Abstract

Transport related greenhouse gas emissions are proving to be one of the most intractable areas for nations to find ways of responding to the Kyoto agreements. Rather than just looking at technological efficiency there is a need to look at urban efficiency in terms of how land use and transport are integrated, the level of travel that settlement patterns generate and the kind of priorities that are in operation in terms of transport infrastructure provision.

Data have been gathered on Auckland, Wellington and Christchurch to compare factors on urban transport and land use, transport energy use, and transport economic investment and network efficiency for New Zealand's main cities. Similar data collected in over 35 cities throughout the world.

In this paper, comparison of urban transport and land use characteristics, and associated transport energy use are made. Results indicate that in transport energy and greenhouse gas contributions, New Zealand cities are more energy efficient than cities in the United States, Australia and Canada, but less efficient than European and Asian cities. Arguments are also presented that appropriate land use is one of the key policy tools for reducing transport energy demand.

1 Transport Energy and CO₂ Emissions

Transport related greenhouse gas emissions are proving to be one of the most intractable areas for nations to find ways of responding to the Kyoto agreements (Newman and Kenworthy, 1998). In 1996, New Zealand's land transport consumed 165.5 petajoules (PJ) of energy out of a total national energy consumption of 432.7 PJ; or in percentage terms, 38% of total energy consumed was for land transport (EECA, 1997).

In terms of carbon dioxide emissions (CO₂), in 1995, New Zealand's land transport contributed 40% of the CO₂ emissions in New Zealand (MIE, 1997). If New Zealand, among other countries, is serious about reducing greenhouse emissions and meeting the commitments made at the Kyoto summit, land transport energy use requires significant reduction.

In transport energy terms, urban land transport energy, excluding air and marine fuel use, is a significant proportion of a city's energy use. In Christchurch, land transport consumes approximately 50% of urban energy demand (Bachels CRC 1996).

2 Why is Urban Transport Important - Sustainability Implications

More and more cities are dominating our lives. In New Zealand, recent population growth in cities is outstripping rural and small town population growth by a factor of more than 2.5 to 1 (between 1991 and 1996 “main urban areas” grew by 8.1% while “secondary urban areas” grew by only 3.1%).

Urban areas are now the focus of more and more resource consumption, including energy demand and use. Transportation is a major part of our urban lifestyles. How we move ourselves and our products around is a complex and multi-faceted activity. As the results below show, we are relying more and more heavily upon private motor vehicles for our transportation needs, with declining use in alternatives transport modes such as public transport, cycling and walking.

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2 Some figures presented in this paper are preliminary and may vary slightly once final figures are received (a final report on New Zealand cities will be produced by the end of the year). However, the thrust of the conclusions reached will remain the same.

3 Total transport emissions of CO₂ were 10983 Giga-grams (Gg) of a total estimated CO₂ emissions of 27367 Gg (including energy, industrial and land use changes) (MIE 1997).

4 Department of Statistics New Zealand, Census 1991 and 1996 “Usually Resident Population”.
As increasing car use dominates our lives and our lifestyles, associated effects of car use are increasing. Such effects include both local and global air pollution, increasing noise from traffic and transport, and in some communities - decreasing quality of our "community" streets.

The tenets of sustainability often discuss and describe social, environmental and economic well-being: to enable our current and future generations to enjoy the quality of life we enjoy today (Newman and Kenworthy, 1998). There is no question that the automobile has enhanced our quality of life. However, there is creeping doubt amongst many analysts, researchers, planners, politicians and members of our community about the sustainability of our growing car dependency.

3 New Zealand Cities – An International Comparison of Transport and Land Use Characteristics

Data have been gathered on Auckland, Wellington and Christchurch to compare factors on urban transport and land use, transport energy use, and transport economic investment and network efficiency for New Zealand's main cities to similar data collected in over 35 cities throughout the world (Newman and Kenworthy, 1989; Kenworthy et al 1997).

