THE ROLE of LAND-USE PLANNING in REDUCING ENERGY USE and "GREENHOUSE GAS" EMISSIONS from URBAN TRANSPORT.

A thesis presented in partial fulfilment of the requirements for the degree

of Master of Philosophy

in Environmental and Resource Planning

at Massey University

Alistair Edward de Joux

1997

Abstract:

Urban transport has been one of the key environmental concerns of the last decades of the twentieth century. Private car use has become a particular focus for the contribution it makes to several key problems, including fossil fuel depletion, climatic change via the "greenhouse effect", air pollution and at more localised levels, severe traffic congestion.

Land use planning has an important role to play in ameliorating the worst impacts of private car use, as different forms of urban development display quite different levels of transport needs. Twentieth century urbanisation patterns have made car ownership necessary in many cities, particularly where post-war development has resulted in the physical separation of various urban activities. Large areas of newly developed land were devoted to single land uses in many cities during the 1950s and '60s, and the private car became integral to moving between the dispersed locations of home, work and other activities. Many planners have identified reintegrating land-uses as a means of reducing this need for extensive intraurban travel.

This thesis examined some of the assertions regarding urban land use by identifying several key factors which help to determine the energy performance of different areas of the city. The study was based on data from the an extensive travel survey conducted in and around Wellington, New Zealand, late in 1988. Some 3000 households participated in the survey, with about 9000 people providing details of their daily travel for one weekday. This data was used to calculate transport energy performance and the levels of greenhouse gas emissions which resulted for 64 residential zones throughout the region. Mean daily household emissions were found to range from 3.3 to 19.6 kilograms carbon dioxide equivalent. (This includes the radiative warming potential of small quantities of other "greenhouse" gases). The "best performing areas" were mainly close to Wellington's CBD but also included zones around other centres in the region. Performance was then analysed further against urban form, transport use and socio-economic factors derived both from the survey data and other sources.

Mean distance of the journey to work, car ownership levels and the proportion of all travel undertaken by walking emerged as the strongest influences on energy and emissions performance. Modal split for bus use, population and dwelling densities, and the distance to central Wellington were identified as moderate influences on these areas of interest, whereas modal split for rail and cycling had little influence on the relative performance of the different areas surveyed. It was concluded that strongly pedestrian oriented forms of development clustered in close proximity to existing public transport services, perhaps with some additional "fine coverage" minibus services, offered the best land-use pattern in terms of minimising energy use and greenhouse gas emissions.

Acknowledgements:

This thesis was written almost wholly away from Massey, so it is perhaps not surprising that many of the people I owe most to for their help are in Wellington, where most of my work was completed.

First of all, the great forbearance of my employers and colleagues in the Environmental Control Business Unit of Wellington City Council was crucial to my completing this thesis. The three years since the Unit's inception have been challenging ones for all who work there, yet somehow my study plans were acceded to with generous allowances of leave and time off. I have no doubt that this meant that others had to work that bit harder, and I am very much indebted to them for this.

Across the road at the Regional Council, too, I found a great deal of assistance. Sharon Braddon-Parsons suggested using data from the Council's 1988 regional transport survey, and made this available for my use. Other staff in the Transport Planning Department also helped with the requests for information I made from time to time. Andrew Smith from the Planning Policy section provided crucial assistance with matching survey and census data, as detailed in Chapter Five, and mapping this information. Up the hill at Victoria University of Wellington, Paul Soldera in the Geography Department carried this work on with digitising the zone boundaries which had been identified in Andrew's work. Other valuable assistance came from city and regional transport operators. Ross Hayward of Tranzrail and Robyn Brown and Ian Cannell of Stagecoach Wellington helped with information which allowed me to make what I am confident are accurate estimates of energy use and emissions from rail and bus vehicles.

At Massey, Dr Murray Patterson provided some valuable pointers on appropriate methods for my data analysis, and Jenny Edwards in Computing Services gave essential support to my attempts to learn SAS programming. Her responses to my many e-mail queries came more often than not within the space of a few hours, and no problem was left unsolved !

For personal support, I am indebted to three people above all others. The first two are my parents, Ted and Eunice de Joux, who offered material support and encouragement throughout my years at university. My wife Leanne was there for me from the start of this project to the finish, and is looking forward even more than I am to seeing what thesis-free life is about !

To all of you then - and I know this is totally inadequate - **thank you !!!**

TABLE OF CONTENTS:

List of Tables:

List of Figures:

MAPS:

Chapter One : Introduction.

Energy supply. Air pollution. The greenhouse effect.

These are familiar problems to inhabitants of the world's major cities. Each carries huge implications for our quality of life and indeed to the very viability of the biosphere. Accordingly they occupy the attention of politicians, policy-makers and planners at every level, from international down to that of individual civic and district administrations.

These issues arise in large part from massive urbanisation throughout the twentieth century. As cities have grown their demands for energy have increased. Construction of physical infrastructure, movement of goods and people, and the supply and maintenance of a generally rising standard of living have all fuelled this demand, and continue to do so. The greater proportion of these energy requirements have been met through massive increases in the use of fossil fuels, and in the last three decades this has resulted in several "energy crises" of varying proportions. Over the same period, air quality has deteriorated in many of the world's cities, including some which are quite small by global standards. Global warming has joined the list of fossil-fuel related concerns. As the writing of this thesis concludes, this issue occupies centre stage as representatives from most countries meet in Kyoto, Japan, to try to reach agreement on limiting emissions of greenhouse gases.

Growing reliance on the private car for most personal travel has been a key contributor to these three problems, and by the far the largest cause of a fourth which has also attracted much attention in large urban areas, traffic congestion.

Focus of investigation in this thesis:

This thesis seeks to identify key factors related to urban land development which influence energy use and emissions resulting from peoples day-to-day movements in the region surrounding Wellington, New Zealand. The key area of investigation is how urban planning can ameliorate the environmental problems identified in this chapter by lowering demand for private transport. Through a survey of literature, several key areas are identified in which planning interventions may be able to improve the identified problem areas. These areas include the interactions between urban and suburban layout on one hand and transport infrastructure on the other, and the effects that both planned and *ad hoc* changes to urban and suburban structure have on fuel consumption and the greenhouse gas emissions which result. In focusing on transport issues, the emphasis in this thesis is on the movement of people rather than goods around the city and its surrounding urbanised region. Some of the literature reviewed refers to transport in more general terms, either as the whole transport sector or of all road transport. Where the discussion encompasses these areas it is explicitly stated. Elsewhere, particularly in the analysis of data from the Wellington region, the term "transport" refers here to movement of people around the city.

The study first examines urban transport's contribution to overall energy consumption, and establishes the links between this and global climatic change. It then focuses on the contribution which urban planning can make to lowering energy use and greenhouse gas emissions, and although the solutions offered seek less specifically to mitigate air pollution and traffic congestion, the inter-related nature of these four issues ensures that gains in one area will result in improvements in the others. Some key hypotheses about the supposed effects of various planning policies are identified from the literature on the subject, and this is followed by an analysis of transport use and urban development in Wellington, New Zealand, and its neighbouring cities. This analysis uses data collected from a survey of some 3000 households, and seeks to evaluate the effects of urban form, transport characteristics and also some demographic factors on energy use and emissions resulting from peoples day-to-day movements around the region.

Some background to the study:

In common with large and small cities around the world, Wellington has in effect been physically restructured over time to facilitate the personalised system of transport offered by the private car and the extensive provision of public roads. From a traffic engineering perspective, the key concern in any city is how to allow people to move around the city in the course of daily life. While Wellington has a reasonably high level of public transport provision most transport investment in recent decades has been in roads so that, as in other cities both in New Zealand and overseas, this has facilitated wider use of private cars. In common with other western cities reported on in the literature, demand for road space has outstripped road construction since the early 1980s. While the problem is comparatively minor here, it is however sufficient to warn against a continuation of policies which have escalated this to a major problem elsewhere. At the local level too, Wellington's climate mitigates against the accumulation of air pollutants just as the geography of other cities tend to the opposite. Where the latter is the case, car exhaust fumes are the major source of atmospheric pollutants in some cities. Given that New Zealand has no minimum emissions standards for motor vehicles, even in Wellington's windy climate very localised concentrations of carbon monoxide and other gases may reach toxic proportions at road verges during peak traffic periods. Elsewhere in New Zealand monitoring of benzene and other aromatics which have now replaced lead in high octane petrol have been found to exceed recommended maximum levels of some countries, particularly in Christchurch (Ministry of Health 1997, 7-8 and 15).

This thesis therefore concentrates on means of curtailing fossil fuel use for the purposes of conserving energy and reducing greenhouse gas emissions. While the policy options offered refer specifically to Wellington, there is however little in this city's local transport-land use situation which is unique, and in tandem with the literature *the analysis strongly suggests that these findings are likely to be applicable in other cities as well.* The measures explored are also likely to result in considerable improvements to air quality and congestion, where these are applicable. Measures introduced elsewhere which aim primarily for improvements in these two areas are therefore also relevant to this enquiry. Some of the literature on these subject areas is therefore considered as well.

The thesis follows a fairly standard format, comprising a discussion of the literature, followed by analysis of data, and then discussion of policy options for which this analysis lends support.

Chapter Two looks at the historical context in which the issues of interest arose. The focus here is urban growth over the last century and a half and the relationship of that growth to transport systems. The scope of this survey is international in its scope, discussing trends in the context of other countries and larger cities than those of New Zealand. The trends identified in this chapter can all be observed in New Zealand to a greater or lesser extent.

Chapter Three looks at the "greenhouse effect" in more detail, and links general concepts of processes leading to global warming to the use of fossil fuels and to the growth of road transport including the private car.

Chapter Four examines studies of the relationship between energy use and emissions on the one hand and urban form on the other. The studies reviewed are mainly quantitative, and various methodologies are identified from which appropriate means of analysing Wellington data are selected in Chapter Six.

The analysis is divided into two main areas. The first, in Chapter Five, considers the data available for study of the Wellington region, and how this is adapted to analyse energy use and greenhouse gas emissions in this region. Energy use and greenhouse gas emissions from personal transport are calculated here for each of sixty four zones in the Wellington region.

In Chapter Six a series of analyses of variance and regression analyses are performed to identify key influences on energy use and the resulting greenhouse gas emissions in the study area. Several variables are identified here for which the analyses demonstrate have a clear effect. on the areas in question.

Chapter Seven considers the implications of these findings in terms of planning options which might be pursued to lower dependence on fossil fuels and to slow or halt the growth in greenhouse gas emissions from urban transport. Some local examples are discussed, highlighting areas which appear to be developing along the lines identified by the analysis as "energy efficient", and identifying others where redevelopment offers opportunities for a more environmentally benign form of urbanism.

Chapter Two : A historical overview of the role of energy in personal transport and urban development.

Readily available cheap energy is perhaps the key foundation on which the structure and form of modern cities are constructed. During the current century a generally abundant supply of fossil fuels and electricity has allowed many new forms of production and consumption, much of which is integral to the built environment. Forms of urban land uses have resulted at a scale which had previously not been seen, including extensive tracts of housing which became the locus of the post-war suburban lifestyle. Historically, the physical extent of any city has always been limited by the available technologies of the time, both in terms of its built form and of transport for goods and people. For most of recorded history the majority of people have had only their own feet for transport, so this was always a key parameter on the arrangement of activities in physical space. Suppliers of food and other items could only sell their wares in places which their customers could access. Compact settlements resulted, with development often constrained also by the presence of defensive perimeter walls. The few very large cities which did develop relied heavily on water transport and the power of beasts of burden, but access to these forms of transport was always the preserve of a minority.

This changed, of course, with the industrial revolution. The invention of the (stationary) steam engine in the late eighteenth century soon led to the development of rail transport, while for seven or eight decades during the nineteenth century horse-drawn trams were widespread. While steam-powered trams also operated for a time in many cities, electrification proceeded from the 1890s and allowed tram lines to spread further from the city centres. The new technologies thus opened up new areas for settlement and economic development and extended the limits of mobility within cities. In Auckland, New Zealand, for example a new railway line to the north-west of the city in the 1880s resulted in new development around rail stations in what became the city's western suburbs, Mt Albert, New Lynn, Avondale and Henderson. At about the same time private tramlines were constructed and operated to the east and north of the city by the St Heliers and Northcote Land Company between 1884 and 1891, leading to the growth of suburbia there (Rogerson 1976, 64). The pattern was repeated in hundreds and perhaps thousands of other cities around the world.

So cities expanded well beyond the range of a few hours walk. In Europe, reorganisation of agricultural production had led to surpluses of workers in the countryside, while throughout the western world advances in medical knowledge contributed to a growing population. Continued industrialisation in the cities provided work both for migrants from the countryside and for the growing city-born and bred working class. Urban growth thus proceeded rapidly throughout the western world during the later half of the nineteenth century and into the twentieth. The new transport technologies were not within the reach of every worker's pocket, however. The majority still needed to live within walking distance of their places of work, so areas around the centres of many larger European, North American and Australasian cities became enclaves of working class housing. In Europe particularly, many city centres had become overcrowded and insanitary early in the industrial era (Engels 1980, 62-94). The prosperous middle class soon developed a preference to live away from the central areas. Suburbanisation gathered momentum, while in New Zealand, Australia and the American west newly established towns were laid out from the start in a much more spacious manner than had been usual in Europe.

While suburban development began in the nineteenth century as a result of the new transport technologies of the time, growing availability of private cars accelerated that development as the twentieth century progressed. Most suburbs established prior to the Second World War relied on provision of public transport to allow access to other parts of the city, but increasing mobility in the post-war years further removed the historical constraints of distance on urban development. As motor vehicle production proliferated, costs dropped, and by the 1960s the majority of people in many western countries were able to afford their own cars. Declining oil prices during this period also helped to make running a private car more affordable (Gammon *et al* 1985, 38-40). Burgeoning car ownership resulted in vastly improved access to a wide range of employment, shopping, social and entertainment opportunities and for many the car became a pivotal point of the suburban lifestyle. In countries where institutional structures were particularly conducive to suburban development, urban "sprawl" resulted. Increased use of cars in turn led to a growing demand for more and better roads, while investment in public transport began to lag far behind.

The drawbacks of widespread reliance on this individualised form of transport soon manifested themselves however. While air pollution had been common in industrial cities in Europe and North America since the nineteenth century, the growing scale of motor vehicle use exacerbated it in the twentieth. In the United States, widespread concern about the effect of car exhausts on air quality appear to have arisen first in the Los Angeles region (Hart 1992, 491).

The unusual combination of climatic and topographic factors there, combined with car ownership levels which were high even by the early 1940s, resulted in the appearance of photochemical "smog". Along with air pollution problems in other parts of the country, this lent impetus to the establishment of the United States' Environmental Protection Agency, followed by the introduction of a Clean Air Act in 1970. This established national air quality standards including maximum levels for a range of air pollutants and required each State to prepare their own air quality management plans. The Environmental Protection Agency suggested a range of strategies to achieve these state-by-state standards including transport oriented measures, while a Federal-Aid Highway Act passed the same year sought to ensure that new highway construction was consistent with the new air quality plans (Voorhees and Associates 1971, 1/1-1/5). A tightening of emissions standards for new motor vehicles soon followed (Berry *et al* 1974, 42). More recent legislation has led to the introduction of Air Quality Management Districts (AQMDs) which have the power to introduce stringent controls at the local or regional level. California's South Coast AQMD has been amongst the most stringent in this respect, and a considerable body of work which is directly relevant to this thesis has resulted from the studies in that area. Commuter travel behaviour has been particularly targeted in recent years as a means of cutting emissions of photochemical pollutants and carbon monoxide (Bae 1993, 65).

As the long economic boom of the post-war period increased many countries reliance on imported oil, concerns mounted as to the extent of recoverable oil reserves. Future energy supply was already a topic of some governments' attentions by the late 1960s (Goss and McGowan 1972, 262-273), and the energy supply crisis of 1973 brought this issue home sharply to developed countries. Research into alternative energy sources and increasing energy efficiency were elevated to matters of national and international importance. This included a resurgence of interest in public transport as a viable alternative to the private car. The period also spawned a body of research on the influence of urban land use patterns on energy use in transport around the city, some of which is reviewed in Chapter Three.

The "oil shocks" had other, deeper effects. Cheap oil had been a cornerstone of the post-war economic boom, and significant rises in energy costs resulted in vastly altered balance sheets for national and international economies (Burchell and Listokin 1982, 6-7; Altshuler 1981, 127-134). Higher oil prices on the international market slowed economic growth, affecting governments' abilities to provide all sorts of physical infrastructure. Relative costs of road building programmes escalated, and maintenance of the road networks constructed earlier in the post-war period also began to incur a significant burden for many regions' roading budgets. Local opposition to many projects proved to be an additional barrier to constructing new roads (Goldberg and Chinloy 1984, 517). Thus when oil supply restrictions eased in the early 1980s and steadily improving fuel efficiency in new vehicles helped to restore the growth in vehicle use in the west, roading provision was no longer able to keep pace with increased car use in most developed countries.

Complex changes in the spatial economy of cities also stimulated increased reliance on the private car. Many western cities have evolved in recent decades from a core Central Business District-oriented, monocentric form to a multi-centred or polynucleated form. This is perhaps a logical progression of widespread suburbanisation of the post-war period, and appears to have been exacerbated to some extent by the recession of the mid and late 1970s. By the time of the first "oil crisis" many central city areas, particularly in the United States and Europe, were in a state of decline as a result of the outflow of residents from the inner city to the suburbs. For a few years during the seventies the areas of fastest residential growth in many western countries were in non-metropolitan or "exurban" locations, and this in turn generated large flows of commuter traffic into the cities. Although this "counterurbanisation" has not been sustained on a large scale since then, periurban and exurban growth has continued in favourable locations with good access to employment centres. In the Wellington region it can be seen with the growth of the Kapiti District 30 to 40 kilometres north of the city. Counterurbanisation during the 1970s was documented in many countries including the United States, Australia and the Netherlands (Champion 1992, 470-471; Klaassen *et al* 1981, 60-61) and while the 1980s saw a return of highest population growth rates to the cities, this was largely suburban and still at the expense of the city centres (Frey 1993, 766-767).

Much of the old industrial infrastructure of western countries was also approaching obsolescence by the time of the 1970s oil shortages, and this contributed to the decline of many inner city industrial districts. Industrial organisation changed dramatically in the wake of the general economic downturn. New manufacturing industries generally favoured locations at the periphery of the cities where cheaper land allowed construction of the extensive single story buildings favoured by "post-Fordist" industry, and ready access to arterial roads and highways allowed "just-in-time" delivery of materials and components. Some commentators have depicted this geographical shift as part of a strategy to move leave a militant working class behind in favour of a non-unionised, often female and frequently casual labour force in the new "greenfield" locations (Soja *et al* 1983, 205-206).

Major new retail developments also favour suburban locations and again this is a continuation of a trend which had been evident throughout the post-war period, as retailers left the city centres to take up the opportunities offered by suburbia (Zupin 1988, 436). Office development has followed, both around some of the shopping malls and also in single use "office parks". For millions of people, this diversification of suburban functions means that they are now just as likely to work in suburbia as they are to live there. In the United States, suburban employment has grown to the extent that it has now outstripped total employment in the central cities (Stanback 1991, 60-62).

The years since the 1970s energy crises have thus resulted not only in substantial increases in commuting to the central cities but also in very significant intra-suburban commuting flows (Stanback 1991, 6-12). To use an American example again, 62 percent of all United States workers were commuting within or between suburbs by 1990 (Chinitz 1990, 7). The expansion in suburban employment thus appears to be responsible for a large part of the resurgence in car use which followed its rather brief down-turn during the oil-shortages. Most public transport infrastructure continues to be oriented towards the centre of most cities, and while this generally matches the "traditional" suburb-to-city work trip, it is poorly fitted to these new suburban commuting patterns. Traffic congestion has thus become more widespread than ever, so that by 1990 it was seen by many Americans "...as the worst problem facing their region(s) in recent years" (Cervero 1991a, 120-121) while in Europe it was also attracting more attention than less immediately obvious environmental problems (NOVEM 1989, 21-22). More recently this issue has attracted considerable media attention in New Zealand (King J in *The Evening Post* 15 September 1997, 1).

Transport thus accounts for an increasing proportion of global fossil fuel consumption. This results partly from shifts from oil to other energy sources by many heavy industries, so that the proportion used in transport would have increased even without an overall increase in consumption. Growth in transport fuel use has also been absolute however. While the road freight and air passenger sectors account for some of this growth, private cars remain the largest single user category. In New Zealand, private cars account for about fifty percent of all liquid fuel consumption (Bone 1995, ix) and petrol consumption here has increased by close to three percent per annum between 1985 and 1995 (ACIL 1997, 12). Over a similar period (1988-1997) the number of cars in this country has increased by some twenty percent (Statistics New Zealand 1997, *pers. comm.*). The pattern is repeated in other developed countries. In the United States the number of cars is reported to have grown three times as fast as the population during the 1980s (Chinitz 1991, 953) while increased private car use in Europe was also documented with total vehicle kilometres travelled growing between 1975 and 1985 by 24 percent in France and Germany, 31 percent in Italy and 35 percent in Great Britain (Button and Pearce 1989, 157).

By the mid-1990s, then, the critique of private car use had crystallised along several themes. As mentioned in the introduction, climatic change precipitated largely by fossil fuel use is currently high on the list of international concerns. This is further considered in Chapter Three. While short-term energy supply is less problematic than had been anticipated during the depths of the 1970s crises, the long range outlook for oil supply is less certain, as indigenous supplies in many countries are quickly being depleted. Countries so affected include both Australia and Great Britain, with regard to oil, and New Zealand with its partial reliance on natural gas derived "synfuels". Higher production costs for new oil fields are likely in most areas, particularly outside the Middle East, and the need to replace much of the world's ageing tanker fleet is also predicted to add significantly to international oil prices over the few years (Hilton 1992, 964-967). Neither has the possibility of periodic disruption to imported oil supplies completely disappeared, as the 1990 Gulf War clearly demonstrated. Air quality has continued to deteriorate in many heavily urbanised regions, and while legislation in the United States and parts of Europe require considerable improvements in car emissions standards over the next few years some of the resulting air quality programmes also involve considerable reinvestment in public transport. Finally, more general perceptions of environmental quality continue to play a strong part in the debate. The emergence of new urban and community ethos have led to a search for improved urban environments which in many cases include promotion of viable alternatives to private motorised transport. The latter has been brought about partly in reaction to the physical deterioration and social deprivation in older inner areas of many larger American and European cities, and partly from dissatisfaction with the architecture and lifestyles of post-war suburbia. Many "inner cities" have received injections of public capital in attempts to rejuvenate these older areas. Architects and urbanists working there have attempted to redesign old city centres to stimulate a sense of local community which many see as having been lost through the course of the twentieth century . Others are applying similar principles to completely new settlements (Southworth 1997, 28-44). The virtues of public as against private transport have figured to some degree in all of this.

These various strands of the urban land use and transport debate have developed in the context of a growing and widespread environmental ethic. Recognising that the earth does not comprise an inexhaustible supply of raw materials, nor an infallible sink for waste products, "sustainability" has become one of the catch-cries of the 1990s, a key term in the debates on the future shape of the world. In New Zealand, the principle of sustainability is enshrined in our Resource Management Act (1991), and here as elsewhere a start has been made to incorporating the idea into our designs for human settlement. Thus while for many years the very idea that cities were a sustainable entity was considered something close to anathema in some intellectual circles, the concept of "urban sustainability" has gained considerable currency. With the increasingly urban character of most of the world's populations, at the broadest level it is becoming ever more important to be able to design human settlements in a way which is sustainable for the long-term.

The relative energy-efficiency of various forms or layouts of urban development is one avenue of research which offers something to all of these themes. Many researchers have claimed that denser forms of urban settlement possess inherent energy efficiencies, so the need to substantiate such claims - or otherwise - is within the gambit of this study. Some cities are experiencing a revival of their older central areas, and while "reurbanisation" and "urban consolidation" have gained a fair measure of intellectual credibility in terms of their perceived benefits, not all commentators in this field are convinced however. A significant component of the literature on energy-efficient urban form argues that the oft-maligned "sprawl" offers its own efficiencies to modern living (Gordon, Richardson and Jun 1991, 416-420).

Having identified the general themes around which this thesis is built, I turn now to considering the role of transport in climatic change and the "greenhouse effect".

Chapter Three : The "greenhouse effect" and the role of transport in climatic change.

The final draft of this thesis was written as government officials from many countries met in Kyoto, Japan, in an effort to reach agreement on targets for reducing emissions of greenhouse gases. We can expect a considerable refocusing of government interest in this issue over the coming months and years as a result of the agreements reached there. It is therefore doubly appropriate that we look more closely at this phenomena, at what it is and what part the transport of people within the world's cities really plays in the emissions budget.

In this chapter, and in the rest of the thesis, a few common abbreviations are resorted to; **GhG** for "greenhouse gases", **GhE** for "greenhouse effect". The terms "Global warming potential" or "relative warming effect" are often used to compare the effects of different gases, and this is referred to as **RwE** in the discussion below.

"The greenhouse effect":

The overall effect can be conceptualised in two parts, natural on one hand and the human induced, enhanced or anthropogenic effect on the other. The natural effect is part of the balance of many factors which control the global climate, and results from solar radiation being trapped by the earth's atmosphere. The GhGs are transparent to short-wave radiation from the sun, which passes easily through the atmosphere to warm the surface of the earth but opaque to the longer wave-lengths which radiate back to the air. Some of this heat radiation is absorbed by the GhGs and so prevented from being lost to space (Solomon *et al* 1985, 3). This buffers the biosphere from much larger diurnal and seasonal variations which would occur in the absence of these gases, with the result that the global average surface temperature is some 33 degrees higher than it would be without this natural greenhouse effect (Ramanathan 1988, 294). As such, it is therefore crucial to sustaining the planet's diverse range of habitats and life-forms. The most important gas in this respect is water vapour, followed by carbon dioxide (CO_2). Methane (CH_4) and nitrous oxide (N_20) are also important naturally occurring GhGs as is ozone (O_3), although the latter is perhaps better known for the importance of stratospheric concentrations, the so-called "ozone layer", in absorbing harmful incoming ultraviolet radiation before it reaches the biosphere (IPCC 1990, 3-6; Wratt *et al* 1991, 8).

Rising atmospheric levels of several of these gases have been documented over several decades. A particularly important programme of atmospheric carbon dioxide measurement began at Mauna Loa, Hawaii in 1958. Over several years it became apparent that concentrations of the gas were rising steadily, and similar programmes were initiated at several other "clean air" sites around the world. These are sampling stations located away from significant emission sources to avoid the likely influence of strong localised variations. Data collated from several widely separated sites revealed steady increases overlying seasonal fluctuations. Analysis of glacier ice-core samples from Greenland and Antarctica has added many tens of thousands of years to the time record of atmospheric carbon dioxide, so that a good record now exists of atmospheric concentrations not only for recent centuries but also back through several glacial events or "ice ages" (Gammon *et al* 1985, 28-29 and 38-45).

The evidence compiled shows that atmospheric CO_2 concentrations have risen steadily since the advent of the industrial era, from 260-285 parts per million (ppm) at the beginning of the nineteenth century to 315 ppm when the Mauna Loa programme began in 1958 (Gammon *et al* 1985, 38), to 353 ppm by 1990 (Wratt *et al* 1991, 14). In contrast, concentrations over the last 10 000 years - the period since the last ice age - have remained consistently within a range of 260-290 ppm. Those of other GhGs have also increased markedly since the pre-industrial era; that of methane has more than doubled from 0.8 to 1.73 ppm, while nitrous oxide has increased by a comparatively low eight percent to its current level of 310 ppm (Gammon *et al* 1985, 36; Wratt *et al* 1991, 15).

These rises have been linked to human activities which generates additional quantities of all of the naturally occurring GhGs. In addition significant quantities of a group of synthetic gases, the chloroflourocarbons, are emitted. These have particularly high infra-red absorption properties. 1987 estimates of total global emissions were around 2.6 billion tonnes of carbon dioxide, 300 million tonnes of methane, 6 million tonnes of nitrous oxide and somewhere in the region of a million tonnes of CFCs (Wratt *et al* 1991). New Zealand contributes around 28 million tonnes of carbon dioxide and 1.5 million tonnes of methane (1989-90 estimates) which is about twice the world per capita average for CO_2 and five times the average for CH_4 (Wratt *et al* 1991).

Modelling of likely increases in atmospheric concentrations indicate that current trends in terms of fossil fuel use and populations growth are likely to result in CO_2 levels of about 415 ppm by 2025 and 520 ppm by 2100 (Anastasi *et al* 1990, 936; IPCC 1990, 14). While the effects of increasing GhG concentrations are not well understood, it is widely accepted by the international scientific community that increases in average global temperature over recent years are one of the key results and that these will continue unless emissions levels are substantially reduced. Much uncertainty exists as to the magnitude of the likely changes, as any attempt at forecasting is complicated by complex natural feedback effects which are likely to act both in enhancing the effect and in providing sinks for some of the additional gases. Local and regional impacts are likely to be quite different from place to place as a result. For example higher temperatures could lead to increased evaporation from both land and water bodies, increasing cloud cover in some areas and perhaps resulting in net cooling for some regions through lower sunshine hours. Other areas may be warmer still as a result of the radiative properties of increased amounts of water vapour, which as discussed earlier is in fact the most important gas in the natural GhE. Recognising these uncertainties, the IPCC generated several scenarios of various levels of emission growth, stabilisation and reduction, and concluded that global mean temperature rises of 1°C to 3°C were likely by the year 2100. This is in the range of temperature rise which occurred about 10,000 years ago, ending the last "ice age" and changing the world's climate to that which exists today. A further rise of this magnitude may therefore bring about climatic change on a similar scale.

