by linear interpolation between these two points (i.e. 18.77 km/h and 62.6 km/h). The GHG emissions rate was assumed to remain constant for speeds above 85 km/h. The GHG emissions rate was assumed to increase as speed dropped below 18.77 km/h (Figure 1).

Figure 1: Vehicle GHG emission rate and average speed of the trip



We assume that the average GHG emission rate for a certain trip is a function of its average speed, and can be calculated using the following equations.

$$E_S = E_{urban} - \frac{(E_{urban} - E_{extra-urban}) \times (S - 18.77)}{62.6 - 18.77}, \qquad (S < 85);$$

$$E_S = E_{urban} - \frac{(E_{urban} - E_{extra-urban}) \times (85 - 18.77)}{62.6 - 18.77}, \qquad (S \geq 85).$$

Where, $\mathrm{E_S}$ is the GHG emission rate (g/km) when the average speed of the trip is S km/h for a certain car; $\mathrm{E_{urban}}$ is the GHG emission rate (g/km) when the average speed of the trip is 18.77 km/h for a certain car, derived indirectly from the Green Vehicle data; $\mathrm{E_{extra-urban}}$ is the GHG emission rate (g/km) when the average speed of the trip is 18.77 km/h for a certain car, derived indirectly from the Green Vehicle data; and S is the average speed (km/h) for the trip.

The emissions from a car trip for a person were calculated by multiplying E_S by the road distance of the trip, and dividing by the number of people in the vehicle n.

$$Emissions\ by\ car\ trip = \frac{Es \times Distance}{n}.$$

3.1.2. GHG emissions from motorcycle trips

The HTS survey motorcycle database was matched with the Total Motorcycle Fuel Economy Guide accessed at http://www.totalmotorcycle.com/MotorcycleFuelEconomyGuide/index.htm. It includes over 5,000 bikes by year, manufacturer and model from 1934 to today, with their fuel economy expressed as L/100 km. If a vehicle type was not found in the Total Motorcycle Fuel Economy Guide Database, the information for the closest vehicle match was allocated.

3.1.3. GHG emissions from taxi trips

Average GHG emission rates were used for the urban and extra urban driving cycles of the HTS survey car fleet. The same method as for private car trips was used to derive $\mathrm{E_S}$. Emissions for a taxi trip for a person were calculated by multiplying $\mathrm{E_S}$ by road distance of the trip, and dividing by the number of people in the vehicle, excluding the taxi driver.

$$Emissions\ by\ car\ trip = \frac{Es \times Distance}{n-1}$$

3.1.4. GHG emissions from bus trips

We used 72 g CO_2-e per passenger per kilometre as the GHG emission rate for the Sydney bus network. Detailed calculation of this emission rate is listed in Appendix 1. A person's GHG emissions for a bus trip were calculated by multiplying this emission rate by distance travelled.

3.1.5. GHG emissions from train, monorail and light rail trips

We used 102 g CO_2-e per passenger per kilometre as the GHG emission rate for the Sydney CityRail network. Detailed calculation of this emission rate is listed in Appendix 2. A person's GHG emissions for a train trip were calculated by multiplying this emission rate by the distance travelled. The same method and same emission rate was used to calculate a person's trip by monorail and light rail.

3.1.6. GHG emissions from ferry trips

We used 376.96 g CO_2-e per passenger per kilometre as the GHG emission rate for Sydney ferries (Smart, 2012). A person's GHG emissions for a ferry trip were calculated by multiplying this emission rate by the distance travelled.

3.1.7. Household travel emissions

The trip level GHG emissions were then aggregated at individual and household levels.

3.2. Definition and calculation of locational and land use variables

3.2.1. Land use mix

Firstly, an 800 m buffer was generated for each Census District (CD) centroid. Using this buffer, land use mix was calculated using the entropy index. The land uses considered, as defined by Australian Bureau of Statistics in Mesh Block, were Residential, Commercial, Industrial, Agricultural, Parkland, Educational, Hospital/Medical, Transport, and Others, with Water not considered in the equation.

$$E_i = -\sum_{j=1}^{9} \frac{A_{ij}}{Si} Ln(\frac{A_{ij}}{Si})/Ln9$$

In this equation, $\mathrm{A_{ij}}$ is the area of land use j in the 800 m buffer of the centroid of CD i, and Si is the area of the 800 m buffer of the centroid of CD i.

