Macro-urban form and transport energy outcomes – investigations for Melbourne

Gavin Alford and Jeremy Whiteman

Department of Transport, Victoria

1 Introduction

Climate change and the issue of peak oil have emerged as two critical global challenges for the 21st Century. With the burning of fossil fuels considered to be the major contributor to climate change, there has been a growing interest around the world in how local communities might be made more energy efficient. Ways of consuming less fuel without compromising productivity are of particular interest.

Urban transport – both freight and passenger – forms a significant proportion of this global energy consumption, and is also a major contributor to greenhouse gas emissions. The transport sector has thus been identified as one in which energy savings could be encouraged.

One way in which scientists, commentators and policy-makers are seeking to address these challenges is to consider what role urban form (i.e. how cities are structured and laid out) might play in the reduction of transport energy consumption. The question, in this regard, may be put simply: which urban form model in developed countries results in lower emissions and more efficient transport energy usage? In other words, how might cities be made more sustainable, more energy efficient, as well as less polluting? The introduction of an Emissions Trading Scheme in Australia is likely to have an impact on transport costs and there will be a spatial dimension to how these increased transport costs will play out.

The Victorian Department of Transport has been undertaking a broad programme of work investigating the transport energy issues and developing a transport energy policy for Victoria. The objectives of this work are to improve the Department's understanding of the relationship between energy and transport, to understand the likely effects that changes in the energy sector will have on transport (including the impact of global warming), and to provide evidence-based policy advice in relation to transport energy.

One component of this work involves an examination of the potential implications of different types of urban form for energy use in transport. This project aims to establish the potential over the longer term for land-use and other related policies to contribute to a significant reduction in transport energy consumption. Project outcomes will also include a projection of the relative impact of different transport infrastructure options on greenhouse gas emissions and transport energy outcomes. This will be used to assist consideration of transport policy and land-use planning issues, such as the potential over the longer term for land-use and other related policies to contribute to a significant reduction in transport energy consumption in Victoria.

This paper focuses on one aspect of the urban form–transport energy project: namely, it provides a discussion of some of the results from the Department's modelling of transport energy outcomes for the Melbourne region, with a focus on the impacts of different macro-urban form typologies on transport energy trip usage. The investigations cover trip energy usage results by mode, by metropolitan region and for a number of case study areas.

2 Literature Review

2.1 Density and dispersal, mode share and urban form

Among commentators there are a range of views as to what would best achieve a significant reduction in transport energy use in a largely 'automotive' city such as Melbourne: some favour more compact, higher-density urban forms, while others favour, and indeed defend, more dispersed patterns of development.

The view among many urban planning theorists is that there is, at least in theory, a strong relationship between urban form and transport energy consumption. Based on a study of 32 cities around the world, Australian researchers Newman and Kenworthy (1989) have argued that there is a strong inverse relationship between the population density prevailing at a given location within a city and the amount of transport energy that is consumed. In other words, the lower the population density, the greater the amount of energy that is likely to be consumed by the population for the purposes of travel. One example they cite is that of Perth, which, like a great many cities throughout Australasia, Britain and North America, experienced the well-known phenomenon of 'suburbanisation' in the post-Second World War period. This strong inverse relationship between density and transport energy consumption is supported by the work of Mogridge (1985), Cervero (1996), Stead (2001) and others.

'Suburbanisation' is characterised by rapid expansion in the physical size of cities (with vast areas of low-density fringe development), and is understood to have resulted in higher levels of transport energy consumption. The reasoning is that suburbanisation and the dominance of private car travel go hand-in-hand. That is, where there is a major shift in the transport technology, such as the introduction of affordable, private motor vehicle travel, a self-reinforcing dynamic occurs. People are attracted to settle in areas of lower density made more accessible by private cars, but the distance between their homes and local commuter public transport services will tend, into the future, to maintain their reliance on the private car to get to work (Newman and Kenworthy, 1989). For these areas, this inevitably results in correspondingly higher vehicle kilometres travelled (VKT) per capita than would tend to be found in areas of higher residential density, where there may be closer proximity to employment sources and public transport services. Such higher-density areas will, in contrast, tend to produce a lower modal share for private motor vehicle use, and require less travel overall.

While theorists generally posit a strong and inverse relationship between population density and transport energy use, it has been acknowledged that, in practice, causal relationships between the two are much harder to establish with certainty (Banister, 2005). This is in large part due to a wider range of variables available in 'real world' situations, and the complex interplay between them, than that often posed in theoretical models, where all variables are assumed to be known (and are often deliberately fewer, for the sake of elegance) (Buxton, 2007).

Newman and Kenworthy (1989), for example, have been criticised for tending to focusing too narrowly on density as a factor in travel patterns, with one reviewer of their work asserting that household income and fuel prices should also be considered as important determinants of travel behaviour (Gomez-Ibanez, 1991). Hughes *et al.* (2004), meanwhile, argue that it is the size of the city rather than its density that is the most powerful determinant of transport energy usage.

There are a variety of factors that have indeed been identified as having an influence on travel patterns and modal choice, and, thus, on the extent of transport energy usage within an urban area. These factors may be said to include:

- the prevailing land-use mix (e.g. local ratio of jobs to workers resident)
- the location of employment, service, shopping and recreational activities
- the extent of city area (Hughes *et al.*, 2004)
- local accessibility to transport infrastructure/modal options, i.e. distance and ease of access to rail, tram and bus, particularly via walking
- the frequency of public transport services/passenger waiting times (Mees, 2000; Cervero, 1996)
- the connectivity between transport modes, e.g. bus/rail connections (Mees, 2000)
- the affordability of public transport fares
- levels of car ownership, as well as the affordability of fuel and other motoring-related expenses (Troy, 1992; Brindle, 1994)
- the availability of parking (Kitamura *et al.*, 1997)
- gender and household structure (Morris and Richardson, 1997)
- attitudinal and other behavioural factors (e.g. Kitamura *et al.*, 1997; Bagley and Mokhtarian, 2002).

It should also be noted that there are some authors who, contrary to the conventional wisdom, are sceptical about the degree to which urban form has the potential to influence travel patterns and consequent energy consumption. Stead and Kitamura, for example, both point to socio-economic factors as being more influential than those related to land-use *per se* (Stead, 2001; Kitamura *et al.*, 1997). Breheny (1995) and Stretton (1996) have argued, for instance, that the energy savings from compaction are not only marginal, they are not worth the ‘pain’ involved in restricting or ‘reversing’ suburbanisation. It has also been said that people actually prefer suburban living because of the lifestyle advantages this is believed to afford (Gordon and Richardson, 1997; Brotchie, 1992; Stretton, 1996; and Troy, 1992). Finally, there are those such as Mees (2000) who argue that it is the quality and extent of public transport services, independently of urban form, that is perhaps most important as a factor determining modal split and, consequently, levels of transport energy consumption.