The possible consequences include major disruption of the world's weather patterns which are likely to be far-reaching in their effects. Changing rainfall patterns are likely to affect production of food and other crops, although it is possible that higher carbon dioxide concentrations will enhance plant growth and thus the productivity for some crops. Partial melting of the polar ice-caps is likely to lead to sea level rises in the order of 30 to 50 cm by 2050 and 1 metre by 2100 (IPCC 1990, 3), posing a coastal erosion and flooding problem for small island nations and for populous delta regions such as those of Bangla Desh and the Netherlands.

Amongst the majority of climate scientists who agree that global warming has been induced by human activity, it is widely recognised that stabilisation of GhG emissions is required in order to avoid the more serious effects of such climatic change. Climatologists meeting at the Toronto Convention in 1988 agreed that this would need to be in the order of a 30 percent reduction by 2020 on then current levels to be effective (Jochem 1991, 119). While reductions of this magnitude would stabilise atmospheric concentrations of these gases, it would however, not bring about an immediate halt to global warming. Reductions in emissions of as much as 60 percent would be required to achieve this (Hughes 1991, 149). Stabilisation at higher levels than those of recent millennia will result in new equilibrium temperatures which may not be reached for many decades, so that continued warming could be expected for some time after stabilisation is achieved. More recently, the Climate Summit at Kyoto, Japan, agreed on world-wide cuts of 5.2 percent on 1990 emission levels by 2010, thus falling far short of the requirements estimated a decade or so earlier. The agreed targets at least give the possibility of agreements on further reductions in the next few years however and will stimulate additional research of technical option for reducing emissions. National and regional aims include six, seven and eight percent respectively for Japan, the United States and the European Community countries, while New Zealand has made a commitment to freeze emissions at 1990 levels. These targets have still to be ratified by the governments of these countries at the time of writing.

Anthropogenic sources of the greenhouse gases:

Reduced emissions of all of the major greenhouse gases which are produced directly by human activity will be needed. At the global level, carbon dioxide is the most important of these in terms of its contribution to the "enhanced" warming effect. Fossil fuel combustion and deforestation are the two biggest sources, with cement production a smaller but also substantial third source. Forest clearance has probably had some effect on atmospheric CO_2 levels for several millennia, with perturbations evidently having exceeded the natural levels of fluctuation over the last two thousand years (Gammon *et al* 1985, 35). However the greatest impact of deforestation has been concurrent with widespread fossil fuel use which has accompanied the industrial era, first in countries such as Australia, New Zealand and the United States with nineteenth century agricultural expansion, and more recently in developing tropical countries. While development of technologies such as the steam engine and production of coke for use in steel production led to a massive increase in use of coal throughout the nineteenth century, it was not until well after the Second World War that its importance was displaced by oil. Rotty and Masters (1985, 67-70, citing earlier research by Marland and Rotty) showed that CO_2 emissions increased by over 4.2 percent almost every year from 1860 to 1949, with the two world wars and the 1930s depression representing the only interruptions to this growth. Oil outstripped coal as the main fuel during the post-war boom years, with consumption growing at seven for every year from 1950 to 1973. Growth of total emissions from all sources also increased during this period, to over 4.4 percent growth every year. Conversely when oil price rises slowed demand substantially from 1973, growth in emissions also slowed to just under 1.5 percent per year. The net result however was a fifty fold increase in annual CO_2 emissions between 1860 and 1982, and a rise in atmospheric concentrations of well over 20 percent since 1800 (Gammon *et al* 1985, 38; IPCC 1990, 6). Transport, as already discussed, made a significant contribution to the emissions budget since 1945. With switches away from oil for electricity generation and industrial fuel since the mid-seventies, this sector accounts for a growing proportion of all oil-derived emissions.

After CO_2, methane(CH_4) is the next most important contributor to the enhanced GhE. Emissions also began to rise early in the industrial age, so that by the early 1980s atmospheric concentrations (as distinct from emissions) were increasing by about one percent a year (Gammon *et al* 1985, 36 and 54). Frow (1990, 5 citing Lassey *et al* 1989) estimates New Zealand's emissions at 1.6 million tonnes a year, about 0.3 percent of the worlds annual total of 530 million tonnes. About three-quarters of New Zealand's emissions result from livestock, and along with considerable emissions which result from anaerobic decomposition of organic waste in landfills this results in a relative warming effect (RwE) which in the short-term is greater than that of all New Zealand's CO_2 emissions. At the global level, rice paddies and fossil fuel extraction (mainly release of gas through coal mining and venting of natural gas in oil fields) also play a significant part in the overall emissions budget. Leaks in the distribution system are another source of anthropogenic methane and although the quantities emitted are comparatively low, this is a factor which needs to be taken into account when comparing the "environmental friendliness" of alternative fuels.

Chlorofluorocarbons (CFCs) make up the third largest part of New Zealand's contribution to the GhE, at around 21 percent of RwE (Frow 1990, 9). However, use of CFCs has dropped markedly over the last few years in line with targets formalised in the Montreal Protocol which took effect in 1989 (Wratt *et al* 1991, 15). CFCs may still be used in some industrial processes such as manufacturing foams for cars and other vehicles overseas, and some of which are imported into New Zealand as components and in built-up vehicles. They are also present in air-conditioning units which are present in a growing proportion of imported used vehicles (Bone *et al* 1995, 23). As with other GhG emissions from offshore production of imported transport equipment, these could be counted as indirect emissions. However they are seldom incorporated into complete emissions budgets due to the uncertainties in calculating the quantities involved.

Small quantities of nitrous oxide (N20) are emitted from fossil fuel sources, including car and other vehicle engines and thermal power stations. As with methane however, agriculture is the largest source, resulting from soil denitrification. This source accounts for some 17 percent of overall contribution to the GhE, as against 1.2 percent for emissions from all other sources including transport.

While the quantities of methane, nitrous oxide and the chlorofluorocarbons emitted are very much smaller than those of CO_2, they all have a much greater ability to absorb longwave radiation than carbon dioxide, so that their contribution to global warming is disproportionate to the quantities produced. While CO_2 is gradually removed from the atmosphere by various processes including ocean circulation, the other gases are all broken down in the atmosphere over relatively long periods. The life-span of these gases is still not completely understood, so estimates of their effects are less certain than those of CO_2. Nitrous oxide is eventually destroyed in the upper atmosphere by the action of sunlight, while methane and some other gases are oxidised by hydroxyl radicals (OH). This process breaks methane down to water vapour and CO_2, so that at the end of the process it contributes an addition to levels of the latter gas. Carbon monoxide, which is a radiatively non-active gas, is also involved in this process. Like methane, it is broken down by the action of hydroxyl radicals and this eventually produces additional carbon dioxide as well. In the process it prolongs the life of atmospheric methane, effectively diverting a proportion of the available hydroxyl radicals from oxidising that gas.

The eventual breakdown of these gases results in quite different figures for their warming potentials relative to CO_2 depending on the timeframe being considered. The main effect of the shorter lived gases will be close to the period of emissions, so that considering a longer period will result in a lower estimated RwE. Thus on a kilogram for kilogram basis methane is considered to have 63 times the warming effect of CO_2 over 20 years, falling to 21 times the effect over a 100 year time horizon and nine times over a 500 year period. The net effect is that, using the New Zealand example, annual emissions of 1.5 million tonnes of methane result in about half the warming effect of the annual 28 million tonnes of carbon dioxide over this longest term, yet is some three times greater than that of carbon dioxide in the short term. For nitrous oxide, RwE is 270 times that of CO_2 for 20 years falling to 190 for a 500 year time frame, while most of the common CFCs have several thousand times the radiative potential of CO_2 (there are some seventeen related products; Bone *et al* 1995, 7). While the warming potential of ozone is also in this order, its effects are in some ways the least well understood of the active gases. The quantities emitted from anthropogenic sources are comparatively small, and coupled with the problem of stratospheric ozone depletion and the accompanying losses to the natural GhE, this gas is generally omitted from equations which seek to gauge overall warming effects.

The role of transport:

While it is obvious that agricultural and industrial processes which predate widespread road transport use contributed a considerable proportion of total emissions, the contribution of the overall transport sector has grown enormously in recent decades. This growth shows little sign of abating. While the demand for energy actually fell in all OECD countries between 1973 and 1987, energy use in all forms of transport grew by 23 percent over the same period, while in road transport alone this rose to 27 percent (Boyle 1990, 35). New Zealand's total energy use in transport is around 34 percent of energy consumed for all uses (based on figures for the 1991/92 year; Statistics New Zealand 1993). The resulting RwE is somewhat lower than this, due largely to this country's high per capita methane emissions. While less than one percent of this originated from transport (5300 tonnes of a total 1.5 million tonnes), the sector generated over 41 percent of CO_2 emissions (11.7 million of the total 28 million tonnes) resulting in 28 percent of RwE from all New Zealand sources for the two gases combined (Wratt *et al* 1991, 19).

Bone *et al* (1995) provide a complete breakdown of emissions between sectors in New Zealand transport, including alternative methods of assessing the contribution of air services and shipping into and out of the country. While the latter accounts for up to 30 percent of all emissions from transport sources, resulting in considerably higher figures than those cited by Wratt, the figure is dependent on the proportion of fuel used in international transport and travel which is ascribed to the New Zealand emissions budget. Domestic sources alone are much less ambiguous, as all fuels are domestically supplied and accounted for. The private car accounts for a substantial portion of the total, as shown by the following figures (Bone *et al*, x):

	All transport sources:	**Private cars:**
CO_2	10.5 million tonnes	5.2 million tonnes
methane	7625 tonnes	5196 tonnes
nitrous oxide	375 tonnes	222 tonnes
CFCs (all types)	71 tonnes	58 tonnes

While calculating the RwE for methane and N_2O emissions is straightforward using published conversion figures, the warming potential of the various CFCs vary widely. Bone *et al* (26) show that dichlorodiflouriomethane (CFC-12) is the largest single CFC type in New Zealand's transport sector, accounting for 78 percent of all CFCs emissions by weight. Almost all of this is used in cars. Thus CFC-12 alone has a GwP equivalent to 441,500 tonnes of CO_2, while for all types this rises to 535,000 tonnes. The 50 year RwE for the four gas groups, using conversion factors from Bone *et al*, are therefore:

CO_2	92.98 percent
methane	1.35 percent
nitrous oxide	0.93 percent
CFCs (all types)	4.74 percent

This equates to a CO_2 equivalent of 11,290,528 tonnes, of which the private car by itself contributes 51.67 percent - about 14.5 percent of the RwE of all New Zealand emissions.

These proportions of emissions from the whole transport sector and from private cars as a proportion of the national total appear to be broadly comparable to several developed countries. In the United States for example, the overall transport sector accounts for 32 percent of carbon dioxide emissions, of which 14 percent comes from private cars (Friedman and Bierbaum (1992, 16). These figures, however, account only for direct fuel consumption. A complete emissions budget would include indirect fuel use in oil extraction, transport and refining, production of raw materials from which vehicles are built and assembly of the vehicles themselves, and provision of infrastructure, primarily roads, including production of associated materials such as concrete and bitumen. As a large proportion of New Zealand's vehicles are now imported in built-up form, this raises questions as to whether these should be ascribed to New Zealand's emissions budget or to those of the producer countries. If demand did not exist in New Zealand, a proportion of that production would naturally be curtailed overseas. Transnet (1990, 7-18) analysed the United Kingdom's land transport sector and concluded that direct fuel use accounts for only 66 to 72 percent of total energy use. No such analysis is attempted here, and an important assumption of this thesis is that these indirect costs are spread evenly as part of the total cost of each kilometre travelled.

The question sometimes arises as to why New Zealand should target private transport in its effort to reduce greenhouse emissions. Our overall emissions budget differs from that of most OECD countries in some important respects, with methane emissions from agriculture comprising a large portion of our total emissions in terms of RwE. Conversely, electricity generation is less reliant on fossil fuels than many countries, with seventy to eighty percent generated by hydroelectric sources - considerable variation occurs between years of high and low rainfall. (ECNZ 1996 (a), 7; ECNZ 1996 (b), 27). This impacts favourably on our fossil fuel-derived emissions. The large contribution of methane agriculture suggest that this is an area which could be targeted for reduction. However recession in the farming sector has resulted in considerable reductions in stock numbers over the last decade, and thus also in emissions from this source. The strongly market-led orientation of government policy makes it unlikely that any intervention would occur should prices for farm products improve and stock numbers rise again. In that event, it might be argued that because New Zealand farming is considerably less energy intensive than the feed-lot practices of some producer countries, it already produces less emissions per head of stock than countries. Conversely, the growth in car numbers and petrol sales which was discussed in Chapter Two indicate that policies which target car use may be of value in halting or even reversing current trends. The possible multiple benefits of such policies, including relieving congestion, reducing other air pollutants and reducing dependency on imported fuel sources are make this area one which is worth further investigation.

We therefore turn now to reviewing studies which evaluate possibilities for reducing car use.

Chapter Four : Previous research in the area of energy efficient urban form.

This chapter examines key studies to see how previous researchers have gone about identifying high and low performing urban lay-outs in terms of transport energy use and emissions. The studies reviewed fall into two main groups. The first of these uses mathematical and operations research type optimisation methods and includes mainly studies which are based on standard transport and land use modelling. The second group consists of statistically based studies. Some non-quantitative studies are also reviewed at the end of the chapter.

The range of cities which have been examined in this body of research is quite diverse, and after even a brief perusal of the literature it becomes quite obvious that what may be true of a city of a particular size, shape, economic make-up or cultural identity may not be true of another city with different characteristics. Some researchers have sought to overcome this problem by resorting to simplified models or "archetypes" of town and city design, particularly in optimisation studies reviewed here as the first group.

Before looking at some relevant studies however, we first consider the general methods used in transport and land use modelling. The first, perhaps obvious enough feature which is common to all of the work reviewed here is the requirement to quantify the effects being examined in some way. Standard transport planning studies may use journey times, total distances or costs as common units to evaluate alternative proposals. When monetary cost are used, this may be the cost of infrastructure or alternatively the actual and sometimes perceived costs for individual travellers. The value of time spent waiting at a bus stop or rail station or in traffic are examples of the latter. While many studies from 1973 onwards were quantified in term of fuel use or other energy measurements, none were found during the literature search phase of this project which use green-house gas emissions as the comparative measure. A few of the studies reviewed here have quantified emissions of pollutants such as carbon monoxide and sulphur dioxide.

General aspects of transport and land use modelling:

Many energy studies carried out during the 1970s energy shortages drew heavily on transport modelling techniques which had been developed earlier in the post-war period. Computer based modelling was firmly established by the time of the "oil shocks", albeit using hardware with just a fraction of the processing power of contemporary desk-top computers. These models were then quickly adapted by researchers to quantify energy use.

Overall, transport needs within any urban area are the result of the collective decisions of all individuals living there as to how to travel between their homes and the various locations they must visit in the course of day-to-day life. For the transport planner, the task of designing transport networks and infrastructure requires information about where people begin their daily travel - usually their places of residence - about the places they visit, and about the means and routes by which they choose to travel. Raw data may be gathered by various means, including surveys of vehicle movements which pass given points and "travel diary" surveys completed by a representative sample of households. This data is then matched to a plan of the transport network, which is represented by a series of links and nodes. The links represent sections of actual or proposed roads and/or railway lines, the lengths of which are known and integral to the model. Nodes are points at which the links converge, such as important cross-roads or road-rail junctions. Most models also divide the urban area into a number of zones, which are likely to be related to the transport network by including a node in the transport network as its centroid. All trips may then be represented as a series of links which begin and end at a pair of zone centroids, with trip lengths averaged to those of the sum length of the links crossed. Intrazonal travel is represented by an average length for those trips which do not cross boundaries between zones, and this is also likely to be included in the calculation of trip length between any two zones. For example, the length of a trip from zone **w** to zone **z** which passes through zones **x** and **y** would equal the length of links **w** to **x**, **x** to **y**, and **y** to **z**, plus the distances for internal trips in zones **w** and **z**. (Clark 1974, 45-47.)

Any trip within the city is thus represented by allocating the points at which the trip begins and ends to the appropriate zones and then adding together the lengths of the appropriate links, together with the average length of intrazonal trips for the origin and destination zone of the trip if these are included in the model.

The level of complexity of the range of activities which are recognised in transport modelling varies considerably. While many early models only took account of trips from home to work, more complex models provide for other activities such as shopping, school and recreational purposes to be dealt with more specifically. This is of course important where the model is used as a tool in planning the overall transport provision of an area, including public as well as private transport.

Running a model of this kind results in trips being allocated to available links. Constraints within the model represent the physical constraints of the actual network, so that as the loading on a link increases travel speeds are adjusted to simulate traffic congestion. If the number of trips between two zones reaches the capacity of the most preferred route, further demand for travel on that route will be assigned to alternative routes across the network. This simulates a situation where a congested road or full commuter service causes individual 'trip-makers' to choose another route, which being the second or third choice will generally be less direct. Most models contain provision for more than one mode or method of travel, and as in real life, overloading of links at peak time may result in transfer of some travellers from private transport to less congested modes such as rail.

Models of this general form were generally designed to assess capacity limitations of planned or actual transport networks. They have also been used to find total travel requirements of proposed urban lay-outs, and have proved readily adaptable for purposes of calculating total energy consumption by "plugging in" appropriate fuel or energy use figures for each mode.

Most planners are concerned with land-use issues which are wider than transport planning alone, and such models are therefore often combined with land-use models to introduce changing patterns of demand into an integrated transport-land use (TLU) models. The assumption behind such models is that transport systems and demand for land or floorspace interact:

> *The relationship between land-use and transportation can be conceptualized as a circular chain* (within which) *land development determines the patterns of trips in the urban area simply because the land use patterns represents the locations of all trip origins and destinations. These trips, when aggregated into an urban travel pattern, define the transportation requirements for an area. As problems arise (or are forecast to arise), additional transportation facilities are constructed, providing accessibility to certain parts of the area. This new*

accessibility causes changes in the value of the parcels of land served by the new facilities. The land is then put to more intense uses, and the circular chain of relationships continues until no further development of the land is possible.

(Schneider and Beck 1973, 14-15).

Many land use models are based on methodology developed by Lowry (1964). Working initially with data for Pittsburgh USA, he developed a model to forecast overall urban land requirements given a known level of industrial activity. Development of the model started with so-called "economic base method" (Hepple 1986 (i), 117), which assumes that overall economic activity is dependent on the industries which export from the region. In this concept of the local economy both service employment and total population are considered to be "induced", the first as a function of "base" industrial activity and the second of the availability of all employment. The model determines the areas required initially for basic industry, housing and services, and a sub-model then allocates these activities to zones, subject to constraints on land availability and suitability for each purpose. In Lowry's original model, this was done by a market potential model, although gravity models were later adopted by other researchers (see Smith 1986, 281-2; Hepple 1986 (ii), 185).

The initial run of the model determines service level requirements and associated service employment levels for each zone. These are then allocated to zones according to demand. Constraints which stipulate a minimum size for service centres may be built-in to the model, simulating the clustering effect of retail and similar services and on overall availability of land in each zone. Employment in these services in turn creates its own demand for housing which is additional to that created by the level and location of basic industry alone, and thus becomes an input for subsequent iterations. The process continues until the changes in demand for housing and further retail/service facilities created by the initial addition of service employment declines to predetermined value, beyond which additional land requirements would be almost negligible.

While any conception of the economy as grounded in the need to service "basic" industry must be questioned in what is increasingly a "post-industrial" age, Lowry-type models have frequently been incorporated into integrated Transport and Land Use (TLU) models. An example is provided by de la Barra and Rickaby (1987, 12-17) who combined a standard Lowry model with a transport sub-model to produce an integrated 12 stage process which simulates changes in urban land use over time. This was used in an energy assessment of urban forms which is reviewed later in this chapter. Their model is considerably more realistic than some earlier versions in that it recognises that residential location is likely to be based as much on ease of accessibility to services as to work opportunities.

Applications of TLU models can be found in a large number of optimisation studies. Some of these seek to optimise a single variable such as total travel time, distance, costs or energy use, while in others additional criteria are also used to assess the performance of various urban configurations. While those which fall into the former category are certainly of theoretical interest, in reality many criteria must of course be taken into account in any urban or regional planning exercise. Without them they cannot expected to gain widespread acceptance (Beaumont and Keyes 1982, 162).

The literature contains analyses of a number of totally hypothetical forms which use this modelling methodology to varying degrees, along with many examples of applications in various cities. We turn now to look at some of these.

Analyses of hypothetical forms:

Studies which predated the energy crisis were primarily concerned with comparing alternative plans in terms of infrastructure costs and travel times or alternatively the actual and perceived transport costs for individual travellers. A few of these are of some interest in the context of this thesis.

Britain's post-war "new town" projects presented unusual opportunities to design completely new cities, and thus allowed quite different forms to be analysed during the design phases. Working on one of these projects, Jamieson *et al* (1967) evaluated several linear and monocentric configurations. The linear configurations featured intensely developed clusters of a half-mile radius located along transport arteries while the monocentric patterns were typical Central Business District oriented towns with several arterial routes converging on the centre (203-211). (This monocentric pattern is a common one which is discussed repeatedly throughout the literature.)

Overall, the linear configurations proved to be superior to the monocentric models for both infrastructure costs and the average journey times. A three strand linear configuration consisting of three parallel transport arteries provided the cheapest infrastructure while a single strand linear configuration resulted in the shortest travel times. However this study dealt only with private transport provision, and almost exclusively with peak hour traffic flows with some additional allowance for peak hour through traffic. Quite different findings could have resulted if data on trips made for other purposes had been included.

Hemmens (1967) carried out a more detailed consideration of the effect of different densities and locational arrangements on travelling times using a simple monocentric model. This included residential, shopping and work-places arranged in various patterns and densities. Hemmens found that with two of the three land uses held constant, the greatest single impact on travel requirements was achieved by varying the pattern of commercial or shopping opportunities. Changes in workplace patterns produced the next greatest impact, with residential patterns having the least impact on travel requirements. Minimum travel requirements were achieved with a "centric" form which featured highest residential densities around the CBD and shopping and work opportunities dispersed through the middle and outer area. "Ring city" (highest residential densities in the outer zones) combined with a strong commercial and employment core yielded the "most costly" result, although it was closely matched by "spread city", which featured even residential densities across the city, combined with the same strong core. While the combination of a strong core with the centric residential pattern resulted in considerably lower total travel time, it still emerged as the third worst performing pattern.

As with many analyses of this kind, Hemmens' conclusions appear to be based on an assumption that, regardless of the residential pattern in a city, people would be able to find employment near their homes if they wanted to. It was of course completed at a time when official unemployment records were very low. However previous work in which Hemmens was involved had showed that various factors may affect peoples choice of residential location including income, availability of own car and race (Hamburg *et al* 1965). The last factor was included in this study as the housing market was strongly racially segregated in the study area at that time. The researchers developed an index of travel time indifference and found that wealthier people appeared to be less affected by travel time than lower income earners who displayed a much greater tendency to live near their workplaces. As this study took place during the post-war period of high suburban growth, it is likely that this travel indifference would have been strongly linked to the location of the most "desirable" new housing which was increasingly on the outskirts of established cities, while most high income employment continued to be located in the old CBDs.

The energy crises of the 1970s stimulated a flush of studies which emphasised comparisons of energy consumption of alternative urban forms. In the United States, the Real Estate Research Corporation produced a study of the environmental impacts of differing neighbourhood and community types included transport energy use as one of several impacts explored, along with air pollution from car use, energy use within building, water consumption and visual effect along with infrastructure costs (RERC 1974). Unlike the studies reviewed above which evaluated hypothetical forms for a whole new city, this one researched the environmental effects of different forms of primarily residential development at the urban fringe. Six "community types" consisting of different mixes of five types of housing were evaluated. Housing types included single family homes in both "conventional" and clustered layouts, townhouses, and two and ten-storied apartments.

Overall a "high density planned" community scored best in terms of environmental costs. This consisting largely of low and mid-rise apartments, some townhouses and a smaller proportion of clustered detached housing. Particular contrasts resulted between this and a "low density sprawl" type community which consisted entirely of single family homes on large allotments. The higher density development was credited with barely 59 percent the petrol consumption of the low density development along with reductions in air pollution resulting from car use of about 50 percent (RERC 135, 147). However several key aspects of this study were seriously flawed. Altschuler *et al* (1981, 387-8) asserted that while partial substitution of public for private transport was responsible for some of the energy savings in the high density community, energy used by "mass transit" was omitted from the calculations. Similarly, whereas fuel savings would result only from shorter distances travelled within the high-density community, commuting trips to the centre of the nearby city were also factored into the calculated fuel savings. Altschuler estimated that only 20 percent of travel would be within the community and that the remainder of the calculated savings "would evaporate". Differences in floor space between the different housing types was another serious short-coming of the RERC study, and this accounts for many of the savings in other areas credited to the higher-density neighbourhoods such as energy used within the buildings. As such the housing types really catered for quite different housing markets (Windsor 1979, 288). Despite these errors, the study was credited with "...establish(ing) a basic intellectual framework for ten years of planning and public policy thinking" (Chinitz 1990, 6). The perceived benefits of higher density residential development subsequently became the subject of considerable debate in planning circles in the United States and further afield.

Looking again at whole-city layouts, Maunsell and Partners (1975) evaluated four contrasting city prototypes for new cities of 250 000 people with densities ranging from one to 25 households per hectare. While energy characteristics were specifically considered, direct comparison of the prototypes is difficult as each was accompanied by a different scenario of the type of future society which might build such a city. These included varying assumptions about the available technologies, including the levels of telecommunications and the resulting degree of substitution between commuting and teleworking. Quite different proportions of public transport use were also assumed. While the findings can therefore only be considered as indicative at best, the Compact City prototype was the best performer in terms of minimising fuel use and emissions of air pollutants from transport. This was a large, almost continuous structure, so it is interesting to note that the household densities suggested are in fact comparable to those of town-house developments which are currently typical of new construction in Wellington's inner residential area. The "megastructure" proposed by this scenario would in fact be able to accommodate densities more akin to those of high density Asian cities although corresponding adjustments in apartment floor area would no doubt be considered desirable.

Edwards and Schoper (1976) evaluated energy and accessibility characteristics of a larger range of hypothetical forms using travel data from an existing urban area. These included concentric, linear, cruciform and polynucleated forms, with work, service, social and non-home based travel all factored into the models. Variations in area were quite extreme. Polynucleated forms were assumed to have very dense developed areas which were only 3 percent the extent of the sprawled concentric forms, implying large areas of open space between the nuclei, so were more akin to the linear forms of Jamieson *et al* (1967) than to the multi-centre configurations which have become apparent in many cities over the last few decades. While the results allow comparison between some of the different layouts which have similar transport provision the results do not adequately differentiate the effects of urban form from those of modal split. The high proportions of trips made by public transport in some layouts appear to have been set arbitrarily rather than by the modelling process and as such seem rather optimistic (for example from 50 to 90 percent public transport in several models). However comparisons between configurations with very similar or identical transport infrastructure are of interest. In concentric forms with car transport only occupying identical areas, concentrating residential and service employment towards the central zones improved both energy efficiency and accessibility. Further energy gains resulted from location of industrial employment in suburban zones, or into two central spines (a "quasi-cruciform" concentric form) with population and service employment concentrated in the adjacent zones, although the latter decreased accessibility somewhat (56-58). Reduction of overall area also produced marked improvements in energy characteristics over the sprawled forms, but not much more so than for the "quasi-cruciform" configuration.

Unlike the configurations of the Edwards and Schoper study, those tested in two United Kingdom studies all retain a dominant centre (Rickaby 1981, 1987, 1991; de la Barra and Rickaby 1982). These use an integrated transport-land use model of the type described in the first section of this chapter. Although the first of these studies was not strictly concerned with urban development patterns, it does provide a comparison between possible benefits concentrating population into urban areas and encouraging various forms of periurban development. This was based on alternatives for progressive concentration of a hinterland population into the regional centre or various linear and satellite developments in the hinterland. The model also incorporated different scenarios to simulate different future levels of energy availability, and also looked at energy used in buildings as well as in transport.

The concentrated-nucleated option which resettled the entire population into the existing urban area emerged as the best transport energy performer under three scenarios of future energy availability and also the best for total energy use for two of them. Under a low energy scenario it emerged second to a dispersed-nucleated option in which the hinterland population shifted into a system of secondary towns and villages with populations of several thousand people in each. While this and another "dispersed-nucleated" patterns consisting of a larger number of smaller villages performed better than two linear development patterns over all three scenarios, the better performance of the concentrated-nucleated option in each case confirmed the robust nature of this form under varying conditions.

Rickaby's second study (1991) used a Geographical Information System (GIS) to analyse land-use patterns in twenty provincial English towns. He then produced a generalised model which represented their common features. Five forms of future development were then analysed using a transport-land use model. These were three containment options and two peripheral development options. While the concentrated options emerged as having slightly lower energy use than the peripheral options, the differences were less than the margin of error for the modelling procedure. Rickaby suggest that in towns of this size the congestion effects alone would not be sufficient to cause any great swing to public transport, and that encouraging walking and cycling would be likely to have a greater effect than significant changes to development patterns.

These two studies are distinguished from some of those reviewed earlier in that it is clear that factors determining energy use such as modal split have been determined by the modelling process rather than determined arbitrarily. A possible draw-back of this reliance on the modelling process however is that floor areas of dwellings vary between different development options, as in the RERC study (1974). In the case of the Rickaby studies this is a function of the relative costs of dwellings in each location, and is thus consistent with the assumptions which are built into the modelling process. The recent boom in inner city apartment development in Wellington demonstrates that it is perhaps not unrealistic to expect people to sacrifice some floor space in order to live in a more centrally located area. However, this again demonstrates a segmentation of the housing market, and it may be that housing preferences would only change on a larger scale in circumstances of greatly increased energy scarcity. In the case of "infill" type housing in established suburbs the area of outdoor living space for each dwelling is reduced but interior floorspace of new dwellings may be no smaller than the older houses in the area. Smaller dwellings are therefore not a necessary outcome of urban consolidation policies in the New Zealand context, although housing prices and markets along with local District Plan standards will probably dictate that this will be the case in some locations.