Households in a same CD were allocated the same land use mix value.

3.2.2. Population and employment density

Population and employment in 2006 was obtained from the Travel Zone (TZ) level from the Bureau of Transport Statistics (BTS) website for the Sydney Statistical Division (SD).

To calculate density from each TZ, a 5 km buffer was first generated for each TZ centroid. Other TZs whose centroids fell within this buffer were taken into account when generating the density for the TZ.

$$Population\_Density_i = \frac{\sum_j Population_j}{\sum_j Area_j}$$

$$Employment\_Density_i = \frac{\sum_j Employment_j}{\sum_j Area_j}$$

Here, $\mathrm{Population\_Density_i}$ is the population density of the TZ i. $\mathrm{Population_j}$ is the population of TZ j whose centroid falls within the 5 km buffer of the TZ i. $\mathrm{Area_j}$ is the area of TZ j whose centroid falls within the 5 km buffer of the TZ i. $\mathrm{Employment\_Density_i}$ is the employment density of the TZ i. $\mathrm{Employment_j}$ is the employment of TZ j whose centroid falls within the 5 km buffer of the TZ i. $\mathrm{Area_j}$ is the area of TZ j whose centroid falls within the 5 km buffer of the TZ i.

Households in a same TZ were allocated the same density values.

For comparison, population density and employment density were also calculated using only the TZ itself. That is to say, the population density of TZ was calculated by dividing its population by its area, and employment density was calculated by dividing its employment by its area.

3.2.3. Distance to CBD

Euclidian distance was used from the centroid of the CD where the household was located to the Centre Point Tower to represent the household's relative location with the CBD.

4. Socio-economic, spatial characteristics and emissions

4.1. Socio-economic and spatial characteristics

Household socio-economic characteristics were obtained from the Sydney Household Travel Survey (2006-2010), and included number of residents, adults, children, full-time workers, part-time workers, usual vehicles, driver licences, and types of dwelling structures and occupancies. Statistics for household socio-economic characteristics are listed in Table1. And table 2 presents a summary of household spatial characteristics for the sampled households.

4.2. Household transport GHG emissions pattern

Among the 6541 households, the minimum daily travel GHG emissions were 0 and the maximum daily transport GHG emissions were 150.6 kg CO_2-e, with an average daily GHG emission of 10.76 kg CO_2-e. We ranked households by their GHG emissions, with the lowest ranked 1 and the highest ranked 6541, and grouped them into emission quintiles (Figure 2). Interestingly, households in the highest emission quintile had on average 28.68 kg CO_2-e GHG emissions every day and accounted for 59.34% of total GHG emissions, while the lowest emission quintile accounted for only 0.25% of the total emissions. This indicated that a small proportion of the population emitted the majority of travel GHG emissions in Sydney.

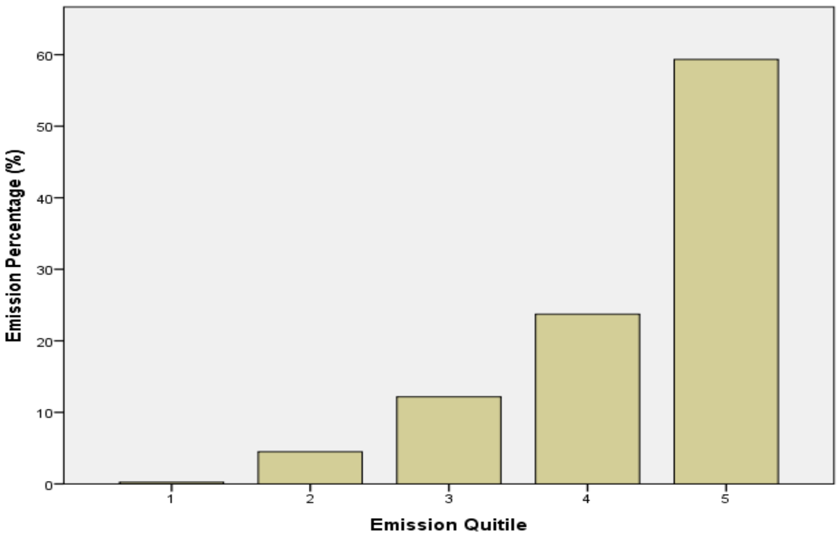
Table 1: Summary of household socio-economic characteristics (6541 households)

