INVESTIGATING PRIVATE MOTORISED TRAVEL AND VEHICLE FLEET EFFICIENCY: USING NEW DATA AND MEHTODS TO REVEAL SOCIO-SPATIAL PATTERNS IN BRISBANE

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ABSTRACT

Australian cities have seen continued growth in car travel that has imposed increasing vehicle energy consumption and greenhouse gas emissions. This paper investigates the spatial patterns of vehicle energy consumption on urban areas through an analysis of vehicle travel and efficiency of the vehicle fleet in Brisbane. This is achieved through by combining motor vehicle registration records and Australian government's 'Green Vehicle' fuel efficiency data. Through a spatial analysis of the vehicle kilometers traveled (VKT) derived from journey to work (JTW) data and fuel energy consumption associated with the private-owned vehicles decomposed to local areas, the results show that vehicle energy use per VKT tends to be greater with increasing distance from the city centre (e.g. CBD). This analysis demonstrates that not only VKT levels but also the lower frequency of highly efficient vehicles in the outer suburbs aggravates vehicle energy consumption in those locations. The paper then compares vehicle energy intensity results for Brisbane against spatial patterns of suburban socio-economic disadvantage. The paper demonstrates that vehicle fleet technology may compound other forms of socio-economic disadvantage and vulnerability.

1. INTRODUCTION

Australian cities have seen continuous growth in car travel (BTRE, 2007). In most capital cities, over 80% of households use private vehicles for trips, including those for work and for other purposes (Australian Government, 2010). With suburbanization continuing, long distance travel and transport congestion is an ongoing problem that has imposed increasing energy consumption, worsened greenhouse gas emissions and constrained mobility in urban areas (Weisbrod et al., 2003). In addition, the increase in automobile dependence in Australian cities has placed them at greater risk from potential adverse social and economic outcomes arising from increasing petrol prices (Dodson and Sipe, 2008). Because automobile dependence has placed increased pressure on urban environment and energy expenditure for households, there is a growing concern about how to reduce transport energy consumption. Developing an improved understanding of the spatial distribution of household transport energy, its variation across urban regions and how this differs according to socio-economic distribution are extremely valuable in helping government to craft appropriate policies to achieve socially affordable and energy efficient transport outcomes. This paper aims to address this issue.

Transport energy consumption is a complex urban phenomenon. A number of social and spatial factors such as local economic structure, residential development, socio-economic composition, and levels of urbanization and transport infrastructure have important influences on household transport energy demand (Banister, 1980; Newman and Kenworthy, 1999; Morris and Richardson, 1997; Mees, 2000; O'Neill and Chen, 2002). Studies attempting to understand urban transport energy have typically focused on the relationship between urban travel demand and transport energy outcomes, arguing that the urban development patterns may have direct influences on household transport energy consumption (Breheny, 1995; Whiteman and Alford, 2009). For example, households located in the dispersed outer suburban areas with low accessibility to public transport typically become car-dependent. For these areas, this results in correspondingly longer vehicle distance travelled and greater fuel energy consumption. In contrast, households in high density areas tend to be closer to employment and public transport services and thus require less motor vehicle travel and energy use (Maher, 1994, Burnley et al., 1997; Whiteman and Alford, 2008).

The level of energy consumption is not only related to household travel patterns, but also on the type of motor vehicle used. This is because a household's preference for vehicle type is strongly influenced by residential location and travel patterns (Kitamura et al., 2001; Bhat et al., 2009; Eluru et al., 2010). This spatial variation is observable in high density areas which tend to have less and smaller parking spaces, narrower street and more congested traffic. These conditions all work in favour of choosing smaller, more manoeuvrable and often fuel efficient vehicles (Choo and Mokhtarian, 2004). In contrast, households in low density areas with less constraints on car transport operations (e.g. larger space, less road traffic) may have lower frequencies of high efficient vehicles (Kockelman and Zhao, 2000; Cao et al, 2006). Such variations in household preferences for motor vehicle use would also result in important differences in household fuel consumption. This relationship between household transport energy outcomes and the motor vehicle type and use has not been fully examined in previous transport energy research in Australia.

This research provides an advanced analytical method for examining the spatial distribution of household vehicle fuel consumption for the Brisbane urban area. This is achieved through the integration of household vehicle travel demand and motor vehicle fuel efficiency and fleet composition. One key element of this work involves an examination of the impact of vehicle fleet energy efficiency on household vehicle fuel consumption. This analysis permits motor vehicle fuel efficiency to be included as a key factor in determining the household transport energy levels. The outputs are then used to evaluate socio-economic disadvantage arising from the unevenly distributed fuel energy expenditure across the urban area. These results provide a much improved evidence base for those with the responsibility for managing urban transport energy growth and mitigating household transport energy vulnerability. For example, one management option might examine how land use policies could be used to alter household vehicle choice and vehicle use characteristics, thereby reducing energy use and emissions.

The remainder of the paper is structured as follows. The next section provides an overview of the literature on household transport energy. The third section describes the study area and datasets used in the analysis. The fourth section describes the methods of analysis and the fifth section provides the results. The paper concludes with a discussion of the limitations of our approach and outlines avenues for future research.