Development options for real cities evaluated with transport and land use models:

While the theoretical work of these studies provides a useful exploratory analysis of the comparative merits of land use variations selected, their application to real cities is dependent on the possibility of incrementally restructuring the city over time. While Rickaby's studies incorporate this requirement as part of the conceptual background to his models, a number of studies during the 1970s analysed the energy implications of options for future growth of specific cities.

Two studies based on Seattle, USA reached slightly different conclusions through similar methods. Schneider and Beck (1973, 15-16) reasoned that all possible combinations of the various activities which take place in urban areas would need to be evaluated in order to find the best performing urban form, and developed a procedure to simulate incremental relocation of residents and jobs within the existing urban frame-work. This generated possible new configurations by moving a pre-determined number of residents or workers between zones and then evaluating the new configuration against performance criteria which included aggregate travel requirements for the entire population. If an improvement resulted the new configuration replaced the original one in the computer's memory. If not, it was eliminated from the search. The process was repeated until all possible "node-pair trip production shifts" had been evaluated. Setting upper and lower limits of residents and jobs at each zone improved the speed of the procedure by reducing the overall size of the "combinatorial space", as well as producing a result which was feasible within the given planning framework. Without these constraints in the modelling process the procedure could be expected to move all residents and jobs to one zone - a politically and physically unlikely result !

While the Schneider and Beck study did not attempt to prescribe any one redevelopment pattern as superior to others, it noted that a balance of residents and jobs in each zone represented the best solution for their specified criteria. No conclusions were drawn as to how even the densities of both jobs and housing should be across the city, or whether maintaining a high density CBD offered any advantages over deconcentration. Only journey to work trips were assessed, which must detract from this study's overall usefulness.

Clark (1974) also used data from the wider Seattle region with a similar methodology of incremental adjustments to accommodate the residential and employment growth projected for a period of two decades. Like Schneider and Beck, he found that the best performing configuration involved balancing the numbers of residents and jobs in each zone. His model indicated that the best patterns would result from concentrating residential development in the central part of Seattle, rather than in surrounding districts as was the tendency at the time that the study was undertaken. However in addition he noted that employment growth in other centres within the region could also achieve good results .

In a similar vein, the energy requirements of future development options for an increment of 500 000 households in Washington DC were assessed using an existing regional transport model (Roberts 1975, 2-11). Development options included dense core oriented development; locating all new employment and housing around planned rapid-rail stations at "somewhat" higher densities than prevailed at the time; arranging new development around radial routes to the centre with green spaces between these ("wedges and corridors"); and two forms of peripheral development. Both the transit oriented and core oriented scenarios performed well, with 55 percent and 57 percent of the energy use of the worst performing option, a low density peripheral increment. The "wedges and corridors" option is of interest in the Wellington context as it is rather similar to the historical pattern of development in the Wellington region. This pattern required about 87 percent of the energy of the "sprawled" option.

Sharpe (1978) considered development options for Melbourne, Australia. These included inner city redevelopment at a density of 125 resident persons per hectare, and development along either of two major transport corridor out of the city, on the city fringe and in satellite towns. All were at densities of 25 persons per hectare. Overall urban consolidation again emerged as requiring the least energy, with about 13 percent less energy used in this pattern than the most energy intensive option which was development of satellite towns. Sharpe appears to have considered residential location only however, without the possibilities of major employment shifts being considered.

Summary of findings of TLU studies:

Two major themes emerge from this group of studies. The first is the benefit of monocentric organisation of cities as opposed to multicentred forms; the second is the perceived benefit of comparatively dense residential development. While evidence for any one form emerging as the most energy efficient is divided in studies of abstract hypothetical forms, concentration of new development near existing city centres emerges as the favoured option in most of the studies of real cities. Both hypothetical and "real city" models favour higher density residential development as resulting in lower levels of energy use. Balancing the location of jobs with that of housing also receives considerable support.

We now turn to the second group of studies, those which use statistical techniques to analyse travel information, to see if these throw further light on these themes or produce others which are of particular relevance for the main concerns explored in this thesis.

Statistical analyses of travel information:

While operations research based optimisation techniques form the basis of much of the research through the 1970s and into the '80s, more recent research has relied strongly on statistical analysis. Many of these studies require less aggregation of data than the transport and land use modelling based methods used for most energy studies of the 1970s, and therefore often allow information to be considered in greater detail (Dimitriou 1992, 40-44). Some earlier statistical studies are also reviewed here.

In a wide-ranging study of the environmental effects of urban form, Berry *et al* (1974) analysed contaminants of air, water, soil, solid wastes, pesticides, radiation and noise. Although not concerned with greenhouse gases or energy use, the findings on the relationships between urban form and concentration of air pollutants is of interest. The study initially included seventy six urban areas in the United States, and used cluster analysis to group these in terms of pollution characteristics. Thirteen urban areas were selected for further analysis from the original seventy-six on the basis of the adequacy of the available data and of choosing at least one representative city from each cluster. Regressions analyses using spatial and non-spatial variables for the smaller group showed that SO_2 and NO_2 levels were more prevalent in low density, dispersed urban regions than in highly centralised cities.

Stewart and Bennett (1975) compared variations in car use in 134 American cities with populations of 200 000 or more by analysing sales figures of gasoline and lubricants for each city. Regression analyses included several socio-economic variables and three density related variables. These were population density of the central city area, population density outside the central city and proportion of the total population living within the central city. However these all proved to be insignificant in explaining sales figures. The most significant variables were per capita receipts of tourist accommodation and the proportion of diversified manufacturing as a percentage of total employment, both of which raised fuel consumption above the national average, and whether the city was a port, which as a group exhibited ten percent lower fuel consumption than the other cities. The researchers interpreted the variation explained by these three variables by: the comparatively high proportion of fuel sales to non-residents; longer average journey-to-work trips resulting from the location of high proportions of employment on the periphery of cities; and the constrained urban form of port cities. The proportion of tourist receipts is irrelevant for comparisons of urban form, while the possibility of long average journey-to-work lengths resulting from employment on the urban periphery is considered in other work which is reviewed later in this section (Cervero 1989; Giuliano and Small 1993). The observations on possible causes for lower car use in port cities is relevant to Wellington's case, however:

> *...they may be regarded as cities with centers at the periphery, or with peripheries telescoped fanlike from a full circle to something closer to a semicircle. This compression, with its associated higher densities, may create conditions more favourable for mass transit. Such urban structures may also be regarded as high-cost for auto-based transportation...*
>
> (369).

Although no topographically descriptive variables were included in the analysis, Stewart and Bennett noted that the presence of rugged terrain that

> *...limits a hinterland or channels and concentrates population and economic activity is common amongst SMSAs with per capita gasoline sales much smaller that predicted by the equation.*

This is a factor which is often credited with Wellington's greater reliance on public transport than cities which are less physically constrained, such as Auckland.

In another study of United States cities, Guest and Cluett (1976) analysed journey-to-work data for ninety-eight metropolitan statistical areas (SMSAs). These were selected on the basis of having three distinct areas between which commuter flows could be identified: the CBDs; central city areas outside the CBD; and suburban areas. They found that the main determinants of choice of transport were car availability and density of residential areas. Income did not always correlate strongly with transit use, as high income groups were found to patronise public transport strongly in some cities. Age of the area had some influence on choice of mode, and this in turn was partly related to the area's historical transit use and partly to present characteristics such as car ownership levels and population density.

Soot and Sen (1979) analysed energy impacts of work trips within America's Chicago metropolitan area. They calculated energy use from average trip distances for each zone and analysed the effects of several geographical and socio-economic variables on overall energy consumption in a series of correlation, weighted least-squares and stepwise regression analyses. Car ownership levels, residential type and population density patterns emerged as important significant characteristics, with high work-trip energy use likely in "areas characterized by single-family homes, low residential densities, (high levels of owner occupation), few one and two member households, and housing built predominantly since 1950." Conversely the socio-economic variables tested had low or almost zero levels of significance. These included ethnicity, employment group, educational attainment, income, and some residential characteristics such as rent levels and property value. Soot and Sen noted the tendency for young couples to seek cheap housing in the outer suburbs (293), and suggested that greater emphasis be put on providing centrally located housing for this group to help counteract the resulting growth in energy consumption.

Newman, Kenworthy and Lyons (1985) used travel diary data and average energy consumption figures for each mode. They used data from a 1976 survey of about 4200 people from 1300 households in Perth, Western Australia to find mean energy use of areas within the city. They found that inner city residents incurred considerably lower energy use and transport costs than the average for the whole city. Energy use per capita in the "worst performing" area was about 2.7 times those of the best performing area for all trips, and 3.8 times for work trips only.

Their analysis found a strong correlation between straight line distance to the CBD and energy use in the journey to work, along with a weaker but still significant correlation between distance to the CBD and total energy use per person. Two urban density variables also produced significant correlations. These were net urban density (population divided by the built up area of the zone with non-urban land uses excluded from the calculation) and dwelling density for each zone. Bivariate and multiple regression analyses were also performed of energy use against the density variables, household income and six measures of modal split. The latter were the percentage of both work trips and of total trips by public transport, by private vehicle and by walking and bicycling. Straight line distance to CBD and urban density variables again emerged as the most important indicators of energy use, but the modal split and to a lesser extent household income also explained a considerable proportion of the variation. Further examination of zones with similar socio-economic characteristics showed that those which had plentiful employment, recreation and shopping opportunities demonstrated lower energy use than those which required travel to other areas for these facilities.

While the USA's Real Estate Research Corporation's 1974 study reviewed earlier in this chapter was credited with providing much of the basis for discussion of urban energy use in the late 1970s and early '80s, Newman and Kenworthy (1989 (a) and (b)) provided much of the stimulus for that of the 1990s with a comparative study of transport use in contrasting cities. They assembled a comprehensive array of data on transport use, infrastructure provision and urban land use patterns from 32 cities on four continents. Transport variables included: fuel use and vehicle ownership per capita; average trip distances for car, rail and public transport over all; and the proportion of workers using various motorised and non-motorised modes. Infrastructure related variables included road supply (metres per capita), parking provision, and average speeds for public transport and all traffic. Each city was then classified along the lines of the Guest and Cluett study reviewed above, into a Central Business District, "inner" and "outer" areas. Generally speaking the "inner area" were rings of mainly pre-World War Two development surrounding the central areas of each city. Population density variables were collected for each of these areas and for the city overall, along with data on the proportion of total resident population and of jobs in the CBD and the inner area.

Newman and Kenworthy used two main approaches to analysing this data. Transport use and urban form variables were tested for their correlation with 21 transport use and infrastructure related variables, and this part of the analysis identified some common features about cities which had high levels of public transport use and walking and cycling. Population density was identified as a key indicator of "automobile-dependency". Cities with higher overall densities were identified as being less dependant on private car use and thus as using less energy per capita than lower density cities. Resident population of 30 persons per hectare was identified as a break point below which public transport provision was considerably less important in fulfilling total transport needs than in higher density cities. Their analyses showed that this was also true of areas within cities, with densely populated central and inner areas demonstrating much lower energy use than low density outer areas (40-52).

The second approach used in the overall analysis took the general concepts of standard factor and cluster analysis techniques to produce what is, essentially, a non-standard methodology. Standard factor analysis seeks to reduce the number of variables to a smaller number of "latent" factors which may help to explain total variation, while cluster analysis seeks to objectively group variables or observations into common groups (Manly 1986, 72-73 and 100). In the case of factor analysis, any choice of the number of factors by researchers is made as part of the analysis itself on the basis of information produced by the procedure, while the number of groups in a cluster analysis is determined wholly by the procedure itself. Newman and Kenworthy performed these groupings themselves on the basis of qualitative judgements. Their "factors" were land use intensity, orientation to non-automobile modes, level of traffic restraint, degree of centralisation, and public transport performance. Their "clustering" method involved adding the composite factor scores for each city and then grouping the cities accordingly in terms of automobile dependence, from "very high" to "very low". While they were able to demonstrate strong correlations between their factor scores and standardised per capita gasoline consumption, the decision on the cut off point between one "cluster" and the next seems somewhat arbitrary. For example one cluster showed combined factor scores for six cities ranging between 433 and 570 and the next, also for six cities, from 574 to 614. Spaces between observations within each of these clusters are substantially greater than the space between the two groups, and in fact the upper values of the first cluster is closer to the upper value of the second than it is to its own cluster's mean (Table 3.15, page 66).

In addition to identifying residential densities which they considered the minimum needed to support viable public transport networks, Newman and Kenworthy concluded that strengthening city centres and supporting rail oriented development were important keys to lessening dependence on the private car. Rail development, they considered, would allow the operation of public transport unaffected by road traffic congestion. Planning for higher density development around suburban railway stations would increase land values there, and thus help to finance this infrastructure through the higher land taxes, ("rates" in New Zealand,) which would result.

While this analysis was certainly impressive in its scope, the methodology used ultimately left it open to wide criticism. This was in part due to the unfortunate choice of terminology, in using statistical terms for what were to a large extent qualitative analyses. However the rigour of the analyses was also widely faulted. Gomez-Ibanez (1991, 376-379) for example, cites a fundamental problem as their consideration of "*...one contributing factor at a time, instead of analyzing simultaneously the various factors that might contribute to auto dependence*". While the study identifies density as the key variable in influencing a city's degree of automobile dependence other factors which were not considered in depth also require examination, such as gas prices, income and subsidies available to public transport or to highway use. Specifically, "*...Disentangling the effects of these factors requires more sophisticated analytic techniques than Newman and Kenworthy employ*". Other critics doubted the transferability of information on travel elasticities from one country to another, and faulted the study's preoccupation with work-related travel, whereas (citing the United States case), "*...the most striking change in ...travel behaviour is the boom in non-work trips associated with social phenomena, such as an aging population, smaller households and higher levels of service consumption* " (Gordon and Richardson 1989, 342-344). Like the growth of suburban commuting patterns of recent decades, the majority of this travel also bypasses the inner cities.

The theme of suburban employment's effect on commuting was taken up by Cervero (1989) in an analysis of suburban employment centres (SECs) in the United States. He noted that these centres include a variety of forms including some largely single-use complexes and others with a significant mixing of retail and office space, with housing present in or close to some centres but absent from others. The commuting characteristics of these comparatively recently developed areas is markedly different from older Central Business Districts. Cervero hypothesised that the "low-density, single-use, and non-integrated characters" of many SECs have compelled people who work there to rely upon cars not only for getting to and from work but also for circulating within the centres themselves, such as where work-places are not located within walking distance of facilities used during work-breaks. He used factor and cluster analyses to identify the key variations between centres and classified them into six "types", followed with stepwise regression to model the influence of SEC characteristics on the use of various modes of transport, job-housing balance and other travel-related characteristics. Explanatory variables for these analyses were descriptive of the centres themselves rather than of the households or individuals involved.

Overall the study found that while higher employment densities in SECs resulted in higher levels of congestion on connecting roads, this also appeared to work in favour of alternatives to the "drive-alone automobile". Lower parking supply at higher-density SECs had a similar effect. The mix of commercial and retail activity in the centres had the greatest effect on modal choice, with higher proportions of office use resulting in increased proportions of drive-alone commuting. As might be expected, SECs with more even jobs/housing balance had a higher proportion of walking and cycling work-trips than less balanced centres. Centres with a high proportion of workers in lower-paid employment categories also tended to require longer commutes (136-154). Cervero suggested that local government promotion of affordable housing offered one solution to the need for many workers to commute long distances, hence offering gains both in traffic congestion and air quality.

The role of a jobs/housing balance in stimulating commuting patterns was taken up by Giuliano and Small (1993) who argued that reliance on "*...stepwise regression...can produce spurious findings by excluding pertinent variables...*" and that Cervero's "*estimated coefficients are barely significant at a conventional significance level, and would almost certainly become insignificant if the estimated standard errors were adjusted for the 'data mining' inherent in stepwise regression...*" As Cervero had used a significance level of 15% in several of his analyses, this latter comment certainly has some basis. Examining Cervero's affordable housing suggestion, Giuliano and Small used a linear programming assignment algorithm developed by Hamilton (1982, 1989) to calculate the minimum required commute at various scales in the Los Angeles region. Affordability of housing was simulated via the assumption that people were restricted to living in housing already occupied by those in the same of eight standard employment categories. Regression analyses were then used to indicate the degree to which jobs and housing were in fact poorly balanced, with the more highly aggregated levels of analysis showing no relationship between the two, and finer levels of analysis showing only a weak relationship. These showed that "more than half" of the "excess commuting time", which the writers define as the difference between required commuting time as computed by Hamilton's assignment algorithm and actual commuting time, remained unexplained by the question of imbalance. They concluded from this that residential preferences played a greater role than availability of housing in determining commuting patterns, and that providing affordable housing around Suburban Employment Centres was therefore unlikely to solve the suburban congestion problem.

Nowlan and Stewart (1991, 165-182) provide evidence for the benefits of balancing housing with employment in a central city area as opposed to SECs. Their study analysed changes in commuting into downtown Toronto brought about by the growth of housing through a thirteen year period in the central area of that city. For the purposes of their analysis they defined an "inner area" of about 20 square kilometres in extent. They used time series data for each of the thirteen years which included: inbound person-trips crossing a perimeter cordon into the central area during the "extended rush period" of 7.00 am to 10.00 am; occupied office floor space; and full-time office employment. Initial findings were tested against additional variables including the number of dwellings in the central area.

A least-square regression analysis tested various combinations of these variables. Averaging the results of several equations, Nowlan and Stewart concluded that each additional 100 residents in the central area reduced growth in rush-hour person-trips across the cordon by about 70. Each additional 100 dwellings reduced inbound trips by between 100 and 150 - an average of about 120 over four equations. These results were consistent with census data which showed an average household size of 1.7 people for new dwellings constructed over the period covered by the times series.

The Nowlan and Stewart study is of interest to cities such as Wellington which are actively promoting the development of inner city apartments. Reduced car use is one of the environmental benefits commonly cited for promoting inner city housing, and the Toronto case demonstrates that this has contributed to a reduction in car trips into the city during peak-hour periods.

Summary of findings of statistical studies:

The major themes which emerge from these statistical studies are similar to those of the transport-land use modelling based research reviewed earlier in this chapter. Most of the studies reviewed here found benefits both in monocentric organisation of cities and in comparatively dense residential development, although Stewart and Bennett were unable to find any such relationship. Those which did not examine questions of residential density and maintaining the strength of city centres specifically discussed aspects of multi-centred cities, but made no direct claims about any inherent energy efficiency which they might possess (Cervero, Giuliano and Small). Their efficiencies are inferred through the extent to which commuters rely on their own motor vehicles for transport to and within SECs. Overall the group of studies reviewed here provides firmer evidence for what we might call the "monocentric" and (residential) "density" hypotheses which were postulated by the studies reviewed in the first part of this chapter. To reiterate these themes, strong city centres together with higher residential densities are considered to contribute to lower reliance on private transport and thus lower energy use. These are hypotheses which will be of particular interest in analysing the Wellington data. Before turning to look at this in more detail however, a few more studies throw some light on possible directions for future development, and the data analysis which follows includes some analyses which may be interpreted as giving some support to these proposals.

Design proposals for reducing car use:

Having considered much of the literature on quantitative studies of transport use, this section briefly considers some further options for the direction of future development. While Newman and Kenworthy amongst others have espoused the benefits of consolidating existing urban areas and city centres, the American preoccupation with suburban traffic congestion in particular has resulted in possible design solutions to this problem.

Atash (1993, 1994) identifies "traditional neighbourhood developments" and "pedestrian pockets" as two design solutions which seek to render the car a little less indispensable for life in the suburbs. "Traditional neighbourhood developments" (TNDs) aims for a "compact, high density, mixed-use pattern of development" set out on a "grid network of highly interconnected streets". In contrast to much post-war suburbia which is laid out on a curvilinear pattern of streets with many culs-de-sac, this dispenses with the usual hierarchy of streets common to much post-war traffic engineering to allow a choice of many different routes between any two points in the development. Street layout includes wide footpaths which are virtually always present in New Zealand but apparently not so in the United States, and cycle-friendly lane widths. Atash cites a 1990 study for the American Society of Civil Engineers which suggests that vehicle distance travelled in TND development could be as little as 57% that of a typical post-war subdivision of similar size(1994, 518-519). Southworth (1997, 28-44) compared two TND developments with a San Francisco suburb established around 1900 and found that while the newer developments provided considerable opportunity for pedestrian accessibility they are as-yet poorly served with transit alternatives to the car in comparison to the older suburb.

While TND type developments tend to be several hundred hectares in extent, "pedestrian pockets" are smaller in scale and perhaps better suited to redeveloping parts of the existing urban fabric. Calthorpe suggests that cities will be best served if we can "introduce the needs of the pedestrian and transit into the auto-dominated regions of our metropolitan areas" rather than "try to absorb a disproportionate percent of growth in our urban centers" (1991, 84-85). His pedestrian pocket strategy aims to redevelop parts of the suburban fabric or to allow incremental extensions at the city edge of no more than 100 acres in extent (about 40 hectares). Orienting these pockets around transit stops so that all homes or work-places are no more than five minutes walk distant would encourage greater pedestrian and transit use while not precluding car use (1989, 6-20). They would therefore be strongly interlinked with other parts of the city, rather than expected to be "stand-alone" communities which provided for all the inhabitants needs.

This type of development is rather similar to that proposed by Newman and Kenworthy in their espousal of the virtues of rail-based transit systems. It has also been suggested in the Wellington area (e.g. Wearne and Almond 1989) and conceptually fits well with the regions pattern of railway lines and bus routes which converge largely on the Wellington's CBD.

These existing transport routes pass through a number of areas where further development is possible.

A recent Californian study developed implementation guidelines for reducing private vehicle use which draws on most of the strategies explored in this chapter (JHK 1995). The study evaluated urban, suburban and exurban communities in California and also in eastern Canada and Portland, Oregon for relative use of cars in terms of vehicle trips and vehicle-miles travelled (VMT) per year for each household. It then formulated performance goals at various levels in terms of vehicle trips, VMT and emissions of air pollutants such as sulphur dioxide, together with a range of strategies which could be used to achieve these goals. Local communities could use the guidelines to select strategy packages suited to each community, with the aim of reaching their statutory air quality obligations. The list of recommended strategies gathers together most of the solutions to growing car use proposed by studies of the last three decades, namely:

- provision and improvement of pedestrian facilities;
- increased residential and employment densities near transit corridors and stations;
- encourage mixed use development rather than large areas of single land use;
- encourage infill housing and "densification";
- encourage centres of concentrated activity;
- strengthen downtown areas;
- develop interconnected street networks;
- tailor parking provision to the needs of an area.

(JHK 1995, 6.7-11).

This list essentially summarises the potential options for reducing car use and thus reliance on imported oil and hence emissions of greenhouse gases, as well as the more toxic emissions at which the Californian legislation is aimed. From here, we move to analysing data from the Wellington region, to identify which of these strategies are likely to have the greatest impact on energy use and greenhouse gas emissions in this local context.

This section uses a methodology based on some of those reviewed in Chapter Four to find energy use for various modes of personal transport. Similar calculations were used to find greenhouse gas emissions for each mode.

The next chapter is concerned mainly with assembling data for an analysis of travel in the Wellington region, which is then used to help identify land-use options for reducing transport energy use and emissions. The main part of the analysis is in Chapter Six, which uses statistical methods used in some of the studies which have been reviewed in this chapter.

Chapter Five : Energy use and greenhouse gas emissions in the Wellington region :

This chapter discusses two areas of the overall study. First, relevant sources of data for the Wellington region are identified which may used to test the assumption put forward by the literature reviewed in Chapter Four. Secondly, initial analysis of the data is discussed. This phase of the project involved finding energy use and GhE for each mode of transport used in the Wellington region, and from here, for each area considered in the next chapter. Some new variables are discussed, including calculation of two urban density variables which were used in the main analysis.

We begin with a brief description of the study area before moving on to consider the available data sources.

The Wellington region:

The region considered in the analyses in Chapters Six consists of four cities and one district made up of several smaller towns (refer **Map 1**, page 45). Two separate corridors of urban and suburban development converge on Wellington, the region's largest city. This is located at the southern end of the study area between a deep-water harbour and open sea, with the central city occupying some comparatively small area of flat land adjacent to the harbour, while most of the suburbs have developed on the surrounding hills. Suburban development is also interspersed along a valley to the north-west of the of city forming a corridor which includes the suburbs of Johnsonville and Tawa and passes on into the neighbouring city of Porirua. This city in turn partially follows the west coast and gives way to countryside which is interspersed with several small towns which together form the Kapiti District.

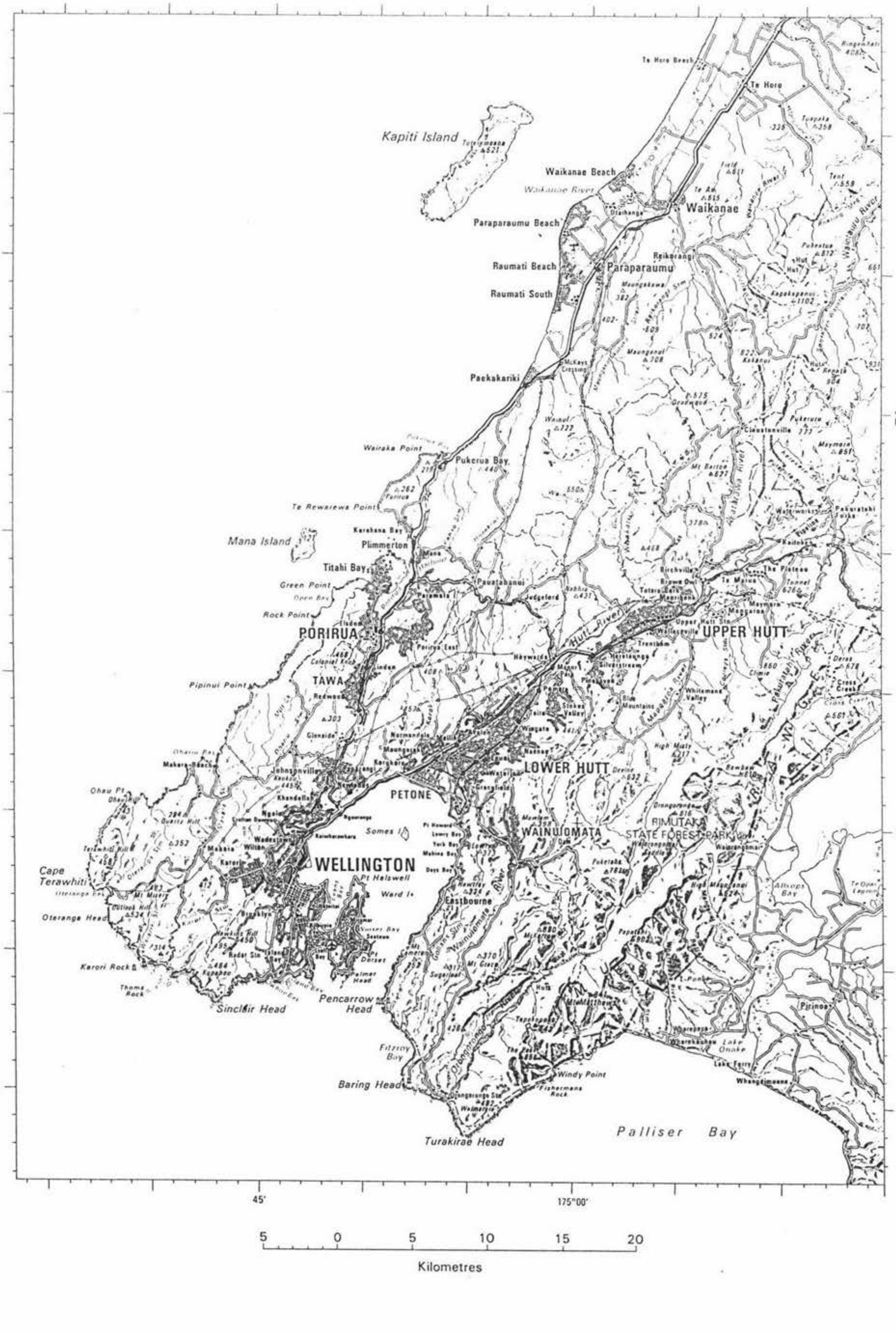
The second of the two main settlement corridors follows the western edge of Wellington's harbour and widens into the Hutt Valley. This is divided into the cities of Upper Hutt and Lower Hutt.

Map 1: Wellington city and the surrounding region.

Railway lines with stations served by electric rail units highlighted:

Lines continue beyond the termini of the Upper Hutt and Paraparaumu lines to other parts of the North Island. These are served by diesel passenger trains at much lower frequencies than the suburban services.

Note that the Johnsonville station is also a terminus, on a different line to Tawa, Porirua and Paraparaumu. Petone and Wellington railway stations were not shown on the original of this map, but are highlighted with short red lines.



Both of the main corridors are served by frequent suburban rail services running on two main lines, with an additional short branch line in the western part of Lower Hutt. Another short suburban rail line serves the suburb of Johnsonville. These can be discerned on Map 1 as black lines which generally follow the line of main roads. (The main line between Wellington to Tawa and Porirua passes through a tunnel for several kilometres; the second line in the north-western part of the city is independent of this one and does not converge with the other two lines before reaching the Wellington Central Business District.

Both main transport corridors are also serviced by one urban motorway each, which converge about five kilometres north of Wellington's CBD at the harbour end of the Ngauranga Gorge.