Over 60 indicators on transport, land use, economic activity, and transport investment were derived and developed for each of these three centres for the years 1991 and 1996. These indicators adopt the approach developed by Newman and Kenworthy (1989) and Kenworthy et al (1997). Only data for 1991 are presented in the main analysis because this is the latest year available for the global data set.

Although not all the results or analysis for the 60+ indicators are presented here, the figures on transport energy use in the three main New Zealand cities are reviewed. A full review of New Zealand city data will be published later in 1998. Comparisons are presented for New Zealand cities and compared to data collected on over 40 cities throughout the world.

3.1 Energy Data Collection: A Brief Synopsis

Transport fuel use in each main New Zealand centre was derived from a number of sources, primarily relating to fuel sales data collected from petroleum company statistics within each relevant area. All of the transport fuel use is for land based transport (thus excluding air and marine transport) and only for that transport which occurs within the metropolitan area.

Fuel use data were gathered from the Local Area Petrol Tax (LAPT) filings for petrol and diesel, for those LAPT areas which covered each metropolitan area. Fuel sales for compressed natural gas (CNG) and liquid petroleum gas (LPG) come from bulk-wholesale suppliers. All fuel figures were adjusted to match respective metropolitan boundaries based upon respective populations.

In addition transport fuel sales figures were separated for private-passenger transport, public-passenger transport and non-passenger transport energy consumption.

Table 1 provides estimated transport energy consumption by sector for 1991 for each metropolitan area.

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5 The authors would like to thank the numerous staff from various New Zealand authorities (local, regional and central government agencies), institutions and companies who have given generously of their time in providing data for this project. As usual, any conclusions reached in this report are the sole responsibility of the authors.

6 Metropolitan areas for each city were defined by respective transport modelled areas. Auckland includes Auckland City, Manakau, North-Shore, Papakura, Waitakere and portions of Rodney and Franklin Districts; Wellington includes Wellington City, Upper Hutt, Lower Hutt, Porirua, and Kapiti Coast Districts; Christchurch includes Christchurch City, Lyttelton and Diamond Harbour (Banks Peninsula), Lincoln (Selwyn), Rangiora and Kaiapoi (Waimakariri).

7 There is a base assumption that fuel purchased within the area is used within the area; although some fuel may be used for travel outside the area, it is assumed that a like amount of fuel was purchased outside, and consumed within, each study area.

8 Following Newman and Kenworthy (1989) private-passenger transport energy use includes both cars and small petrol driven trucks (<2000cc); in this study small petrol-powered trucks for New Zealand cities make up c. 5-7% of total private-passenger transport energy use. Public-passenger transport energy consumption figures were provided by the three respective regional councils: Canterbury, Wellington and Auckland.
Table 1: Estimated Transport Energy Consumption by Metropolitan Area (1991)

<table>
<thead>
<tr>
<th>Metropolitan Area</th>
<th>Private Passenger Transport</th>
<th>Public Passenger Transport</th>
<th>Non-Passenger Transport</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Petrol (MJ)</td>
<td>Diesel (MJ)</td>
<td>LPG (MJ)</td>
<td>CNG (MJ)</td>
</tr>
<tr>
<td>Auckland</td>
<td>22,418,411,692</td>
<td>128,443,629</td>
<td>1,083,225,000</td>
<td>370,014,837</td>
</tr>
<tr>
<td>Wellington</td>
<td>7,406,015,553</td>
<td>71,243,519</td>
<td>366,927,437</td>
<td>75,855,302</td>
</tr>
<tr>
<td>Christchurch</td>
<td>7,504,303,301</td>
<td>189,412,578</td>
<td>388,861,615</td>
<td>8,082,577,494</td>
</tr>
</tbody>
</table>