2. GEOGRAPHICAL STUDY OF URBAN TRANSPORT ENERGY

The distribution of household energy consumption and its variation in the urban and regional context has received growing attention over the last decades (Newman and Kenworthy, 1989). Whilst there has been a great deal of attention that has focused on the spatial nature of urban form and transport energy consumption. For example, Rickwood et al. (2008), investigated spatial patterns of energy consumption, suggesting a relationship between land use characteristics and household transport energy consumption. The implications of urban spatial structure for transport energy patterns were also widely debated in Holden and Norland (2005); Permana *et al.*, (2008); and Brownstone and Golob (2009)..

While much research has shown that the spatial variation in household transport energy consumption is related to urban spatial structure and human travel behavior, very little research has investigated the spatial nature of the technological dimension of transport energy cost and its impact on the household energy consumption and vulnerability. Weghe and Kennedy (2007) applied a spatial-based approach to analyze the transport energy consumption by different motorized travel modes in the Toronto metropolitan area. Although the analysis provided a measure of fuel energy consumption based on the vehicle travel data, the use of uniform vehicle fuel efficiency coefficients across all vehicle types is a limitation. In a more recent study, Lindsey et al. (2011) used recent vehicle travel survey data to analyze vehicle energy use in metropolitan Chicago. Through an explicit analysis of travel patterns and vehicle energy efficiency, they found that the variation in household transport energy consumption can be partly explained by differences in the vehicle fleet. These studies demonstrated that it is possible to track spatial travel behavior by motor vehicle type in an effort to understand the spatial nature of household transport energy.

In the urban transport literature, social-spatial analyses of household vehicle energy use receives little attention. Dodson and Sipe (2007) developed a vulnerability index for petroleum expense (VIPER) based on the analysis of the number of motor vehicles owned, motor vehicle use in the journey to work and household income to assess socio-economic oil vulnerability n Australian cities. The results showed that household oil vulnerability is a socially regressive condition. The relative weaker socio-economic households in outer suburbs are most vulnerable to the higher fuel energy price. The issue of household energy pressure from the composition of vehicle fleet was recently further investigated by Dodson et al. (2009) who used Queensland motor vehicle registration data at the postcode level to compare the socio-economic status with the age and engine size of the vehicle fleet for Brisbane. Although the analysis used a relatively crude measure of vehicle fuel efficiency, the result confirmed that outer urban disadvantaged groups tend to be more vulnerable to fuel energy cost due to their higher frequent use of old and large engine vehicles.

Thus, transport energy consumption is a more complex problem especially when considering household travel dynamics and the efficiency composition of vehicle fleet in a large urban area. Current approaches for assessing urban transport energy consumption and oil vulnerability do not address the links between household vehicle travel demand and energy efficiency of private motor vehicle fleet, and the resulting levels of transport energy consumption. This paper addresses this gap through an analysis of combined contribution of household vehicle travel demand and the efficiency composition of the vehicle fleet to the household vehicle energy consumption. The methodological contributions of this paper are: (1) it links current vehicle fleets to standard vehicle fuel efficiency ratings at an individual vehicle level; and (2) it applies advanced geographical techniques to analyze vehicle kilometers traveled (VKT) using journey to work (JTW) data. The results provide a richer depiction of household transport energy cost, not only of the car ownership and urban vehicle fleet, but also of the relative levels of fuel consumption of that fleet under current household travel demand. These results are then linked to socio-economic data to develop an improved understanding of the relationships between socio-spatial structure and suburban transport energy consumption to examine whether vehicle fleet may compound other forms of socio-economic disadvantage and vulnerability.

3. DATA

Three databases were used in the study: 1) Queensland motor vehicle registration data; 2) Australian Green Vehicle data; and 3) JTW data.

Queensland motor vehicle registration data

Motor vehicle registration data are collected by the Queensland government. The data was obtained for the fourth quarter of 2008 and comprises 441,930 private motor vehicle records containing the make, model, year, body shape, number of cylinders, suburb and postcode location.

Australian Government Green Vehicle data

The Australian Government Green Vehicle data provides information on the environmental performance for 14,996 vehicle types (makes and model) that were sold in Australia between 1986 and 2003, and manufactured in 2005 and 2009. The Green Vehicle data provides air pollution rate, CO_2 emissions, noise, and standard vehicle fuel consumption, and vehicle make/model. For this study, the fuel consumption rate (litres/100km) was extracted and used for the vehicle energy efficiency analysis as it provides accurate information on vehicle fuel consumption in urban driving.

JTW data

The JTW datasets collected by the Australian Bureau of Statistics (ABS) for the 2006 Census were used to calculate the household VKT. The JTW matrix comprises one column and one row, specifically a destination zone and an origin zone and the total number of trips (car trips only) between each origin and destination. There are 210 origin and 210 destination zones for the Brisbane urban area. The standard spatial units used to represent these zones are Statistical Local Areas (SLA).

4. METHODOLOGY

4.1. Measuring VKT

The average VKT for each area was measured using JTW data from the 2006 ABS Census. The advantage of using JTW data is that it is a complete enumeration of the population, which provides more accurate information on travel demand than that provided by sampled travel survey data.