2.2 Studies on transport energy and the pattern of urban development

Studies that specifically analyse the transport energy or greenhouse gas emission outcomes for different patterns of development are more limited in number.

One such study is the Victorian Urban Villages Project (Buxton, 1996). This project aimed to assess the potential for existing well-located urban areas to accommodate projected demand for housing. The project also included estimates of the potential for transport energy and greenhouse gas emissions savings from redirecting urban growth to 800 urban villages and away from more traditional suburban locations. The urban villages were all located within a 400-800 metre radius of a public transport stop. These centres were seen by the study as being capable of redevelopment into mixed-use centres with medium density housing. The study developed six scenarios for 2011 and tested different levels of housing development within the urban villages, from a low scenario of 8 per cent of new dwellings through to a high scenario of 76 per cent. The study estimated that the major urban village options would result in energy emission savings of around 14 per cent. Depending on the level of job self-containment (i.e. jobs closer to homes), greenhouse gas emission reductions of between 21 and 27 per cent could be achieved (Buxton, 1996).

A study (Newton 1997) undertaken by the Australian Housing and Urban Research Institute (AHURI), as part of the Inquiry into Urban Pollution in Australia, included an examination of air quality and emissions from different macro-scale urban development scenarios for Melbourne. The scenarios allocated an additional 500,000 persons by 2011, with comparison made against a 1991 base (with a population of 3 million). They included the following options: business-as-usual; compact; edge city; corridor development; regional city (called ultra city); and fringe city. These scenarios were modelled using a CSIRO “integrated land-use-transport-emission-air shed model”, which allocated projected population across 26 Journey-to-Work zones.

The results from the AHURI study showed that the Compact City modelled scenario had the lowest greenhouse gas emissions by some margin, while the Corridor, Edge and Fringe city scenarios each had higher emission levels (but similar to one another). The Business-as-usual scenario had the highest emission levels. The AHURI study also included results for daily fuel consumption, which it used as a proxy for energy consumption. The results were of similar proportion to that produced for emissions with the Compact City scenario. This scenario produced significantly lower Vehicle Kilometres Travelled (VKT) than the alternative configurations, and, as a consequence, this resulted in lower emissions.

Both the Urban Villages 1996 study and the AHURI 1997 study relied on a macro-scale strategic transport model to ascertain the potential impacts of urban form on greenhouse gas outcomes. They were only able to use a limited number of trip zones to estimate the impact of the various scenarios. From the conclusions it appears that the key factor driving the lower-emission scenarios was that these scenarios exhibited more job self-containment and/or fewer VKT.

3 Macro Urban Form and Transport Energy Project

3.1 Outline

The hypotheses for this study are that there are strong links between transport energy outcomes and the nature of urban form; and that different levels of transport energy consumption will result from different types of urban form.

In examining these hypotheses, the study has estimated transport energy outcomes for representative examples of different urban form typologies within Melbourne. Examination then took place of the differences in the results between areas, of the factors that made each area different, and how these factors might have influenced the emission and energy results.

Factors that were considered to illustrate significant variations in the urban form typology included: location; population density, employment density, and the type and level of public transport infrastructure. In the terms of this study these factors might be described as ‘macro’ urban form determinants.

The use of a macro-urban form approach supports the application of a metropolitan scale strategic transport model to the analysis undertaken as part of this study. It allows quantitative measures to be applied consistently across the entire metropolitan region, which might not be achievable if a more fine-grained, detailed, and possibly qualitative, micro-urban form factors were used. This is not to dismiss the importance of more micro-urban form measures, such as urban design and street permeability. Rather, it recognises that the macro-urban form factors are more manageable to use and match the tools available for use in this study.

3.2 Methodology

The steps involved in this study included:

i. Identifying and applying the macro-urban form typology indicators across all transport zones in Melbourne
ii. Identifying Case Study Areas that would provide representative examples of the various types of macro-urban form (for illustrative purposes)
iii. Estimating the number of trips generated from each case study area
iv. Converting trip volumes and transport energy equivalents.

3.2.1 Macro-urban form indicators

This project is attempting to link variations in transport energy outcomes to variations in macro-urban form typologies. Four measures were developed for analysis. These measures had the benefit of being able to be used consistently across Melbourne; they were also readily available for all transport zones, and had data outputs that matched the data outputs provided by the transport model.

Measures used were as follows.

- **Location:** straight line distance from the transport zone centroid to a central point in the Melbourne CBD (nominally, the former GPO at Bourke and Elizabeth Streets).
- **Population density:** transport zone population as at 2006, divided by the total area of the transport zone in hectares.
- **Employment density:** transport zone employed persons as at 2006, divided by the total area of the transport zone in hectares.
- **Type and level of public transport infrastructure:** a calculation was made for each transport zone, based on the level of service for train, tram and bus services traversing the transport zone for the average weekday.

The main spatial geography used in this analysis is MITM Transport Zones (described in section 3.2.3).

3.2.2 Selection of illustrative case studies

To assist our understanding of the different transport energy and emission outcomes from different areas across Melbourne, 21 transport zones were identified for further analysis and comparison. These zones were selected on the basis that they provide a broad cross section of the transport zones found across Melbourne.[1]

3.2.3 Trip estimates

The Department's Melbourne Integrated Transport Model (MITM) was used to calculate the number of motorised trips and mode of travel generated in Melbourne. The trip results were then converted to transport energy outputs. Results were produced for each transport zone within the Melbourne Statistical Division.

MITM is based on the traditional four-step approach to transport modelling.[2] It produces results for a 24 hour period, and has separate model components for the AM and PM peak

[1] The selection of the Case Study Areas (based on MITM Transport Zones) was also based on work undertaken by SGS Economics and Planning, under the direction of the Department of Transport (Victoria).

[2] This 'four-step' method generally involves estimating trips based on activities in land use patterns, and how they are distributed among destinations, how they are split amongst travel modes, and according to how they are assigned to specific routes.

periods, inter-peak and off-peak periods. These reflect the different travel patterns that are experienced across the day. MITM's zone system has been disaggregated to 2253 zones (plus 19 external zones). The model allocates trips between eight home-based and six work-based trip purposes, covering white collar, blue collar and educational activities.

Ordinarily, one might allocate the outputs of the AM and PM peaks separately, based on the different AM and PM trip origins. However, as the purpose of the analysis was to reveal the spatial spread of transport energy outcomes across Melbourne, particularly for residential locations, the outputs for the PM peaks were allocated to the zone of origin for the AM trips (i.e. the initial point of departure and final destination for commuting journeys, understood as two-way, single purpose trips). This was done for residential zones only, so as to capture the spatial impact on dispersed residential locations. If trips home were not recorded according to AM zone of origin (but, rather, to the PM zone of origin, i.e. where the jobs are), this would produce results not reflective of the transport energy efficiencies of the resident zones. That is, emissions and energy outcomes would be significantly higher for high employment density areas (such as the CBD) than their resident populations might otherwise be expected.

