ANALYSING PASSENGER TRANSPORT ENERGY CONSUMPTION FROM TRAVEL SURVEY DATA: A CASE STUDY OF NELSON MANDELA METROPOLITAN AREA

S O Mohammed[1] and C Venter[2]

[1] Built Environment, CSIR, PO Box 395, Pretoria 0001,
smohammed@csir.co.za, Tel (012) 841-3991, Fax (012) 841-4044
[2] Department of Civil Engineering, University of Pretoria, Pretoria, 0002,
christo.venter@up.ac.za, Tel (012) 420-2184, Fax (012) 362-5218

ABSTRACT
Energy consumption is emerging as a major area of public and political concern worldwide. The need for local and metropolitan authorities in South Africa to consider energy more explicitly in the developing of their transport plans is growing. As strategies to reduce or manage energy consumption are developed, better data is needed to monitor and predict energy consumption impacts both at the regional and household levels. In addition, a better understanding of energy consumption patterns, and the socio-economic, land use, and transport-related factors that accompany these, will be needed. The paper reports on a study with a two-fold objective: to develop and test a methodology to measure transportation energy consumption at a spatially disaggregate level; and to explore the impact of various socio-economic and land use factors on transport energy use. The data is from the Nelson Mandela Metropolitan Area Travel Survey, a 24-hour survey conducted in 2004. The focus is on passenger travel by all modes. Preliminary findings include a significant direct relationship between motor ownership and energy consumption. Moreover, statistical analyses suggest relatively weak relationships between land use factors, such as population and job densities, and transport energy consumption. These findings suggest that a reduction in energy consumption might be achieved more effectively through car use limitation than through slower-paced changes in land use.

INTRODUCTION
The transport sector in South Africa is second only to commerce and industry in terms of net energy consumption. But what stands out most is the fact that the transport sector is solely dependent on petroleum as its energy source (DoT, 1992; DME et al, 2002). With the problematic global outlook for traditional oil supplies, attention is shifting towards reducing the transport sector's unsustainable dependence on oil.

South Africa's national transport policy doesn't address energy concerns head-on. Direct mention of energy use and efficiency in cities' transport plans is oblique or non-existent. Although transport authorities' emphasis on reducing travel time for motorists and promoting public transport might be beneficial from an energy point of view, planning that specifically aims to reduce energy consumption in the total transport system is needed.

The development of energy-aware transport strategies require a better understanding of the energy implications of different land use and socio-economic factors. With that in mind, the aims of this paper are to answer the following questions:

- Can detailed and disaggregate patterns of transportation energy use be obtained from available travel survey data?
- Which socio-economic and land use variables influence energy consumption in personal transport?
- How do these variables affect personal transport energy use?
- What are the implications for transport policy and implementation?

The data was from the Nelson Mandela Metropolitan Area Travel Survey (NMMM, 2004), conducted in 2004, supplemented by transport supply data obtained from the NMMM. The study is

Proceedings of the 28th Southern African Transport Conference (SATC 2009) 6 – 9 July 2009
ISBN Number: 978-1-920017-39-2 Pretoria, South Africa
Produced by: Document Transformation Technologies cc Conference organised by: Conference Planners

restricted to personal surface transport modes and excludes freight and commercial transport systems due to data unavailability.

LITERATURE REVIEW

International studies on urban form and transportation energy

One of the best known studies of energy use in relation to urban densities is from Newman and Kenworthy (1992). They measured per capita petroleum consumption and population densities in a number of large cities around the world and found a clear negative relationship between the two. Also car usage was lower and provision of public transport higher in the cities with the highest densities. Their relationship between urban density and annual private passenger energy use agrees with UITP's (International Association of Public Transport, 2002) finding that the most economical cities in terms of energy expenditure on personal transport are the densest cities.