	Number	Minimum	Maximum	Mean	Std. Deviation
Number of Residents		1	13	2.69	1.43
Number of Adults		1	9	2.12	0.97
Number of Children		0	8	.57	0.97
Number of Full-time workers		0	5	.95	0.86
Number of Part-time workers		0	4	.27	0.52
Household Income (adjusted to 2006 $)		-$5,006	$402,741	$80,741	$59,485
Number of Usual vehicles		0	8	1.56	1.02
Total number of Licences in household		0	9	1.79	0.98
Households in Separate houses	4429 (68%)				
Households in Other types of dwellings	2112 (32%)				
Dwelling Owned, outright	2541 (39%)				
Dwelling Owned, paying off	2113 (32%)				
Dwelling Rent from government	318 (5%)				
Dwelling Rent privately	1502 (23%)				
Other types of Dwelling occupancy	67 (1%)				

Table 2: Summary of household spatial characteristics

	Minimum	Maximum	Mean
Distance to CBD (km)	0.06	94.16	23.74
Population density (TZ) (persons/hectare)	.00	654.25	34.56
Population density (5km) (persons/hectare)	.00	59.84	24.23
Employment density (5km) (persons/hectare)	.00	95.86	15.86
Total of Employment and population density	.00	152.41	40.09
Land use mix	.00	.75	.34

Figure 2: Emission percentage by emissions quintiles



5. Relationships between travel emissions and household socio-economic spatial characteristics

We analysed household travel emissions against individual socio-economic and spatial characteristics. A multivariate regression model was developed to quantitatively reveal the detailed effects of household socio-economic spatial characteristics on transport GHG emissions.

5.1. Emissions and socio-economic variables

From Figures 3-4, it is apparent that household emissions increased with the number of residents and number of adults. Although it may not be clear from Figure 5 whether there is a relationship between the number of children present and emissions, we will see later when we detail our regression results (in Section 5.3) that there is a positive relationship between number of children and household emissions. Unsurprisingly, however, the relationship is not as strong as that between the number of adults and household emissions. As shown in Figure 6, households with more workers emitted more transport emissions.

As shown in Figures 7-8, households with more vehicles and drivers produced more transport GHG emissions. The reason may be that such households tend to make more car trips, and car trips emit more GHG emissions per person per distance than public transport trips and other non-emission trips such as walking and bicycling trips.

From Table 1, separate houses accounted for 68% of the overall number of dwellings. Figure 9 also indicates that households living in separate houses emitted twice the amount of GHG on average than people in other types of dwellings, with no large emission differences observed between households living in other types of dwellings.

Figure 10 shows household emission differences between different dwelling occupancies. Households living in dwellings rented from the government emitted much less GHG than other occupancies, which was likely related to their lower incomes and associated lower use of cars. It is interesting to note that households in which the dwelling was owned but under mortgage emitted 50% more GHG than people who owned dwellings outright.

We grouped households into ten categories, with each category having the same number of households. From Figure 11, it is apparent that households with higher income produced more travel emissions. This may relate to higher income households having more full-time workers and emitting more GHG, or having more vehicles and income to spend on travel.