The MITM model is used primarily to test strategic transport infrastructure options. Land use components are provided as exogenous inputs, as is the case with the traditional four-step models. This means that both different land use scenarios and different transport investment scenarios, or different packages of land use and transport, can be tested.

3.2.4 Transport energy assumptions

Using the MITM model, transport energy outcomes were able to be calculated for private motor vehicles, buses, trains and trams, with the results produced at the transport zone level. Outputs from MITM include: the total number of trips; total distance travelled; and total travel time of each trip made in each transport zone in Melbourne. Average travel speeds can be calculated from these figures. By applying fuel consumption rates, mode share and vehicle occupancy rates, as well as energy consumed per trip, energy consumed by trip kilometre and energy consumed per passenger kilometre can be calculated for each transport zone[2].

For private motor vehicles and for buses, energy calculations were derived from estimates of fuel consumption rates. Different rates applied depending on estimated travel speed.

For trains and trams, estimates of vehicle electricity usage rates, based on estimates specific for the Victorian electricity industry, were used.

Private motor vehicle (PV) fuel consumption rates (FCR) were estimated using the Austroads (2006) Urban Journey Speed VOC Model.

$$\text{FCR (L/100km)} = 0.361 + 528 \div (\text{Average Speed}) + 0.000785 \times (\text{Average Speed})^2 \quad \text{Equation (1)}$$

Private vehicle energy usage rate of 34.2 megajoules per litre (MJ/L) were sourced from Australian Greenhouse Office (2006, Table 3). Private vehicle energy usage rates for MJ per vehicle kilometre were calculated as follows:

$$\text{PV (MJ/veh-km)} = \text{PV FCR (L/100km)} \div 100 \times \text{Energy Usage Rate (MJ/L)} \quad \text{Equation (2)}$$

Buses were all assumed to have a fuel consumption rate of 26.7 L/100km, sourced from the Australian Greenhouse Office (2006, Table 12). Bus energy by vehicle kilometre was calculated as follows:

$$\text{Bus (MJ/veh-km)} = \text{Bus FCR (L/100km)} \div 100 \times \text{Energy Usage Rate (MJ/L)} \quad \text{Equation (3)}$$

Energy per passenger kilometre was calculated by adjusting MJ vehicle kilometre rates by vehicle occupancy. Private vehicle occupancy rates applied were the average workday figures from the VATS data base.

The public transport vehicle occupancy rates for bus, tram and train were those average all-day figures as reported by the public transport system regulator.

Total person trips taken by mode were calculated as follows:

$$\text{Total person trip by mode} = \text{total trips by origin zone} \times \text{proportion of mode trips in the SLA} \quad \text{Equation (4)}$$

Total trips by mode were calculated as follows:

$$\text{Total mode trips} = \text{total person trips by mode} \div \text{average mode occupancy rate} \quad \text{Equation (5)}$$

Distance travelled by mode was calculated as follows:

$$\text{Mode (veh-km)} = \text{Total mode trips} \times \text{average PT trip distance for transport zone} \quad \text{Equation (6)}$$

Emission outcomes are not expected to mirror transport energy outcomes. The reasons being, firstly, that different transport modes have different greenhouse gas emission profiles for the energy they consume per passenger kilometre, and secondly, the mode split may vary across transport zones. That is, while two transport zones may have the same energy outcomes, different mode shares will lead to differing emission levels.

4 Macro-Urban Form and Transport Energy Outputs

4.1 Mode results

The fuel consumption rates and energy rates for private vehicles, buses, trams and trains are outlined in Table 1. All figures have been calculated for the average weekday as at 2006. The MITM outputs make allowance for variations in vehicle speed.

As expected, buses consume substantially more fuel, and correspondingly consume substantially more energy, than private motor vehicles. However, when considered in terms of energy consumed by passenger kilometre, buses are around two and a half times more energy efficient than private motor vehicles.

Table 1 – Average metropolitan transport energy: MITM outputs by mode, 2006

Vehicle	*Speed (km/h)*	*FCR per vehicle (L/100 veh-km)*	*Energy usage (MJ per vehicle-km)*	*Energy usage (MJ per passenger-km)*
PV average	43.5	14.0	4.78	3.19
PV minimum	31.9	17.7	6.06	4.04
PV maximum	67.5	11.8	4.02	2.68
Bus	n/a	26.7	10.31	1.32
Tram	n/a	n/a	10.74	0.43
Train	n/a	n/a	62.60	0.40

Figure 1 and Figure 2 show the variation in energy consumed by mode per vehicle kilometre travelled and per passenger kilometre travelled. In terms of the energy consumed per vehicle kilometre travelled, the trams and buses consume approximately the same amount, despite having different energy sources.

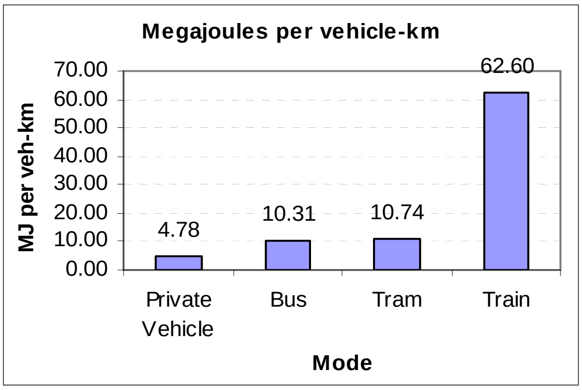

Figure 1 – Energy usage per vehicle kilometre by mode, 2006

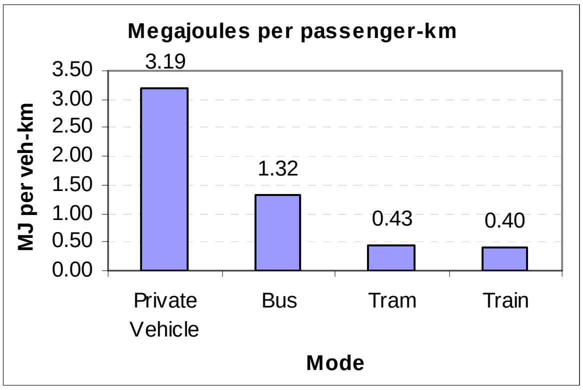

Figure 2 – Energy usage per passenger kilometre by mode, 2006

Trains are by far the greatest consumers of energy per vehicle kilometre of all the modes. However, when energy consumed per passenger kilometre is considered, trains are equal with trams as the most efficient mode, and are approximately eight times more efficient than private motor vehicles. It is noteworthy that trams, despite having a substantially lower vehicle occupancy capacity than trains, recorded similar energy consumption levels on a per passenger kilometre basis, all of which demonstrates their relative energy usage.