Average VKT is computed for each SLA using Queensland road network data to determine the distance between each origin and destination. Because SLAs are a relatively large geographical unit, especially for peri-urban areas, the measure of JTW distance using geographic centroids was deemed not to represent the multiple available route possibilities for car travellers. To remedy this situation, ten points were located randomly within each SLA and each point was used as the single departing location and arrival location of travel. Then the average point-to-point road travel distances were computed for each SLA. The SLA-SLA network distance then multiplied by the number of vehicle trips between each origin-destination pair, and the total travel distance for all vehicle trips for the 210 SLAs. The average VKT for each SLA was then derived from the total number of private vehicle trips in the SLA.

4.2. Spatial analysing the urban automobile fleet and fuel efficiency

The question raised earlier suggests that in addition to the vehicle travel demand (VKT), the distribution of private vehicle fleet and fuel efficiency is a critically important determinant in fuel energy consumption. This study investigates the issues of motor vehicle efficiency and spatial distribution through a combination of Queensland motor vehicle registration records and the

Australian government's 'Green Vehicle' fuel efficiency data. The Green Vehicle data describes the fuel efficiency and carbon emissions for a broad range of vehicle types, whilst the vehicle registration data provide important information on the spatial distribution of vehicle types. The fuel consumption rate by make and model was allocated to each vehicle in the vehicle registration database.

The main issue with matching records between these two databases was that there were a large number of vehicle types in the vehicle registration database that were not found in the Green Vehicle database. Therefore, if a vehicle type was not found in the Green Vehicle database, the information for the closest vehicle match was allocated. For example, if the fuel consumption rate for the registered *Alfa Romeo 156* was not available, the fuel consumption rate for *Alfa Romeo 159* (the closest match in terms of vehicle make and model) in the Green Vehicle database was used.

In some cases a match was not found resulting in approximately 20% of vehicle types in the registered vehicle database being omitted from the analysis. Fortunately, these vehicle types represent a small number of vehicles in the overall registered motor vehicle fleet (0.7 %), thus the impact of their omission is not statistically significant. Once the fuel efficiency information was allocated to the vehicle registration data, the data were then aggregated at the postcode level and the average vehicle fuel efficiency calculated.

4.3. Mapping the vehicle fuel consumption

To calculate fuel energy consumption from household private vehicle travel, we combined the results of average vehicle efficiency with the average VKT derived from JTW data. It is noted that there is a mismatch between use of 2008 private vehicle registrations and of 2006 JTW data, we assume there is no major vehicle ownership change between 2006 and 2008 for the study area. As the geographical identifier in the vehicle efficiency (postcode) was spatially non-conterminous with the desired mapping unit (SLA), a method of allocating postcodes to SLAs was required. This was achieved by using ArcGIS software to find the spatial intersection between SLAs and postcodes. The vehicle fuel efficiency value for a SLA was estimated based on the proportioning the postcode value by area, based on the geographic intersection between the two mapping units. Although this process can potentially introduce errors into the analysis, it was deemed acceptable given that more than 80% of SLAs were solely contained by postcodes (i.e. no overlapping boundaries). Once the average vehicle efficiency was allocated to SLAs, they were multiplied by the average VKT for each SLA (derived from JTW data) to calculate the average litres of fuel consumed from private vehicle travel for that SLA.

5. RESULTS AND DISCUSSION

The results are presented in four parts: 1) the VKT distribution; 2) vehicle efficiency distribution; 3) distribution of fuel energy consumption; and 4) socio-spatial vulnerability.

5.1. VKT Distribution

The spatial distribution of average household VKT by SLA for Brisbane is shown in Figure 1. It shows that the VKT tends to be smaller for those living closer to the CBD, whilst those living further from the CBD have larger VKTs. Vehicle travel distance thus appears to increase as one moves away from the city centre. The reason for this is because people living in outer suburban areas have more dispersed commuting patterns, and many commute across-suburbs (not to the CBD). These type of trips are not well supported by public transport, which leads to increased reliance on private vehicles and travel distances. The average VKT in some suburbs around a regional centre (e.g. Ipswich) are considerably higher than the regional average distance (14 km). This may be due to the decentralized form of suburban development found in Brisbane that has not been strongly concentrated around the major activity centres to form strong clustering of employment into centres. Instead, development has been more dispersed, reflecting weaknesses in planning compact and self-contained sub-regional centre. The inset map highlights that the average VKT for car commuters from inner city areas (e.g. Brisbane CBD and Spring Hill) appear to be longer than those in the surrounding inner suburbs. The longer VKT for reverse commuting from inner city Brisbane can be related to the occupational profile of local residents. For example, there are large number of professionals and government employees who live in the Brisbane City but commute to the Gold Coast.