Figure 3: Emissions -- number of residents

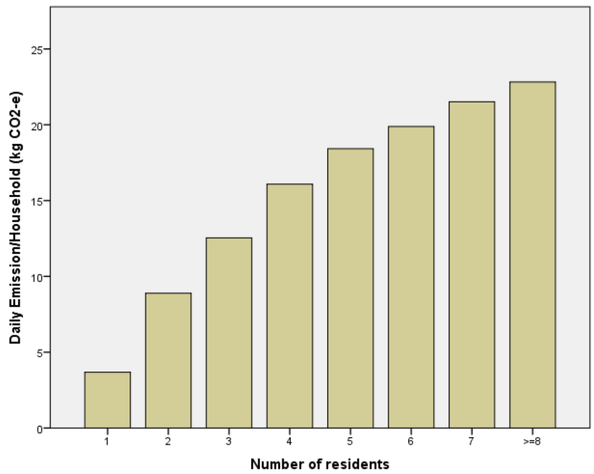


Figure 4: Emissions -- number of adults

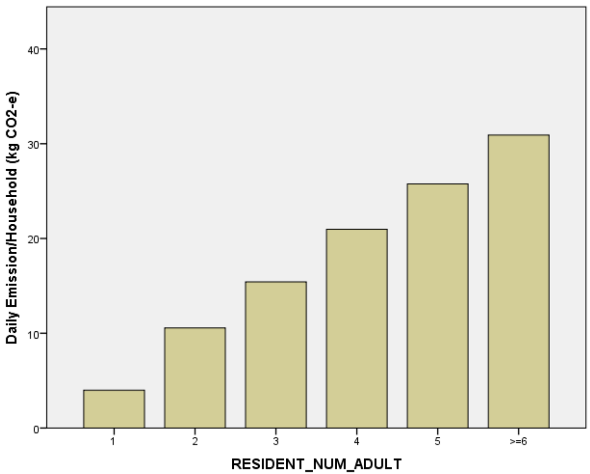


Figure 5: Emissions -- number of children

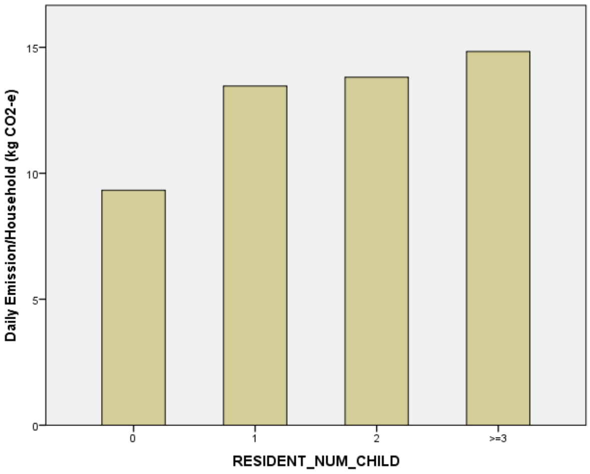


Figure 6: Emissions – fulltime workers number

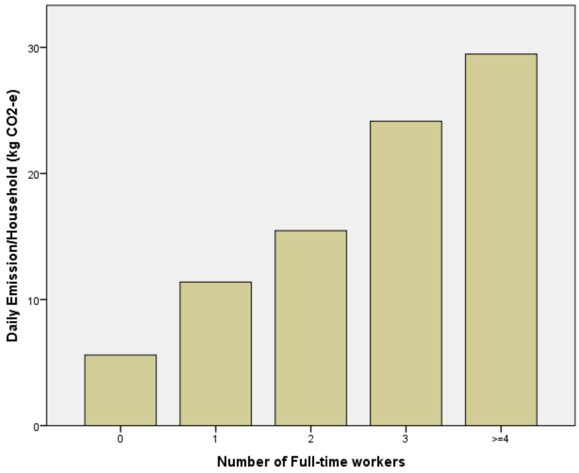