A number of researchers challenged Newman and Kenworthy's findings (Breheny, 1995; Gordon and Richardson, 1989; Gommez-Ibanez, 1991). Breheny is of the opinion that energy savings from urban containment are likely to be disappointingly low. Using empirical analyses he concluded that other simpler and relatively more immediate measures can achieve the same or even higher levels of energy savings than the urban containment policies. Gordon and Richardson (1989) argued that development of polycentric cities driven by market forces is the most effective way of dealing with energy consumption problems instead of relying on public interventions. Gomez-Ibanez (1991) also argued that by focusing on urban densities, Newman and Kenworthy (1989) have ignored the significant effects of household income and gasoline prices on fuel consumption. Kenworthy (1999) defended his focus on density as the major determinant of gasoline consumption by arguing that economic determinants are unlikely to be used seriously as policy tools by politicians and that leaves land use measures as the most effective means of reducing urban energy consumption. It is thus clear that while there might be broad agreement on the merits of urban containment, especially for the environment, there is debate on the feasibility, effectiveness, and social costs of implementing drastic land-use changes.

Methodologies for studying land use-transport energy relationships

Generally, studies of the effects of urban form on vehicle usage can be divided into aggregate and disaggregate studies. Aggregate studies use spatially defined averages for all variables, observations usually being for cities or metropolitan areas such as the method used by Newman and Kenworthy (1989). These studies need to control for the socio-economic and demographic differences among households in each area as well as the differences in transportation infrastructures, and the cultural, political, historical and economic differences among the areas. Handy (1996) reviewed many studies and concluded that aggregate studies are generally not capable of uncovering true relationships between land form measures and travel. Disaggregate studies, on the other hand, use household observations of vehicle usage and city-wide, zonal or neighbourhood averages for urban form variables (e.g. Golob and Brownstone, 2005; Dieleman et al., 2002). Refer to Mohammed (2008) for a brief overview of disaggregate studies.

South African studies and policies

The White Paper on National Transport Policy (DoT, 1996) shows a strong awareness of the significance of environmental considerations in relation to transport policy. It notes that "The South African transport system is heavily dependent on non-renewable energy sources …", "One of the strategic objectives for land passenger transport is to ensure that…..operations are more environmentally sensible and sustainable and are energy efficient." The Draft White Paper on Energy Policy (DME, 1998) addresses transport energy related issues such as research on alternative fuels for various modes. Formulation of guidelines to assist planning authorities when considering the impact of land use, transportation and traffic management on energy use is also highlighted. Despite this, little awareness of the need for change is evident in the transport sector at present (Prozzi & Sperling, 2002). Despite some early efforts to establish methodologies for assessing the energy implications of transport strategies (DOT, 1992), no systematic analysis of transport energy patterns could be found either at the city-level or at the more disaggregate household level.

It can be concluded from the literature that a relationship exists between socio-economic and land-use factors and transport energy consumption. Questions about the form and extent of these relationships need to be answered for South African cities, to allow better-informed decisions to be made about land use and transport strategies.

RESEARCH DESIGN

Background and survey data

The study area is the Nelson Mandela Metropolitan Area located in the Eastern Cape Province. It has a population of approximately 1.5 million and land area of 1 845 square kilometres (NMMM, 2004).

In 2004, the Nelson Mandela Metropolitan Municipality undertook a travel survey to determine travel demand characteristics in the area. The survey area was subdivided into 548 sub-zones, grouped into 188 larger travel zones. A total of 2 828 households (10 200 individuals) were included in the survey representing 1.08% of the total number of households in the study area. The survey included a 24-hour travel diary covering weekdays (excluding holidays); as one of the first travel surveys that extended beyond peak periods it offered much more complete travel data than traditional survey sources. Standard travel and demographic data was collected.

For estimating energy consumed for transport, trip distance and public transport occupancy needed to be obtained. Trip distances were extracted from a zonal distance matrix based on shortest route road distances between zone centroids. Public transport occupancy figures were obtained from the Current Public Transport Record (CPTR), which recorded occupancy by time of the day.