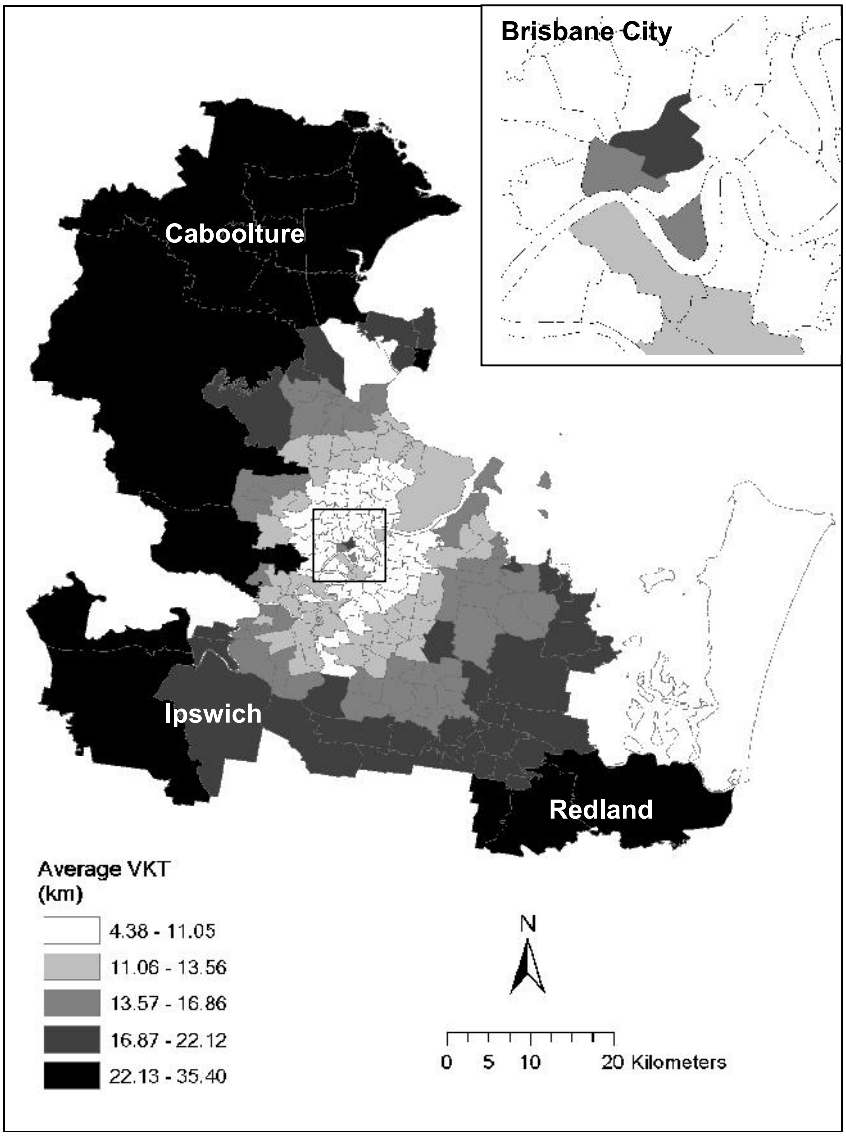

Figure 1: Average household VKT by SLA

5.2. Vehicle Fuel Efficiency Distribution

Some important differences in vehicle fuel efficiency in Brisbane metropolitan area are shown in Figure 2. Vehicle energy use per VKT tends to be relatively lower in the inner urban areas surrounding the Brisbane CBD. These areas are surrounded by SLAs with moderate average vehicle energy efficiency. In contrast, SLAs to far north, far west, and southeast exhibit the lowest vehicle efficiency in the urban area. Energy use per VKT tends to be more intensive with increasing distance from the city centre (e.g. CBD), however some local variations exist. For example, the average vehicle efficiency in Kenmore Hills appears to be slightly lower than surrounding suburbs. This can be explained by the higher proportion of large/high performance vehicles (e.g. SUVs) used in some high income suburbs that reduced overall energy efficiency. The lower vehicle efficiency observed in some industry-based suburbs (e.g. Rocklea and Kingston) suggests that the occupation and industry sector of local residents may affect their vehicle choice (e.g. a higher proportion of minivans, utes and light trucks).