Figure 7: Emissions -- number of vehicles

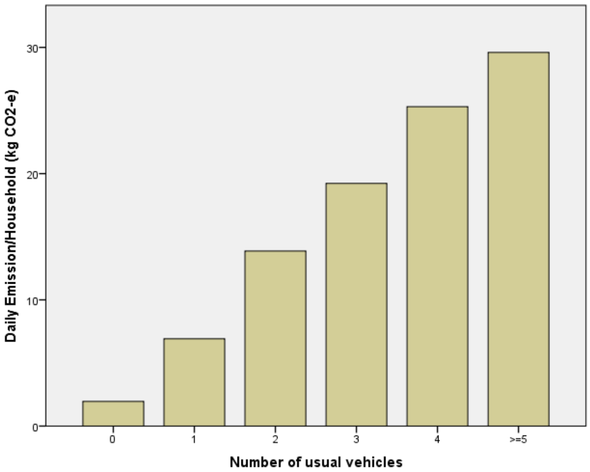


Figure 8: Emissions -- number of drivers

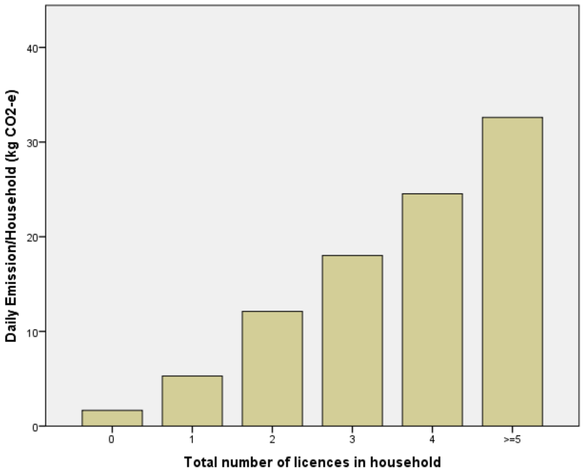


Figure 9: Emissions -- dwelling structure type

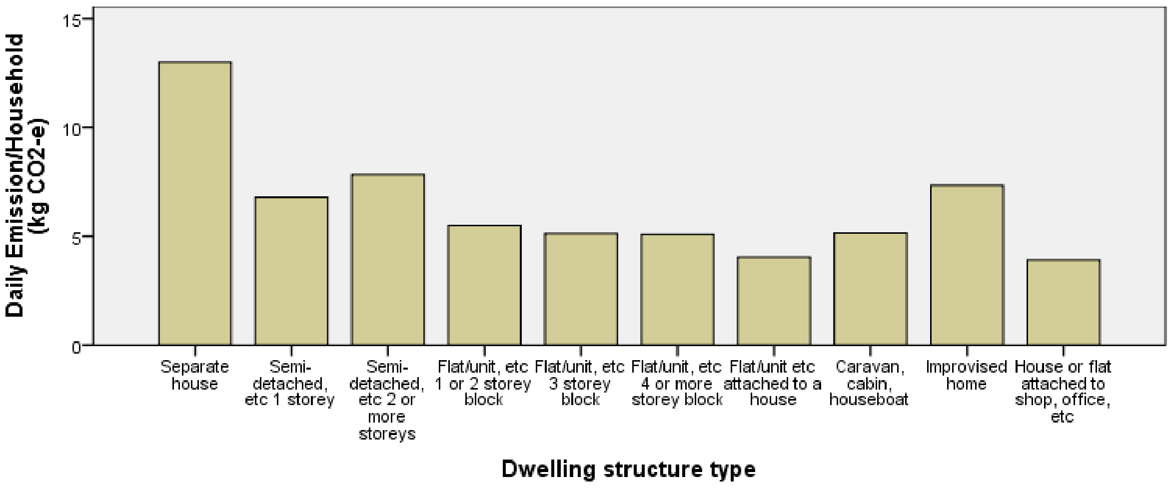


Figure 10: Emissions – dwelling occupancy

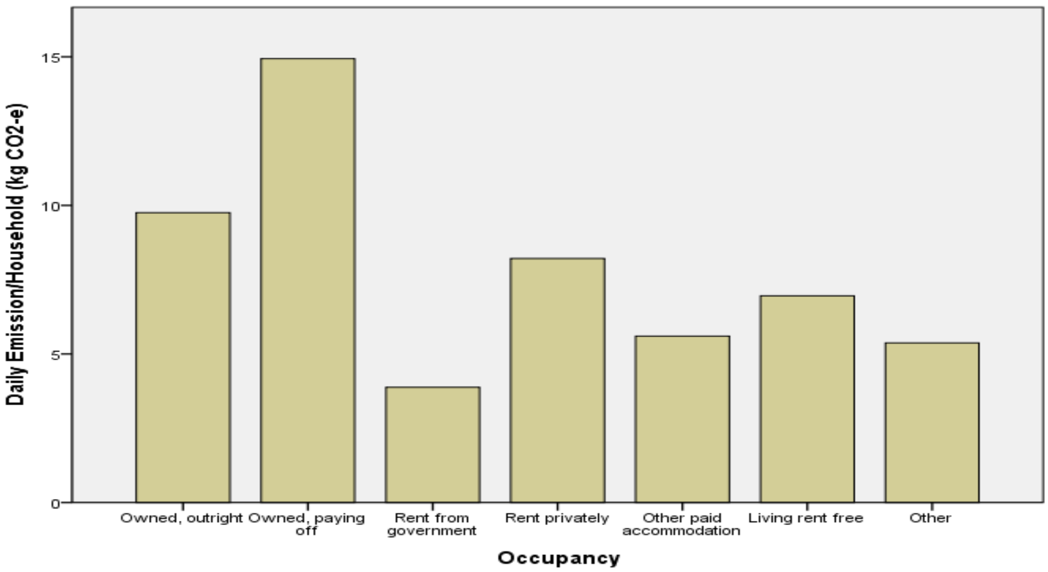
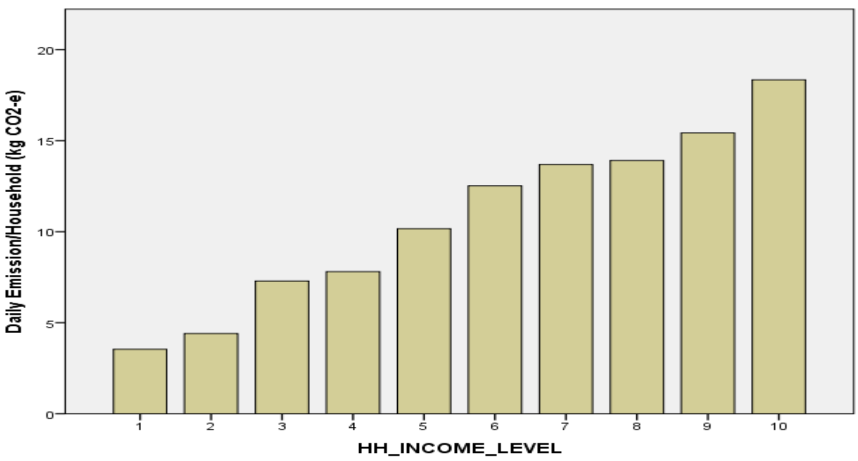