Notes:
1) All figures based upon petrol company Local Area Petrol/Diesel Tax (LAPT) filing less non-transport fuel use based on national estimates (MOT 1995): Auckland fuel consumption is based upon 93% of the LAPT filing, Wellington figures are based upon 98% of the LAPT filing corresponding to the proportion of the transport study area population within the LAPT boundary.
2) LPG Association regional figures weighted for population within the study area.
3) CNG data provided by Enerco CNG wholesalers.
4) Diesel split between truck and private transport is estimated using national figures from MOT (1995) and recent diesel vehicle registrations; public transport energy use is provided by respective regional councils; tour bus diesel is included in private passenger transport.
5) Energy conversions are made using gross calorific values consistent with Newman and Kenworthy (1989): petrol 34.69 MJ/litre, diesel 38.29 MJ/litre, LPG 26.26 MJ/litre; CNG energy figures provided in MJoules by wholesalers.
6) Public-passenger transport energy use is estimated, still awaiting final figures (Wellington figures currently exclude electricity energy requirements for trolley and passenger rail).

Urban Density Figures for New Zealand Cities

Figures on the urbanised area of each metropolitan area were provided by respective regional and city councils, and required extensive data analysis and manipulation, using a number of different sources including landsat photographs, vacant land registers and figures from the New Zealand valuation database. All figures were derived using geographic information systems mapping to match each metropolitan study area. The urbanised area is generally defined by those areas either built upon (residential, commercial, industrial, roading, etc.), or used for recreational and community purposes (sports grounds, schools, hospitals, etc.). The figures presented are actual land use as opposed to zoned land use. Large bodies of water, agricultural space, forests, regional scale open space and vacant land were excluded. Urban density, in people per urbanised hectare for Auckland, Wellington and Christchurch are shown in Table 2.

Table 2: Urban Density for New Zealand Cities (1991 and 1996)

<table>
<thead>
<tr>
<th>Metropolitan Area</th>
<th>1991 Density (persons per urbanised hectare)</th>
<th>1996 Density (persons per urbanised hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auckland</td>
<td>18.1 (10)</td>
<td>18.9</td>
</tr>
<tr>
<td>Wellington</td>
<td>23.0</td>
<td>22.0</td>
</tr>
<tr>
<td>Christchurch</td>
<td>16.0</td>
<td>17.0</td>
</tr>
</tbody>
</table>

9 Specific definitions of what is included as “urbanised land” can be provided by contacting the author(s).
10 Fitzsimons (1990) came to a very similar figure in work done by census-area-unit, where she identified a density of 18.14 person/ha for analysis of 182 census area units.
Transport and Land Use Energy Relationship

In seminal work on transport energy and land use relationships, Newman and Kenworthy (1989) presented data on 32 international cities comparing transport energy use with urban density. Effectively, what Newman and Kenworthy showed was that as urban density increases, transport fuel use decreases. This paper adds New Zealand’s main cities to the updated international city comparison which now includes over 40 cities (Kenworthy et al. 1999).

As shown in Figure 1, New Zealand cities “fit” nicely into this transport and land use energy relationship. In general, in terms of private passenger transport energy usage, New Zealand cities are less transport energy demanding per capita than cities in the United States, Australia or Canada; however, they use more transport energy than cities studied in Europe or Asia.

The correlation between private passenger transport energy use and urban density is very strong, with an $r^2$ or variance component of 0.848 (an $r$ value or correlation of 0.92), signifying that 85% of urban private passenger transport energy use is “explainable” or related to the population density of the city!

It is important to note that this correlation between transport energy use and urban density has increased (gotten stronger) as more cities have been added to this international city comparison (for the “32” city analysis made on fuel use (Newman and Kenworthy 1989), the $r^2$ value was 0.737 whereas as it is 0.848 for the cities in this sample).

Estimated Urban Transport CO₂ Emissions

Public and private urban land transport CO₂ emissions per capita for each of the international cities is presented in Figure 2. As transport CO₂ emissions are a direct result of transport energy usage, again the correlation between CO₂ emissions per capita and urban density is quite strong ($r^2=0.785$, an $r$ value equivalent to 0.89$^{13}$), or 79% of the variance in CO₂ emissions per capita is explained by urban population density.$^{13}$

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$^{11}$ Data for 1996 are available for New Zealand but not presented as other city data is presently only available for 1990/1991.