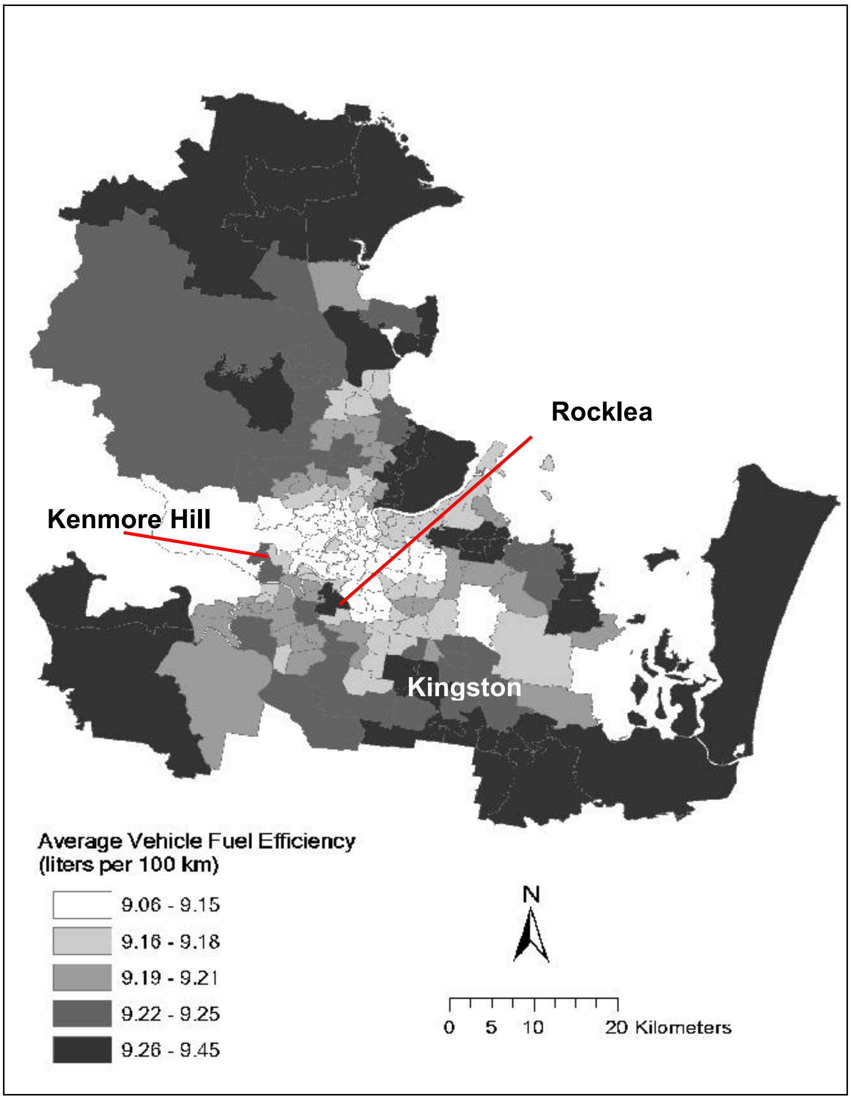

Figure 2: Average vehicle fuel efficiency (litres per 100km) by SLA

5.3. Household Vehicle Fuel Consumption Distribution

The distribution of household vehicle fuel consumption is shown in Figure 3. This only includes households who use private vehicles for commuting. The overall pattern is similar to that of VKT in Figure 2, however again there are some local variations that can be explained by the differences in vehicle fleet fuel efficiency. In general, the average vehicle fuel consumption for households in the inner city areas is high because of their moderate commuting distance. Households in the inner urban areas exhibit relatively low vehicle fuel expenditure, reflecting their closer proximity to employment and higher levels of energy efficient vehicles. In contrast, the average vehicle fuel consumption in the middle-urban to outer-urban areas is greater, given the fact that these areas of higher level of VKT are typically those with a relatively low proportion of energy efficient vehicles. Those living in outer urban area households tend to travel longer distances for work, and use less energy efficient vehicles which increases vehicle fuel consumption in these areas.