Figure 11: Emissions -- income level



5.2. Emissions and household locations

Figure 12 indicates that households living farther from the CBD produced more transport GHG emissions. Figure 13 shows the average daily travel GHG emissions by SLAs.

Figure 12: Emissions – distance to CBD

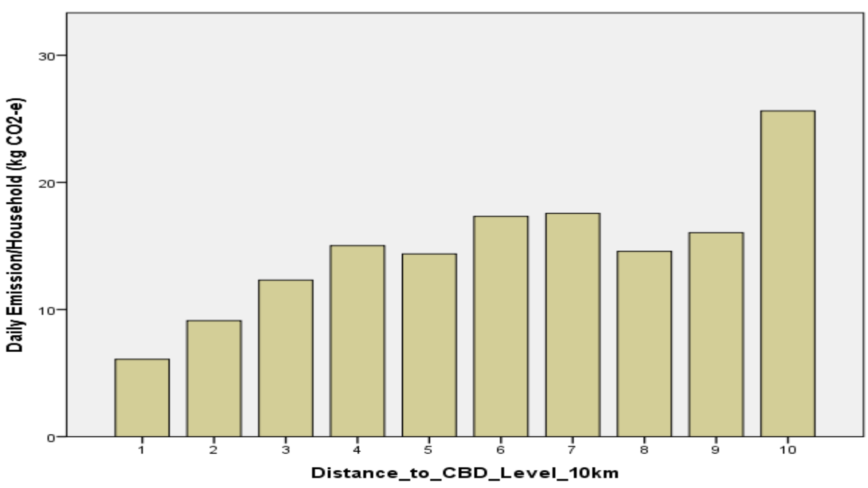
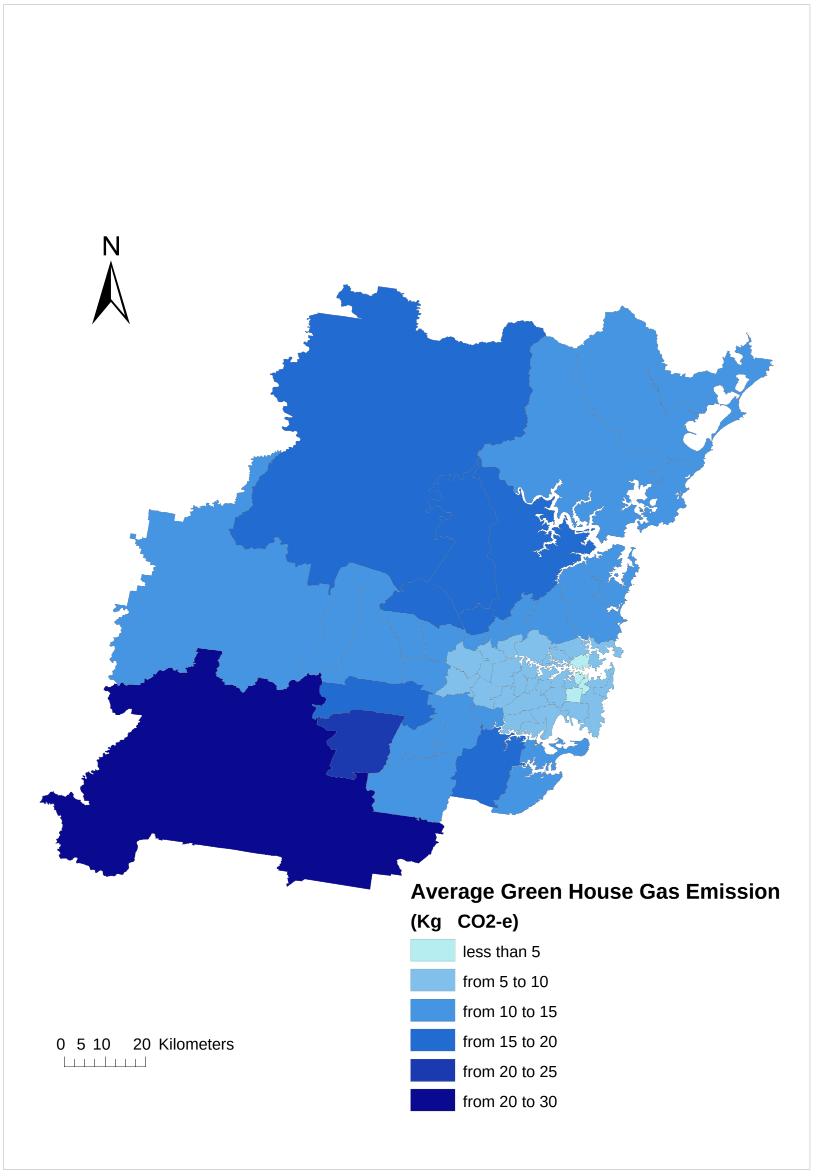