$^{12}$ The lower $r$ value in this relationship compared to the energy data is partly explained by the fact that different fuel types have lower emissions of CO₂; the international cities data account for fuel type, with for example, electricity generated from hydro sources, and used in electric public transport systems, having zero CO₂ emissions, whereas electricity from low grade coal has very high emissions of CO₂.

$^{13}$ CO₂ emissions are presented for only one Canadian city, as other CO₂ city data were not available for this paper.
3.5 New Zealand City Data – A Comparison

The three New Zealand cities use less private passenger transport energy per capita than Canadian and Australian cities and are far below US cities. In 1991, Auckland used the highest private passenger transport energy per capita followed by Christchurch, and then Wellington (Wellington is by far the most transport energy efficient New Zealand city in per capita terms). The figures for each city are presented in Table 3.

Table 3: Private Transport Energy Use per Capita (1991 and 1996)

<table>
<thead>
<tr>
<th>City</th>
<th>1991 Private Transport Energy Use (MJ per Capita)</th>
<th>1996 Private Transport Energy Use (MJ per Capita)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auckland</td>
<td>27,200</td>
<td>28,477</td>
</tr>
<tr>
<td>Wellington</td>
<td>22,359</td>
<td>23,544</td>
</tr>
<tr>
<td>Christchurch</td>
<td>24,962</td>
<td>25,323</td>
</tr>
</tbody>
</table>

In private passenger transport energy use per capita in both 1991 and 1996, Auckland used about 10% more than Christchurch and 20% more than Wellington per capita.

Average urban density across the countries/areas studied for 1991 is shown in Table 4.

Table 4: Average Urban Density (1991)\(^4\)

<table>
<thead>
<tr>
<th>Country</th>
<th>Average Urban Density 1991 (People/Urbanised Hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>12.3</td>
</tr>
<tr>
<td>United States</td>
<td>14.2</td>
</tr>
<tr>
<td>New Zealand</td>
<td>19.1</td>
</tr>
<tr>
<td>Canadian</td>
<td>28.5</td>
</tr>
<tr>
<td>European</td>
<td>49.9</td>
</tr>
<tr>
<td>Asian</td>
<td>161.9</td>
</tr>
</tbody>
</table>

Adelaide, and cities are on average more dense than US and Australian cities but less dense than Canadian cities, and far less dense than European or Asian cities included in the study.

Some key insights into the New Zealand city data in terms of transport energy use can be suggested as follows:

- **Auckland** is by far the most car dependent New Zealand city – with car use approaching (and in some cases) exceeding the car use of Australian and Canadian cities. The population and job density is reasonably low (considerably lower than Wellington). There are some topographical constraints in Auckland (the various water bodies, etc.) which may provide some natural limits to growth on the one hand, but in essence may ultimately be extending journey lengths (journey-to-work 1991 was 12.6 km, increasing to 13.9 km for 1996 – by far the longest amongst New Zealand cities studied). Overall, the use of public transport is low (journey-to-work mode split was 7.6% for 1991 declining to 6.0% for 1996).

- **Wellington** has reasonably low car use and reasonably high public transport use. High public transport use is largely based on linear corridors and nodal development combined with a very focused job market in the central business district; the "natural" land use topography of Wellington, with well-defined corridors (constrained at either end), enable good quality public transport service provision and a viable alternative to car use, resulting in a journey-to-work mode split for public transport of 15.0% for 1991 (which actually increased marginally to 15.5% for 1996).

- **Christchurch** has reasonably low energy use per capita (slightly higher than Wellington), although its density is not extremely high. The comparatively low energy use appears to be a function of the city's reasonably short average trip distances and the "permeability" of its grid street network providing more direct travel options to destinations than a curvilinear street network. Average journey lengths in Christchurch are shorter than in both Wellington and Auckland (average journey-to-work trip lengths for 1991 were: Christchurch 8.0 km, Wellington 10.6 km, Auckland 12.6 km). In addition, partially due to its flat topography, Christchurch has a reasonably high use of cycling as well as walking (journey-to-work 1991 mode split for cycling and walking was: Christchurch 15.0%, Wellington 10.6%, Auckland 7.5%). Public transport use is the lowest of the New Zealand cities reviewed with just 4.7% (1991) of the journey-to-work (and even lower at 4.2% for 1996).