Data sources for the Wellington region:

Wellington Regional Council's 1988 land transport survey:

The main data source originates from a survey undertaken by the Wellington Regional Council (WRC) in late 1988, which was undertaken in conjunction with the Council's Greater Wellington Land Use and Transport Strategic Review (GATS). Some three thousand households living in the greater Wellington area took part in the survey, with over nine thousand individuals completing travel diary-type questionnaires with details of their travel for one week day. The urban centres included Wellington City, Upper and Lower Hutt, the Kapiti Coast and Porirua. Individual participants were asked to provide details of all their travel movements for the day including the purpose, origin and destination of each trip, and for each part of a trip in the case of those which involved switching between different modes. An example of the latter is a person travelling to work who is dropped off by car at the local railway station, travels to the main interchange in the city where they work and transfers there to a bus for the next leg of the trip. A final leg might involve walking from the bus-stop to place of work. (Each stage of such trips are referred to here as a trip "leg" to avoid confusion with ticketing "stages" on bus services.) Each trip (or trip leg) was then fitted to a 127 zone model of the region, so that each is described in terms of its origin and destination zones. Information was also collected about the participating households and individuals, and along with the trip information this was numerically coded into three separate files. The data provided by the Regional Council was therefore in a form which was almost ready for analysis, with interzonal centroid to centroid distances as a fourth file. After matching the appropriate interzone distance with each trip's origin-destination zone pair, the data was thus ready for analysis.

In addition to the coded data, WRC also provided addresses from the survey for both origins and destinations. This allowed extraction of further variables from the data through use of a Geographical Information System. This is discussed further below.

One possible drawback to the use of this data source is its age. Undertaking a new survey was considered briefly for the purposes of this thesis, but it quickly became apparent that the resources available would allow only a comparatively smaller sample of households to be included. Given the very comprehensive nature of the information available from the existing data it was obvious that the quality of the results which could be achieved from this source was likely to far out-weigh the benefits of a more recent but much smaller survey. The 1988 survey's applicability to the present is dependent on the degree to which peoples' daily travel patterns have remained unchanged over the last nine years. There have been no major changes to the region's roading system during this period, although deregulation of public transport has brought about privatisation of key publicly owned private transport providers. Frequency of rail services were increased within a couple of years of this survey being undertaken, and bus routes changed about the same time in Wellington to allow more "through running" of buses. Most services in 1988 originated or terminated at one of two points in the city centre (the railway station at one end of the CBD and Courtney Place at the other). This has since changed, with pairs of some of the more important old services amalgamated so that the new routes now run right across the city. Whether this has changed trip-making patterns appreciably is debatable. For some patrons, the pairing of old services has no doubt coincided with their travel desires or needs. Where this has not occurred, transfers between services in the centre of town are still necessary.

Growth in car ownership is another possible factor in changing trip making patterns. As discussed in Chapter Two, the number of registered cars in New Zealand rose by some 20 percent between the years 1988 to 1997. The influence of this factor is investigated in some depth in Chapter Six.

The national Census:

The five yearly Census of Population and Dwellings forms an important source of data for analyses of all types of social behaviour, and provides a possible additional information source. Census data was used here to allow population and dwelling densities to be introduced into the analysis. The lack of fit between the areas used to present census data and the zones of the WRC survey presented a potential barrier to using this data source however.

Matching of survey and census data is discussed further below.

Fuel use and greenhouse gas emission data:

A study commissioned by the Ministry of Transport (Bone *et al* 1995)[1] provided most of the data used in calculations of energy use and greenhouse gas emissions with additional information provided by local public transport providers. Information from this source was vital to these calculations. It included energy conversion ratios, GhE per unit weight and volume of each fuel type, the component of electricity which is generated from thermal (fossil-fuel) sources and mean car fuel use for the various fuels. (The latter includes not only petrol but also diesel, liquefied petroleum gas (LPG) and compressed natural gas (CNG)).

The MoT study sampled 10 percent of all vehicles registered in New Zealand in 1992 and classified these into more than one hundred vehicle types. These were then grouped into fifteen classes of vehicle and further classified by engine size, vehicle age and overall fuel consumption to arrive at a mean fuel use and emissions for all vehicles in each class.

Differences between urban and rural driving cycles were also averaged in these figures. This is likely to result in fuel consumption being somewhat understated for cars. Calculations of energy use and emissions for buses and trains in this thesis is based on data provided by local service providers however, so that the resulting calculations are likely to be more accurate than those for cars. The implications of these different data sources for the resulting calculations are discussed further in the last section of this chapter.

[1] While this is listed in the bibliography under the names of the authors, it is referred to from time to time throughout the remainder of this thesis as "the MoT (Ministry of Transport) study" where this is more convenient than the usual, although in this case rather cumbersome, style of referencing.

The data:

Three data sources were thus brought together in the main analyses. The WRC data formed the core of the analysis, with inputs on energy use and GhE emissions from Bone *et al.* Four new variables were produced from Census data with the help of a GIS analysis of address information from the raw survey data. These are two measures of density and two measures of proximity to public transport services.

WRC survey variables:

Most of the data from the survey was in the form of classification variables, that is, the values given represent discreet groups rather than absolute quantities. For example the variable **age** is given in six classes: 0-4 years of age, 5-14, 15-19, 20-39, 40-64 and 65 years and over. The first four of the household variables listed below are all continuous however, as are two trip variables, **distance** (recognising that this is an average for each zone to zone pair) and **number of people in car** (where applicable).

Several variables were evaluated in univariate analyses for their effects on energy use and emissions. These are listed in Chapter Six in the discussion of the relevant analyses, in Tables 6.6, 6.18 and 6.20. The variables provided from the survey are listed below, grouped by household, individual respondent and individual trip or trip leg. The full list of variables from the WRC survey are listed below, grouped by household, individual respondent and individual trip or trip leg. Analyses were all performed using the PC version of SAS, a powerful statistical software package which is also still frequently used on mainframe computers. The eight letter abbreviated forms for each variable which were used in writing programs for the analysis are included in the list here as some of these appear in output included in Chapter Six.

1. Unique identifier for each household (**houshold**)
2. Identifier for each person (**personno**): Numbered consecutively for each household, but converted to a unique identifier in some programs.

Information on trips made by each person:

3. Identifier for each trip undertaken by each person (**tripnumr**): Also numbered 1, 2, 3 etc. for each person, and converted to a unique identifier in some programs.

4. Trip leg (**stage_no**): Legs of multi-leg trips are consecutively numbered except for the final leg which is always numbered 10. Single leg trips are identified by a value of 20.
5. Origin of trip or leg (**origzone**): By zone, with trips external to the area identified as zone 128.
6. Destination of trip or leg (**destzone**): values as for **origzone**.
7. Place or purpose of trip origin (**origpurp**).
8. Place or purpose of trip destination (**destpurp**).
9. Method of travel (**tripmode**).
10. Number of people in vehicle, where known (**numincar**).
11. Distance of trip from interzone matrix (**distance**).

Information on individual participants:

12. Age group of respondent (**persnage**).
13. Respondents employment status (**persnemp**).
14. Need car at work (**needcarw**): yes or no.
15. Respondents occupation group (**pjobtype**).

Household variables:

16. Total number of trips made by all members of the household (**hhtotrip**).
17. Total number of people in the household (**hhmmbers**).
18. Total number of motor vehicles available to the household, including vehicles owned by employer or people otherwise outside the household and including cars, trucks and motorcycles (**totavveh**). This is continuous variable.
19. Total number of motor vehicles owned by household members, including cars, trucks and motorcycles (**carownno**). This is classification variable.
20. Income (**hhincome**): Household income.
21. Date of travel (**survdate**).
22. Household category (**hhcatgry**): These provide an extensive breakdown of employment status and age groupings. The groupings were created for use in population forecasts included in the GATS analyses.
23. Zone in which the household resides (**homezone**):

Rearrangement of zones for analysis:

Participants lived in 107 of the original survey's 127 zones. These have been regrouped into 64 zones for the analyses carried out here. This was because the number of participating households and individual respondents in some of the original zones the were too few to contribute statistically significant results to the analysis. These have therefore been aggregated with neighbouring zones to allow a minimum of 30 households for each "new zone" used in the analysis. This is recommended by standard statistics texts as the minimum number of observations for analyses of variance (ANOVA) which are carried out in Chapter Six. Households from three of the "original" zones were redistributed between "new zones" on the basis of the streets in which respondent households resided. These were obtained from the raw survey data as described further below in the discussion of how density variables were derived from census data.

In addition to the 64 homezones, five of the original zones in the Wellington Central area are used in one analysis as a basis for measurements between each residential zone and central Wellington. This is discussed in Chapter Six.

Residential zones are referred to throughout the remainder of this thesis as **homezones**. Their locations are listed below in Table 5.1 , and these are illustrated in Map 2 (page 53).

Additional variables produced with help of GIS:

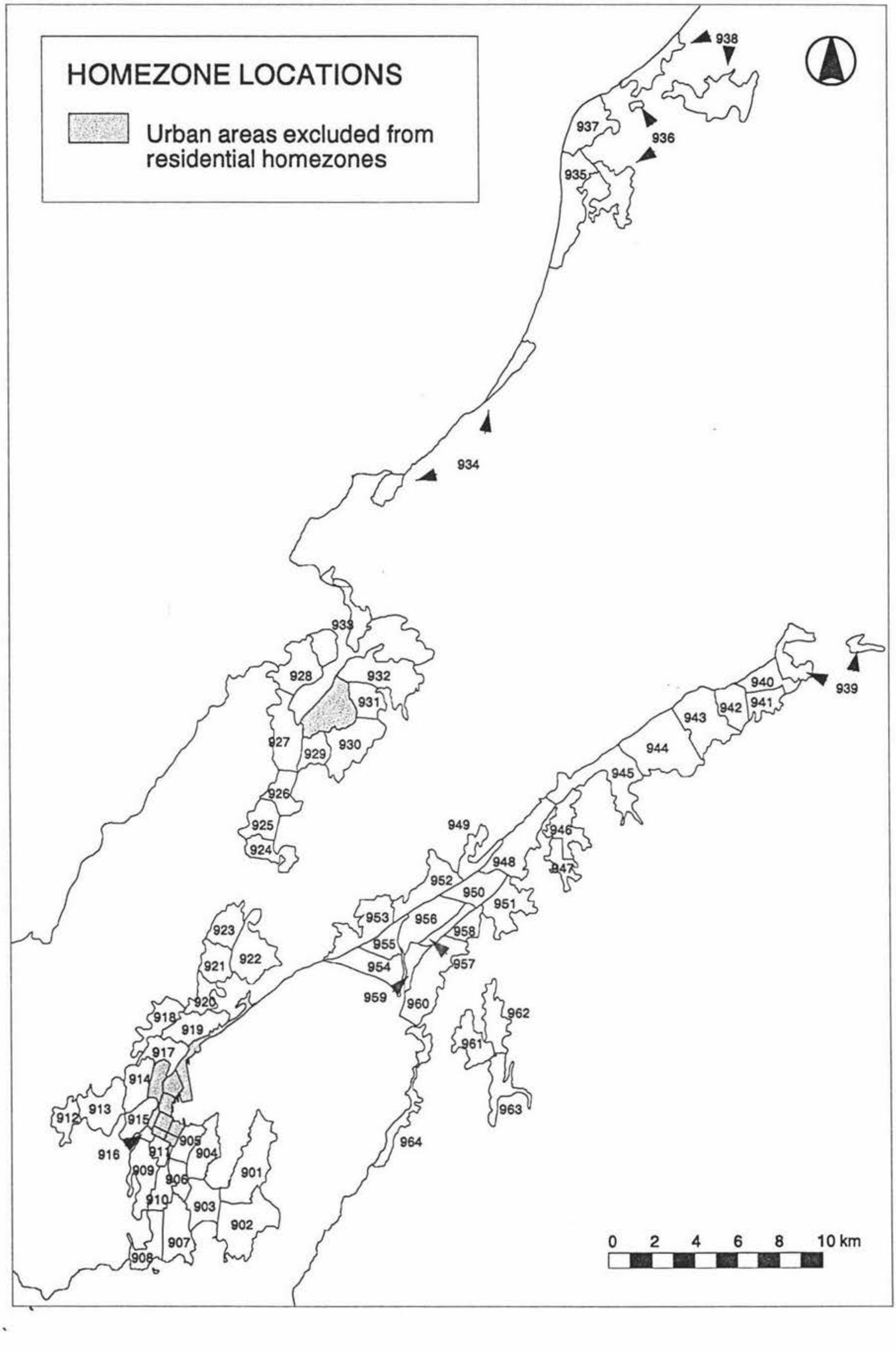
Two distinct levels of GIS utilisation were used to create these variables. Access to Wellington City Council's Land Information system and Palette-based Mapping system was available on a daily basis throughout the analysis phase of this thesis, and formed a valuable tool for checking address information, street layout for bus-routes and making simple point-to-point measurements. The main GIS analysis described below was performed by Andrew Smith of WRC using Arc-Info software (refer Acknowledgements section of this thesis).

Density variables:

Many of the studies reviewed in Chapters Four found that density had a strong bearing on transport use and energy consumption. It was therefore considered important to be able to introduce this dimension to the analysis.

901.	Miramar, Maupuia	933.	Mana-Camborne, Plimmerton
902.	Seatoun, Strathmore, Miramar South	934.	Pukerua Bay, Paekakariki
903.	Kilbirnie East, Lyall Bay	935.	Raumati South, Raumati Beach
904.	Roseneath, Hataitai	936.	Paraparaumu Central, Otaihanga
905.	Mt Victoria, Oriental Bay	937.	Paraparaumu Beach
906.	Newtown	938.	Waikanae Central
907.	Melrose, Island Bay East	939.	Te Marua, Akatarawa,. Maoribank (north)
908.	Island Bay West, Ohiro Bay	940.	Totara Park, Maoribank (south)
909.	Vogeltown, Brooklyn	941.	Ebdentown
910.	Berhampore	942.	Elderslea
911.	Mt Cook	943.	Wallaceville, Trentham North
912.	Karori Park	944.	Brentwood
913.	Karori East	945.	Pinehaven, Silverstream, Manor Park
914.	Northland, Wilton	946.	Stokes Valley (north)
915.	Kelburn	947.	Stokes Valley (south)
916.	Aro Valley-Nairn St	948.	Taita, Avalon
917.	Wadestown	949.	Kelson, Belmont
918.	Ngaio west, Crofton Downs	950.	Naenae West, Boulcott, Epuni West
919.	Ngaio, Rangoon Heights	951.	Naenae
920.	Khandallah Park	952.	Belmont, Normandale
921.	Raroa	953.	Maungaraki, Korokoro
922.	Newlands	954.	Petone
923.	Johnsonville North, Churton Park	955.	Alicetown, Melling
924.	Tawa South	956.	Lower Hutt Central
925.	Central Tawa	957.	Woburn North, Waterloo
926.	Linden	958.	Epuni East
927.	Elsdon, central Porirua	959.	Moera
928.	Titahi Bay, Onepoto	960.	Waiwhetu
929.	Porirua East, Ranui Heights	961.	Wainuiomata North
930.	Cannons Creek	962.	Wainuiomata West
931.	Waitangirua , Ascot Park	963.	Wainuiomata South
932.	Whitby, Paremata	964.	Eastbourne

Table 5.1: Residential zones used in the analysis.



Map 2: Homezones used in this analysis (refer Table 5·1 p 52 for key).

Areas not allocated to homezones are those where no survey respondents were recorded. Unclassified areas include some obviously residential land such as parts of Thorndon, and also Wellington's CBD which is further divided here into several zones for the purposes of one of the analyses in Chapter Six. These are shown in greater detail on Map 4 (page 103).

Some of the studies reviewed such as Guest and Cluett (1976) and Newman and Kenworthy (1989 (a)) divide each city in their respective analyses into just a few areas; the CBD, an inner area which is outside the CBD, and an outer area which may be primarily residential or interspersed with a variety of other urban land uses. Other studies such as Newman, Kenworthy and Lyons (1985) consider density at a finer level of zones throughout the city. This was the approach used in this thesis.

The areas arrived at in the procedure described in this section should be regarded as representative densities. As discussed here, the method used to find densities in effect samples 'chunks' of each homezone, rather than measuring the whole zone.

Area measurements are available from Statistics New Zealand of the various local and regional units for which census data is published, so this represented one possible way of calculating population densities. The smallest unit at which census data is published is the meshblock, which in the survey area can be from less than a hectare to several hundred hectares in size, depending on resident population. The next largest area is the Census Area Units (referred to here as AU), which is generally composed of somewhere in the region of ten to thirty meshblocks. Neither meshblocks nor AU boundaries coincide with the zones of the original survey, so in order to use either of these areas as a basis for calculating densities some matching of survey data with the census areas was necessary. This was done by using the uncoded addresses of survey respondents to locate respondent households in the appropriate meshblock.

Not all addresses in the raw survey information were complete however. While street names were recorded for almost all trip origins and destinations in the raw data, street numbers were frequently omitted. For most households at least some of the individual trip records did not have the street number included in the address, and for around one thousand households this was the case for *every* trip recorded in the coded trip file as beginning and ending at the respondents home. Nevertheless about two thirds of households had at least one complete home address in the "raw" trip record, and in most of these cases there were at least two or three full address observations for each household so that this could be selected as correct with some confidence. These were extracted from the raw file in their complete form using SAS programming. The output was then visually checked for any obvious anomalies between home address and homezone and edited accordingly. The main error found at this stage involved duplication of street names within the same city; for example in Lower Hutt several streets in

Eastbourne and Wainuiomata have common names. This is historical, resulting from when the two areas were separate boroughs.

The corrected file was then processed using Arc-Info GIS software to match each full home address to the census area unit and meshblock in which it is located. The new data was then imported back into SAS.

Matching this information with meshblock areas and populations required one further manipulation. Precise comparison of published data from each census is complicated somewhat by shifts in boundaries between AUs and creation of new meshblocks between one census and the next. This potential problem is overcome by Statistics New Zealand by retabulating old census data to new meshblocks. Although the 1988 survey did not coincide even roughly with a national census, it was conducted almost exactly mid-way between the 1986 and 1991 census. With population figures tabulated to common (1996) meshblocks and Area Units, an estimated late-1988 population was therefore found for each by averaging the populations of the two earlier census. Data was then reconfigured into the survey zones. This resulted in a list of addresses, the meshblocks in which they were located and their respective populations and areas, for each homezone. In all likelihood this covers only part of the zone. However, it does allow full address data to be used in analyses involving census information for the appropriate meshblock or Area Unit.

One problem with these is that Census Area Units and even meshblocks may include both urban and rural land within their boundaries. Newman and Kenworthy discuss the question of how to deal with open space in calculating urban densities for their "three areas" approach (1989, 28). It is of course arguable that all reserve areas within built up areas are an urban land use, and should therefore be counted as part of the urban area for calculating densities. However where an Area Unit lies at the edge of the built up area, it often includes rural land which is clearly outside the urban area and should not be included in the calculation. In the case of Wellington City, some areas of open space within the city area are also excluded. Much of the transport network here is arranged in corridors which converge on the city centre, so that in spite of the dissected topography of the city the infrastructure is strongly monocentric in its physical organisation. Corridors of residential development flank most of the transport routes but are frequently separated from neighbouring suburbs by extensive areas of open space. As such they can be conceptualised as fingers of urban development interspersed with the open space which, like the countryside which separates the cities of the region, can be factored out of density calculations for that particular suburb.

The process of matching survey home addresses with meshblocks allowed those which consisted mainly of rural land to be eliminated from the density calculations by cross-checking with a map showing both meshblocks and the extent of urban development as it was about the time of the survey. A few additional meshblocks were eliminated in this way. A program was then written to select one observation for each remaining meshblock in each zone, and to sum area, population and dwelling numbers for these meshblocks alone. Densities were then divided out from the resulting figures.

The census contains several household and population counts, including Census Night Population, Usually Resident Population, Total Occupied Dwellings, Private Occupied Dwelling, Non-private Occupied Dwelling, Unoccupied Dwellings (Residents Away), and Unoccupied Dwelling (Under Construction), all for both 1986 and 1991. "Usually Resident Population" and "Total Occupied Dwellings" were selected as the appropriate data on which to base mean density variables. It was not expected that these two variables would be totally correlated, due to higher numbers of people per household in some areas than others, so the effects of both were tested. Differences between Private and Non-private dwellings were examined in the process of choosing these variables, but as very few or nil observations of the latter occurred for each meshblock, the difference between "Private" and "Total" categories appears to be negligible. The two density variables obtained were:

(i) Population density for each homezone; and

(ii) Dwelling density for each homezone.

Accessibility to public transport services:

Material reviewed in Chapter Four, as well as personal observation and experience, suggests that ease of access to public transport services is an important influence on people's choice of transport method. Distance of home to bus stop or railway station is one simple measure of public transport accessibility. Two GIS analyses were performed to allow analyses to be made on the importance of these variables in determining overall energy use and choice of mode.

Co-ordinates for each railway station in the region are recorded in the Digital Cadastral DataBase (DCDB) which forms much of the core information in the WRC GIS. Distances to nearest rail stations were therefore obtained relatively easily by processing the file of complete addresses in Arc-Info, which calculated the shortest path from each survey home address to the closest railway station, using address information incorporated in the DCDB.

Measuring distances to nearest bus stops was a more complex exercise. Buses service a much wider area than rail, and as stops are generally more closely spaced than rail stations there are hundreds of bus-stops in the study area. Co-ordinates for each bus-stop were not present on the WRC GIS database, requiring this data to be collated from other sources. In order to bring the size of this task down to reasonably manageable proportions a decision was made to include only those parts of Wellington City which were serviced by the old Wellington City Council Transport Department and NZR Road Services buses on a **daily** basis. (A few locations serviced by weekend only routes, run by the latter operator in the northern part of the city, were thus excluded from this analysis). These routes coincide almost exactly with the routes now run by Stagecoach Wellington, but exclude services operated by the city's other major operator, the Newlands Bus Company. A list of *current* bus-stops was provided by the Wellington City Council (WCC) Traffic and Transportation Department, which gave locations of fixed assets such as bus-stop shelters, signs and seats in terms of the closest street address. Possible changes to locations of some bus-stops was a potential problem which had to be sorted out before matching survey and bus-stop addresses. Where routes had changed, some of these were picked up through reference to aerial photographs flown in the mid-1980s. However discussion with WCC Traffic and Transportation staff, along with personal knowledge of some suburbs, confirmed that the main changes were where completely new services had been introduced. Bus-stops on those routes were therefore deleted from the WCC list before matching. The list was then edited to a form which the GIS could accept, so that distances to bus-stops were measured from the road frontage of the survey home address to the road frontage of the property adjacent to the bus stop. In some cases these addresses were totally incompatible with the DCDB, for example "corner of Tahi and Rua Streets". Access to the Wellington City Council Mapping and Land Information System allowed such addresses to be identified for editing purposes.

Due to time constraints, not all parts of the city were covered in equal detail, so for some routes not every bus-stop was entered on the edited address file. The analysis undertaken in Chapter Six therefore considers only those zones where the location of all 1988 bus stops had been adequately established.

Calculation of energy use and greenhouse gas emissions:

Fuel and energy use:

The first stage of the analysis was calculating energy use and greenhouse gas emissions. With distances and modes of each trip identified, the simplest calculation uses an average fuel consumption figure for each mode to calculate energy use for each trip. Similarly, fuel use was used to calculate a mean level of greenhouse gas emissions for each mode. This included the fossil-fuel generated component of electricity used by trains and trolley buses. The main transport modes included in the survey data are now considered here in turn.

Car drivers and passengers:

Mean fuel consumption for cars from the MoT study (Bone *et al* 1997) are used here as the basis for energy use by that mode. While petrol is the motive power for the bulk of the national "car fleet", small proportions of diesel, LPG and CNG powered vehicles have also been included in the calculations which are set out in Tables 5.2, 5.3 and 5.4. An assumption is made that these vehicles are evenly distributed across the country, and that the proportions in the 1992 sample are the same as those in the 1988 survey. In fact the number of LPG and CNG powered vehicles have fallen somewhat in this period, while the number of diesel cars is increasing relative to petrol driven cars. As diesel generates considerably lower GhEs per kilometre than the other three fuels for similar power output (refer to Table 5.3; page 61), this may decrease the overall emissions figure slightly. However as diesel powered cars comprised only 1.2 percent of the national car fleet in the 1992 sample, this inaccuracy is unlikely to influence the overall figures to an appreciable extent. Any effect from this source is likely to be far outweighed by two other factors. These are the increase in the number of registered vehicles in the same period, which the analysis in Chapter Six confirms as particularly having a particularly important effect in overall energy use and emissions; and differences in fuel consumption between the urban and rural driving cycles.

This second factor posed a problem as to how to allow for the higher than average fuel use and resulting emissions which result from driving in urban areas. Most car engines are designed to run most efficiently at speeds of 80 to 90 km an hour, whereas typical urban driving speeds are frequently under 50 kilometres an hour. Fuel consumption figures for two 1983 model British cars, the 2 litre Ford Granada GL Mark 2 and the Vauxhall Cavalier 1300 SL, are probably fairly typical of the characteristics prevalent amongst Wellington cars in the late 1980s (de la

Barra and Rickaby 1987, 25). Fuel consumption at 40 km/hour was 30 to 35 percent higher than at the optimum speed of 80 km/hour for both cars and 18 to 21 percent higher at 50 km/hour than the optimum. At higher speeds, fuel consumption only reaches the 40 km/hr levels at 110 km/hour for the Cavalier and 120 km/hr for the Granada. It can therefore be deduced that if the proportion of total distance driven at open road speeds in the study area is less than the national average, which seems probable, that the MoT fuel consumption figures will therefore understate the true figures for trips recorded in the survey.

One possible approach to this problem would be to estimate the difference between urban driving speeds and average speeds for the whole country, and attach an appropriate penalty to the published figures. This approach was not followed however due to the likelihood of introducing greater inaccuracies into the calculations than already existed there. Another approach would involve factoring average trip speeds into the entire energy calculation, as used by Newman, Kenworthy and Lyons in their 1985 Perth study (reviewed in Chapter Four). As start and finish times were recorded by survey respondents in the WRC survey this method appeared to be a feasible option. However these variables were not requested in the data originally supplied by WRC, and unfortunately when supplied later most of the file became corrupted in the process of transferring it on to disk. Thus only a small sample was available for analysis of trip speeds, covering 142 households. It was subsequently decided to omit this aspect from this study, partly because this sample was unevenly distributed across the study area and partly because the potential for erroneous calculations again appeared to outweigh the possible understated fuel consumption which is likely to arise from using the MoT data.

Cold-running is another factor which influences overall fuel use (Bone *et al* 1995, 59-61). Internal combustion powered vehicles must generally be driven for several kilometres before the engine is warmed up (unless the vehicle is first left to run while stationary). Fuel consumption is higher during this warm-up period. Bone *et al* (1995, 60) cite studies which show additional fuel consumption of between 23 and 37 percent over the first four kilometres of travel by petrol and diesel cars at air temperatures of 10 to 20°C. (The penalty for diesel is one to two percent lower than for petrol driven vehicles.)

Analysis of car trip lengths in the Wellington area show that mean trip length was approximately 7.5 kilometres (n=17111). Of these, some 46 percent are no more than four kilometres in length. Times for car drivers from a smaller sample of 143 households in the Wellington area show that means of intervals between trips were four and a half hours for work trips and 53 minutes for all non-work trips (n=970). Daily shopping trips were the only trip category where average intervals were less than half an hour, with trips classified as "personal business" slightly over this at 31.2 minutes. These trip categories accounted for some 20 percent of all trips (238 of a total 1181). The mean trip interval for the remaining 80 percent of trips implies a significant proportion of cold starts. A count of all trips shows that some 36.5 percent of intervals between all trips were more than 30 minutes and 27.5 percent were over 45 minutes.

Fuel use and emissions calculations used in this study are therefore likely to be understated somewhat, perhaps by as much as 25%. It is also likely that this will be greater for travel in peak-periods when traffic speeds are slower around the region as a whole, and for inner city areas at other times. Driving in outlying areas and on motorways in non-peak periods would give closer to optimum fuel consumption, and could therefore be somewhat lower than the MoT calculations. The net result is that vehicle use in more peripheral zones in the study area is likely to be more accurate than for inner city areas.

Greenhouse gas emission calculations:

These were calculated assuming the same proportions of each vehicle fuel type shown in Table 5.2, which were then multiplied out by the figures in Table 5.4 to arrive at an average for all New Zealand cars in the MoT sample. This average is assumed for vehicles in the Wellington region at the time of the survey.

Electricity use in suburban rail and trolley buses and resulting emissions:

A large proportion of New Zealand's electricity is derived from sources which create little in the way of carbon dioxide and other emissions. Hydroelectric generation produces no direct emissions, and while indirect emissions which result from construction of dams may be greater than that involved in commissioning thermal power stations due to the scale of the works involved, averaging these emissions over the life of a hydroelectric facility is likely to result in negligible emissions per unit of electricity generated. As with construction of motor vehicles, this source is seldom factored into the overall emissions budget. Thermal generation accounts for appreciable quantities of carbon dioxide which must be factored into emission calculations for electrically powered buses and trains. Geothermal power generation also results in some emissions.

Table 5.2: Energy conversions for New Zealand cars, (means for all ages), 1992:

Motive fuel:	Number of cars in NZ, 1992	Proportion of all cars:	Fuel use - kg or litres / 100 km	MJ / litre or kg	MJ/100 km:	Portion MJ, "mean energy use" (columns 3*6)
Petrol	1,742,930	96.21%	9.2 litres	35.07	322.64	310.41
CNG	30,690	1.69%	8.2 kg	55.60	455.92	7.71
LPG	15,740	0.87%	7.7 kg	50.00	385.00	3.35
Diesel	22,280	1.23%	6.6 litres	37.80	249.80	3.07
Total:	1,811,640	**Mean for all cars, MJ/100 km:**				**324.54**

Source: Bone *et al* 1995.