Land-use data

Variables such as population density, job density and accessibility index were included in the analysis to assess their impact on transport energy consumption. Population density is a measure of the number of people found per gross area in the zone of residence for each survey household. The number of people in each zone was obtained from the 2001 national census. Job (Employment) density is a measure of the number of jobs found per gross area within the zone. The job figures were obtained from the Travel Model report (NMMM, 2004).

An accessibility measure was constructed to reflect the relative location of a household in relation to activity opportunities in nearby zones, in order to test the effect of access on energy consumption. A gravity-based measure was used (El-Geneidy, 2007), with locally derived impedance factors (α) describing the sensitivity to separation based on a combination of activity (trip purpose) and income (NMMM, 2004). It was used in the computation of accessibility index as follows:

$$\boxed{A_i = \frac{\sum d_j . f(w_{ij})}{\sum d_j} \qquad (1)}$$

; where: $\mathrm{A_i}$ - Accessibility index of zone i to opportunities;

$\mathrm{d_j}$ - The opportunities at zone j; $\mathrm{f}(\omega_{\mathrm{ij}})$ - The impedance function to travel between i and j,

$\mathrm{f}(\omega_{\mathrm{ij}}) = e^{-\alpha\omega_{ij}}$; w_{ij} - Distance from zone i to zone j; α - Parameter = 0.15

The number of jobs in each zone was used as the opportunity measure in calculating the accessibility index.

Estimating transport energy consumption

The transport energy estimation process required determining energy intensity for each of the different travel modes. Fuel consumption per vehicle-kilometer depends on traffic conditions as well as vehicle characteristics. Lack of these data limits the disaggregation of energy intensity to the desired trip level. An alternative, simpler, broad measure of energy intensity for transportation could be average fuel consumption per vehicle for all vehicles, but the results would be strongly influenced by the mix of vehicles, which varies enormously among countries and over time. Sivanandan and Rakha's (2003) study in India showed that, despite significant differences in fuel consumption depending on vehicle type, energy intensity estimates based on an average composite vehicle tend to produce conclusions that are consistent with the explicit modelling of the various vehicle types.

The Nelson Mandela Metropolitan Area is serviced by only one bus operator, Algoa Bus Company, whose estimate of fuel consumption was used for buses. For the other types of vehicles, vehicle data from the NATIS (National Automobile Traffic Information Service) were collected for all registered vehicles in the Nelson Mandela Metropolitan Area. A weighted average of petrol and diesel fuel consumption was calculated to arrive at the estimate of fuel consumption per vehicle type. A summary of the final energy intensity (in liters/100veh-km) used for each mode in the survey is given in Table 1.

Table 1 Energy intensity

Walk	0	Bicycle	0
Motorcycle	2.8	Car	10.8
Pickup taxi	10.3	Minibus taxi	14
Bus	47.5		

The fuel consumption for each trip made by each individual interviewed during the survey was calculated as:

$$\text{Fuel Consumption (l/person-trip)} = \frac{\text{Distance (km)} \times \text{Fuel consumption intensity (l/veh-km)}}{\text{Occupancy}} \qquad (2)$$

One mode that is not mentioned in the above list is the rail. Rail transport in Nelson Mandela Metropolitan Area uses electric power. In such cases the electric power consumption should be converted to the primary energy consumption. But there is no standard method for such conversion. From a study conducted by Del Mistro (2006), the energy consumption and maximum occupancy for rail using 9M commuter trains was found to be 10.3 Mj/couch-km and 255 respectively. Del Mistro (2006) assumed 100% occupancy in peak direction and 20% in the opposite direction, i.e. 60% average occupancy. Using these figures, and assuming the same applies to the Nelson Mandela Area, the energy consumption for each trip made by rail was calculated as:

$$\text{Energy consumption (Mj)} = \frac{\text{Distance(km)} \times \text{Energy Consumption Intensity (Mj/coach-km)}}{60\% \times \text{Maximum Occupancy per couch}} \qquad (3)$$

Results from equation (2) were converted to Mega joule (Mj) to enable comparison across different modes. The conversion factor 36.7 was used which is an average of energy equivalent of petrol (34.8) and diesel fuels (38.6). The final step in the transport energy estimation process was the summation of the energy consumption by each trip according to the levels of analysis.