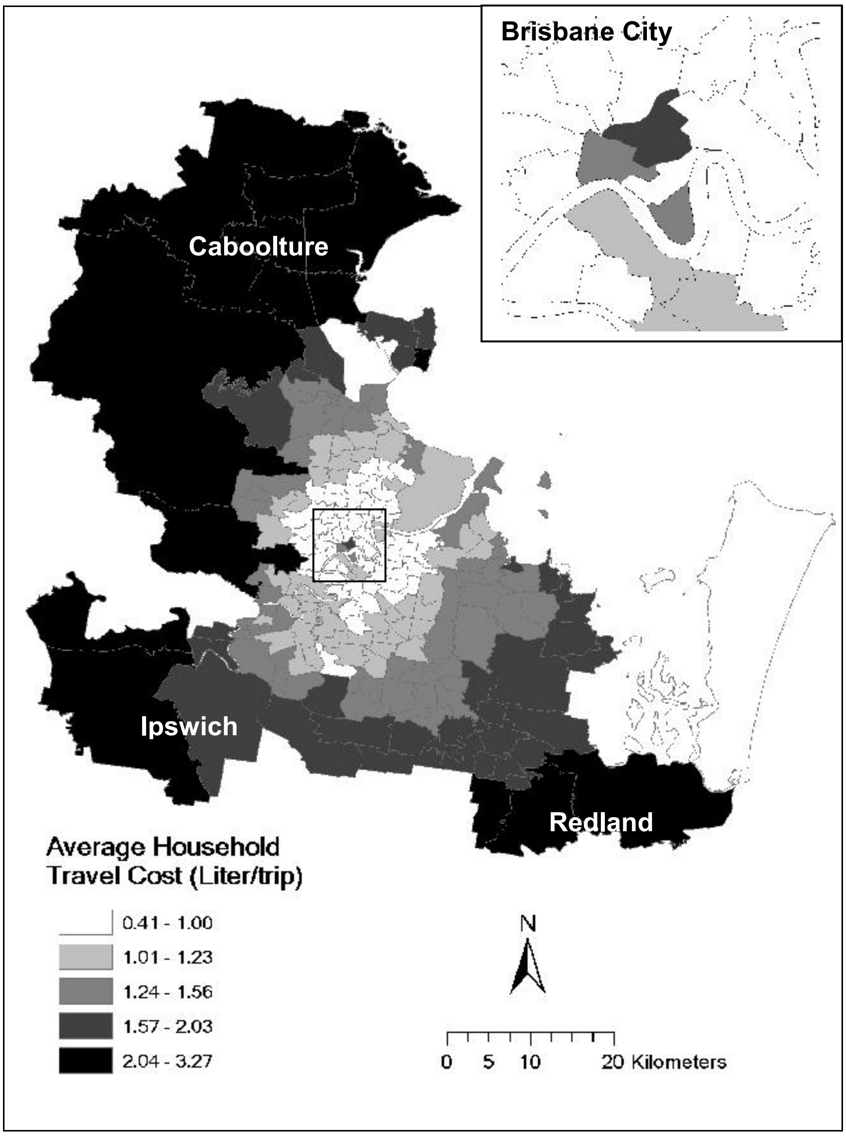

Figure 3: Average household vehicle fuel consumption (liters per trip) by SLA

5.4. Socio-Spatial Vulnerability Distribution

In this section, we compare the vehicle energy intensity results with household socio-economic status in an effort to assess energy vulnerability across the Brisbane. Household socio-economic status is an important factor when assessing resilience to increasing petrol prices (Dodson and Sipe, 2007). For this research, the, ABS Socio Economic Index for Areas (SEIFA) for 2006 was used as our measure of socio-economic disadvantage. The distribution of the SEIFA is provided in Figure 4. Those socio-economic disadvantaged households, as indicated by low SEIFA values, have less ability to afford higher petrol prices than households with higher SEIFA values.

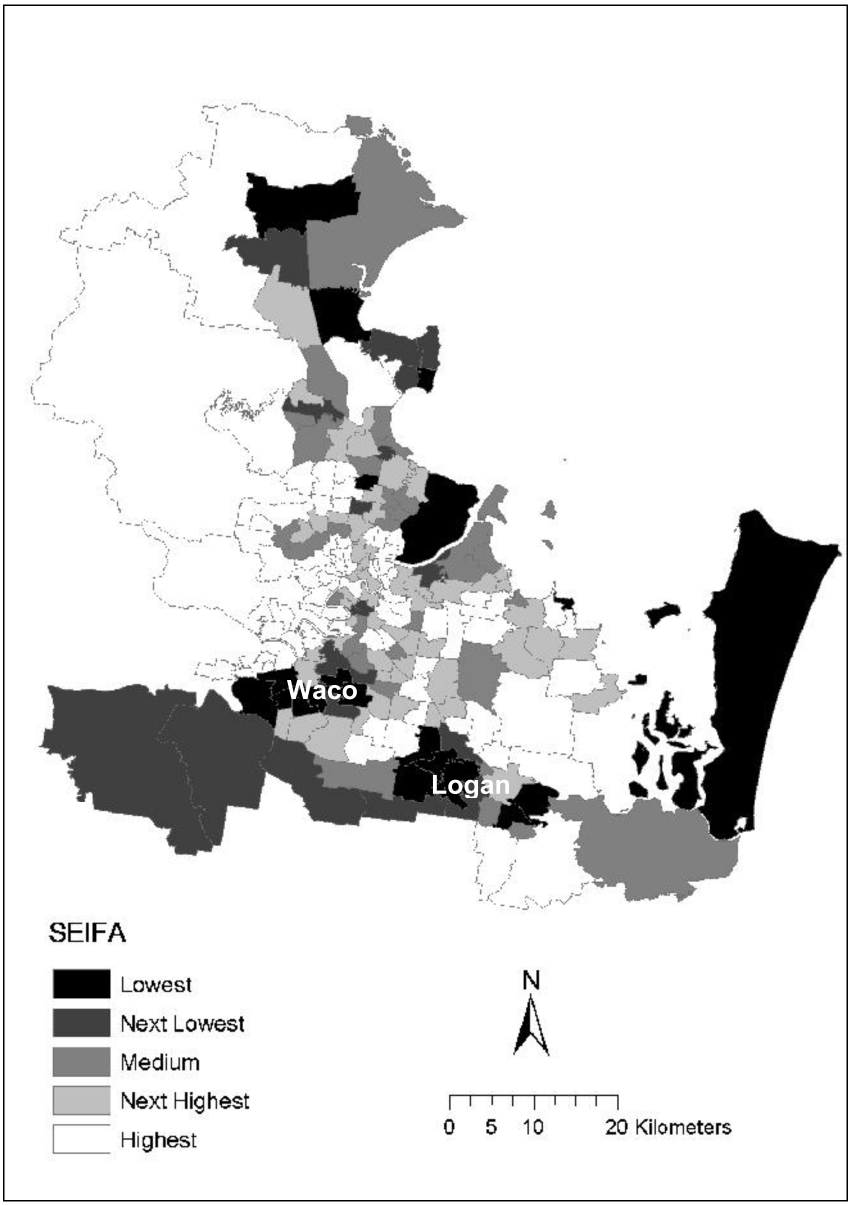

Figure 4: Socio Economic Index for Areas (SEIFA) by SLA

To assess vulnerability, we first examine the relationship between the vehicle fuel intensity and the suburban social-economic disadvantage. As shown in Figure 5, there is a non-linear relationship between fuel energy intensity and suburban socio-economic disadvantage. SLAs with a lower SEIFA scores tended to have higher and more dispersed fuel energy expenditure patterns than did SLAs with a higher SEIFA scores. The results suggest that the socio-spatial patterns in Brisbane are likely to be compounded by the impact of energy consumption for private motor vehicles. The highest average fuel energy consumption was not represented by the lowest SEIFA households due to their less dispersed travel patterns and lower uptake of energy efficient vehicles than the households in the next lowest SEIFA category. Households living in the highest SEIFA SLAs were found to consume higher levels of fuel than the households in the next highest SEIFA SLAs due to higher travel demand and higher ability to afford less energy efficient motor vehicles.