Table 5.3: Relative warming effects of four car fuels, (50 year RwE):

	CO_2	CH_4	N_20	Total RwE
Petrol	3.3	0.056	0.0392	3.40
Diesel	3.2	0.012	0.0392	3.25
LPG	2.9	0.04	0.0392	2.98
CNG	2.7	0.6	0.0392	3.30

Source: Bone *et al* 1995.

Table 5.4: Relative warming effects of the "average" mix of four car fuel types, (50 year RwE):

	Energy MJ/vehicle km	GhE: g CO_2/ vehicle km	RwE - all GhG
Petrol	3.23	228.61	235.21
Diesel	2.49	173.61	176.38
LPG	3.85	223.30	229.40
CNG	4.56	221.40	273.81
MEAN	**3.28**	**227.77**	**235.08**

Source: Bone *et al* 1995.

Bone *et al* use 1991-92 figures for CO_2 generation from New Zealand electricity sources (1995, 22). Some 4,667,300 tonnes of CO_2 were produced in that year resulting in an average generation of 154.7 tones per GWh. Bone *et al* used this figure in their subsequent calculation, which also form the basis of those used here. They cite hydro lake inflow which was 95% of the average in that year, consider this to be a "reasonable average year, compared with a range of 87% and 122% over the last six years". More recent publications cite an average of 3,976,430 tonnes CO_2 for the seven years from 1989 to 1995, or about 85 percent of the figure used in the MoT study. It is likely therefore that the calculations used here *overstate* actual emissions from rail and trolley buses for most years. While this increases the discrepancies between car and public transport use, this does allow the calculations here to be cited as applicable to years of low hydro-inflow, and also makes some allowance for additional thermal generation capacity which is likely to come on-stream over the next decade of so.

Bus and rail energy use:

Figures for bus and train use reflect actual local fuel use rather than a national average, as they are largely derived from information provided by Stagecoach Wellington and Tranzrail (formerly New Zealand Railways [NZR]). Some of this information was provided on the understanding that it would not be included here in its raw form due to its commercially sensitive nature. However, energy use per passenger were calculated from this information, and only these figures have been included in the results shown below.

As rather different information was supplied by the two operators, different calculations were required for each. In the case of suburban rail services, figures for ticketed passenger-kilometres for the 1992/93 year were supplied. Bone *et al* (67-68) provide a breakdown of NZR / Tranzrail fuel and energy use in various services, separating out electricity use for Wellington's suburban rail system. Annual electricity use for 1986 to 1992 cited by Bone *et al* varies by up to 4 percent. A projected figure only was given for the 1992/93 year, but as this differed from the 1992 figure of 20.67 GWh by only 0.1 GWh, the 1992 figure was used rather than that for 1988, which was some 2 percent higher. This was converted to megajoules and divided out to give an energy use per passenger-kilometre. Electricity *costs* per passenger-kilometre were also provided. While those for Hutt Valley and Porirua services were similar, those on the Johnsonville line were considerably more. This perhaps reflects the older units used on that service, but possibly also the considerably steeper gradient of the line. This has been factored into calculations for the Johnsonville rail service. The results are set out below in Table 5.5 (page 66).

Energy use and GhE per passenger-kilometre were therefore found simply by dividing out energy use by passenger-kilometres travelled for the appropriate year, and using the appropriate emissions conversions.

Bus fuel consumption figures are based on Stagecoach Wellington's fleet, which includes both electric "trolley" and diesel buses. Information provided by Stagecoach included a profile of bus types and fuel use for each model and the total distance travelled by trolley and diesel buses per year. Most of the latter are forty-plus seaters with fuel consumption ranging from 33 to 42 litres per 100 kilometres, with just two twenty seaters which use about 12 litres of fuel per kilometres km. Information on total passenger-kilometres travelled was not provided, so this was derived from a calculation of annual fuel use for the fleet along with an average bus trip length taken from the 1988 survey. Three different mean bus trip lengths were examined for this calculation. These were:

(i) The area covered by Wellington City Council bus routes in 1988. This is generally the central and southern parts of Wellington city, which is included in zones 901 to 917 of the study area (refer to Map 2 , page 53).

(ii) The area covered by Wellington City Council bus routes plus Ngaio and Khandallah, which were served by NZR buses in 1988 (zones 918 to 920).

(iii) The rest of the region, including the northern part of Wellington City which was not served by either of these companies on a daily basis.

(iv) The three areas combined.

The mean trip distance for the area served by WCC and NZR buses was selected for the energy calculations, as this is the area now served by Stagecoach Wellington. This mean distance is 5.6 kilometres.

Mean fuel consumption per vehicle kilometre travelled by diesel buses is based on the assumption that all diesel buses fleet travel the same distance over the course of the year. The simple calculation:

$$\frac{\text{(fuel consumption for model [litres/km])*(number of buses of that model in the fleet)}}{\text{(total number of diesel buses in the fleet)}}$$

gives a mean fuel consumption of 38.44 litres per 100 kilometres.

Annual fuel use for all diesel buses would then equal

total diesel kilometres travelled* mean fuel consumption [litres/km]

To find fuel use per passenger-kilometre, total number of passenger-kilometres must first be calculated, and an assumption made that this is distributed between diesels and trolleys in proportion to vehicle kilometres travelled per year.

Annual passenger-km = number of passengers carried per year*mean trip length

= 10,800,000 * 5.559 = **60,037,200** passenger-kilometres.

So average loading = Total bus km per year / passenger-kilometres per year

= 60,037,200 / 4,824,100

= **12.45**

and fuel use per passenger-kilometre (F.pass-km):

F.pass-km = mean vehicle fuel use / passenger loading

= 38.44 / 12.45

= 3.09 litres / 100 km.

Using the fuel conversion figuresfor diesel from Table (page 61), this equates to 116.71 MJ, or 1.17 MJ per passenger-kilometre.

Energy use for trolley buses was calculated on the basis that average trip lengths are the same as for diesel buses. This was checked against the equivalent for the old Wellington City Council bus routes (zones 901-917) but as the difference in mean distance was about 10 metres this difference was not considered to be significant. Electricity use by trolley buses is 3 kWh per vehicle kilometre or a total of 7 GWh per annum (Bone *et al*, appendix C). This converts to 10.8 MJ per vehicle kilometre. Stagecoach Wellington operates the only trolley bus fleet in New Zealand, and their slightly lower figure gives a vehicle-kilometre energy consumption of 10.26 MJ (Cannell *pers. comm.* 1996). Divided out by the mean bus loading calculated above (12.45) this is 0.82 or 0.87 MJ per passenger-kilometre. The lower figure was used in the calculations which follow.

Carbon dioxide emissions per v.k.t equals

CO_2 generated * electricity consumption

= 154.7 (kg/MWh) * 0.285 MWh per 100 km

= 44.089 kg / 100 km

= 440.895 g / kilometre.

Emissions per passenger kilometre

= 440.895 / 12.45

= **35.41 g/km.**

An assumption has been made that energy use per passenger-kilometre for Stagecoach Wellington's diesel buses is typical for the whole region, and this must be qualified somewhat. A recent road-side survey of transport use over the entire region shows that current bus loadings in Wellington city are considerably higher than for the rest of the region (Traffic Design Group 1996), and it is safe to assume that this was also the case in 1988. A further assumption has been made that differences in bus size balances these differences in passenger loading, resulting in similar fuel consumption across the region per passenger-kilometre travelled. Many services in the Hutt Valley and elsewhere within the region are run with smaller buses such as the 20 seaters operated by Stagecoach, which use only about one third as much fuel as the mean for all Stagecoach diesel buses. The situation at the time of the survey was considerably different, with New Zealand Rail and private services running many larger buses on many comparatively lightly patronised routes. Thus while the survey data provides a "snap-shot in time" of transport use as it was in late 1988, the average bus fuel consumption which has been used here may therefore understate the actual fuel consumption per passenger-kilometre in many Porirua, Kapiti and the Hutt Valley services at that time. On the other hand, the smaller buses used there now may mean that the figures reflect the present situation more accurately than the time of the survey.

The mean energy use for all diesel buses is also assumed for school buses (mode 5). This may be too low, as regular school bus services run only in their passengers' "peak time". Older, less fuel efficient buses are often used for these services, but this is unlikely to outweigh the higher than average loadings. School bus trips account for about 13 percent of all bus trips (and part trips) in the 1988 survey and slightly over one percent of all trips recorded. While this will therefore have some effect on overall consumption figures, producing a more exact figure would require a considerable amount of further work. This was not considered to be desirable in view of the greater significance of inaccuracies for car fuel consumption, and the need to analyse factors in the overall analysis rather than spend more time refining the energy consumption and emissions figures.

While the figure of 1.17 MJ per passenger-kilometre has therefore be used over most of the region, a split between trolley and diesel services has been apportioned to the old WCC bus service area, zones 901 to 917. The proportion of total vehicle distance travelled by the two main vehicle types was estimated at 56.26 percent of the total for trolley bus services and 43.74 percent diesel. The split over all Stagecoach routes is closer to 51/49 in favour of trolley buses (Cannell 1996 *pers. comm.*). However if Khandallah and Ngaio (the old NZR area) are assumed to account for 10 percent of all vehicle kilometres travelled by buses (VKT_{bus}), then the figure for the rest of the city is 90 percent of total VKT_{bus}:

$$4\ 824\ 100 * 0.90 = 4\ 341\ 690$$

As total distance travelled by trolley buses per year is 2 442 704, $VKT_{trollies}$ is 56.26 percent of the total. Mean energy for zones 901-917 therefore = (0.82*.5626)+(1.17*.4374)=**0.973 MJ**.

For GhEs, the calculation is

(35.41*0.5626)+(**100.38***0.4374)=19.92+43.91=**63.83 g CO_2/passenger km**

These figures are factored into the overall calculations for energy use and emissions for zones 901 to 917. While they are reasonable means for all bus travel in these zones, true mean energy use and emissions for the trolley bus routes alone would in fact be around 60 percent of this figure.

The figures for energy use and emissions from bus transport is set out with those for rail in Table . It may be noted here that figures for trolley bus are very close to those for suburban rail on the Johnsonville line.

Table 5.5: Energy use and CO_2 emissions per passenger-kilometre for bus and train:

Mode:	Energy MJ/passenger km	GhE: g CO_2/ passenger km
Diesel buses	1.17	100.38 (CO_2 equivalent)
Trolley buses	0.82	35.41
Mean for buses zones 901-917	0.973	63.83
Rail: Hutt and Paraparaumu lines	0.44	18.88
Rail - Johnsonville line	0.85	36.44

Other modes:

Treatment of "Work's transport" and "Other motorised" (modes 4 and 7 in the WRC trip file) required additional assumptions for energy estimates. Company cars accounted for some 7 percent of New Zealand vehicles in 1992 (Bone *et al* 1995, Table A; Appendix C) so it seems a reasonable assumption that a large number of mode 4 trips would in fact be by car also. The number of people in work vehicles was checked using the SAS Frequency procedure (PROC FREQ). This variable was recorded for some 80 percent of mode 4 trips, and of these 75 percent record one or two people per vehicle. A further 12.6 percent of trips record between three and five people, so it is feasible that all of these trips were made by car. Calculations of energy use and GhE make an assumption that this is the case. The remaining 13 percent of trips had occupancies of 6 to 13 people, and an assumption was made that these were made by buses or mini-buses with similar per-passenger fuel consumption to buses. Of course some trips with six or even seven people could have been by car or van, but if this were the case fuel consumption per passenger would actually be less than mean diesel bus energy use. The number of trips in this category however are insufficient to have effect the overall figures to a significant extent.

Where the number of people in the vehicle is not given the proportions in each group were used to produce a mean value:

(0.87*mean car fuel use)+(0.13*mean bus fuel/pass_km).

"Other motorised" trips (mode 7) involve rather more guess-work. Running the frequency procedure shows that observations of the variable **numincar** are missing for just under 15 percent of trips. However, of the 85 percent of observations for which this variable is recorded, none have more than 7 people in the vehicle, and 98 percent 4 or less. A check of trip distances shows very similar mean trip lengths for this mode to those for modes 1 and 2, so on this basis all mode 7 trips are treated as car trips for energy calculations.

Walking and cycling are treated as requiring no energy from external sources and producing no greenhouse gas emissions.

Energy and emissions for homezones:

Having calculated energy and emissions for each mode of transport, a program was then written and run using SAS software to calculate the mean energy and emissions for each household. These two variables were used in most of the analyses described in Chapter Six, and where the analyses were performed at the level of individual survey respondents and households, the program was readily adapted to sum energy use and emissions at these lesser levels of aggregation.

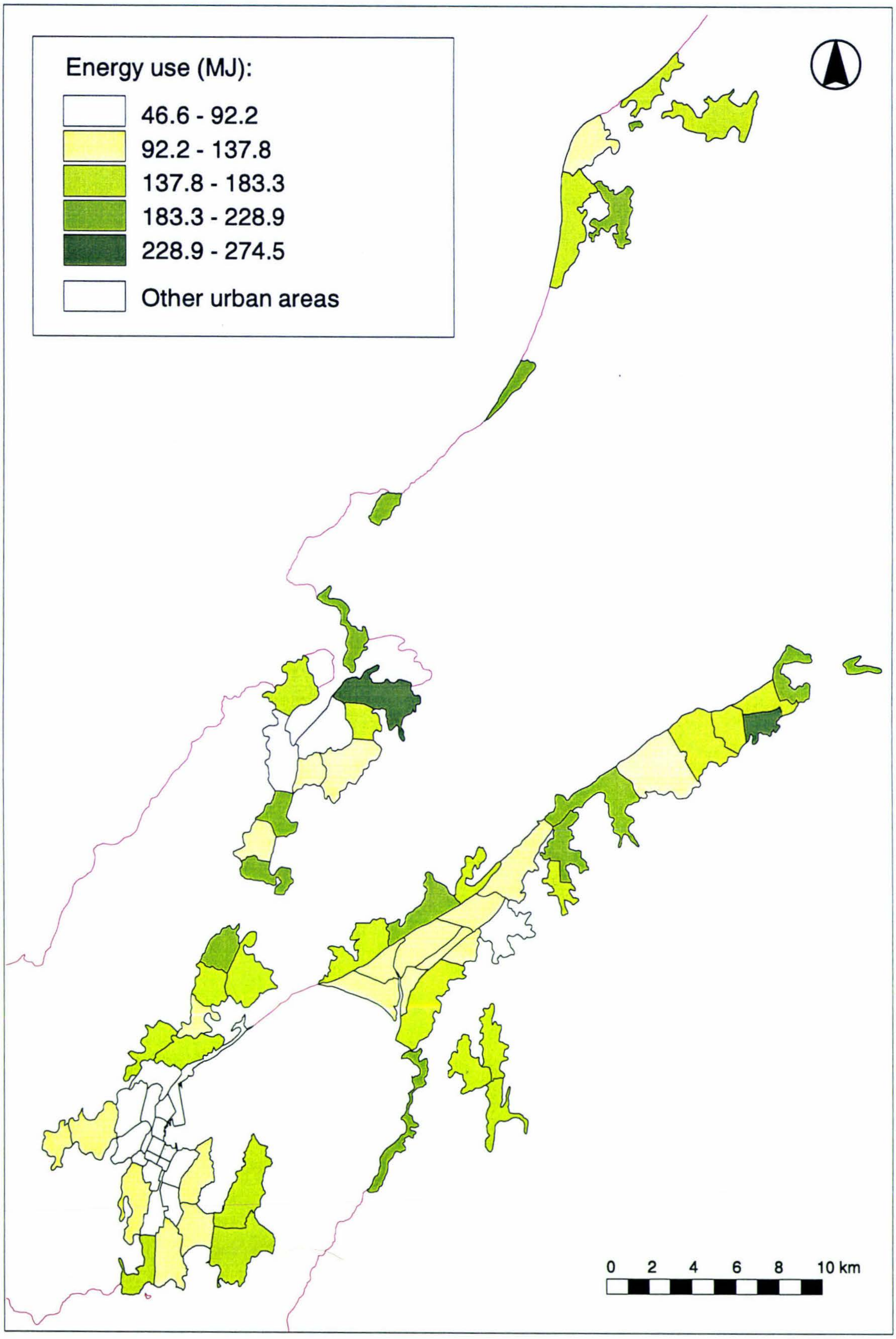
Table 5.6: Mean household energy use and greenhouse gas emissions for Wellington region:

R1 = ranking for homezones in ascending order of mean energy use per household;
R2 = ranking for homezones in ascending order of mean energy use per household.

Homezone	Mean energy use (MJ / household)	R1	Mean emissions (g CO_2 equivalent / household)	R1	Homezone	Mean energy use (MJ / household)	R2	Mean emissions (g CO_2 equivalent / household)	R2
901	141.06	31	10099.16	32	933	212.87	58	15006.91	58
902	144.13	34	10289.89	34	934	218.82	61	15311.12	60
903	96.86	15	6907.11	15	935	161.76	40	11526.88	39
904	111.02	21	7944.88	22	936	203.64	55	14532.21	55
905	46.61	1	3272.19	1	937	134.99	30	9647.81	30
906	56.69	3	4001.08	3	938	178.77	47	12945.8	50
907	95.19	14	6838.68	14	939	214.23	59	15297.79	59
908	150.71	36	10801.99	36	940	175.14	44	12569.78	44
909	111.31	23	7949.08	23	941	231.44	63	16492.87	63
910	47.45	2	3369.73	2	942	177.59	46	12674.37	46
911	64.74	4	4611.54	5	943	153.98	37	10931.94	37
912	107.70	18	7779.04	19	944	126.47	27	8979.37	27
913	94.05	12	6732.37	12	945	205.12	56	14590.63	56
914	85.53	9	6055.27	9	946	205.36	57	14686.7	57
915	75.78	6	5506.93	6	947	181.12	51	13021.28	51
916	80.79	8	5772.08	8	948	99.43	16	7089.81	16
917	78.02	7	5578.36	7	949	142.78	33	10102.51	33
918	142.23	32	10048.26	31	950	108.40	19	7703.12	18
919	161.00	39	11554.5	40	951	65.06	5	4562.47	4
920	103.63	17	7376.58	17	952	202.63	54	14453.11	54
921	179.75	49	12774.27	47	953	166.38	42	11893.04	41
922	166.08	41	12018.38	43	954	93.90	11	6784.15	13
923	218.04	60	15616.76	61	955	95.07	13	6665.17	11
924	192.46	53	13703.58	53	956	123.35	26	8852.2	26
925	128.38	28	9058.99	28	957	110.89	20	7861.15	20
926	189.58	52	13477.37	52	958	111.24	22	7871.11	21
927	89.07	10	6311.5	10	959	131.82	29	9333.3	29
928	178.99	48	12806.43	48	960	180.02	50	12812.85	49
929	121.31	25	8669.39	25	961	175.63	45	12596.18	45
930	119.33	24	8480.12	24	962	155.03	38	11147.29	38
931	166.57	43	11941.78	42	963	148.58	35	10658.4	35
932	274.50	64	19570.24	64	964	220.94	62	16078.42	62

Mean household energy use and emissions for each homezone are listed above Table 5.6. Comparison of the sorted lists shows that there is little difference in the order of the homezones between the two. Twenty zones change position, but most of these are simply swapped with the zone above or below it.

This information presented in this table is included in two additional tables in Appendix One. These sort mean household energy use and emissions in ascending order, into two separate tables.



Map 3: Energy use in urban transport for the Wellington region, 1988: mean weekday MJ per household. Mapping greenhouse gas emissions on this equal interval basis results in exactly the same groupings, with the mean weekday CO_2 equivalents as follows:

1	3.27 to 6.53 kilograms	**4**	13.05 to 16.31 kilograms
2	6.53 to 9.79 kilograms	**5**	16.31 to 19.57 kilograms
3	9.79 to 13.05 kilograms		

Chapter Six : Data analysis:

Models tested in the analyses:

This chapter analyses the comparative performance of the sixty-four homezones into which respondent households have been grouped. The two standard measures of the relative performance of the zones are mean energy use and mean emissions per household. The aim of the analysis was to discover the key influences on these two measures.

Fifteen groups of statistical analyses were performed using both the original survey variables and new ones which were derived from the survey and census data. Exploratory analyses were first performed on energy use and emissions at the level of individual respondents and households. This required summing of energy use and emissions to the appropriate level for each analysis. Simple regression and analyses of variance (ANOVA) were used depending on whether the variable being modelled was continuous or grouped into classes. Most of the analyses were however performed at the homezone level using mean household energy use or emissions as the dependent variable. From these univariate analyses, a smaller range of variables were selected for multiple regression modelling.

As discussed in Chapter Five the original WRC survey included several variables to describe different characteristics of the individual respondents and of the households they lived in. For convenience, these groups of variables are referred to in this chapter as "household-variables" and "person-variables".

Several analyses were performed by most of the SAS programmes written. Each program is referred to here as a Model, and most of these include several "sub-models" which analyse different variables in turn. Thus one program is used to perform a similar analysis on several different paired combinations of variables. For example Model 4 analyses each of the household-variables which are modelled in turn against household energy use and then household emissions. The results are then presented as Model 4(a) through to 4(h).

The full list of analyses carried out are listed below:

Anova analyses:

1-3. Person-variables at various levels of aggregation.

4, 5. Categorical household-variables at various levels of aggregation.

Univariate regression analyses:

6, 7. Continuous household-variables at various levels of aggregation.

8. Proportional person-variables and household-variables.

9. Models mean energy use (MJ) by distance to central Wellington zones.

10. Models mean energy use and emissions against 10 modal split variables.

11. Models mean energy use and emissions against mean distance for trips for a range of purposes.

12. Models mean energy use and emissions against homezone population and dwelling densities.

13. Models the effects of (a) distance to nearest railway station and (b) proportion of total distance travelled each household by rail (modal split 6) against household energy use; (c) and (d) analyses of modal split 6 against distance to rail.

14. Modifies model 13 to consider distances to nearest bus-stop and modal split for bus travel for a limited number of Wellington City homezones.

Multiple regression analyses:

15. Uses significant variables identified by preceding models in stepwise regression models for both energy use and emissions.

Suitability of data for the chosen methods of analysis:

The dominance of classification variables in the original survey suggest that analyses of variance (ANOVA) would be the obvious statistical tool for examining these data. Simple regression analyses of each of the continuous variables quickly showed that at least one of these had some influence on overall energy use and the resulting emissions. The possibility of using a common method of analysis to allow some multivariate modelling of the data was therefore investigated. One way to do this would have involved grouping each of the continuous variables into several classes, although selecting an appropriate means of dividing the data into groups would raise its own methodological issues. A major disadvantage of this approach is the inevitable loss of some of the descriptive detail of any variables treated in this way. Given the small range of absolute values for variables such as **total available vehicles** this was not considered to be a practical option. It was possible however to create new continuous variables using the categorical variables, which would then be suitable for including in regression analyses. This was by considering the proportion of households or individuals in each variable class as a percentage of those surveyed in that homezone. Thus the classification variable **persnage**, for example, is converted for some analyses at the homezone level into the continuous variables **pragegr1** (e.g. **pr**oportion of respondents in **age gr**oup **1**), **pragegr2**, **pragegr3**, **pragegr4**, **pragegr5**, and **pragegr6**.

ANOVA analyses:

One-way analyses of variance were performed on each of the classification variables for individuals and households, against energy use and emissions at the appropriate level in each case.

Underlying purpose of analyses of variance:

The classic method of framing a research question is to find sufficient evidence to reject the "null hypothesis", that there is no difference between observations. In the case of ANOVA analysis, the object is to detect differences between classes or groups of observations, for example whether participants in the six age classes used in the WRC survey show any discernible differences in energy use, and whether this "...represent(s) a chance occurrence or a systematic effect" (Shavelson 1988, 342). While a full explanation of the overall structure of this statistical procedure is not necessary for the purposes of this thesis, a brief outline of the logic behind these tests is helpful to understanding the program output.

Variation between each observation results from two sources, variability *within* the class or group evaluated and variability *between* the groups, generally a combination of the two in each case. Measures of the two sources of variation are summed and squared to produce scores for each, which are then divided out to produce the F statistic. In ANOVA analyses which are carried out without the benefit of statistical software, the null hypothesis can be rejected or otherwise by comparison of the value for F to the range of F distributions which is published in standard Eton Statistical Tables. The F statistic calculated for the test, which may be referred to as F observed, is compared to a critical F value (F critical) which is the threshold level for accepting or rejecting the null hypothesis. This is found in the Tables by reference to the "degrees of freedom" for the test. There are two varieties of these, namely between groups or classes of the variable of interest, and within the groups. They are included in the output from SAS and other software packages, but are simple enough to work out in non-computerised calculations. Degrees of freedom "between groups" (*df*B)is equal to the number of classes minus 1, so that for the variable **person age**,

*df*B = 6-1 = 5.

The Degrees of freedom within groups (*df*w) is made up of the sum of the degrees of freedom within each group, which in turn is the number of subjects or observations (n) in that group, minus 1. So,

*df*w = *df* within group 1 + *df* within group 2... *df* within group *k*.

Effectively, this is the number of observations minus the number of classes. For each person-variable of the WRC survey, this results in several thousand observations in each case, although this number differs between variables as several have a proportion of missing observations.

The Degrees of Freedom table tabulates the "between groups" and "within groups" with F critical usually given for both five percent and one percent confidence levels. If F observed for a given model is less than the critical value, the null hypothesis is accepted at that level of significance. In other words, the model does not provide evidence to show that there is a significant difference between means. Otherwise the null hypothesis is rejected; the experiment gives clear evidence that significant differences do in fact exist between the groups or classes.

Software packages such as SAS allow the user to by-pass most of this procedure, as the level of significance is included in the standard output for the ANOVA procedure. The SAS output also includes *R squared* values, which are a measure of **strength of association** between dependent and independent variables (SAS *undated*, 141; Shavelson 361-363). Put another way, it is a measure of the degree to which variation in the independent variables (respondent's age, household income and so on) account for differences in mean energy use and emissions.

In addition to the standard statistics output by the ANOVA Procedure in SAS, several *post hoc* tests are available which compare significance levels of each class within the variable being analysed. While these can prove useful, standard statistics texts alert researchers to important features of these tests. Whereas *a priori* tests selected before the analysis may be used to confirm, or otherwise, the explanatory power of a hypothesis, *post hoc* tests are essentially exploratory in nature. They can be used to learn more about the data if the F and p values delivered by the initial analysis show that the differences in values are highly significant. If the tests are not significant, *post hoc* tests are of no validity whatsoever (Cody 1987, 114).

Where the analysis of variance emerges as significant, some of the *post hoc* tests can be used to tell which groups have significant differences of means and which ones do not. **Duncan's multiple range test** is one such test which outputs a ready visual comparison in the case of variables where there are more than two classes. It is therefore applicable for all of the variables tested here except for "need car at work", of which there are only two groups ("yes" and "no"). Some software packages such as ***Systat*** output similar information in the form of box-plots, which also show the range covered by each variable. This facility is not available in the ANOVA procedure in SAS, although scatter plots and other graphs may be generated in procedures such as PROC GLM (analyses using the General Linear Model) and PROC REG (regression analyses). Duncan's multiple range test can be used to provide the essential information presented graphically by box-plots in other software in order to allow the significance of different classes in the variable of interest to be assessed.

Some of the main data output from the models described in this chapter are summarised in tables within the body of the text. While the statistics included here are sufficient to understand whether each model is of any real interest, additional SAS output is included in Appendix Four. Output for Duncan's multiple range tests are included for some of the sub-models in the main text over the next few pages.

Testing the "person" variables: Models 1, 2 and 3.

Three different analyses of variance were modelled against each of the four person-variables, first against energy use and then against emissions as dependent variables. These considered the two dependent variables at the level of the individual respondent and at two levels of aggregation. The aim of the analyses was to find which characteristics of the individual respondent, if any, affected energy use and emissions, and whether any of them warranted further investigation. The chosen levels for each of the two dependent variables were analysed in separate models as follows. The variable names used in the programs are included here as they are reproduced in the SAS print-outs, of which portions are also included as Figures in this chapter:

Model 1: the individual respondent; TLENERGY and TLEMISNS.

Model 2: mean energy use (or emissions) for respondents in each homezone; EPERS_HZ and EMMN_PHZ.

Model 3: mean household energy use (or emissions) for each homezone; ENGYMEAN and EMISSNMN.

While almost all of the models emerged as highly significant, with just two exceptions, inspection of the R squared values for each shows that they do not actually tell us much about what influences energy use or emissions at each level of analysis. The greatest degree of "explanation" is offered by Model 1. While R squared values for each variable tested in that model show that they certainly have some effect on individual energy use and emissions, none of them emerge as particularly important. Strength of association with energy use and emissions is thus quite weak even when these are considered without any aggregation of the data. Modelled against mean energy or emissions per person or household, this association is almost negligible.

Comparing sub-models for the same independent variable modelled against energy use and emissions show that the difference between the two dependent variables is negligible. While the very similar order of energy use and emissions in Table 5.6 (page 68) suggest that this might be the case, both were analysed separately to see whether any important differences did exist.

The independent variables are now considered in turn. Results from most of the Duncan multiple range test are also included here.

Persons age:

Model 1 shows some effect on both energy use and emissions. Duncan's multiple range test shows significant differences in means between three or four groupings across the six age classes. The age group **1 to 4 years of age** is by far the smallest group between the energy use and emissions sub-models are negligible, and if this was omitted from the model the remaining age groups would form into three discreet groupings. Models 2 and 3 show fewer significant differences between age groups, partly accounting for the lower F values.

Table 6.1: Class variables on individual survey respondents used in ANOVA analyses.