ANALYSIS AND FINDINGS

Bivariate Analysis

Correlation analyses were performed to assess the direct relationships between land use and socio-economic variables with energy consumption. Table 2 shows the correlations between household-level variables and the number of trips, distance travelled and energy consumed. The high correlation between distance travelled and energy consumption is attributable to the way that energy consumption was calculated.

The variables that have the strongest relationship with energy consumption are motor ownership and household income with correlation coefficient (R) of 0.641 and 0.609 respectively. The positive correlation between motor ownership and energy consumption is due to the strong relationship between the former and distance travelled; there is no significant correlation with number of household trips. Number of workers in the household and the population density of the residence zone are also significantly associated with energy consumption. As expected the population density is negatively associated with energy consumption, i.e., the denser the area of residence, the less energy is used for transport. Notable is the result that household size and accessibility index are not associated with energy consumption even though in both cases there are significant relationships with number of household trips and distance travelled.

At the individual level, household income plays the most significant role in energy consumption (see Table 3). Notable though is the significant negative correlation between household size and personal energy consumption. The number of person trips generated by a household member is associated with household size; a person from a larger household tends to make fewer trips over shorter distances and thus consumes less energy.

Table 2 Correlation at household level

	Motor Ownership	Income	Number of Workers	Household Size	Population Density	Job Density	Accessibility Index	Household Trips	Distance Travelled	Energy consumption
Motor Ownership	1	.718(**)	.393(**)	-.111(**)	-.448(**)	.063(**)	.041(*)	-.026	.211(**)	.642(**)
Income	.718(**)	1	.454(**)	-.058(**)	-.409(**)	.092(**)	.082(**)	.041(*)	.283(**)	.609(**)
Number of Workers	.393(**)	.454(**)	1	.163(**)	-.228(**)	.056(**)	.049(*)	.248(**)	.403(**)	.403(**)
Household Size	-.111(**)	-.058(**)	.163(**)	1	.315(**)	-.076(**)	.084(**)	.504(**)	.251(**)	-.014
Population Density	-.448(**)	-.409(**)	-.228(**)	.315(**)	1	-.072(**)	.303(**)	.111(**)	-.114(**)	-.348(**)
Job Density	.063(**)	.092(**)	.056(**)	-.076(**)	-.072(**)	1	.373(**)	-.011	-.042(*)	.005
Accessibility Index	.041(*)	.082(**)	.049(*)	.084(**)	.303(**)	.373(**)	1	.135(**)	-.051(**)	-.011
Household Trips	-.026	.041(*)	.248(**)	.504(**)	.111(**)	-.011	.135(**)	1	.617(**)	.203(**)
Distance travelled	.211(**)	.283(**)	.403(**)	.251(**)	-.114(**)	-.042(*)	-.051(**)	.617(**)	1	.643(**)
Energy consumption	.642(**)	.609(**)	.403(**)	-.014	-.348(**)	.005	-.011	.203(**)	.643(**)	1

Table 3 Correlation at individual level

	Age	Income	Number of Workers	Household Size	Population Density	Job Density	Accessibility Index	Number of Trips	Distance Travelled	Energy Consumption
Age	1	.110(**)	.064(**)	-.208(**)	-.132(**)	.028(*)	.041(**)	.204(**)	.246(**)	.270(**)
Income	.110(**)	1	.406(**)	-.095(**)	-.382(**)	.070(**)	.030(*)	.024(*)	.215(**)	.416(**)
Number of Workers	.064(**)	.406(**)	1	.153(**)	-.222(**)	.039(**)	.024(*)	.014	.178(**)	.212(**)
Household Size	-.208(**)	-.095(**)	.153(**)	1	.316(**)	-.084(**)	.093(**)	-.037(**)	-.107(**)	-.169(**)
Population Density	-.132(**)	-.382(**)	-.222(**)	.316(**)	1	-.072(**)	.339(**)	.065(**)	-.136(**)	-.288(**)
Job Density	.028(*)	.070(**)	.039(**)	-.084(**)	-.072(**)	1	.346(**)	.006	-.026(*)	.010
Accessibility Index	.041(**)	.030(*)	.024(*)	.093(**)	.339(**)	.346(**)	1	.115(**)	-.071(**)	-.023
Number of trips	.204(**)	.024(*)	.014	-.037(**)	.065(**)	.006	.115(**)	1	.473(**)	.146(**)
Distance traveled	.246(**)	.215(**)	.178(**)	-.107(**)	-.136(**)	-.026(*)	-.071(**)	.473(**)	1	.643(**)
Energy Consumption	.270(**)	.416(**)	.212(**)	-.169(**)	-.288(**)	.010	-.023	.146(**)	.643(**)	1