### How Much Do We Use Our Cars – VKT Comparisons

The amount of travel by car in vehicle kilometres travelled (VKT) per year per capita also shows a strong relationship to our city's land use, as shown in Figure 3 ($r^2 = 0.816$ or 82% of explained variance, and $r = 0.90$). These figures suggest there is a reasonably stark difference between Auckland (which is more comparable to some of the Australian cities), and Christchurch and Wellington which have much lower car use per capita; overall, in a global perspective, the New Zealand cities are fairly similar.

![Figure 3: Car Kilometres per Capita versus Urban Density (1991)](image)

Public transport trips per capita versus urban density are shown in Figure 4 for the whole international sample. The correlation shows an $r^2$ value of 0.706, which implies that 71% of the variance in public transport trips is related to
urban density. These results support the practical contention that more people in a physical area means public service levels can be higher and thus public transport can provide a viable alternative to many car trips. It is interesting to note how low public transport trips per capita are in Auckland and Christchurch in comparison to other cities; Auckland and Christchurch show very little public transport use per capita even in comparison to Australian cities whereas Wellington has comparable public transport trips per capita to most Australian cities (except for Sydney which is significantly higher at 160 trips per capita).15

Figure 4: Public Transport Trips per Capita versus Urban Density (1991)

3.7 Car Ownership and Urban Density

Car ownership per 1000 people is placed against urban density in Figure 5, with quite a high negative correlation ($r^2=0.735$), suggesting that low density cities actually require greater car ownership. Conversely, higher density cities have much lower car ownership, allow for shorter trips which are more conducive to cycling and walking, and enable improved provision of public transport services - in total providing viable alternatives to car ownership (and use).

Figure 5: Car Ownership and Urban Density (1991)

15 Figures on 1991 patronage for Wellington are provided by the Wellington Regional Council (WRC); however, there is some variation in reported patronage and final figures are still to be confirmed (1991 patronage estimates provided by the WRC range from 26.6 million to 31.5 million; the figures presented here use the lower estimate).
There is a long standing dispute regarding which policy tool is “best” to reduce environmental effects from transport: economic signals, technological improvements, or land use (and transport) planning (OECD/ECMT, 1996).

The evidence produced in this paper for New Zealand cities suggests that appropriate land use is a necessary component to reduce transport energy use and associated greenhouse gas emissions. There is no question that technological improvements (more efficient vehicles, low-emission engines, etc.) and proper pricing mechanisms are also necessary tools to reduce the environmental effects of transport.

Within New Zealand there are various signals coming from central government as to how best to deal with environmental effects of transport.

The MOT (1997) investigated methods for reducing the impacts of vehicular emissions, particularly within local/regional air sheds. The report recommends a 60% reduction for carbon monoxide emissions from vehicles, and investigates technological vehicle fleet improvements (including more efficient engines/vehicles, cleaner fuels, tuning, etc.), pricing mechanisms, and land use and transport planning approaches to achieve that target. The report concludes that non-technical means (reducing demand and local traffic and land use planning provide the most likely solutions for reducing local CO levels): “ultimately, managing the demand for (urban) travel, and its supply by means of the motor vehicle, should govern the long term policy for emissions control” (p 97) and continues: “Non-technical measures applied to traffic corridor management appear to provide the best means of preventing local air quality CO exceedances occurring within the near term.” (MOT, 1997, p 138)

Even in US cities, where dramatic improvements in vehicle technology have reduced air emissions, there is acknowledgment that the growth in vehicle trips will soon erode the gains made in air quality. In Denver (Colorado) an Environmental Protection Agency scientist recently stated: “The number of vehicle trips is projected to double by the year 2010... We anticipate that at some time, the gains we’ve made [in air quality] will be overcome by the increase in trips people take. If you’re going to get better, cleaner air, you’ve got to deal with cars. You have to start looking at getting people out of their cars” (Christian Science Monitor, April 21, 1998, p 5).