1.	Age group of respondent (**persnage**):	
	0-4 years	1
	5-14 years	2
	15-19 years	3
	20-39 years	4
	40-64 years	5
	65 years and over	6
2.	Respondents employment status (**persnemp**):	
	Full time (more than 30 hours a week)	1
	Part time (8-30 hours a week)	2
	Full time education	3
	Unemployed	4
	Retired	5
	Other	9
3.	Need car at work (**needcarw**):	
	Yes	1
	No	2
4.	Respondents occupation group (**pjobtype**):	
	Professional, technical and related workers	1
	Administrators and managers	2
	Clerical and related workers	3
	Sales workers	4
	Service workers	5
	Agriculture/Fishing/Hunting workers	6
	Production, transport, labourers	7
	All others	8
	Not recorded by surveyor	9

Table 6.2: Effects of persons age on energy use and emission.

(i) Person age: energy	**F Value:**	**R-Square:**	**Significance:**
Model 1a (individual energy use):	186.91	0.109028	0.0001
Model 2a (mean energy person / HZ):	9.69	0.005347	0.0001
Model 3a (mean energy HH / HZ):	12.93	0.007031	0.0001
(ii) Person age: emissions			
Model 1b (emissions for individual):	183.45	0.107227	0.0001
Model 2b (mean emissions person / HZ):	9.67	0.005338	0.0001
Model 3b (mean emissions HH / HZ)	12.96	0.007047	0.0001

It may be noted from reference to the Duncan test output that Model 1 includes fewer observations than Models 2 and 3. For example while 642 respondents are recorded in the age group 1 to 4 years of age for these two sub-models, only 20 of these appear in the trip records, and thus only 20 are included in Model 1(a) and (b). There are also some missing observations for the other age groups, although these are fewer in number than for the youngest age group. This is due to the fact that Models 2 and 3 analyse the independent variables for all respondents. While the lower number in Model 1 is at least partly due to some respondents not leaving home on the day that the household was surveyed, it is also probable that details were not completed by or for some household members.

```
MODEL 1(a):  EFFECT OF AGE ON ENERGY USE BY INDIVIDUALS.

Duncan's Multiple Range Test for variable: TLENERGY

Duncan Grouping          Mean      N  PERSNAGE

             A          76.42   2036   5
             A
             A          74.81   2966   4

             B          42.47    439   6
             B
        C    B          34.77    811   3
        C
        C    D          17.17     20   1
             D
             D          10.61   1371   2
```

```
MODEL 2(a):  EFFECT OF PERSON-AGE ON MEAN PERSON-ENERGY USE / HZ.

Duncan's Multiple Range Test for variable: EPERS_HZ

Duncan Grouping          Mean      N  PERSNAGE

             A        49.7358   2250   5

             B        48.3074   1452   2
             B
             B        48.0301    880   3
             B
             B        47.8352    642   1
             B
             B        47.3239    650   6
             B
             B        47.0536   3260   4
```

```
MODEL 3(a):  EFFECT OF PERSON-AGE ON MEAN HH ENERGY USE / HZ.

Duncan's Multiple Range Test for variable: ENGYMEAN

Duncan Grouping          Mean      N  PERSNAGE

             A        149.063   1452   2
             A
             A        147.962   2250   5
             A
             A        147.578    642   1
             A
             A        146.210    880   3

             B        142.079   3260   4

             C        134.382    650   6
```

Figure 6.1: Duncan's multiple range tests for person-age submodels.

Persons employment status:

Model 1 shows full and part-time workers and those in full-time education all formed discreet groups, with the other classes forming a fourth group with significantly different mean energy-use and emissions from these three. As in the person-age models, aggregate energy use at the mean household level again had a marginally higher F and R-squared values than the mean for all individuals in each homezone. The means for all respondents in each homezone were the only sub-model pair which did not emerge as significant in the various analyses of variance of person-variables. The Duncan test grouping shows two discreet groupings in Model 3, with unemployed and retired people significantly different from the other classifications (Figure 6.2, page 80).

Table 6.3: Effect of person's employment status on energy use and emissions.

(i) Employment status:energy use	**F Value:**	**R-Square:**	**Significance:**
Model 1c (individual energy use):	231.51	0.131594	0.0001
Model 2c (mean energy person / HZ):	1.79	0.000995	0.1103
Model 3c (mean energy HH / HZ):	7.12	0.003881	0.0001
(ii) Employment status: emissions			
Model 1d (emissions for individual):	226.43	0.129078	0.0001
Model 2d (mean emissions person / HZ):	1.78	0.000984	0.1141
Model 3d (mean emissions HH / HZ)	7.19	0.003922	0.0001

"Need car at work":

The F values for this variable are the highest of the independent variables for all three models, indicating a higher difference in means also (Figure 6.4, page 85). As there are only two groups for this variable, no Duncan test outputs are produced.

While most of the variables provided by the WRC are unambiguous, this one is however open to question as to what exactly constitutes a "need" to take one's car to work. For some people, the nature of the need might be that there is no public transport alternative available at the time they travel to work, for example for night shift-workers, while for others it might be that they would have to walk further than they prefer to in order to access a frequent transport route. Unfortunately it is not known how the surveyors were asked to frame this question to respondents, so any information provided by this variable must be regarded as highly suspect unless without further supporting evidence.

```
MODEL 1(c):    EFFECT OF EMPLOYMENT STATUS ON ENERGY USE BY
               INDIVIDUALS.

Duncan's Multiple Range Test for variable: TLENERGY

Duncan Grouping            Mean       N  PERSNEMP

          A              83.144    3713  1

          B              67.723     620  2

          C              43.833     576  5
          C
          C              43.350     548  9
          C
          C              41.657     210  4

          D              15.555    1978  3
```

```
MODEL 3(c):   EFFECT OF PERSON-EMPLOYMENT STATUS ON MEAN HH ENERGY
              USE / HZ.

Duncan Grouping            Mean       N  PERSNEMP

          A             148.037    1322  9
          A
          A             146.638     661  2
          A
          A             146.457    2114  3
          A
          A             144.752    3889  1

          B             138.192     854  5
          B
          B             135.828     296  4
```

Figure 6.2: Duncan's multiple range tests for employment status submodels.

(Model 2(c) is not tested as the as the ANOVA did not produce a significant result.)

Table 6.4: Effect of "need for car at work" on energy use.

(i) Need car at work: energy use	**F Value:**	**R-Square:**	**Significance:**
Model 1e (individual energy use)::	461.23	0.094143	0.0001
Model 2e (mean energy person / HZ):	61.13	0.013051	0.0001
Model 3e (mean energy HH / HZ):	40.25	0.008503	0.0001
(ii) Need car at work: emissions			
Model 1f (emissions for individual):	468.35	0.095457	0.0001
` Model 2f (mean emissions person/HZ):	61.41	0.013109	0.0001
Model 3f (mean emissions HH / HZ)	40.32	0.008517	0.0001

Occupation group:

While all three models again emerge with high levels of significance for both energy use and emissions, this variable has the lowest R squared value of the four person-variables. Reference to the Duncan test outputs shows a looser grouping of significant and non-significant variables, with considerable overlap between the three groupings.

Table 6.5: Effect of occupation group on energy use and emissions.

(i) Occupation group: energy use	**F Value:**	**R-Square:**	**Significance:**
Model 1g (individual energy use):	13.31	0.023915	0.0001
Model 2g (mean energy person / HZ):	4.63	0.008168	0.0001
Model 3g (mean energy HH / HZ):	4.18	0.007271	0.0001
(ii) Occupation group: emissions			
Model 1h (emissions for individual):	13.49	0.024235	0.0001
Model 2h (mean emissions person / homezone):	4.53	0.007996	0.0001
Model 3h (mean emissions HH / HZ)	4.14	0.007208	0.0001

Accepting or rejecting the "person" variables:

As most comparisons between classes for the person-variables are significant at the 5% level or better, the overall high levels of significance for these four variables give ample evidence to reject the null hypothesis in all cases except for submodels 2 (c) and 2 (d), employment status modelled against mean energy use and emissions for all respondents in each homezone. In each case the analysis of household means produces slightly higher R-square and F values than the corresponding means for individuals in each homezone. While both appear to have little explanatory power compared to analyses against unaggregated energy use and emissions, the significance of the four person-variables here was sufficient to warrant further investigation by way of the linear regression analyses which are discussed later in this chapter. First however we continue with analyses of variance of the household classification variables.

```
MODEL 1(g):  EFFECT OF OCCUPATION GROUP ON ENERGY USE BY INDIVIDUAL.

Duncan's Multiple Range Test for variable: TLENERGY

Duncan Grouping              Mean      N  PJOBTYPE

              A            117.32     25  6
              A
      B       A            104.57    242  4
      B       A
      B       A            100.00    619  2
      B       A
      B       A             87.40    640  7
      B       A
      B       A             81.69   1486  1
      B       A
      B       A             66.37    442  5
      B
      B       C             62.61     85  8
      B       C
      B       C             61.76    811  3
              C
              C             15.48      4  9
```

```
MODEL 2(g):   EFFECT  OF  PERSON-OCCUPATION  GROUP  ON  MEAN  PERSON-ENERGY
              USE / HOMEZONE:

Duncan's Multiple Range Test for variable: EPERS_HZ

Duncan Grouping              Mean       N  PJOBTYPE

              A            57.261       4  9
              A
      B       A            54.139      28  6
      B       A
      B       A            51.397      93  8
      B       A
      B       A            50.654     648  2
      B       A
      B       A            49.256     262  4
      B       A
      B       A            48.565     847  3
      B
      B                    47.896     661  7
      B
      B                    47.801    1560  1
      B
      B                    46.053     473  5
```

```
MODEL 3(g):  EFFECT OF PERSON-OCCUPATION GROUP ON MEAN HH ENERGY USE /
              HOMEZONE:

Duncan's Multiple Range Test for variable: ENGYMEAN

Duncan Grouping              Mean       N  PJOBTYPE

              A            182.88       4  9
              A
      B       A            163.71      28  6
      B
      B                    150.80     648  2
      B
      B                    149.68      93  8
      B
      B                    148.96     661  7
      B
      B                    148.17     262  4
      B
      B                    145.04     847  3
      B
      B                    141.45    1560  1
      B
      B                    140.42     473  5
```

Figure 6.3: Duncan test outputs for analyses of occupation group and energy use.

Table 6.6: Classifcation "household-variables" used in ANOVA analyses:

1. Income (**hhincome**):

$0 - 15,000	1
$15,001 - $25,000	2
$25,001 - $35,000	3
$25,001 - $45,000	4
$45,001 - $55,000	5
$55,001 - $70,000	6
$70,000 and over	7
Not recorded	9

2. Date of travel (**survdate**):

Survey data was gathered over a period of ten weeks between late September and early December 1988, on a total of 51 days. These are coded by day and month, for example ***3011*** for ***30 November***.

3. Household category (**hhcatgry**):

Households were grouped into one of 24 categories which provided quite an extensive breakdown of age groupings, as follows:

One adult, age 65 or over	1
Two adults, age 65 or over	2
One adult, employed	3
One adult, not employed, under age 65	4
One adult, employed with children age 0-14	5
One adult, not employed, with children age 0-14	6
One or more adult, age 65 or over and one employed adult under age 65	7
One or more adult, age 65 or over and one adult under age 65, not employed	8
One adult, one infant age 0-4	9
Two adults, not employed	10
Two adults, one employed	11
Two adults, both employed	12
Two adults, not employed, with children age 5-14 and with or without infants age 0-4	13
Two adults, one employed, with children age 5-14 and no infants (age 0-4)	14
Two adults, one or both employed, with children age 5-14 and no infants (age 0-4)	15
Two adults, one or both employed, with children age 5-14 and infants (age 0-4)	16
Three or more adults, not employed	17
Three or more adults, one employed	18
Three or more adults, two employed	19
Three or more adults, all employed	20
Three or more adults, one employed, with children age 5-14 and/or infants age 0-4	21
Three or more adults, two employed, with children age 5-14 and/or infants age 0-4	22
Three or more adults, all employed, with children age 5-14 and/or infants age 0-4	23
Two adults with infants age 0-4	24

4. Total number of vehicles owned by household members, including cars, trucks, motorbikes (**carownno**).

Zero	0
One	1
Two	2
Three or more	3

Testing the "household" variables: Models 4 and 5.

Four ANOVAs were performed modelling each of the four household variables against energy use and emissions at two levels. These were:

Model 4: energy / emissions for each household; and

Model 5: mean household energy use /emissions for each homezone.

Once again the dependent variables are named TLENERGY and TLEMISNS (Model 4) although this time the total referred to is for the household rather than for individual respondents as in Models 1 to 3. Model 5 uses **y** variable names ENGYMEAN and EMISSNMN, and these are exactly the same as in the earlier models.

All models emerge with high confidence levels, and some of these have some explanatory value although this is weak to moderate.

Like the person variables, none of the four household variables show much influence on overall energy use, although modelled against individual household energy use three of the four show a small amount of influence. Car ownership level is ahead of the rest in this respect, a result which we might expect intuitively.

Household income:

Analysis at the level of the individual household shows a positive relationship between income and energy use. Analysed against mean energy use for the homezone, association between explanatory and dependent variables is weak.

Table 6.7: Effect of household income on energy use and emissions:

(i) Household income: energy use	F Value:	R-Square:	Significance:
Model 4a (energy use for household):	51.30	0.110874	0.0001
Model 5a (mean energy use HH / HZ):	6.94	0.015924	0.0001
(ii) Household income: emissions			
Model 4b(emissions for household):	50.55	0.109448	0.0001
Model 5b(mean emissions HH / HZ):	6.91	0.015861	0.0001

```
MODEL 4(a): SIGNIFICANCE OF HOUSEHOLD INCOME ON H'HOLD ENERGY
            USE.

Duncan's Multiple Range Test for variable: TLENERGY

Duncan Grouping            Mean       N  HHINCOME

                A        211.03     490   7
                A
                A        200.06     403   6

                B        170.17     401   5

                C        143.31     473   4
                C
          D     C        121.36     448   3
          D
          D              114.43      78   9

                E         89.23     340   2

                F         57.51     255   1
```

```
Model 5(a): EFFECT OF HOUSEHOLD INCOME ON MEAN HH ENERGY USE for
            HZ.

Duncan's Multiple Range Test for variable: ENGYMEAN

Duncan Grouping            Mean       N  HHINCOME

                A        147.560    482   4
                A
          B     A        146.169    403   5
          B     A
          B     A        146.112    497   7
          B     A
          B     A        145.558    407   6
          B     A
          B     A        141.771    456   3
          B
          B     C        137.211    367   2
                C
          D     C        130.117    314   1
          D
          D              124.423     82   9
```

Figure 6.4: Duncan test outputs for analyses of household income and energy use:

Survey date:

Comparison of the two analyses here shows one notable difference from other categorical variable analyses, in that association proved to be markedly higher without aggregation. This suggests that the conditions for a given day may exert a greater influence on the amount of energy used at the homezone level than any of the other variables. Reference to a 1988 calendar shows that a small number of travel dates were in fact Fridays, Saturdays and Sundays, although the WRC had advised that all surveys were to be carried out on the other four days of the week only. This could have been due to respondents ignoring the surveyors requests to complete their travel diaries on one of these weekdays, although there is no way of ascertaining whether this is the case now. It could also be due to errors in entering the data, as one survey date is given as 31 November (a non-existent date).

To check this, the survey date variable was therefore used to create a new variable, **Day of the week**, which was modelled against mean household energy use. This was found to be totally insignificant; the following statistics are extracted from the output. The Duncan test output from the main model which has not been included in the here due to its length. The Duncan test result for **Day of the week** is however included below (figure 6.5, page 87).

Table 6.8: Summary statistics for ANOVA on 'Day of the week':

F Value:	**R-Square:**	**Significance:**
0.65	0.001318	0.6920

Another possibility for explaining this difference is the weather. Casual observation of rush hour traffic suggests that many people who are quite happy to use public transport in fine weather probably drive to work during less favourable conditions. Most bus-stops and rail stations are not particularly comfortable places on cold, windy days, and the majority of bus stops do not provide any shelter at all. It would have been quite possible to compile a simplified record of daily weather to allow further analysis of this variable. This could be of particular value to any study of individual modal choice and travel behaviour. However, this variable accounts for only a small amount of the variation in energy consumption and emissions at the homezone level. As this was the main area of interest here further analysis of this variable was not carried out.

Table 6.9: Effect of survey date on energy use and emissions:

(i) Survey date: energy use	**F Value:**	**R-Square:**	**Significance:**
Model 4c (energy use for household):	1.57	0.026854	0.0063
Model 5c (mean energy use HH / HZ):	5.41	0.083639	0.0001
(ii) Survey date: emissions			
Model 4d (emissions for household):	1.58	0.027041	0.0056
Model 5d (mean emissions HH / HZ):	5.41	0.083645	0.0001

```
Duncan's Multiple Range Test for variable: TLENERGY

Duncan Grouping              Mean       N  DAYOWEEK

              A            163.15      26   6
              A
              A            152.74     804   3
              A
              A            151.32     799   4
              A
              A            145.29     600   5
              A
              A            144.33     709   2
              A
              A            126.01      11   1
              A
              A             42.04       3   7
```

Figure 6.5: Duncan's multiple range test for significance of day of the week on household energy use.

Day 1=Sunday, Day 2=Monday and so on through to Day 6=Saturday.

Household category:

While this variable proved to be significant, the Duncan test output shows that means between several of the categories are not. The Model 5 analysis of this variable shows only very minor differences between means, with three classes (categories 14, 15 and 18) showing included in a group which shows a significant difference from all remaining categories. As result the explanatory power of this submodel is weak.

Table 6.10: Effect of household category on energy use and emissions:

(i) Household category: energy use	F Value:	R-Square:	Significance:
Model 4e (energy use for household):	22.90	0.152219	0.0001
Model 5e (mean energy use HH / HZ):	3.01	0.022166	0.0001
(ii) Household category: emissions			
Model 4f (emissions for household):	22.49	0.149971	0.0001
Model 5f (mean emissions HH / HZ):	3.05	0.022425	0.0001

```
MODEL 4(c):  SIGNIFICANCE OF HOUSEHOLD CATEGORY ON
             HOUSEHOLD ENERGY USE:

Duncan's Multiple Range Test for variable: TLENERGY

Duncan Grouping                Mean      N  HHCATGRY

               A              18200    342  17
               A
       B       A              13818     18  18
       B       A
       B       A   C          13428    329  19
       B           C
       B       D   C          12149    695  11
       B       D   C
       B       D   C          11904     24  20
       B       D   C
       B   E   D   C          11558     96  21
       B   E   D   C
   F   B   E   D   C          10812    140  12
   F   B   E   D   C
   F   B   E   D   C G         9828    294  13
   F   B   E   D   C G
   F   B   E   D H C G         9036    216  14
   F   B   E   D H C G
   F   B   E   D H C G         8407      4   5
   F   B   E   D H C G
   F   B   E   D H C G         8184     21  23
   F   B   E   D H C G
   F   B   E   D H C G         7817     17  22
   F   B   E   D H C G
   F   B   E   D H C G         7333     33   4
   F       E   D H C G
   F       E   D H C G         7169     56   6
   F       E   D H   G
   F       E   D H   G         6456     40  10
   F       E   D H   G
   F       E   D H   G         6142    195   3
   F       E   D H   G
   F       E   D H   G         5493     69  15
   F       E   D H   G
   F       E   D H   G         5482    130   2
   F       E     H   G
   F       E     H   G         5167      5  24
   F             H   G
   F             H   G         4258     23   8
                 H   G
                 H   G         3702     49   7
                 H   G
                 H   G         3464     12  16
                 H
                 H             2741    120   1
                 H
                 H             2465     28   9
```

Figure 6.6: Duncan's multiple range test for significance of day of household category on energy use by individual households.

Car ownership:

This variable shows a moderate association with energy use and emissions at the household level, although the relationship suggested by the R-square is negligible when modelled against the mean dependent variables. However the Duncan test output shows that each class is significantly from all others at the 5% level. This is in contrast to every other variable tested up to this point, as all have had at least one pair of variables for which the mean is not significantly different. This variable is therefore strongly significant both at the level of individual households and for mean household energy use (and emissions) at the homezone level.

Table 6.11: Effect of car ownership on energy use and emissions:

(i) Car ownership level: energy use	**F Value:**	**R-Square:**	**Significance:**
Model 4d (energy use for household):	264.50	0.211799	0.0001
Model 5d (mean energy use HH/ homezone):	62.13	0.057136	0.0001
(ii) Car ownership level: emissions			
Model 4h (emissions for household):	265.21	0.212299	0.0001
Model 5h (mean emissions HH / HZ):	62.31	0.057293	0.0001

```
MODEL 4(g): SIGNIFICANCE OF CAR OWNERSHIP ON HOUSEHOLD ENERGY
            USE:

Duncan's Multiple Range Test for variable: TLENERGY

Duncan Grouping              Mean       N  CAROWNNO

                A         256.803     509  3

                B         183.015     950  2

                C         103.790    1235  1

                D          25.212     263  0
```

```
Model 5(g): EFFECT OF CAR OWNERSHIP ON MEAN HH ENERGY USE for HZ:

Duncan's Multiple Range Test for variable: ENGYMEAN

Duncan Grouping              Mean       N  CAROWNNO

                A         157.616     511  3

                B         150.499     957  2

                C         136.925    1302  1

                D         117.345     310  0
```

Figure 6.7: Duncan's multiple range tests for significance of car ownership on energy use.

Accepting or rejecting the "household" variables:

While most of the submodels tested here show excellent levels of significance, examination of the Duncan test output shows considerable overlapping between larger groups of classes for several models. At the mean energy (and emissions) level, car ownership emerges as being the only variable tested in Models 6 and 7 which show significant differences for every group. Only **survey date** and **day of the week** failed the five percent significance level tested against household energy use, and all variables tested against **engymean** are significant at the 0.1% level. Consequently none of these variables can be eliminated from the analysis at this stage.

Regression analyses:

Underlying purpose of linear regression analyses:

Linear regression analyses aims to establish whether a linear relationship exists between dependent and independent variables in the analysis. A perfectly linear relationship will result in a steady increase in the value of the dependent variable for increases in the independent variables if the relationship is positive, or a decrease where the relationship is negative.

The dependent variables, energy use or emissions, always appear on the y-axis of the plots such as those included below, so may also be referred to as the **y** variable. Independent variables are plotted from on the x-axis, and are also known as **x** variables, predictors or explanatory variables. The latter two terms apply to the use of these data where strong correlations with the dependent variable exist, in which case they can be used to "predict" values of **y** within confidence levels set by the level of significance for each test. Alternatively, the **x** variables can be said to "explain" the variation in the latter.

The terms **x** and **y** variables, or more simply just **x** and **y**, will be used frequently in the discussion here, as they are readily accepted as alternatives to the longer terms in statistical literature. As in the ANOVA analyses of household variables, **y** variables are TLENERGY and TLEMISNS (Model 6), and ENGYMEAN and EMISSNMN (Model 7).

A perfectly linear relationship is seldom found in reality, but where some "cause and effect" is obvious from plotting the x and y variables, a line of best fit may be estimated, from which the value of y may be predicted with an appropriate margin of error. The "least-squares" method is a common method of estimating this line. This was used in several of the studies reviewed in the Chapter Four. This method "*...chooses the prediction line...that minimises the sum of the squared error of prediction...for all sample points* " (Ott 1993, 441).

As in analyses of variance, the R-squared values output by each analysis is of particular interest. This reflects variation in the **y** variable which is "*accounted for by a linear combination of all the independent variables*" (Cody 1987, 78). This is then corrected to account for the number of independent variables in the equation to produce the adjusted R-square, which slightly lower than the (unadjusted) R-square. The adjusted R-square is the estimated slope of the fitted prediction line, and is useful as an indicator of the "goodness of fit" of the model or sub-model, and is often expressed in terms of the proportion or percentage of variation explained by a particular **x** variable.

Data for most of the regression was plotted as part of the analysis using standard options involved in the SAS regression procedure (PROC REG). Scatter plots of x plotted against y allow a quick visual check of the strength of linearity. Values predicted by the regression procedure may be plotted separately or overlaid on the scatterplot. The latter option was done for most of the graphs presented in this thesis. These are included both in the text and also in Appendix Two. Plots for models which have strong explanatory value are included in this chapter, while others for models which are of some interest but do not have any great explanatory value are included in the appendix. It may be noted that the predicted values in the SAS plots appear as individual symbols, whereas in some other software packages these are drawn as a continuous line. While this is not a serious drawback to the use of these plots, it does affect the visual resolution to some extent.

Most of the remaining analyses use simple univariate linear regression, with one model at the end using stepwise regression to find a group of independent variables which together offer considerable explanatory value for mean energy use and emissions per homezone. The stepwise technique is discussed further at that stage.

Regression analyses of continuous household variables; Models 6 and 7.

Several continuous variables were included in the data file of household information. Simple linear regression analyses were run on these, using one independent variable per model (i.e. univariate modelling). These are considered in turn:

Total number of trips made by all member of household:

The adjusted R-square indicates that this explains about a quarter of the variation in energy use and emissions at the level of the individual household. This is just as we might expect however, as common sense alone tells us that there is a "cause and effect" relationship between **x** ,and **y**. Examination of the plots for **tlenergy** shows a tight, non-linear clustering of observations with a few outliers which appear to have a strong influence on the predicted values (Appendix Two, Table of Plots 1). In common with the plots for the Model 6 submodels which follow, the **y**-axis scale covers a much wider range of values than that for Model 7, reflecting the much wider spread of values for individual household compared to the means for each homezone.

Table 6.12: Effect of total number of trips by household on energy use and emissions:

(i) Total trips by household: energy use	**Adjusted R-square:**	**Significance:**
Model 6a (energy use for household):	0.2750	0.0001
Model 7a (mean energy use HH / HZ):	0.0126	0.0001
(ii) Total trips by household: emissions		
Model 6b (mean energy use HH / HZ):	0.2742	0.0001
Model 7b (mean emissions for HH/HZ):	0.0128	0.0001

Total number people in household:

Again, we might expect a fairly obvious relationship between the number of people in the household and total energy use. The statistical output shows that this is not the case however. The adjusted R-square indicates only a weak relationship, and it is apparent from the plot that the linear relationship between **x** and **y** is almost non-existent. (Appendix Two, Table of Plots 1).

Table 6.13: Effect of total number of people in household on energy use and emissions:

(i) Number of people in household: energy	**Adjusted R-square:**	**Significance:**
Model 6c (energy use for household):	0.0559	0.0001
Model 7c (mean energy use HH / HZ):	0.0083	0.0001
(ii) Number of people in household: emissions		
Model 6d (emissions for household):	0.0552	0.0001
Model 7d (mean emissions for HH/HZ):	0.0084	0.0001

Total number of motor vehicles available to the household:

This is a rather similar variable to car ownership, but includes vehicles owned by employers or people otherwise outside the household. The "vehicle ownership" variable was of course a classification variable, whereas this is continuous. As with that variable (submodels 4g, 4h, 5g and 5h) moderate casual relationships exist with **tlenergy** and **tlemisns** although this is much weaker for **engymean** and **emissnmn**. Plots of predicted values for **y** overlaid on a plot of **x** against **y** again show little linear relationship at either level of the analysis. (Appendix Two, Table of Plots 2).

Table 6.14: Effect of total number of vehicles available to household on energy use and emissions:

(i) Availability of vehicles: energy	**Adjusted R-square:**	**Significance:**
Model 6e (energy use for household):	0.1977	0.0001
Model 7e (mean energy use HH / HZ):	0.0466	0.0001
(ii) Availability of vehicles: emissions		
Model 6f (emissions for household):	0.1980	0.0001
Model 7f (mean emissions for HH/HZ):	0.0465	0.0001

Summary of regression analyses on household variables:

While **total trips** is a strong influence on energy use and emissions at the household level, this variable in not explicitly considered further in the overall analysis. This is not to discount the obvious importance it has on energy use and emissions, but rather is an acknowledgement of the means which planners have at their disposal to influence this. Strategies designed to lower demand for travel within cities which are likely to be successful will be those which aim to create conditions which favour fewer single purpose and a greater proportion of multi-purpose trips, as opposed to seeking directly to reduce the number of trips made. If these strategies work, a decline in trips per household should follow and thus also a corresponding reduction in energy use and greenhouse gas emissions.

The effect of total number of people in household is weak at the level of the individual household, and while the result is highly significant in terms of probability, the effect of either y variable is negligible at the homezone level.

Total vehicles available to the household while still only showing moderate explanatory value at the household level is of considerable interest when considered in the light of the analyses of variance of other variables related to car ownership and the need for their use. These two (class) variables are analysed further below.

Regression analyses of "proportional" variables; Model 8.

As the likelihood of performing at least one stepwise regression analysis was envisaged at an early stage of this study, the categorical variables analysed in the ANOVA analyses were also examined by converting them into new continuous variables. As discussed briefly early in this chapter, this was achieved by calculating the proportion of each group at the homezone level. For example homezone 901 records approximately 8, 12, 6, 36, 30 and 8 percent (all rounded) in each class of the variable **persnage**, so these become the values for the new variables **pragegr1** through to **pragegr6**.

Table 6.15: Summary statistics for Model 8 person-variables (submodels 1 to 21).

Submodel:	**New variable:**	**Adjusted R-square**	**Level of significance:**
8 (1)	Age 1	0.0071	0.2334
8 (2)	**Age 2**	0.0831	0.0119
8 (3)	Age 3	-0.0121	0.6196
8 (4)	**Age 4**	0.0527	0.0379
8 (5)	**Age 5**	0.0641	0.0245
8 (6)	**Age 6**	0.0784	0.0142
8 (7)	Employment status 1	-0.0148	0.7770
8 (8)	Employment status 2	-0.0024	0.3608
8 (9)	Employment status 3	0.0071	0.2329
8 (10)	Employment status 4	0.0448	0.0512
8 (11)	Employment status 5	0.0182	0.1461
8 (12)	Employment status 9	0.0314	0.0861
8 (13)	**Need car at work 1 (yes)**	0.2222	0.0001
8 (14)	**Need car at work 2 (no)**	0.2222	0.0001
8 (15)	Occupation group 1	0.0001	0.3202
8 (16)	**Occupation group 2**	0.0457	0.0495
8 (17)	Occupation group 3	-0.0125	0.6410
8 (18)	Occupation group 4	-0.0161	0.9921
8 (19)	Occupation group 5	0.0020	0.2921
8 (20)	Occupation group 6	0.0252	0.1102
8 (21)	Occupation group 7	-0.0020	0.3526

A total of 21 new person variables and 35 new household variables resulted from this procedure. These were then run as simple univariate regressions. Unlike the previous models, only energy use is modelled in this one, as it was by now quite apparent that the differences between energy use and emissions were rather minimal and there was obviously little to be gained from running an additional 56 submodels.