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

A simple ANOVA (Analysis of Variance) test with gender as the grouping variable reveals that the mean energy consumption by male travellers is significantly higher than that of women. Referring to Table 4, the mean number of trips by men is lower than that of women but, on average, men travelled significantly longer distances than women. This implies that the higher consumption in energy by men is either because they travel long distances and/or use modes of travel that consume more energy such as motor cars. A similar test on occupation type reveals the mean energy consumption of employed people to be the highest and that of scholars the lowest. While the difference in energy consumption between unemployed and scholars is small, there is a huge gap in consumption compared to that of employed people. This further stresses the significance of income in energy consumption.

Table 4 Gender and Occupation ANOVA

Gender	Mean number of trips	Mean distance (Km)	Mean Energy (Mj)
Female	3.13	18.0	20.8
Male	2.96	19.3	28.9
Total	3.05	18.6	24.7

Occupation	Mean number of trips	Mean distance (Km)	Mean Energy (Mj)
Employed	3.3	27.8	46.9
Unemployed	3.3	14.7	13.8
Scholars	2.7	11.8	8.8
Total	3.1	18.6	24.7

At trip level, the statistical significance of the differences in energy consumption between peak and off-peak travel, and among travel modes was tested using ANOVA. The average energy consumption of trips made during peak hours was found to be significantly higher than that made during the rest of the day (see Table 5). This is due to the longer distances travelled during peak times, contradicting the expectation that energy consumption would be higher during off peak hours because of the lower occupancy during these times.

Table 5 On/Off Peakhour ANOVA

Peak (On/Off)	Mean distance (Km)	Mean Energy (Mj)
Off	5.2	6.0239
On	6.9	9.7033
Total	6.1	8.0807

The mean energy consumption for all trips by motor car is around three to five times that of trips by motorcycle, minibus taxi or bus (Table 6). This is due to a number of reasons such as lower occupancy, higher distance travelled and higher energy intensity of motor cars. Energy consumption of trips using buses is slightly higher than that of trips made by minibus taxi. Again the main contributing factors are occupancy, energy intensity and distance travelled. Buses may have the potential to carry more people per trip than minibuses but because of the nature of their service (relatively fixed schedules) the seats are not fully utilized. Minibuses normally start their trips when their seats are fully occupied. Table 6 shows that the mean occupancy of buses during peak hours is significantly higher than during off-peak hours contributing to higher energy per occupant. Also the bus energy intensity is more than three times that of minibus taxis. The average distance travelled by buses is about four kilometres more, both during on and off peaks, than that of minibuses. These reasons could explain why buses consume slightly more energy than minibus taxis.

Table 6 Mode of travel

Mode of Travel	Sample N	Percentage	Mode intensity (l/100veh-km)	Mean Energy (Mj)	Average Occupancy		Average Distance (km)	
					Peak hour		Peak	
					Off	On	Off	On
Non-Motorized	9785	46.1	0	0.0	1.00	1.00	1.8	1.9
Motorcycle	50	0.2	2.8	5.6	1.03	1.00	5.9	4.7
Motor car	5333	25.1	10.8	25.8	2.02	1.95	8.3	10.2
Minibus Taxi	4751	22.4	10.3	4.8	9.30	9.43	8.0	9.5
Taxi Sedan	45	0.2	10.8	8.9	2.80	2.81	5.9	7.0
Taxi Bakkie	89	0.4	14	9.3	4.67	4.87	12.9	10.9
Bus	1120	5.3	47.5	7.1	32.94	44.38	12.3	14.6
Train	57	0.3	-	1.7	-	-	32.0	23.8