What is missing in these debates is an awareness of how land use can shape car use and transport energy use (and associated CO₂ emissions). In particular, the need to re-urbanise car dependent low density cities is obvious. Many of our urban environments are already increasing in density, especially in the inner and central city areas. The figures collected in this project show that between 1991 and 1996 Wellington’s central business district (CBD) population density doubled, from 7.3 to 14.2 person/ha; Auckland figures suggest CBD population density increased almost three fold from 3.7 to 9.6 person/ha; and Christchurch CBD also increased from 13.2 to 15.4 person/ha¹⁶. Inner city suburb populations also increased across all three New Zealand cities. This trend toward increasing CBD and inner city suburb population density are findings consistent with the other cities studied (Newman and Kenworthy, 1998; Kenworthy et al 1999).

5 Household Energy Budgets: Location versus Design

Energy analysts often focus on housing design and household technology energy efficiency in an effort to reduce household annual energy demands. Seldom is the transport energy component of individual household energy budgets considered. However, transportation makes up a significant proportion of total household energy consumed.¹⁷ And importantly, the location of where we choose to live, and our proximity to attractions (shopping, work, recreation, etc.), combined with our mode of travel, have a profound effect upon our household energy consumption.

A modelling effort by Browning et al (1998) of two generic household total energy budgets reveals that location can dominate the household energy equation. Two households were modelled: one new energy efficient household located in a Portland suburb, and another 90-year old energy inefficient household in Portland’s inner city. The modelling results suggest that the highly energy efficient household located in the suburb has a higher total energy budget (112%...

¹⁶ Note the Christchurch CBD area (419ha) is almost twice as large as the Wellington CBD area (218ha) and basically equal to the Auckland CBD area (396 ha), thus change in the Christchurch CBD will be slower or require significantly faster population growth to increase density.

¹⁷ Estimates made for Urban Christchurch indicate that land transport energy consumption comprised approximately 30% of total energy consumed (Bachels 1994, CRC 1996).
higher) than an inefficient household located in Portland’s inner city. Thus if a household is located where car dependence is a necessity, household transportation energy demands outstrip any energy savings made in energy efficient household and appliance design. The conclusion by the authors with respect to household energy use:

"where we build ultimately has more impact on our overburdened environment than what we build" (p 39).

6 Conclusions

It is clear from the results presented that to reduce urban transport energy use and associated CO₂ emissions we need land use policies which encourage increasing urban density. Increasing urban density enables a number of elements to occur:

- Reduces car travel (and trip lengths)
- Provides improved public transport opportunities (for viable alternatives to car trips)
- Encourages walking and cycling (along with land use and traffic planning which supports these slow modes)

There is no question that increasing urban density has environmental and social effects (both positive and negative). Many of the potential negative effects can be addressed through community consultation and with the development of guidelines which enable appropriate developments focused into central cities, sub-centres and corridors. Increasing urban density does not mean covering a city with higher density housing, it means choosing the right places in which strategically increase densities at focal points to enable public transport to operate effectively, and to encourage increasing use of walking and cycling.

Although reducing greenhouse gases and transport energy use appear to be intractable problems, there are attractive opportunities to improve our city’s land use and transport development to reduce our transport energy use. As increases in urban density are already occurring, the real question is can we enable it to occur in such a way that quality city environments are developed which further support reducing our car dependence?

References


18 Browning et al (1998) assume that a typical suburban household is more car-dependent (48,000 km/year) whereas the inner city household is less car-dependent (24,000 km/year) based upon figures from Calthorpe (1993). In addition, the non-transport energy consumed by the inefficient inner city home is 148% higher than the more efficient newer suburban home (248,570 MJ/year compared to 167,120 MJ/year).

In this paper, the risks that can be assessed in terms of risk and viability of the renewable energy option.