Inspection of the summary statistics included in Table 6.15 (page 94) show that the majority of these "proportional variables" do not meet the 5% significance level. As with the previous regression tables, the adjusted R-square and significance levels only are presented here. While the majority of these cannot be considered to have any explanatory power whatsoever, a few from each group are significant at the 5% level, while those related to car use and ownership are all significant at the 0.01% level.

Each of the variables which emerged as significant was plotted to allow a visual examination of linearity. In the case of the four age variables identified as significant, linearity was at best weak, as in submodel 8(4) (**age group 4**; proportion age 20-39 years). This submodel is strongly influenced by the presence of a few outliers (Appendix Two, Table of Plots 3). Removal of the highest mean energy user and five or so observations at the lower right hand side of the plot (a high proportion of 20-39 year olds and low energy use) would result in a grouping which is almost completely non-linear in nature. Sorting the variable **age group 4** by **engymean** and inspecting the output confirms the influence of the highest and lowest energy users. The first five observations are:

OBS	HOMEZONE	PROPAGE4	ENGYMEAN
1	905	61.4679	46.612
2	910	48.7500	47.452
3	906	48.9362	56.686
4	911	61.8421	64.742
5	951	30.4348	65.063

and at the bottom of the output,

63	941	34.9057	236.132
64	932	38.5057	274.497

Observation 63 is in the main, oval-shaped grouping of observations in this plot, but is included here to show that the homezone with the highest energy use, the upper-most outlier on the plot, is clearly homezone 932, which was identified in Chapter Five as the highest energy user. Homezones 905, 906, 910, 911 and 951 are the lowest energy users, demonstrating the influence of both the lowest and to a lesser extent, the highest values on the shape of the plot. The other **age-proportion** variables are all similarly weak in terms of linearity.

The next significant submodels are the two **need car at work** variables (Figure 6.8, page 97). These produce exactly the same adjusted R-square value and level of significance, which is hardly surprising as they are virtually the same variable expressed in two different ways. While the plots exhibit a much stronger linearity, they also exhibit a larger spread for the higher values for **needcar1** ("yes") and lower values in the case of **needcar2**. This indicates a likely violation of one of the standard assumptions about data used in regression analyses, namely that variance in the data is evenly distributed. This is known to statisticians as ***homoscedasticity*** (Pledger 1997, 113). While it is often detected through plotting residuals it is easily detected in the x-y variable plots here. The residual of each variable is the difference between the actual and predicted value. Plotting the residuals gives a band arranged about a the predicted values which are plotted as a horizontal line. In these plots the predicted values are a diagonal line, so this inequality of variance or ***heteroscedasticity*** is also apparent on a plot of dependent variables against independent variables. (Unfortunately the plot of predicted variables was not saved at the time these plots were run, so cannot be shown here. However it is included in plots later in this chapter which demonstrate this.)

One solution to non-linear relationships between the **x** and **y** variables is transform either or both variable through using the square, square root or log of its actual value. This is appropriate where a plot of **x** against **y** shows definite curvature. The degree and direction of the curvature gives clues as to which transformation is likely to provide the best fit (Ott 1993, 454-459). Such transformations are not appropriate where heteroscedasticity is apparent, and it is possible that weighted regressions would be more appropriate for such data (Snedecor and Cochran 1988, 352). This technique was used by Soot and Sen (1979) in their study of travel data from Chicago. It was not attempted here however due to the writers lack of experience with these somewhat more advanced techniques.

The last "person-proportional" variable is occupation group 2, administrators and managers. Again, examination of the plot reveals little obvious linearity, with homezone 932 again exerting considerable influence on the predicted values (Appendix Two, Table of Plots 4).

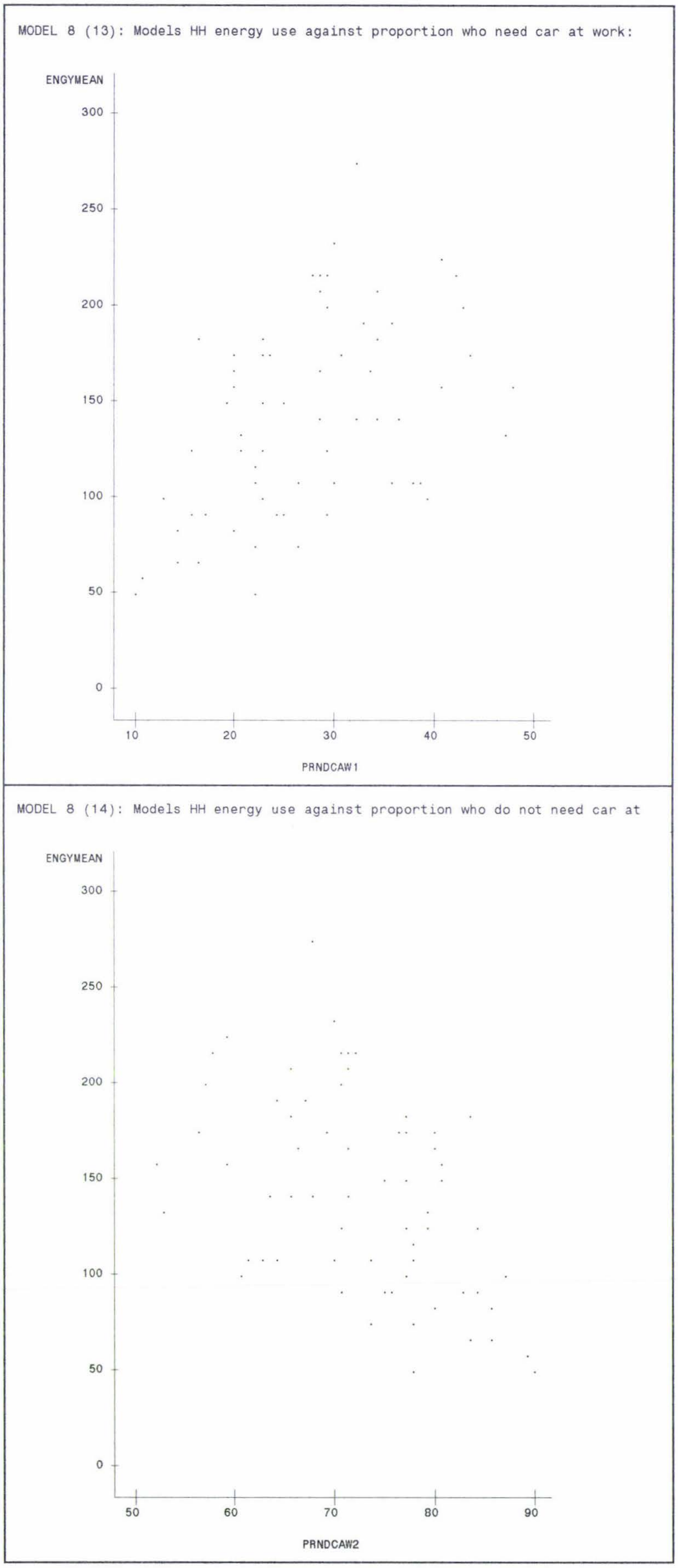


Figure 6.8 Plots of submodel 8 (13) and 8 (14), effect of requirement for car at work on mean energy use (MJ).

Table 6.16: Summary statistics for Model 8 person-variables (submodels 22 to 56):

Submodel:	New variable:	Adjusted R-square	Level of significance:
8 (22)	**Income group 1**	0.0944	**0.0078**
8 (23)	Income group 2	0.0318	0.0846
8 (24)	Income group 3	-0.0125	0.6400
8 (25)	**Income group 4**	0.0546	**0.0351**
8 (26)	Income group 5	0.0039	0.2691
8 (27)	Income group 6	-0.0010	0.3370
8 (28)	Income group 7	-0.0029	0.3696
8 (29)	**Household category 1**	0.0869	**0.0103**
8 (30)	Household category 2	0.0023	0.2889
8 (31)	Household category 3	0.0428	0.0552
8 (32)	Household category 4	-0.0153	0.8184
8 (33)	Household category 5	-0.0083	0.4900
8 (34)	Household category 6	0.0239	0.1160
8 (35)	Household category 7	0.0394	0.0631
8 (36)	Household category 8	-0.0000	0.3215
8 (37)	Household category 9	-0.0064	0.4409
8 (38)	Household category 10	-0.0054	0.4185
8 (39)	**Household category 11**	0.0584	**0.0304**
8 (40)	Household category 12	-0.0136	0.6938
8 (41)	Household category 13	-0.0159	0.9049
8 (42)	**Household category 14**	0.1704	0.0004
8 (43)	Household category 15	0.0362	0.0715
8 (44)	Household category 16	-0.0083	0.4904
8 (45)	Household category 17	0.0164	0.1570
8 (46)	Household category 18	-0.0045	0.3993
8 (47)	Household category 19	-0.0020	0.3526
8 (48)	**Household category 20**	0.0580	**0.0309**
8 (49)	Household category 21	0.0111	0.1958
8 (50)	Household category 22	-0.0160	0.9222
8 (51)	Household category 23	0.0028	0.6762
8 (52)	Household category 24	-0.0155	0.8410
8 (53)	**Car ownership 0**	0.3456	**0.0001**
8 (54)	**Car ownership 1**	0.2997	**0.0001**
8 (55)	**Car ownership 2**	0.3568	**0.0001**
8 (56)	**Car ownership 3 or more**	0.4650	**0.0001**

Turning to the proportional household variables, two of the seven income group variables and four out of the 24 household categories are significant at the 5% level while all four car ownership variables are significant at the 0.1% level.

Heteroscedasticity is again apparent in several groups including submodel **8.22** (income group 1 - One adult, age 65 or over) with a negative slope and all of the car ownership submodels (8.53 to 8.56). Several submodels exhibit little in the way of recognisable linear patterns, including **8.25** (income group 4; one adult, not employed, under age 65); **8.48** (household category 20; three or more adults, all employed) and to a lesser extent **8.39** (household category 11; two adults, one employed). The plot for **8.42** (household categories 14**;** two adults, one employed, with children age 5-14) is somewhat more recognisably linear (Refer Appendix Two, Table of Plots 5 and Table of plots 6).

It is the car ownership variables which are of particular interest however as they individually explain up to 46 percent of total variation and with a 0.01% level of significance these submodels confirming the pivotal role which car ownership plays in overall energy use. Interestingly, the plots show that the proportion of households owning one vehicle is negatively correlated with energy use while this changes to a positive relationship with the proportion of two vehicle households (Figure 6.9).

Summary of results from proportional variables:

While several of the variables from both "person" and "household" groups are of some interest, vehicle ownership is obviously the key area shown by these analyses to be of importance in overall energy use. A number of other variables were also extracted from the survey data, and the next section considers these.

Regression analyses on additional variables derived from survey data:

Examination of the mean household energy use and greenhouse gas emissions at the homezone level suggested a number of additional variables which could be derived from the original survey data through relatively straight forward programming. The cluster of "high performing" zones close to the centre of Wellington city suggest that close proximity of people's homes to their places of work, and perhaps to their other daily activities in this area, may help to explain this.

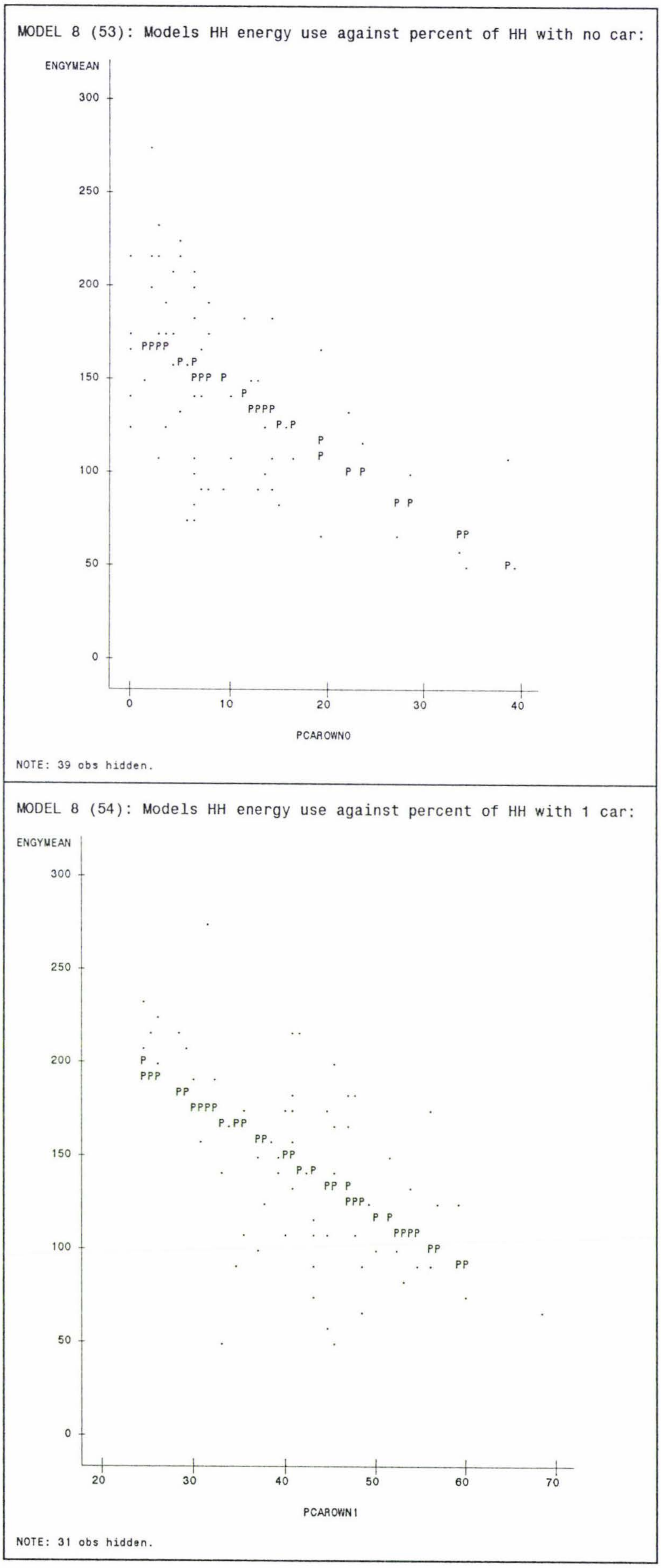
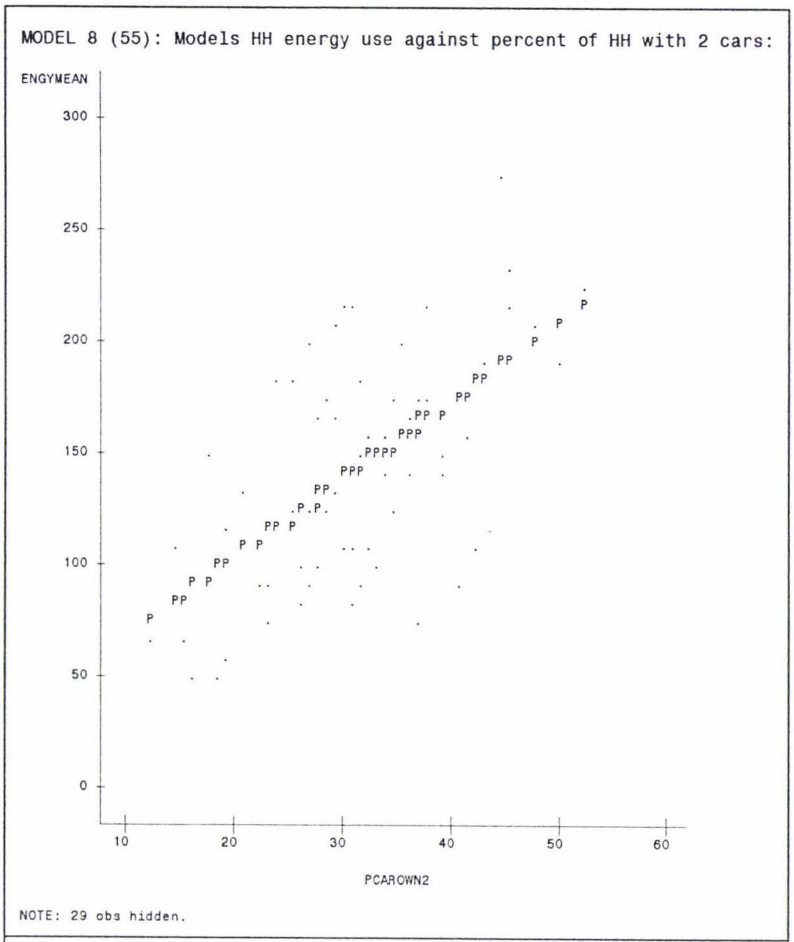


Figure 6.9: Plots of submodels 8(53) and 8(54), effect of car ownership levels on mean energy use.



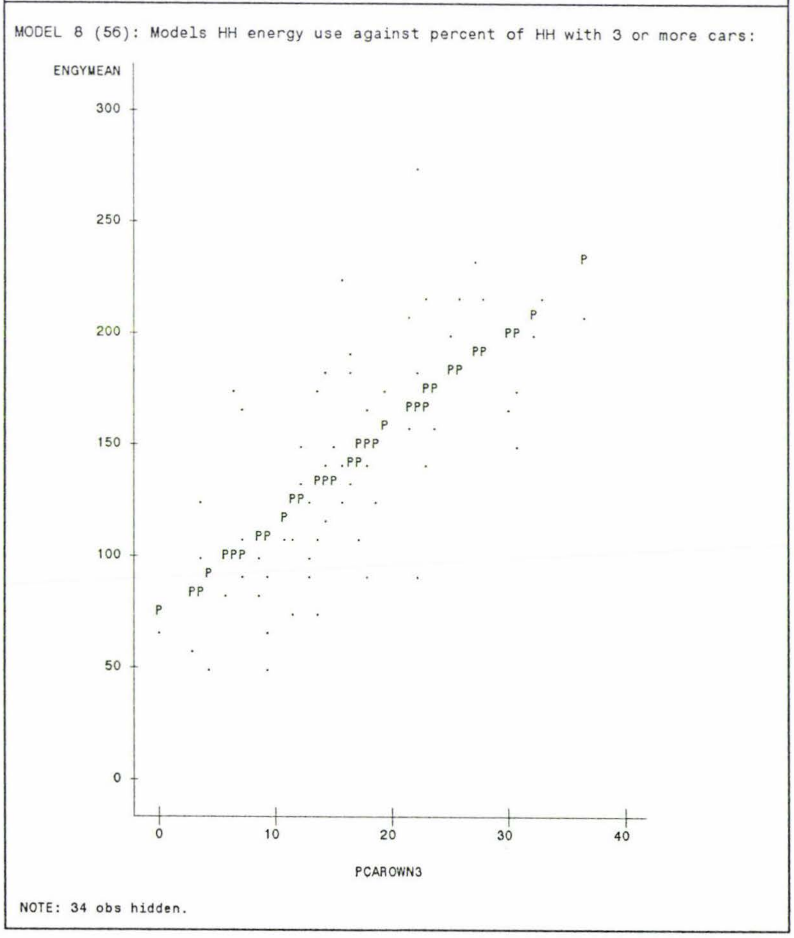


Figure 6.10: Plots of submodels 8(55) and 8(56), effect of car ownership levels on mean energy use.

Two zones outside the centre of Wellington city appear in the lowest 20 percent bracket for energy use and emissions. These are homezones 951 (Naenae, Lower Hutt) and 927 (Elsdon and central Porirua). Two southern Lower Hutt homezones (954: Petone and 955: Alicetown) were also amongst the best performers of the next twenty percent bracket.

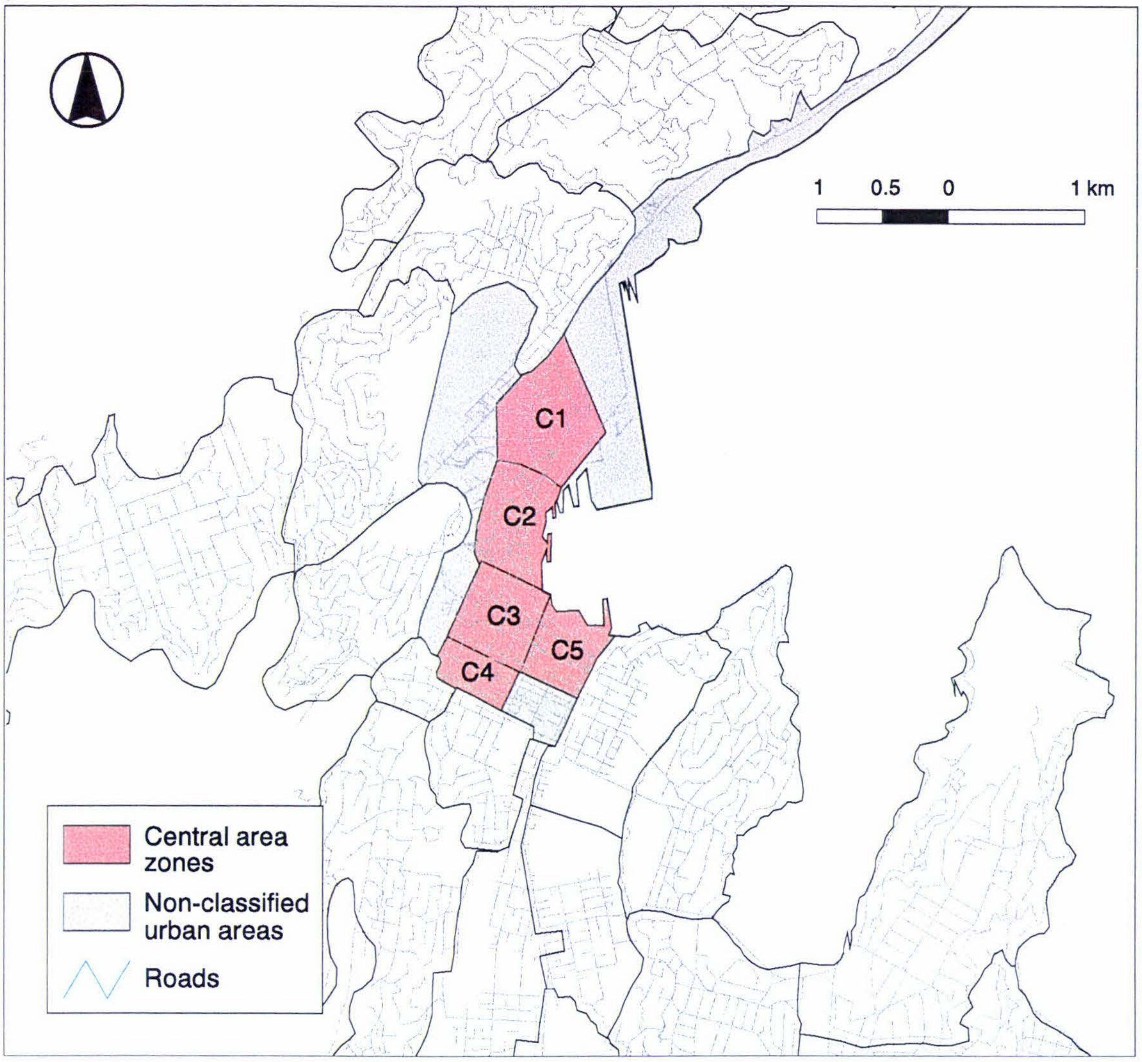
While Naenae is further from the centre of Lower Hutt than other zones which are less energy efficient, this area does have a well-established local shopping centre which may provide a large percentage of local employment. Elsdon is close to the centre of Porirua and also to some industrial areas between its residential area and the nearby city centre, while the two southern Lower Hutt zones both enjoy good rail and road access to central Wellington while also being close to employment centres in both Petone and central Lower Hutt.

This suggests two further variables for analysis. These are the distances to central Wellington and the mean distance to work for each homezone. Distances to central Wellington were derived using the original zone centroid to zone centroid distances. The fact that most of the original zones had been amalgamated presented a small problem in terms of new zone cetroids. This was resolved by taking a mean of the old interzone distance. Zone 902 for example, was an amalgamation of zones 3 and 4 of the original survey. While 76 households were surveyed from zone 3 only three households were surveyed from zone 4. Interzone distances to central Wellington were therefore weighted in this proportion in favour of the distance for old zone 3.

Choosing an appropriate point as the centre of Wellington City was a cause for some conjecture, so rather than choose one zone arbitrarily as the central point an analysis was run against five central zones. Unlike the residential homezones these had not been amalgamated for the first part of the analysis.

The analysis of mean journey-to-work distances was easily repeated on other trip purposes, so this was run across all trip types and also over non-home based trips. (This includes all trips which did not begin or finish at the respondents' homes, regardless of their purpose.) For mean trip distance by trip purpose, the equation related to the proportions from each "old" zone counted for each trip purpose.

As with Model 8, only **engymean** has been used as the dependent variable in the models which follow.



Map 4: Central Wellington zones used in Model 9 analyses for purpose of defining mean distance from each homezone to the central city.

Table 6.17: Summary statistics for Model 9, distance from homezones to central Wellington zones:

New variable:	Adjusted R-square	Level of significance:
Mean distance to zone C1:	0.2813	0.0001
Mean distance to zone C2:	0.2874	0.0001
Mean distance to zone C3:	0.2927	0.0001
Mean distance to zone C4:	0.3032	0.0001
Mean distance to zone C5:	0.2990	0.0001

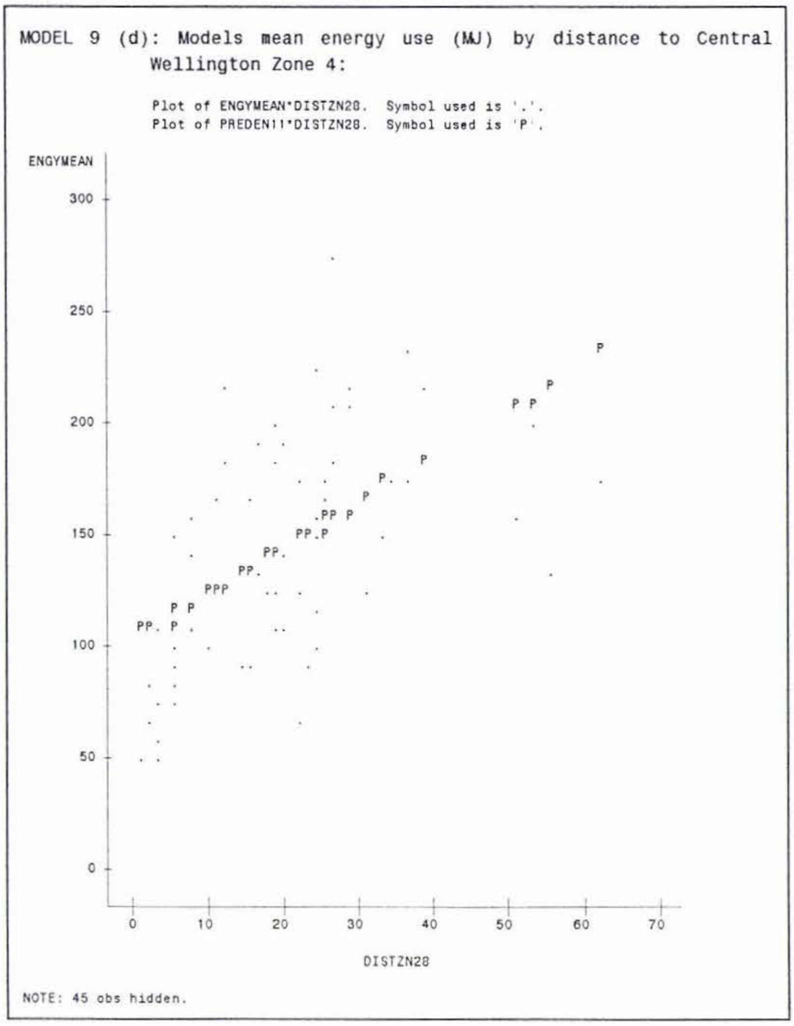


Figure 6.11: Plot of submodel 9 (d), effect of distance to central Wellington on mean energy use.

Regression analyses on distance to central Wellington; Model 9:

The five destination zones for this analysis were centred approximately on the railway station in the northern end of the CBD (C1), at the southern ends of Lambton and Customhouse Quays (C2), the area between Manners and lower Dixon Streets (C3), upper Cuba Street (C4) and Courtenay Place (C5). Adjusted R square values infer moderate explanatory value. Central zone C4 exhibits the highest value at about 30%. This zone is unlikely to be the work destination for most respondents who work in the CBD, and its location is perhaps an indication that a weighted regression would result in a higher R-square for one of the other zones.

Some heteroscedasticity is displayed in plots of the **x** against **y** variables. In examining the plots it should be noted that the variable names for the **x** variables refer to the original zone numbers used in the 1988 survey and that these have been renumbered here.