Regression Analysis

The final step in the data analysis involved estimating multivariate regression models to estimate transport energy consumption based on the combination of demographic and land use measures included in the database. Two different models were derived based on the level of analysis: household and individual. The number of trips made and the distance travelled were not included as independent variables as they were used directly to estimate energy consumption at the household and individual levels, the dependent variable.

Household level

The results from the regression analysis (Table 7) at household level clearly shows the high significance of socio-economic variables to the consumption of household transport energy. Motor car ownership was found to have the strongest impact on energy consumption among all the variables considered. Because of the high correlation between motor car ownership and household income, the latter was excluded from the regression analysis. All the demographic variables except household size have a higher impact on energy use than the land use variables. Accessibility index was found to have the least effect and because it didn't meet the requirement of P>0.05 it was not entered into the model. The other two land use variables, population and job densities, showed a significant reverse relationship with transport energy consumption, as expected.

The adjusted R^2 of 0.446 indicates that the combination of demographic, economic and land use variables entered into the model explains approximately 45% of the variation in household transport energy consumption. In light of the large number of variables that influence travel behaviour and energy consumption, the explanatory power of this model is noteworthy.

Table 7 Household Transport Energy Regression

R	R Square	Adjusted R Square
.667	.446	.444

Variables	Unstandardized Coefficients		Standardized Coefficients	t
	B	Std. Error	Beta	
(Constant)	13.491	4.193		3.217
Motor Ownership	61.350	1.948	.548	31.489
Number of Workers	17.839	1.797	.164	9.926
Household Size	2.010	.753	.043	2.669
Job Density	-.002	.001	-.041	-2.805
Population Density	-.002	.000	-.082	-4.703

Individual level

At the individual level, the ordinates gender and occupation was included in the model (Table 8), defined as follows:

Gender dummy: 0 = Female, 1 = Male
Occupation dummy 1: 0 = Employed or scholar, 1 = Unemployed
Occupation dummy 2: 0 = Employed or unemployed, 1 = Scholar

Again, the socio-economic variables affected transport energy consumption more than the land use variables, income and occupation taking the lead. The land use variables population and job densities seem to affect energy consumption more than do household size and gender. Accessibility index has the least impact on energy consumption but is related positively. This means that the more accessible to jobs an area is the more transport energy is consumed to reach that area. The reason could be that employees afford to buy private cars and are encouraged to use it to get to work by the provision of parking facilities in those areas.

The gender dummy coefficient of 4.348 shows that women consume less transport energy than men by that amount. Women could be using more public transport systems or men could be travelling longer distances. The occupation dummies suggest that employed people use more energy for their transport. Unemployed people consume the least amount of transport energy, even less than scholars. Financial constraints could prohibit the unemployed to use motorized mode of transport. The adjusted R^2 of 0.288 indicates that the combination of demographic, economic and land use variables entered into the model explains approximately 29% of the variation in individual transport energy consumption.

Table 8 Individual Transport Energy Regression

R	R Square	Adjusted R Square
.536(i)	.287	.286

Variables	Unstandardized Coefficients		Standardized Coefficients	t
	B	Std. Error	Beta	
(Constant)	26.381	2.397		11.006
Income*	.242	.009	.306	26.963
Occupation Dummy_2	-20.651	1.553	-.214	-13.294
Occupation Dummy_1	-23.702	1.373	-.200	-17.259
Age	.354	.045	.124	7.870
Household Size	-.919	.222	-.045	-4.133
Gender Dummy	4.348	.973	.046	4.469
Population Density	-.001	.000	-.116	-9.193
Job Density	-.001	.000	-.047	-4.263
Accessibility Index	.031	.014	.026	2.185