4.2 Metropolitan results

Transport energy usage for the Melbourne region as at 2006 is estimated at around 32,000 megajoules per 1000 trips on an average weekday. As Figure 3 shows, when the metropolitan area is, however, divided into the 2253 transport zones of the Melbourne Integrated Transport Model (MITM), it is evident that there is substantial spatial variation in this transport energy usage across Melbourne.

Transport zones within the Melbourne CBD's immediate environs recorded the lowest transport energy usage per 1000 trips, recording outputs in the 9,000-12,000 MJ per 1000 trip range, less than one-third of the metropolitan average. Outer metropolitan areas had the highest usage, or least efficient trips, with usage rates commonly above 50,000 MJ per 1000 trips.

Figure 3 shows that the major industrial areas have higher transport energy usage. The areas around the Port of Melbourne, Laverton, Melbourne Airport and Dandenong South all have noticeably higher transport energy usage when compared to their neighbouring areas.

Superimposed onto Figure 3 is an outline of the metropolitan railway network. The railway network in Melbourne is a radial network spanning out from the CBD. Areas of lower transport energy usage tend to follow the railway network, most notably in the middle ring suburbs. Figure 3 shows that corridors without railway lines, such as the Doncaster and the Rowville Corridors, have higher transport energy usage relative to neighbouring areas with railway corridors. It also shows that locations within the tram network catchment, including the inner northern suburbs, experience higher energy usage levels per trip.

As would be expected, there is a correlation between high public transport mode share and transport energy usage per trip. This is because each of the public transport modes has lower energy usage per passenger kilometre compared to that of private motor vehicles.

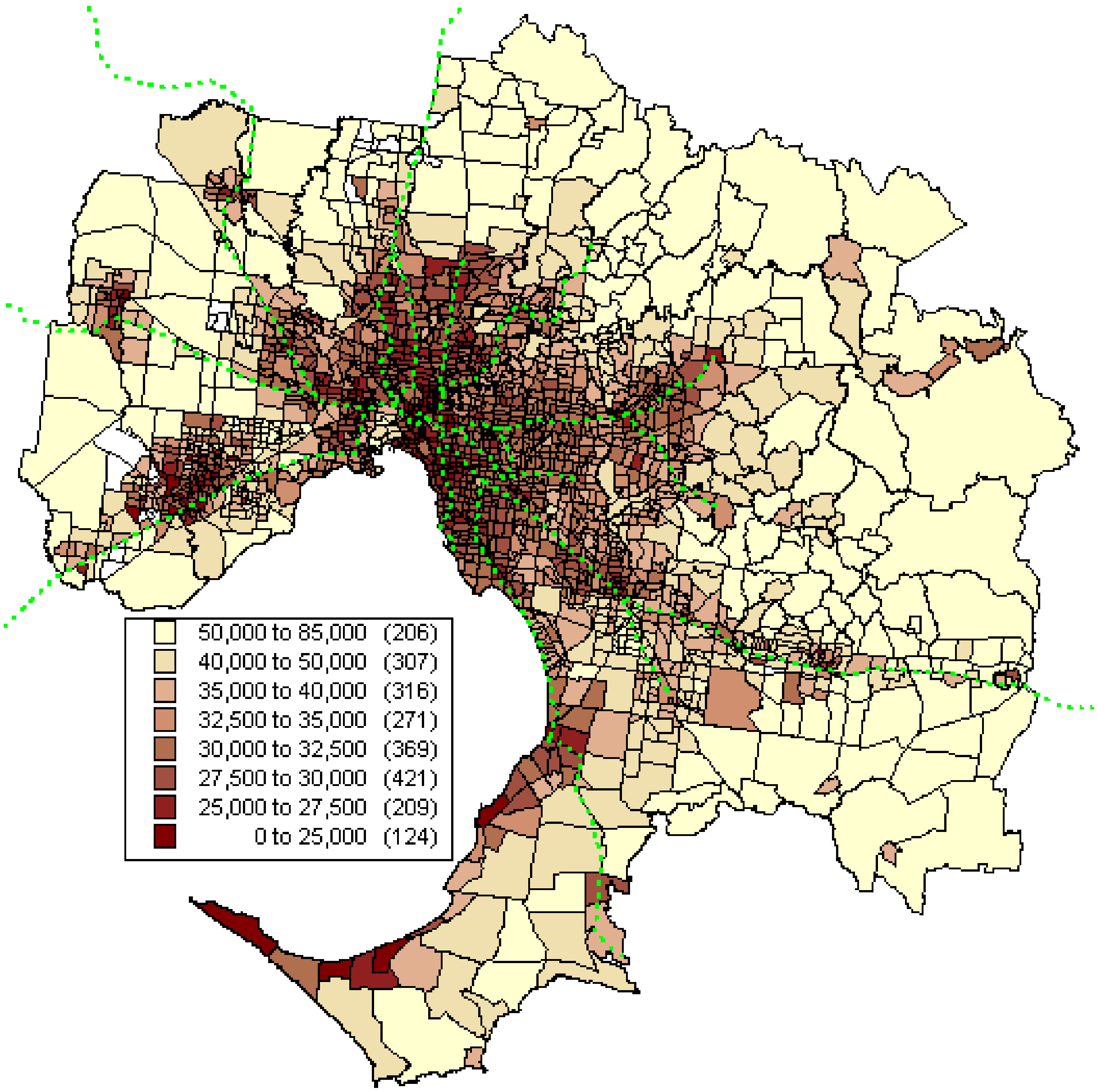

Figure 3 – Transport energy usage per trip – Melbourne, 2006 (MJ/1000 trips)

Source: MITM simulations

The results show that there is a cluster of transport zones with average weekday transport energy usage levels around 24,000 MJ/1000 trips, and a public transport mode share within the 17-25% range[3]. The results also show that if public transport mode share reaches the 65-75% range, then transport energy use falls to around 12,000 MJ/1000 trips, i.e. a trebling of public transport mode share is required to reduce transport energy usage by half.

Figure 4 shows that distance from the CBD does have an impact on the level of transport energy usage, albeit at a relatively weak correlation. As already noted in the discussion of Figure 3, corridors with a railway line exhibit higher transport energy usage per trip than corridors without a railway line. As a general rule, it might be assumed from Figure 4 that transport zones above the line indicate zones that are further away from public transport than the zones below the line.

[3] The map and chart showing PT mode share and trip efficiency has not been included in this paper due to limited space availability. The map shows a pattern generally similar to that illustrated in Figure 3.