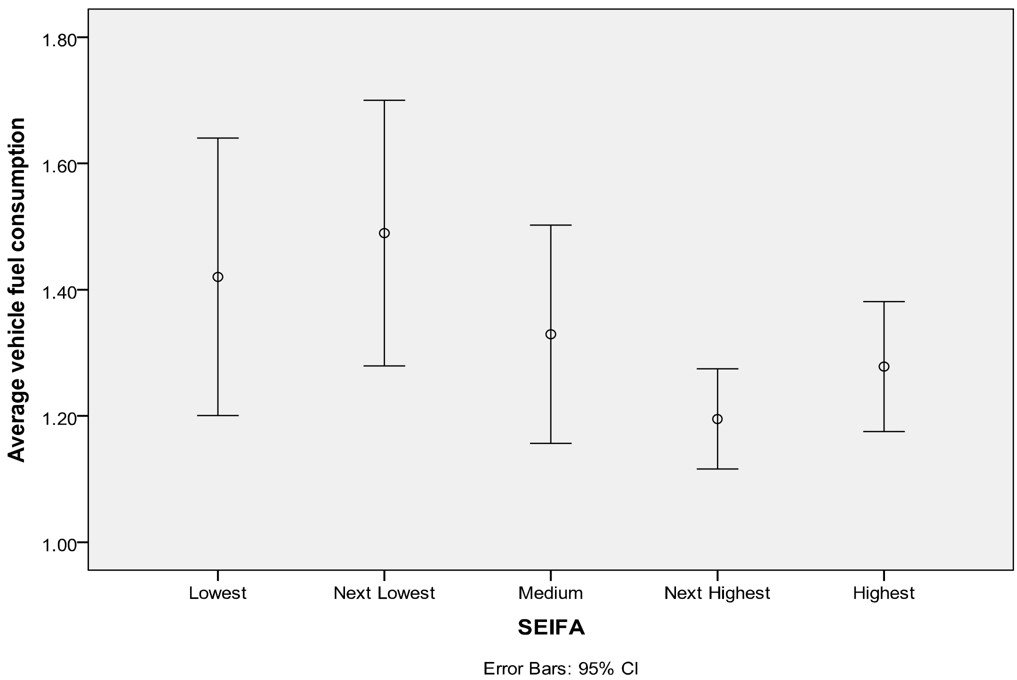

Figure 5: Relationship between average vehicle fuel consumption and SEIFA

The next step in assessing vulnerability was to overlay the most energy intensive suburbs, from a transport perspective, with the most socio-economic disadvantaged suburbs. This analysis identified 'hotspots' of transport energy impact and social vulnerability. The most energy intensive suburbs were classified as those suburbs with average vehicle energy values greater than one standard deviation from the mean (1.72 liters/trip). The most socio-economic disadvantaged suburbs were those with SEIFA scores in the lowest decile.

The analysis shows that the one-third of the most disadvantaged suburbs (11 out of 33) in the Brisbane urban area are situated within the most vehicle energy intensive class. Households in these areas are deemed highly vulnerable to the high vehicle fuel consumption. As shown in Figure 6, the most energy vulnerable areas are concentrated along Brisbane's outer suburbs -- Ipswich in the west, Logan City and Beenleigh in the south, and Caboolture in the north. Some of the most disadvantaged suburbs in Brisbane were not situated within the high energy intensity class (e.g. Wacol), and households in those suburbs were not deemed as highly oil vulnerable due to their moderate transport expenditure. These results yield some slightly different results than those found in previous analyses of oil vulnerability for the Brisbane urban area (Dodson and Sipe, 2007). For example, by including the local vehicle fuel efficiency and the local travel distance into the analysis (which were not used in the previous studies), previously identified highly vulnerable areas along Brisbane-Ipswich corridor, Hemmant-Lytton in the east, and Griffin in the north have become moderate fuel energy vulnerable suburbs. This analysis demonstrates the value in approaching questions of oil vulnerability with a variety of methodologies. In this instance revealed VKT provides an alternative measure of car dependence to that used by Dodson and Sipe (2007, 2008) who used vehicles per household and proportion of JTW trips by private motor vehicle as their fuel dependence variable.