Figure 13: Average household daily travel GHG emissions by SLAs in Sydney



5.3. Multivariate regression model

We developed a multivariate linear regression model using SPSS 19 software to identify the key socio-economic spatial characteristics that explain the variation in travel GHG emission per household. The stepwise regression method was also used. The initial variables selected were number of vehicles, number of adults, number of children, number of full-time workers, number of part-time workers, population density, dwelling density, employment density, 5 km population density, 5 km employment density, 5 km population and employment density, land use mix, separate house, dwelling owned outright, dwelling owned paying off, dwelling rented from government, dwelling rented privately, distance to CBD, income and number of drivers.

Table 3: Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
	.592	.350	.349	9.9575

Table 4: ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
	348572.755	11	31688.432	319.594	.000
	647166.610	6527	99.152		
	995739.365	6538			

Table 5: Linear regression model for household daily travel GHG emissions[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	-.901	.760		-1.185	.236
Number of vehicles	1.821	.191	.151	9.536	.000
Population density (5km) (persons/hectare)	-.086	.014	-.107	-6.049	.000
Number of adults	1.758	.225	.139	7.830	.000
Income ($10,000)	.197	.031	.095	6.344	.000
Distance to CBD (km)	.099	.012	.144	8.402	.000
Dwelling owned, payingoff	1.242	.294	.047	4.220	.000
Number of full-time workers	1.449	.228	.101	6.366	.000
Number of children	.650	.134	.051	4.858	.000
Number of part-time workers	1.157	.268	.048	4.309	.000
Number of drivers	1.032	.270	.082	3.815	.000
Land use mix	-3.111	.925	-.035	-3.364	.001

a. Dependent Variable: Household daily travel GHG emissions

As seen from Tables 3-5, in the final model, eleven variables were statistically significant, with the R^2 of the model being 0.350. An increase in one more vehicle and one more driver in a household increased daily travel GHG emissions by 1.821 Kg CO_2-e and 1.032 Kg CO_2-e, respectively. An increase of one adult and one child increased emissions by 1.758 Kg CO_2-e and 0.650 Kg CO_2-e, respectively. An increase of one full-time worker and one part-time worker increased transport emissions by 1.449 Kg CO_2-e and 1.157 Kg CO_2-e, respectively. Households emitted 0.197 Kg CO_2-e more GHG per day on average, if their annual income increased by $10,000. Households living in dwellings owned with a mortgage tended to emit 1.424 Kg CO_2-e more GHG every day. Households emitted around 0.1 Kg CO_2-e more transport GHG emissions if they moved 1 km further from the CBD. Households living in communities that had higher population density and land use mix emitted less transport emissions.