There are some transport zones that exhibit relatively low transport energy usage and are at a relatively long distance from the CBD. For example, there is a zone at 56 km from the CBD having approximately 18,000 MJ/1000 trips (compared to an average of around 48,000 MJ/1000 trips at this distance). The assumption made after the further analysis of these particular zones is that there are some outlying zones that experience low VKT because of demographic or socio-economic factors specific to residents from these zones (e.g. they have a higher proportion of older people, who tend to make shorter trips). The zones themselves are at or near the old town centres of Pakenham and Werribee and on the Mornington Peninsula.

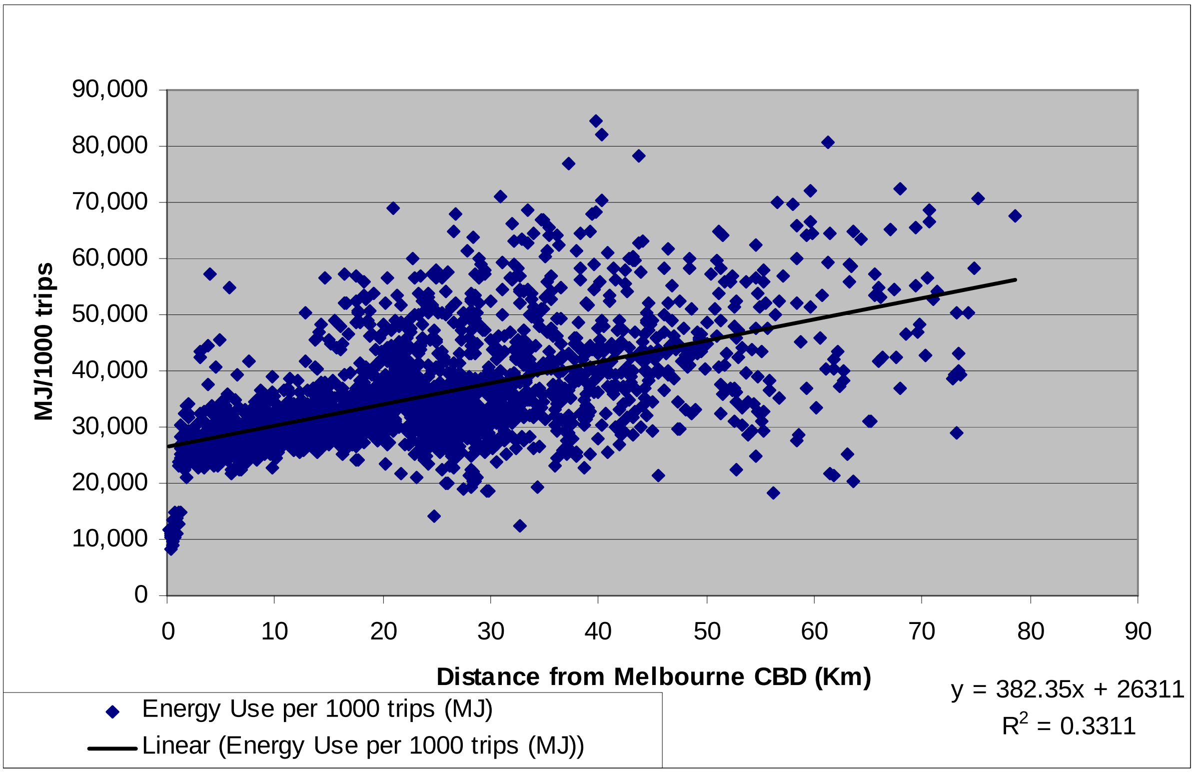

Figure 4 – Transport energy usage per trip vs distance from Melbourne CBD

Figure 5 compares transport energy usage by the total resident population and number of employed persons within each transport zone on a per hectare basis.

The results show that there is a correlation between density and transport energy use, with the increase in density reflecting a lowering of transport energy usage[4]. There is also a levelling out of energy use by density, with little change in trip energy usage per trip experienced from around 75-90 persons (resident population and workers) per hectare. Lower density zones had a marked increase in the transport energy usage levels experienced.

[4] There are a few zones that have recorded population and employment by hectare levels beyond the 195 hectate maximum registered for the X axis in Figure 5. These zones are primarily within the Melbourne CBD, have a high employment density and have relatively higher trip efficiency levels, generally around the 12,000 – 14,000 MJ/1000 trips.

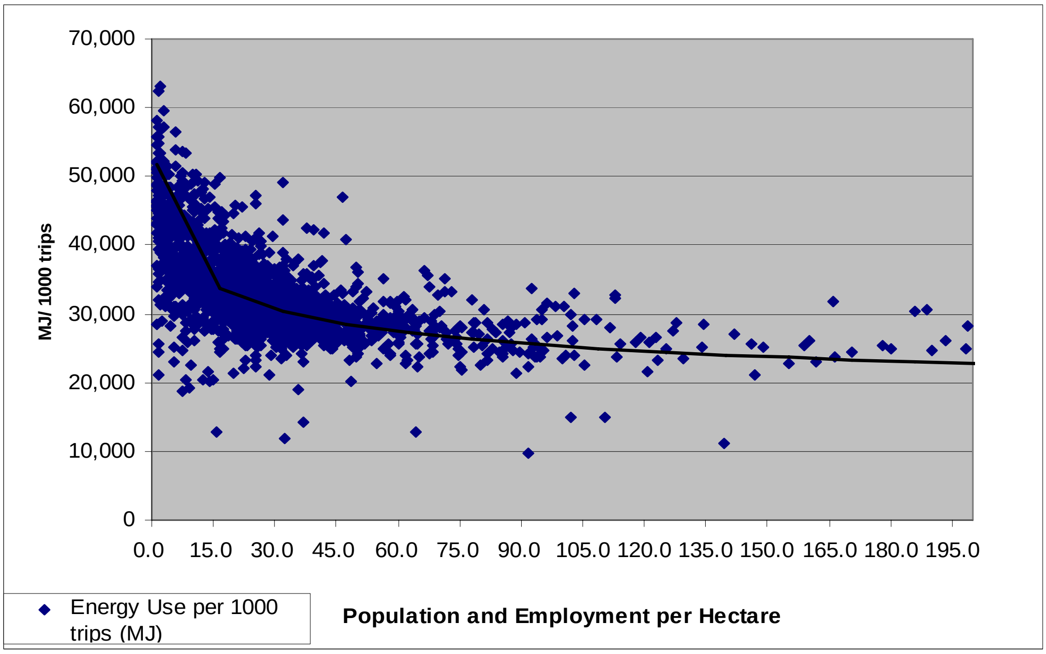

Figure 5 – Transport energy usage per trip vs population and employment density

4.3 Transport energy outputs for the case study areas

The modelling also showed that, across the Case Study Areas, there were some general correlative relationships between particular elements of macro-urban form and how efficient each area was in terms of transport energy usage.