DISCUSSION AND CONCLUSIONS

As a first analysis we tested only for linear relationships between the independent variables and energy consumption, which imposes a limitation on the results. Previous studies have shown, for instance, that logarithmic relationships might exist between land-use variables and travel variables (e.g. Newman and Kenworthy, 1992). Nevertheless, the results suggested that transport energy consumption is influenced by both socio-economic characteristics of the tripmaker, and characteristics of the surrounding land use, but that the former's effects are much stronger. The finding of a strong influence of car ownership and income level on energy consumption is a common global phenomenon. In South Africa this poses strong challenges in terms of addressing energy concerns. The trajectory of economic growth, income growth, and expanded car ownership would tend to work in the direction of significantly expanded energy consumption for travel. The implication is that measures to incentivise more energy-efficient travel patterns, generally included under travel demand management strategies, would have to play a major part in developing a strategic response.

In the long run, change in land use has major influences on the use of transportation modes and thereby on transport energy consumption. The land use factors in this analysis, including population density, job density and accessibility, show relatively weak relationships with transport energy consumption. Controlling for other factors such as income and car ownership, denser areas do seem to accommodate less energy-intensive travel, raising hopes that the densification and urban containment strategies being promoted at metropolitan level might support the achievement of desirable energy outcomes.

However, further analysis is needed to understand regional and especially neighbourhood-level urban design effects. This study, being cross-sectional, does not address response time issues. The point that land use change has a slow and uncertain influence has been well made elsewhere: Poudenx (2008) argues that Curitiba's programmatic attempts at land use change over a 40 year period did not succeed as a means of reducing energy use as compared to other Brazilian cities without large scale land use programmes.

The potential for leveraging energy consumption savings might also be different across user groups. In Nelson Mandela Bay, as elsewhere, women take shorter and more frequent trips than men, and use motorised modes less, thus already consuming less energy than men. It is the long-distance journey to work that is the most energy-intensive (for both genders); in the short run the poverty-alleviating benefits of having such journeys surely outweigh their environmental costs. Easier, and more profitable in terms of energy use reduction, might be to shift some non-work trips to the off-peak or to less energy-intensive modes, such as buses with spare capacity. However, since women make more non-work trips in the course of performing household activities, the equity (especially gender) impacts of such policies would need to be carefully considered.

Lastly, the regression analysis was descriptive and not meant to deliver a predictive model. As such the methodology presented to link demographics, land use and travel behaviour with transport energy via travel survey data, proved viable and useful. Improvements might come from improved data collection (especially the inclusion of vehicle size and fuel type data in questionnaires), and further experimentation with models that might be used to assess energy impacts of land use and transport policies predictively, taking travel behaviour responses into account.

REFERENCES

Banister, D., 2005. *Unsustainable Transport*. 1st ed. New York: Routledge.

Behrens, R., 2003. 'Energy efficiency characteristics of passenger transport modes.' *City Energy Strategies Conference 2003*, UCT.

Breheny M., (1995). The compact city and transport energy consumption. *Transactions of the Institute of British Geographers*, Volume 20, Number 1, March 1995 , pp. 81-101(21)

Dasgupta M., Oldfield R., Sharman K., Webster V., 1994. Impact of transport policies in five cities. Transport Research Laboratory, Project Report, 1994.

Del Mistro, RF & Aucamp, CA 2000, 'Development of a public transport cost model', Paper presented to the South African Transport Conference, South Africa, 17 - 20 July.

Del Mistro, R., ROMANOD@ITLS.USYD.EDU.AU, 2006. *Information on Transportation Energy*. [online]. Message to S.O. Mohammed (semira79@yahoo.com). Sent 9 November 2006.

Department of Minerals and Energy (DME), *White Paper on the Energy Policy of South Africa,* December 1998, Pretoria.

Department of Minerals and Energy (DME), Eskom, Energy Research Institute, University of Cape Town, 2002. *Energy Outlook for South Africa: 2002*. May, 2002.