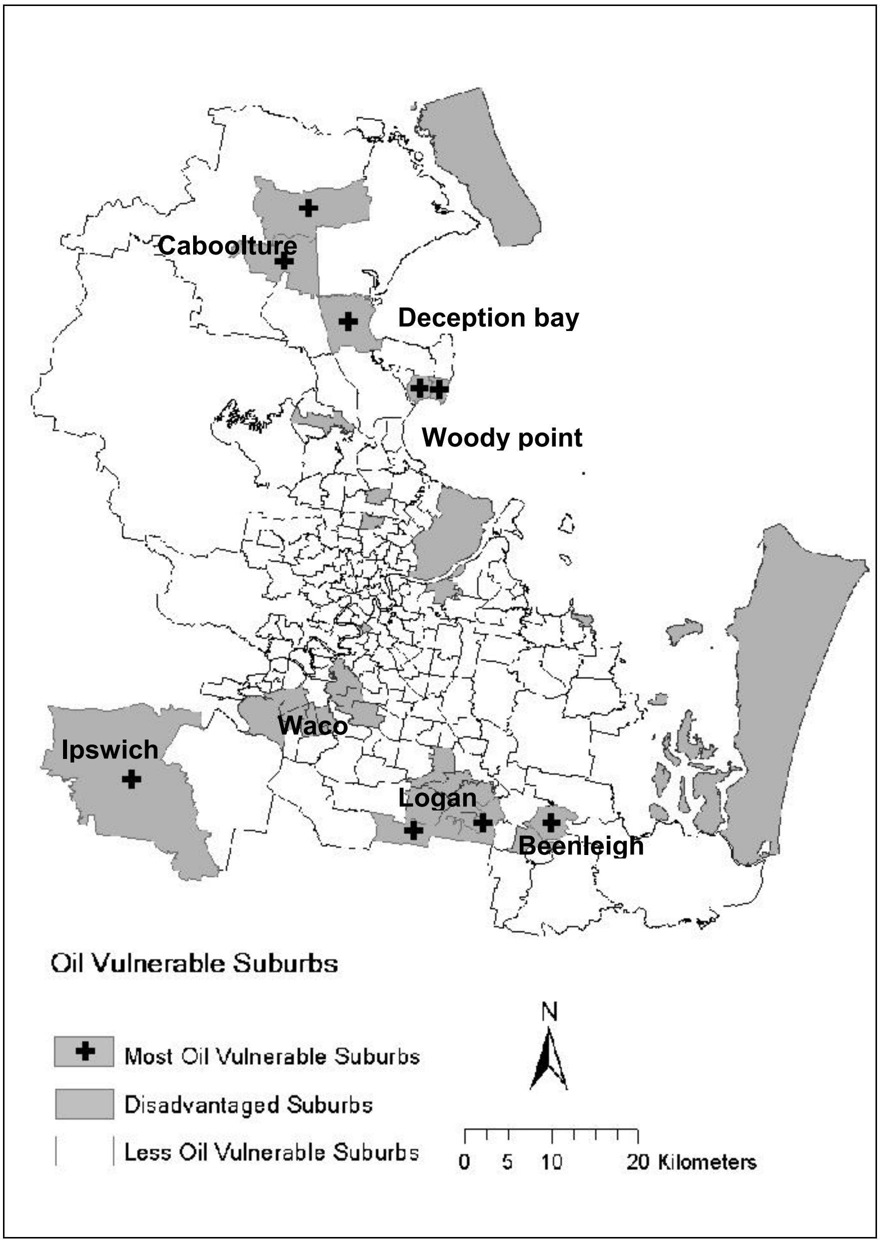

Figure 6: Distribution of oil vulnerable SLAs

6. CONCLUSIONS AND FUTURE WORK

The analysis of household vehicle energy consumption has gained increasing importance in recent years in the face of rising concerns about transport energy sustainability, greenhouse gas emissions and oil vulnerability in Australian cities. This paper has provided an exploratory analysis of the spatial patterns of vehicle energy consumption based on an analysis of household vehicle travel and the efficiency composition of the vehicle fleet in Brisbane. Through a spatial analysis of VKT derived from JTW data and fuel energy consumption associated with the private-owned vehicles, the results show that vehicle energy use/VKT tends to increase as one moves away from the CBD. This demonstrates that not only VKT levels, but also the lower frequency of efficient vehicles, in the outer suburbs increases vehicle energy consumption in these locations. Further spatial analysis was done to test the relationship between the fuel energy intensity and the socio-economic characteristics. By comparing the vehicle energy intensity results with patterns of suburban socio-economic disadvantage, we demonstrate that the composition of the vehicle fleet exacerbates household exposure to higher transport costs, and compounds other forms of disadvantage and vulnerability.

This paper has focused on the household vehicle energy patterns and vulnerability. While the methods and data presented are applicable to model the spatial patterns of household vehicle fuel consumption, there remain a number of areas that will form the basis of future research. First, the temporally consistent datasets (motor vehicle data and JTW data) should be used to better investigate the spatial relationship between vehicle travel pattern and vehicle ownership and fuel efficiency across the region. Second, a spatially disaggregated analysis should be applied to better explore how household vehicle fuel consumption patterns differ according to their socio-economic status at the local level. Both data collection and analysis should be improved in the future research. In addition, in extending this research it will be important to do more analysis to explore the patterns of household energy consumption from vehicle travel activities for all trip purposes -- not only the JTW. Finally, while this paper examined spatial patterns of vehicle energy consumption for a single city – Brisbane; further work should be done to see how the findings for Brisbane compare with other Australian metropolitan areas.

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