The ranking of the Case Study Areas, in terms of energy usage per trip, and population density, can be seen in Figure 6. A standard measure for efficiency was required that allowed comparison of transport zones varying in population size and area. 'Efficiency' here is, for each given area, defined as a factor of: the amount of energy consumed (MJ); the number of trips and distance travelled (1000 trips); and the area of the zone (hectares). Lower emissions (MJ/1000 trips per persons per hectare) indicates higher efficiency.

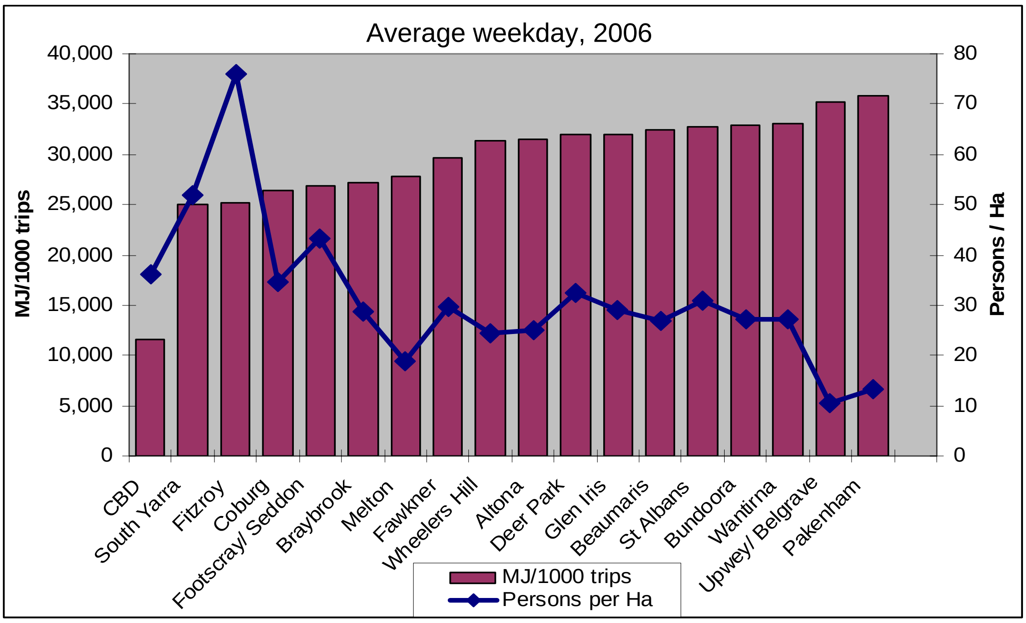

Figure 6 – Trip energy usage per trip and density

The results here show that higher densities tend to be correlated with higher transport efficiency. For example, the Case Study Areas which have higher densities (the CBD[5], Fitzroy, South Yarra, Footscray/Seddon and Coburg), are also ranked higher in terms of transport energy efficiency (as reflected in their lower rates of MJ/1000 trips). Those located in the middle and outer ring of suburbs (Bundoora, Fawkner, Glen Iris, Wheelers Hill and Braybrook), with lower population density, tend to be ranked roughly in the middle. Those areas, meanwhile, that are closer to the periphery of Melbourne, and show an even lower population density (Wantirna, Upwey/Belgrave, St Albans, Deer Park, Pakenham and Melton), appear to have the least efficient use of transport energy.

The results also reveal (as seen in Figure 7) a correlative relationship between transport energy efficiency and modal split, i.e. the proportion of motorised trips taken by public transport in each respective Case Study Area. The highest proportion of public transport usage is in the inner city areas, which is to be expected, given that they have better access to rich public transport infrastructure and, potentially, to intermodal or networked public transport infrastructure. For the CBD, the figure is as high as 72 per cent, and this is followed by Fitzroy (19%), South Yarra (12%) Footscray/Seddon (11%). The public transport mode share in those Case Study Areas representative of intermediate and outer suburbs, where public transport access and service levels tend to be comparatively poorer, show considerably less variation (ranging between 4 and 8 per cent).

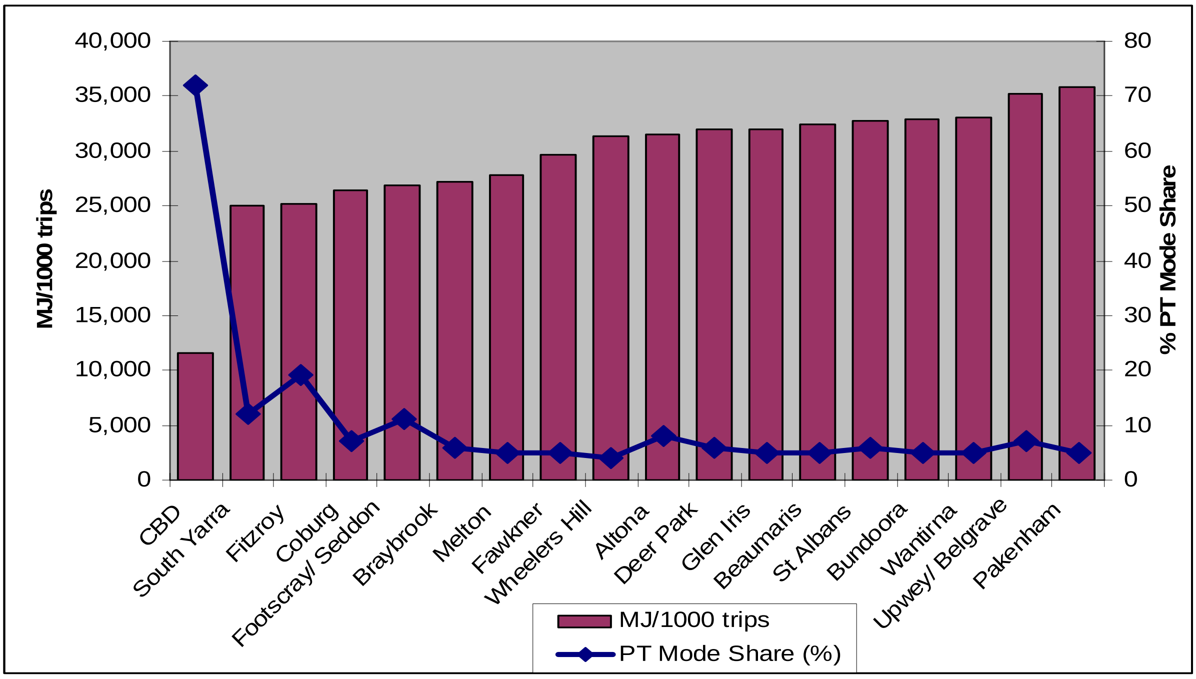

Figure 7 – Trip energy usage and public transport mode share

5 Comparing Case Study Areas – Fitzroy and Wheelers Hill

To illustrate the role played by macro urban form in determining transport energy outcomes, one may compare two separate travel zones that represent a 'classic' contrast between 'pedestrian-era' and 'automotive-era' urban development in Melbourne: Fitzroy and Wheelers Hill. Higher density inner-city Fitzroy was planned and developed in the 19th Century, before

[5] The estimates for the CBD represent a single central transport zone within the Melbourne CBD area. They do not represent an average for the whole Melbourne CBD or SLA. 'Persons per hectare' in Figure 7 refers to resident population and does not include the number of employed persons, hence the lower CBD figure.

the advent of the motor car, while outer suburban, lower density Wheelers Hill is a product of Melbourne's post-war growth, particularly from the 1970s, when car ownership was becoming increasingly prevalent.