Department of Transport (DOT), *Guidelines on Measures for Achieving Transport Energy Savings in Urban Areas,* RR 91/447. April 1992, research report prepared by HS Joubert & AJ Bouwer, Jordaan & Joubert Inc., Pretoria.

Department of Transport (DOT), *White Paper on National Transport Policy, Department of Transport*, August 1996, Pretoria.

Department of Transport (DOT), *Moving South Africa: Action Agenda,* May 1999, Pretoria.

Dieleman F M., Dijst M., Burghouwt G., 2002. Urban Form and Travel Behaviour: Micro-level Household Attributes and Residential Context. *Urban Studies*, Vol. 39, No. 3, 507–527, 2002

El-Geneidy A., Levinson D., 2007. Mapping accessibility over time. Working paper 200709. University of Minnesota: Nexus Research Group.

Freeman P N W., Naude C M., Pretorius J., Coovadia T., Matjila S M., 2000. WWF Macroeconomic reforms and sustainable development in Southern Africa: The transport sector – energy use and environmental impacts. Transportek CSIR, Project Report, 2000.

Golob T. F., Brownstone D., 2005. The impact of residential density on vehicle usage and energy consumption. Working Paper UCI-ITS-WP-05-1, Institute of transportation studies, University of California Irvine.

Gomez-Ibanez J., 1991. A global view of automobile dependence - review of P Newman and J Kenworthy Cities and automobile dependence: a sourcebook. *Journal of the American Planning Association* 57 376-9

Gordon P and Richardson H., 1989. Gasoline consumption and cities - a reply. *Journal of the American Planning Association* 55 342-S

Handy S., 1996. Methodologies for exploring the link between urban form and travel behaviour. *Transport Research –Part D*, Vol. 1, No. 2, pp. 151-165

International Association of Public Transport (UITP). Transport and the Natural Environment. 2002.

Kenworthy, J., 1999. *Global* review of energy use in urban transport systems and its implications for urban transport and land use policy. *Transportation Quarterly*, 53 (4).

Kenworthy, J., 2003. ‘Transport Energy Use and Greenhouse Gases in Urban Passenger Transport Systems: A Study of 84 Global Cities’. *International Conference of the Regional Government Network for Sustainable Development*, Notre Dame University, Fremantle, Western Australia, 2003.

Mohammed, S.O. 2008. Analysing passenger transport energy consumption from travel survey data: A case study of Nelson Mandela Metropolitan Area. Master’s project. University of Pretoria.

Nelson Mandela Metropolitan Municipality (NMMM) 2004. Travel Survey 2004.

Newman P and Kenworthy J, 1989. Cities and automobile dependence: a sourcebook. Gower, Aldershot and Brookfield, Victoria

Newman P and Kenworthy J, 1992. *Is* there a role for physical planners? *]ournal of the American Planning Association* 58 353-62

CarToday " SUVs to be hit hard by green tax." May 23 2007.

Prozzi J.P., Sperling D., 2002. Transportation in Developing Countries: Greenhouse Gas Scenarios for South Africa. Pew Center on Global Climate Change.

Poudenx, P., 2008. The effect of transportation policies on energy consumption and greenhouse gas emission from urban passenger transportation. *Transportation Research Part A*. 42 (2008).

Rodrigue, J. and Comtois, C., 2006. *The Geography of Transport Systems*. Routledge.

Sivanandan R., Rakha, H., 2003, 'Vehicle aggregation impacts on fuel consumption and emission estimates'. *TRB Annual Meeting.* January 2003.

State of Energy Report for Cape Town 2003: Transport Sector.

Wood, R., Munro, D C., 1992. The impact of urban form on transportation efficiency. Paper 6, Department of Transport 1992

Winkler, H., Borchers, M., Hughes, A., Visagie, E. and Heinrich G., 2005, *Cape Town Futures: Policies and scenarios for sustainable city energy development.*

Wright, L. and Fulton, L., 2005*. Climate Change Mitigation and Transport in Developing Nations. Transport Reviews. 25 (6).*