6. Conclusions and discussion

We studied how a variety of socio-economic spatial characteristics affected household daily transport GHG emissions, and determined the following.

Firstly, population density and land use mix had statistically significant and negative impacts on the carbon emissions of household daily travel. Distance to CBD, together with socio-economic characteristics such as number of adults, number of children, number of vehicles, number of drivers, number of full-time workers, number of part-time workers and income had statistically significant and positive effects on the GHG emissions of household daily travel. Therefore, transport GHG reduction policies should target commuting trips and high income households to effectively achieve policy objectives. In addition, increasing community density and land use mix can also have positive effects on emission reduction.

Secondly, only a small proportion of the population emitted the majority of the travel GHG emissions in Sydney. Households in the highest emission quintile emitted 59.34% of total GHG emissions, while the lowest emission quintile only accounted for 0.25% of total emissions. This indicated that transport GHG reduction policies could efficiently achieve their objectives by targeting high quintile households. However, there might be a proportion of households in the high emission groups who are required to drive but are in relatively poor socio-economic conditions. They may suffer from increased travel costs if policies such as emission taxes were implemented. Therefore, for equity concern, it is worth identifying such households and providing some form of compensation so that they can maintain their mobility and not be socio-economically disadvantaged.

Acknowledgements

The main data used in this study was obtained from the Household Travel Survey (HTS) dataset from the New South Wales Bureau of Transport Statistics (BTS). The authors wish to thank the BTS for providing permission to use the HTS data for analysis. Also, we wish to extend thanks to Jasmina Dilevska (UTS Masters student) for calculations supplied in Appendix 1 and Appendix 2.

Appendix 1. GHG emission rate of bus trips

Sydney buses are run on diesel (State Transit Authority, 2011) or CNG which, due to high level of fuel consumption is not necessarily more carbon efficient. We therefore assume, for the calculation of GHG emission per passenger per km, the following coefficients for diesel (DCCEE, 2011):

74.5 [gCO_2-e/ MJ] total emission factor for GHG

0.295 [L/km] average fuel consumption rate for bus in NSW

Assuming that energy consumption per passenger- km is 1.09 [MJ/p-km] as specified by Kenworthy et al. (2001), we use the emission factor of 74.5 [gCO_2/ MJ] to calculate the GHG emissions per passenger – kilometre.

[GHG Emissions factor] x [Value of Energy used per p-km] = [GHG Emission/p-km]

[CO_2-e/ MJ] [MJ/p-km] [CO_2-e/ p –km]

74.05 [gCO_2-e/MJ] x 1.09 [MJ/p-km]=80.71 [gCO_2-e/p-km]

GHG emission per passenger per kilometre is equal to 80.71 [gCO_2-e/ p-km] for bus network in Sydney.

Appendix 2. GHG emission rate of train trips

Sydney has electrified train system. In order to established GHG emissions per passenger-km for train users in Sydney, we use the following factors listed in National Greenhouse Accounts Factors workbook (DCCEE, 2011):

296 [gCO_2-e / MJ] total emissions for end user

Electricity GHG emission factor for the end user include electricity trade and electricity transmission and distribution loss data (DCCEE, 2011). The loss of energy in the rail system is little, due to high voltage and because distribution and transmission losses occur manly within the CityRail network (Rickwood, 2009). For that reason we have adjusted the GHG emissions for the rail network to be equivalent of 28.8 [g CO_2-e/ MJ] giving total GHG emissions factor for CityRail network equivalent of 277 [gCO_2-e /MJ].

To calculate the CO_2 emissions per passenger – kilometre we use the value of 0.42 [MJ/p-km] for energy consumption per passenger-km for train travel (Rickwood, 2009):

[GHG Emissions factor] x [Value of Energy used per p-km] =[GHG Emission/p-km]

[CO_2-e/ MJ] [MJ/p-km] [CO_2-e/ p –km]

277 [gCO_2-e/ MJ] x 0.42 [MJ/p-km] = 116.34 [gCO_2-e/ p –km]

GHG emission rate is equal to 116.34 [gCO_2-e/ p-km] for CityRail network in Sydney.

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