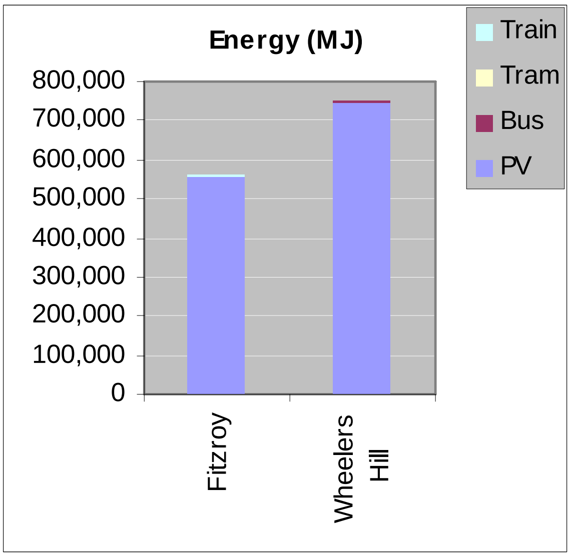

Figure 8 – Total transport energy usage, Fitzroy and Wheelers Hill, average weekday, 2006

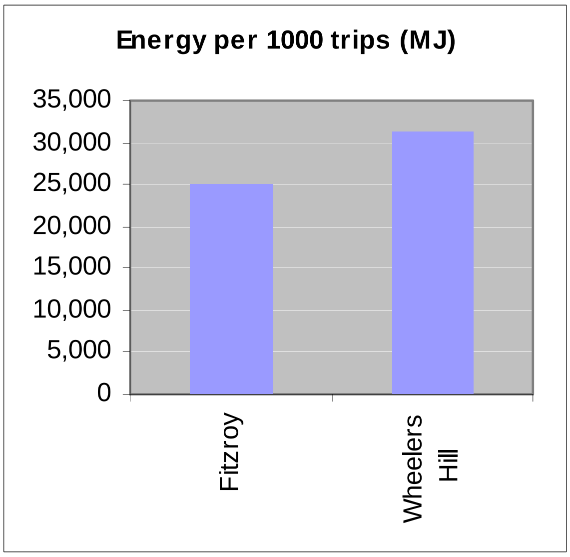

Figure 9 – Transport energy usage rate, Fitzroy and Wheelers Hill, average weekday, 2006

As shown in Figure 8 and Figure 9, the Wheelers Hill area consumes more energy for personal transport purposes, and more energy per 1000 trips, than does the Fitzroy area. This is unsurprising, given the respective modal splits (for motorised travel) and average trip distances for these two areas (as illustrated in Figure 10 and Figure 11). Over ninety per cent of those travelling from the Wheelers Hill area by motorised means do so by private car, with the remainder travelling by bus (the only mode of public transport directly available in that location), or by driving to a railway station outside the transport zone. These motorised journeys are, on average, longer than those undertaken by residents of the Fitzroy area.

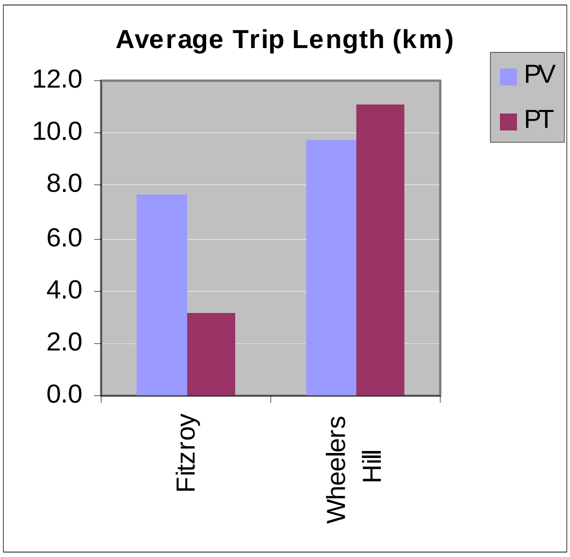

Figure 10 – Average trip length, Fitzroy and Wheelers Hill, average weekday, 2006

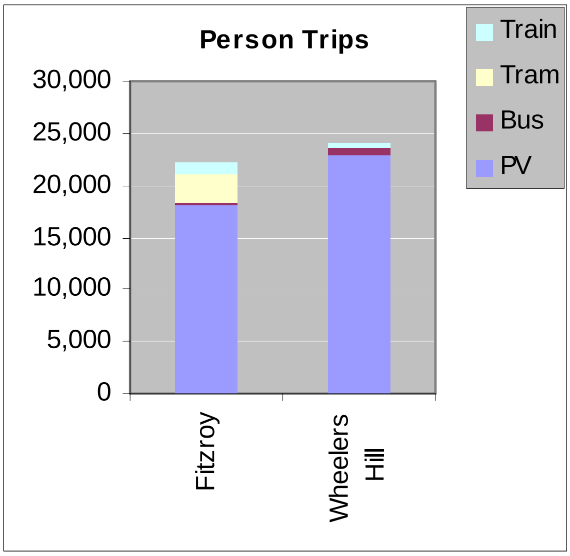

Figure 11 – Person trips by mode, Fitzroy and Wheelers Hill average weekday, 2006

Some 80 to 83 per cent of the return trips originating in the Fitzroy area are undertaken by private motor vehicle, with most of the remainder being tram and/or train journeys. Car dependency is thus stronger in Wheelers Hill than in Fitzroy, although car travel is by far the major mode in both areas.

There are a number of aspects of macro urban form, other than population density, that are likely to play a role in explaining why energy consumption in terms of motorised travel should be higher in Wheelers Hill than in Fitzroy. For instance:

- Wheelers Hill is much further than Fitzroy from the CBD, a major trip-attractor in Melbourne (and, consequently, journeys tend to be longer)

- In terms of infrastructure provision, Fitzroy is much better serviced by public transport than Wheelers Hill, in that its residents have more immediate access to the full range of modes (bus, tram and train), whereas Wheelers Hill is serviced only by buses (which consume more energy per passenger kilometre than trams or trains)

- Although both areas are predominantly residential, the Fitzroy study area has more of a mixed-use character, with a far greater employment density (an average of 105.4 jobs per hectare compared to only 8.6 for the Wheelers Hill study area)

- Likewise, the density of jobs is higher in areas adjacent to Fitzroy; and lower in areas adjacent to Wheelers Hill.

Factors such as these may help to explain why energy outcomes for Fitzroy are lower than those for Wheelers Hill. For instance, it is generally understood that higher density and job-ratios will tend to shorten average motorised trip distances for a given area, and may also create a ‘reinforcing effect’ for public transport: i.e. a denser passenger catchment area may improve the viability of higher service levels and greater route coverage, thus leading to higher patronage levels and less driving overall.

6 Conclusion

The results from the modelling indicate that various macro-scale urban form indicators correlate with energy efficiency. These correlations substantiate the view that there is, indeed, a relationship, at a macro-level, between urban form and transport energy consumption. That is, areas that have higher residential and employment density, and higher levels of public transport availability, are likely to consume transport energy more efficiently than those areas with lower density and less public transport. The findings show that a trebling in public transport mode share results in a halving of transport energy consumed. There was also a moderate correlation between energy use and distance to the CBD area.

Where variations from a trendline occur, these may be largely explained by the fact that the transport zones across Melbourne have specific, and often different, combinations of the values of the four independent variables (the principal ‘macro-scale’ elements of urban form applied in this study). That is, two zones might share a similar population or employment density, but differ in terms of their respective distances from the CBD or their transport infrastructure; alternatively, they might have similar transport infrastructure, but differ in regard to other indicators.

It should also be noted that urban form may also play a role in influencing the incidence of non-motorised trips in a given area. While data on non-motorised transport modes such as walking and cycling have not been included in the above analysis, evidence from other studies has shown that certain elements of urban form, such as location, employment density (at a macro level), and street patterns and permeability (at a micro level), will likely promote a higher modal share for this 'carbon-free' transport mode. A higher mode share for walking and cycling will have a positive impact on overall energy and emissions outcomes in any one travel zone.

The above conclusion, that indicators of macro-urban form show a correlation with transport energy outcomes, and that denser, more transport-rich locations will tend to exhibit higher transport energy efficiency, has obvious implications for policy around such areas as transport, transport energy and land-use planning. It underscores the importance, first of all, of integrated planning solutions to questions of urban sustainability. Above all, it shows that land-use and transport policy do have real potential to result in better transport energy outcomes for Melbourne, at a time when such considerations are becoming increasingly important, if not crucial, for our future.

7 Next steps

As a next step in the overall urban form and transport energy project (not covered by this paper), a number of scenarios are being developed that reflect a range of potential options for Melbourne's future urban development. An assessment is to be made of the capacity of each of these scenarios to effect significant change in Melbourne's transport energy consumption, the results of which will be available to inform policy-making.

The impact of land use and urban form on greenhouse gas emissions is also an area requiring further analysis. The methodology and general approach taken in the study of transport energy, as described in this paper, can also be applied to the analysis of greenhouse gas emissions. It is intended that the broader Macro-Urban Form and Transport Energy project also incorporate analysis of greenhouse gas emissions. This analysis would include consideration of the relative impacts of different urban development scenarios on emission outcomes.

References

Austroads (2006). *Update of RUC unit values to June 2005*. Report No. AP-T70/06, Austroads: Sydney.

Australian Greenhouse Office (2006). National greenhouse gas inventory analysis of recent trends and greenhouse indicators 1990 to 2005, APS: Canberra.

Bagley, M. V. and Mokhtrarian, P. L. (2002). 'The impact of residential neighbourhood type on travel behavior: a structural equations modelling approach', *Annals of Regional Science*, 36, pp. 279-297.

Banister, D. (2005). *Unsustainable transport – City transport in the new century*. Taylor and Francis: London.

Breheny, M. (1995). 'Compact cities and transport energy consumption', *Transactions of the Institute of British Geographers*, 20(1), pp. 81-101.

Brindle, R. (1994). *Lies, damn lies and automobile dependence – Some hyperbolic reflections*, 19th Australasian Transport Research Forum: Lorne, Vic.

Brotchie, J. (1992). 'The changing structure of cities', *Urban Futures*, Special Issue 5, pp. 13-26.

Buxton, M. and Scheurer, J. (2007). 'Density and outer suburban development in Melbourne', *Urban Policy and Research*, 25(1), pp. 91–112.

Buxton, M. (1996). 'Energy, transport and urban form in Australia', pp. 54-63. In Williams, K., Burton, E. and Jenks, M. (eds) *The compact city: A sustainable urban form*, Spon Press: London.

Cervero, R. (1996). 'Mixed land uses and commuting: Evidence from the American Housing Survey', *Transportation Research A*, 30(5), pp. 361-377.

Gomez-Ibanez, J. (1991). 'A global view of automobile dependence', *Journal of the American Planning Association*, 57(3), pp. 45-56.

Gordon, P. and Richardson, H. (1997). 'Are compact cities a desirable planning goal?', *Journal of the American Planning Association*, 63(1), pp. 95-106.

Hughes. B., Chambers, L., Lansdell, H. and White, R. (2004). 'Cities, area and transport energy', *Road and Transport Research*, 13(2), pp. 72-84.

Kitamura, R., Mokhtarian P. and Laidet L. (1997). 'A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay area', *Transportation*, 24(2), pp. 125-158.

Mees, P. (2000). *A very public solution: Transport in the dispersed city*. Melbourne University Publishing: Melbourne.

Mogridge, M. J. H. (1985). 'Transport, land use and energy interaction', *Urban Studies*, 22(6), pp. 481-492.

Morris, J. and Richardson, A. (1997). *The emerging transport needs of women in contemporary urban Australia*, Proceedings of the National Conference of Women's Travel Issues: Baltimore, United States.

Newman, P, Kenworthy, J. (1989). *Cities and automobile dependence: An international sourcebook*. Aldershot: UK.

Newton, P (1997). *Re-shaping cities for a more sustainable future – Exploring the link between urban form, air quality, energy and greenhouse gas emissions*, Research Monograph 6, Australian Housing and Urban Research Institute: Melbourne.

Stead, D. (2001). 'Relationships between land use, socio-economic factors, and travel patterns in Britain', *Environment and Planning B*, 28(4), pp. 499-528.

Stretton, H. (1996). 'Density, efficiency and equality in Australian cities', In Jenks, M., Burton, E. and Williams, K. (eds) *The compact city: A sustainable urban form?*, Spon Press: London.

Troy, P. (1992). 'The new feudalism', *Urban Futures*, 2(2), pp. 36-44.