Regression analyses on mean distances for each trip purpose; Model 10:

This group of variables includes the mean length by homezone of trips between home and place of work. The program written to produce this variable was then modified to produce variables for other home-based trips for each purpose (trips either beginning or ending at the respondents home) and non-home based trips for all purposes. The data sets for each analysis were compiled by deleting all trips which did not conform to the purpose being analysed, and then outputting one trip per respondent for each submodel. This avoided possible skewing of means that could have resulted from counting every trip for the few respondents who made many trips for the same purpose. The extreme example of this is people who, from comparison of the coded and uncoded trip files, appear to work in occupations such as couriers and taxi drivers. Their work related trips are coded as either "work" or "employers business". In a homezone with close to the minimum number of households (30), this could influence the mean distances for these trip types as a few such respondents recorded more than 20 trips for this purpose. If most other workers in the homezone made only two such trips for the day, including every trip would then result in the respondent with a large number of trips having an undue influence on the mean trip length.

This approach also results in only one distance for a journey to work being included in the mean for any respondents who had more than one job. Similarly, only one trip for each respondent was output for shopping, recreation and so on.

Table 6.18: Trips purpose classifications used in Model 10.

Purpose of trip (**origpurp** and **origpurp**):	
Home	1
Permanent place of work	2
On employers business	3
Attending full-time education	4
Daily shopping	5
Durable shopping	6
On personal business	7
Social, sport, recreation	8

All submodels are significant at the 5% level, and several show significant influence on energy use. Mean work trip is particularly important, with an adjusted R-square indicating that this explains close to 50 percent of the variation in energy use. Personal business and non-home based trips also appear to have strong explanatory value. The all encompassing nature of the "non-home based" variable is however perhaps somewhat vague for purposes of measuring relative energy and emissions performance as it is likely to be closely related to overall car use.

Recognisably linear patterns emerge in the plots for each submodel, all exhibiting some degree of heteroscedasticity.

While it is difficult to envisage any planning measures that could be taken to reduce demand for "personal business" and "non-work based" trips categories, the work trip sub-model confirms the premise cited in much of the literature reviewed in Chapter Four that proximity of work and housing is has a strong bearing on transport energy use. Although there are difficulties with the assumption that people will necessarily locate close to their workplaces, this sub-model lends support to the proposals to mix compatible urban land-uses.

Table 6.19: Effect of mean trip lengths for homezone by trip purpose on ENGYMEAN:

Submodel:	Mean distance by trip purpose:	Adjusted R-square:	Level of significance:
10 (a)	Work:	0.4990	0.0001
10 (b)	"Employers business":	0.1953	0.0002
10 (c)	Full time education:	0.1222	0.0027
10 (d)	Daily shopping:	0.0889	0.0112
10 (e)	Durable shopping:	0.1435	0.0030
10 (f)	Personal business:	0.3047	0.0001
10 (g)	Social, sport, recreational:	0.1462	0.0011
10 (h)	Non-home based trips:	0.3700	0.0001

Analyses of modal split; Model 11:

This group of analyses modelled mean distance travelled by various modes against both energy use and emissions, first for all trips and then for trips to work only. As Models 1 to 7 have provided ample evidence that there is little difference in energy use and emissions, summary statistics for the two dependent variables are presented together in Table 6.21. The separation shown in these tables is between all trips and work trips only, rather than between energy and emissions as for the earlier models.

The modal split variables used here were derived from the Wellington Regional Council's survey simply by summing the distance travelled by each mode. This is a reasonably simple process using SAS, although as with the much of the analysis in this thesis it did require that the programming language be learned first. Summing distances for each trip or trip leg avoided the classification difficulties that might otherwise arise with allocating multi-leg trips to appropriate modes. Some researchers have introduced combined modes for some analyses, but the approach used here made this unnecessary (for example Newman, Kenworthy and Lyons in their 1985 study of Perth travel data, for the purposes of their energy calculations).

Table 6.20: Class values used in **tripmode** variable.

These were used as a basis for new modal split variables in Model 11.

Car, van or motorcycle driver	1
Car, van or motorcycle passenger	2
Bus passenger	3
Work's transport	4
School bus passenger	5
Train passenger	6
Other motorised	7
Walk	8
Bicycle	9

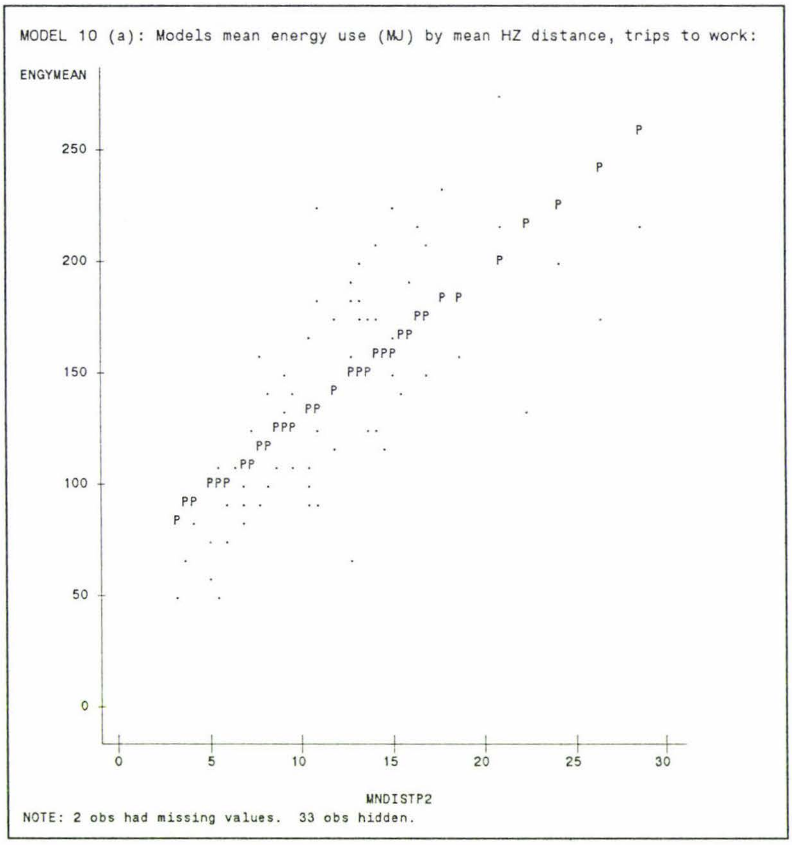


Figure 6.12: Plots of submodel 10 (a); effect of mean distance to work on mean energy use. (MJ).

In addition to separate analyses for car drivers and passengers (Modes 1 and 2), these two modes were included combined for analysis as Mode **C**. Mode 5, school bus, was not analysed by itself but instead included in an analysis with scheduled bus services (Mode 3) as Mode **B**. Mode 7, "other motorised" was excluded from this model due to the uncertainties as to the vehicles types included in this group. The data was examined for some clues about this, as the harbour ferry and Kelburn cable-car (a steep grade tram type vehicle) were two public transport modes which were not specifically identified in the survey. Few mode 7 trips passed through the appropriate zones for these to be of any significance in this analysis however. Inspection of uncoded survey address data also gave no indication that either of these forms of transport were included there.

Regression modelling shows that modal split for cars results in a moderate influence on energy use and emissions, as might be expected from analyses in previous models. Proportion of travel by scheduled bus services also has an appreciable explanatory effect, although combined with school bus services the effect is insignificant. Surprisingly, the extent of rail use has no bearing at all on energy use or emissions.

The strongest effect however does not result from any of the motorised modes of transport, but from the proportion of distance travelled by walking. This explains about 47 percent of variation for both dependent variables. Cycling (mode 9) was also tested, but without any significant result. Walking and cycling combined (mode **wabi**) show a moderate effect on energy use and emissions, with about 37% of variation explained by this variable. However comparison of the summary statistics for walking and cycling shows that the submodel of the two combined appears to result effectively in a "downgrading" of the result for walking.

Table 6.21: Summary data for Model 11; analyses of effect of model split on energy use and emissions.

Submodel:		**Adjusted R-square, energy use:**	**Level of significance, energy use:**	**Adjusted R-square, emissions:**	**Level of significance, emissions:**
Modal split, proportion of travel by each mode for homezone for all trips:					
11 (1)	**Mode split 1**	0.2494	0.0001	0.2531	0.0001
11 (2)	**Mode split 2**	0.0272	0.1017	0.0276	0.1000
11 (3)	**Mode split C (1+2)**	0.3588	0.0001	0.3637	0.0001
11 (4)	**Mode split 3**	0.2812	0.0001	0.2696	0.0001
11 (5)	**Mode split B (3+5)**	0.0751	0.0161	0.0679	0.0212
11 (6)	**Mode split 4**	-0.0135	0.6889	-0.0134	0.6855
11 (7)	**Mode split 6**	-0.0086	0.4991	-0.0113	0.5881
11 (8)	**Mode split 8**	0.4738	0.0001	0.4747	0.0001
11 (9)	**Mode split 9**	-0.0128	0.6529	-0.0127	0.6461
11 (10)	**Mode split WABI (8+9)**	0.3705	0.0001	0.3716	0.0001
Modal split, proportion of travel by each mode for homezone, work trips :					
11 (11)	**Mode split 1**	0.1999	0.0001	0.2027	0.0001
11 (12)	**Mode split 2**	0.0818	0.0125	0.0844	0.0114
11 (13)	**Mode split C (1+2)**	0.3093	0.0001	0.3147	0.0001
11 (14)	**Mode split 3**	0.2305	0.0001	0.2211	0.0001
11 (15)	**Mode split B (3+5)**	-0.0015	0.3450	-0.0016	0.3459
11 (16)	**Mode split 4**	-0.0153	0.8204	-0.0152	0.8159
11 (17)	**Mode split 6**	-0.0088	0.5046	-0.0111	0.5807
11 (18)	**Mode split 8**	0.3456	0.0001	0.3451	0.0001
11 (19)	**Mode split 9**	0.0044	0.2625	0.0043	0.2636
11 (20)	**Mode split WABI (8+9)**	0.1921	0.0002	0.1910	0.0002

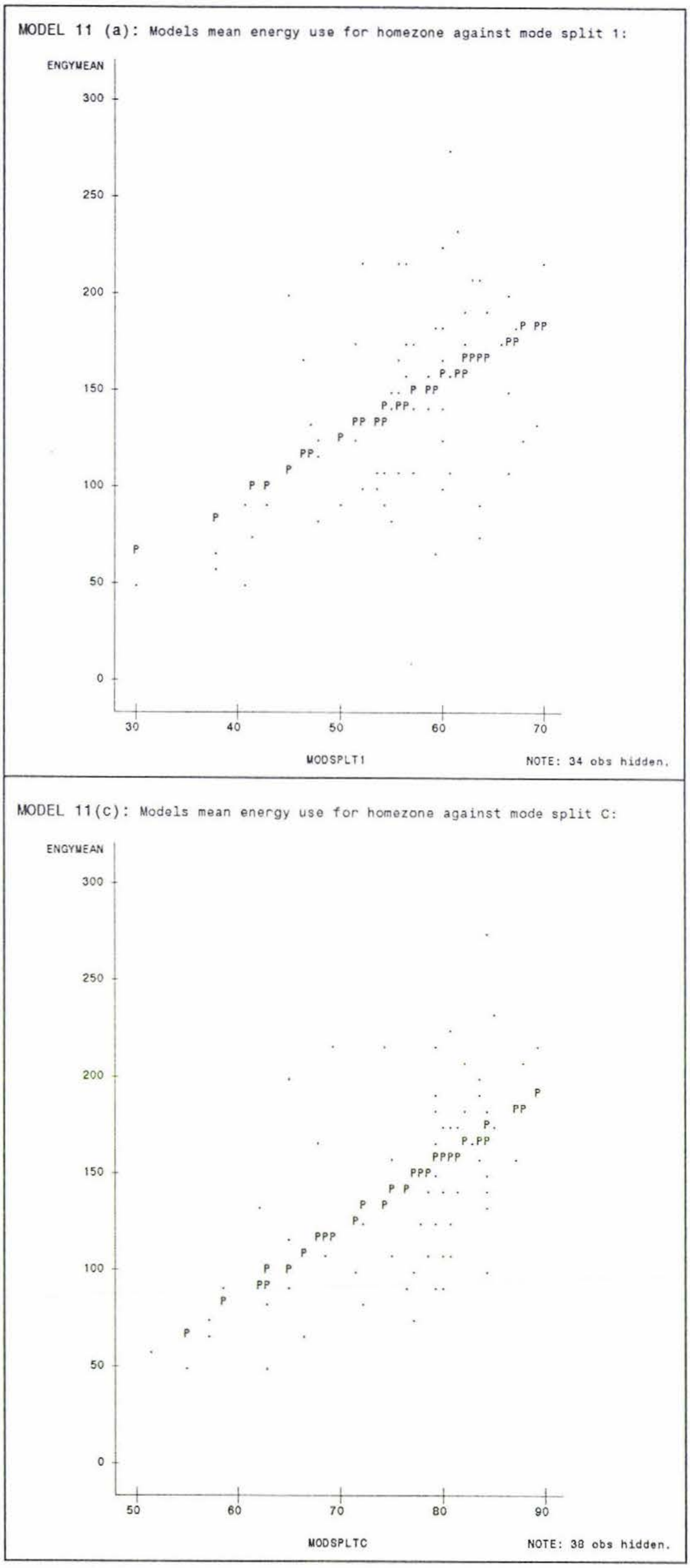


Figure 6.13: Plots of submodels 11 (a) and (c); effect of modal split for car drivers and all car trips on mean energy use (MJ).

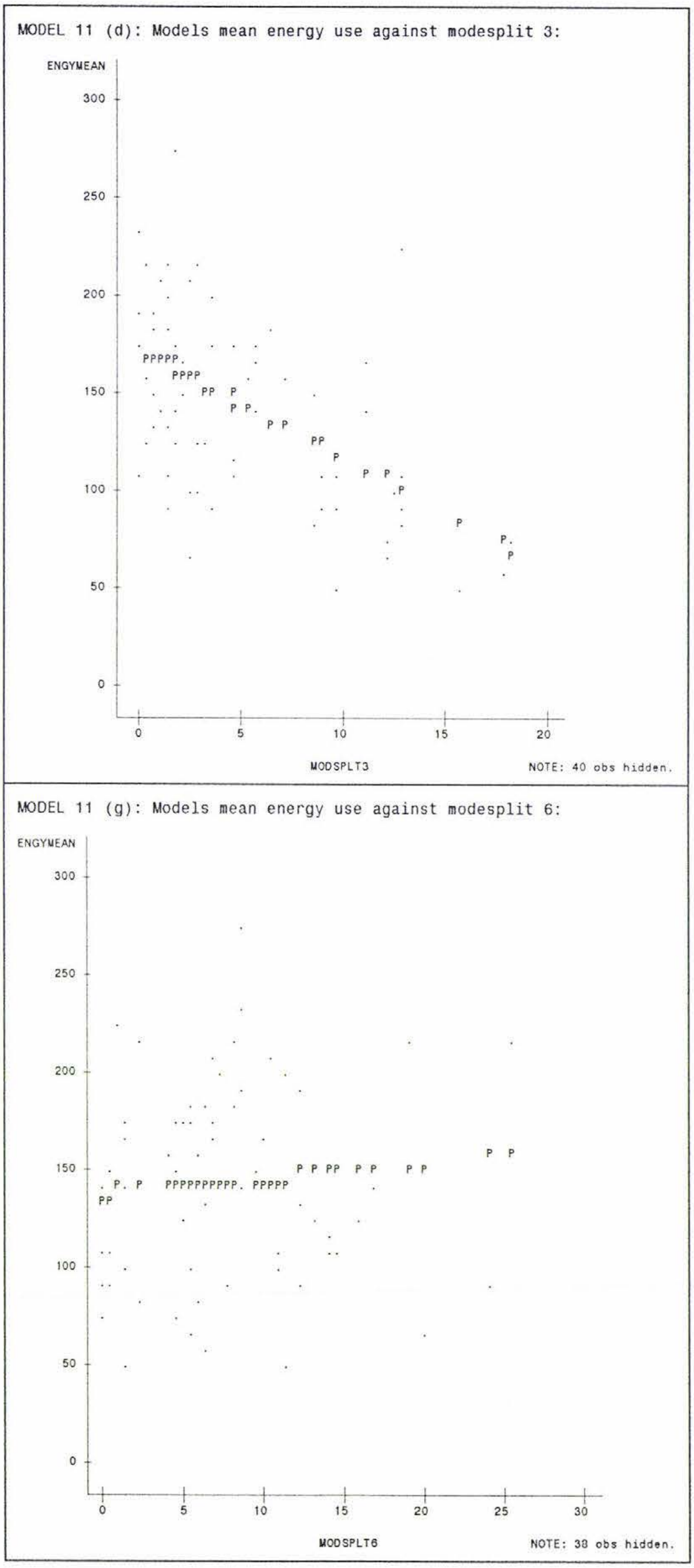


Figure 6.14: Plots of submodels 11 (d) and (g); effect of modal split for scheduled bus and rail services on mean energy use (MJ).

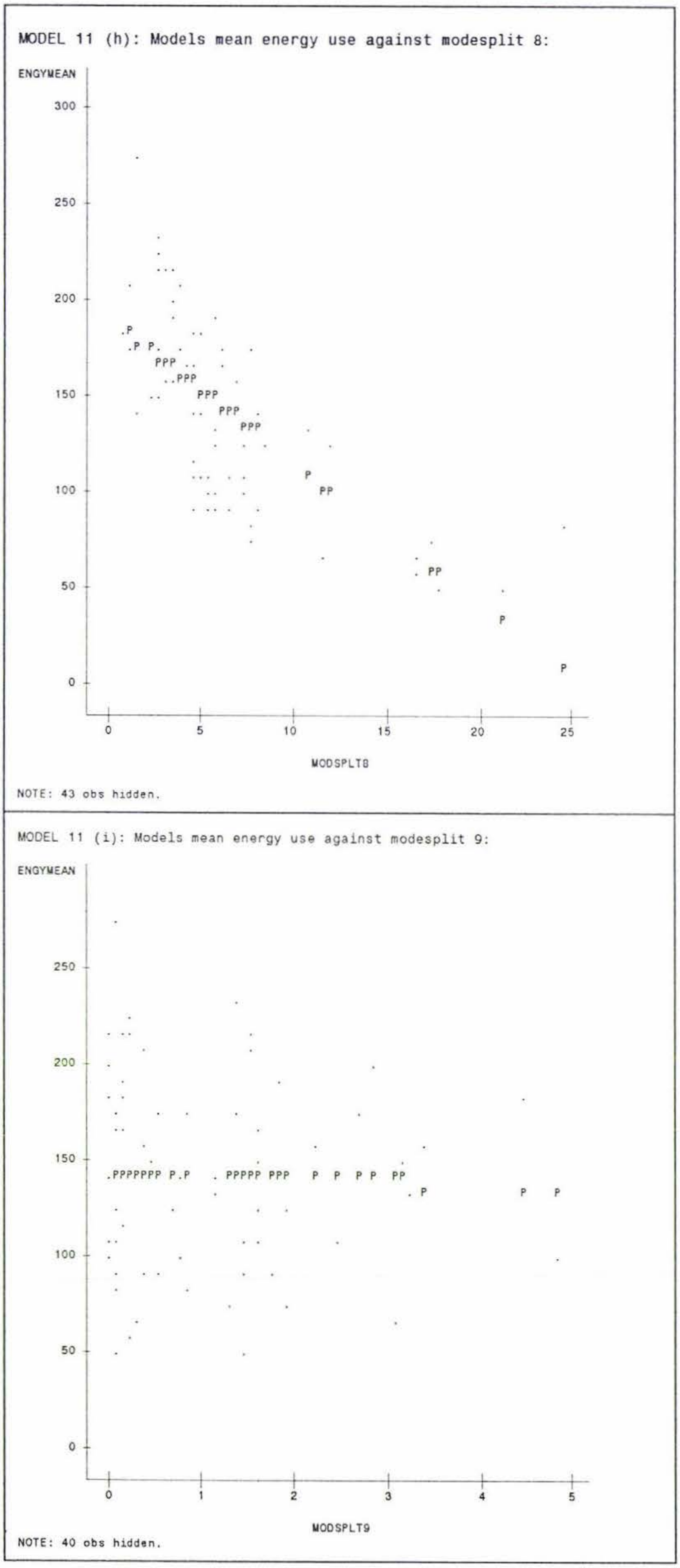


Figure 6.15: Plots of submodels 11 (h) and (i); effect of walking and cycling (analysed separately) on mean energy use (MJ).

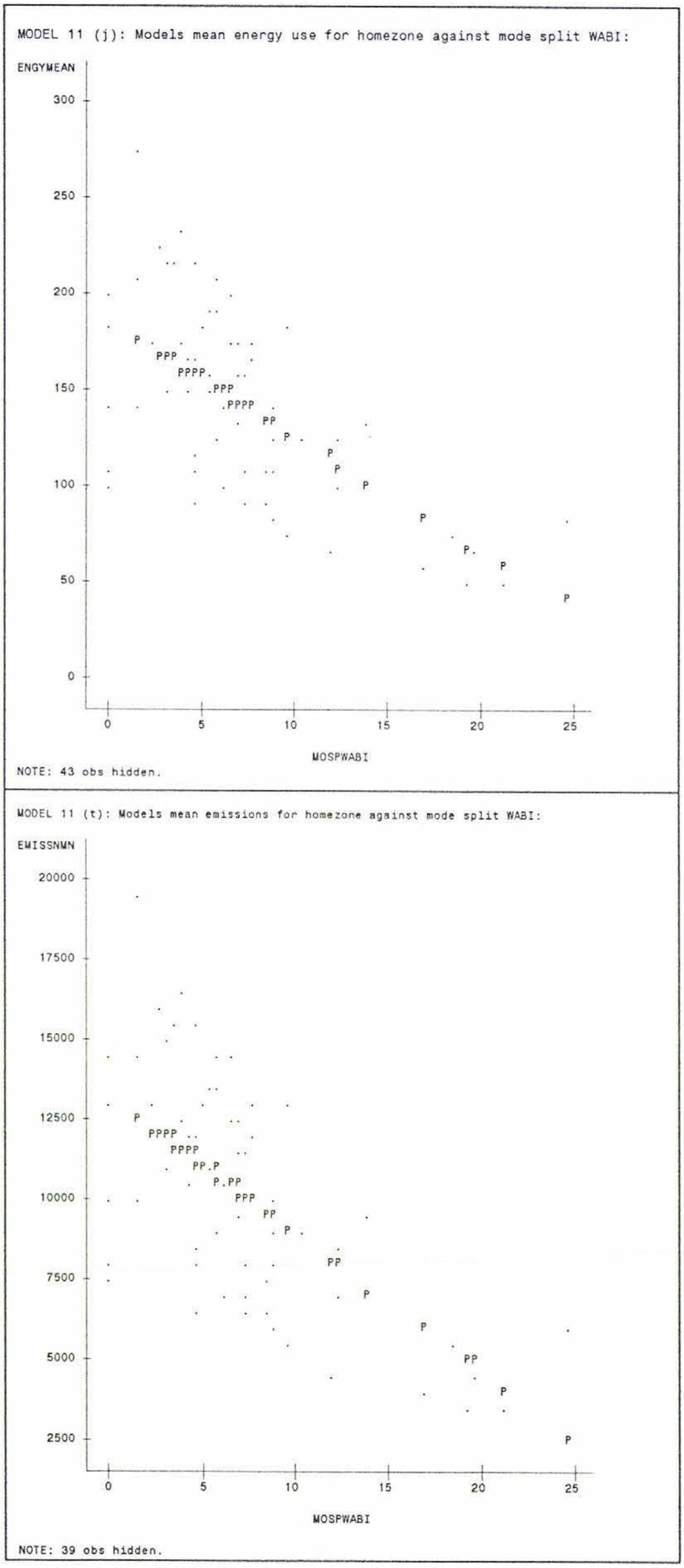


Figure 6.16: Plots for submodels 11 (j) and (t); effect of combined modal split for walking and cycling on mean energy use (MJ) and emissions (g/CO_2 equivalent). Note the similarity of the patterns of plotted values for the alternate dependent variables.

Maps of modal split based on Model 11 input data:

Several maps have been produced using input data used in Model 11 to show modal split for a selection of the models tested here. Those mapped include car drivers and passengers (mode C), bus (mode 3), suburban rail, walking, cycling and a combination of these two non-motorised modes (mode **wabi**). The maps are based on equal intervals across the range of the split for each mode.

The maps are included after the results of the next analysis, Model 12. The maps are (with page references):

Density variables; Model 12:

This model analysed the effects of both population and dwelling densities in accounting for energy and emissions. As discussed in Chapter Five, the densities calculated are representative of each zone rather than covering all of each zone.

Table 6.22: Models density variables against mean household energy use and emissions:

Submodel:	Mean energy use (HH/HZ):	Adjusted R-square, energy use:	Level of significance, energy use:	Adjusted R-square, emissions:	Level of significance, emissions:
12 (1)	**Population density for zone**	0.2650	0.0001	0.2663	0.0001
12 (2)	**Dwelling density for zone**	0.3229	0.0001	0.3243	0.0001

The four submodels all show an inverse relationship between **x** and **y** variables. The effect is at best moderate however, with dwelling density providing more explanatory power than population. While this offers some support for the applicability to the local situation of work by researchers such as Guest and Cluett (1976), Newman Kenworthy and Lyons (1985) and

Newman and Kenworthy (1989), this does not emerge as one of the most important variables in the overall analysis in this thesis.

One possibility for this discrepancy between these results and those of other researchers is the possibility that the method used to find these densities may have eliminated too much open space from some of the measurements. While using sample meshblocks as a way of calculating densities is likely to be very accurate in completely urban zones, density of those at the periphery of the region were probably somewhat overstated by the approach taken. Zones 934, 936, 938 and 939 are all non-contiguous, reflecting the fact that patches of residential development there are separated by rural land. As with other zones only completely built-up meshblocks were selected for use in the density calculations, whereas the largely rural character of the areas would have justified retaining the meshblocks which are mainly of as well. It was a case here of where to draw the line in deciding between urban and periurban areas. One way around the problem would be to simply eliminate the areas in doubt from the analysis.

Newman and Kenworthy (1989) considered that 30 persons per hectare was a breakpoint in supporting public transport services. Fourteen zones in this analysis have population densities equal to or exceeding this figure. While these are mainly zones with "low energy" characteristics, several are close to the centre of Wellington and are shown in the Model 11 analysis to have a high mode share for walking. These are listed in Appendix One.

Although density variables were not considered further here, this suggests that further analysis with partly rural zones eliminated would be worthwhile.

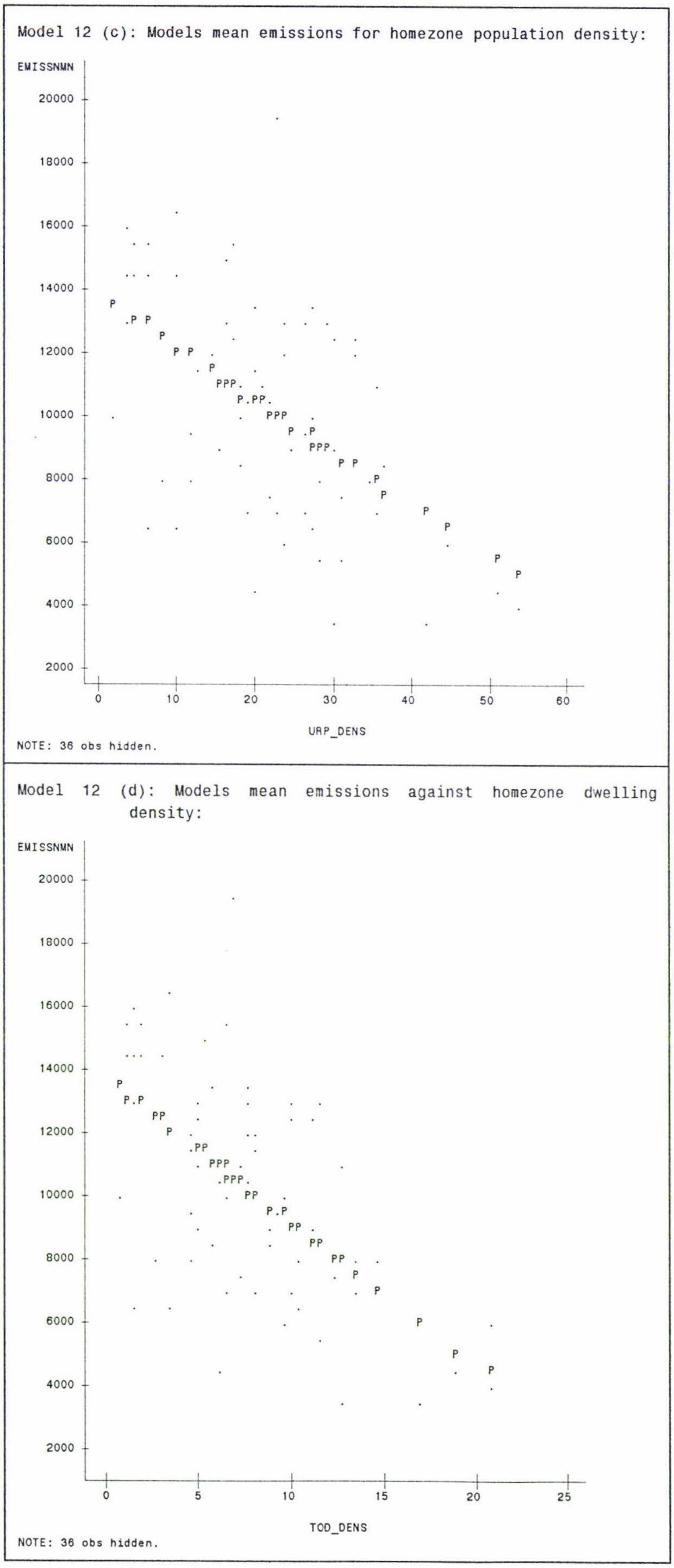
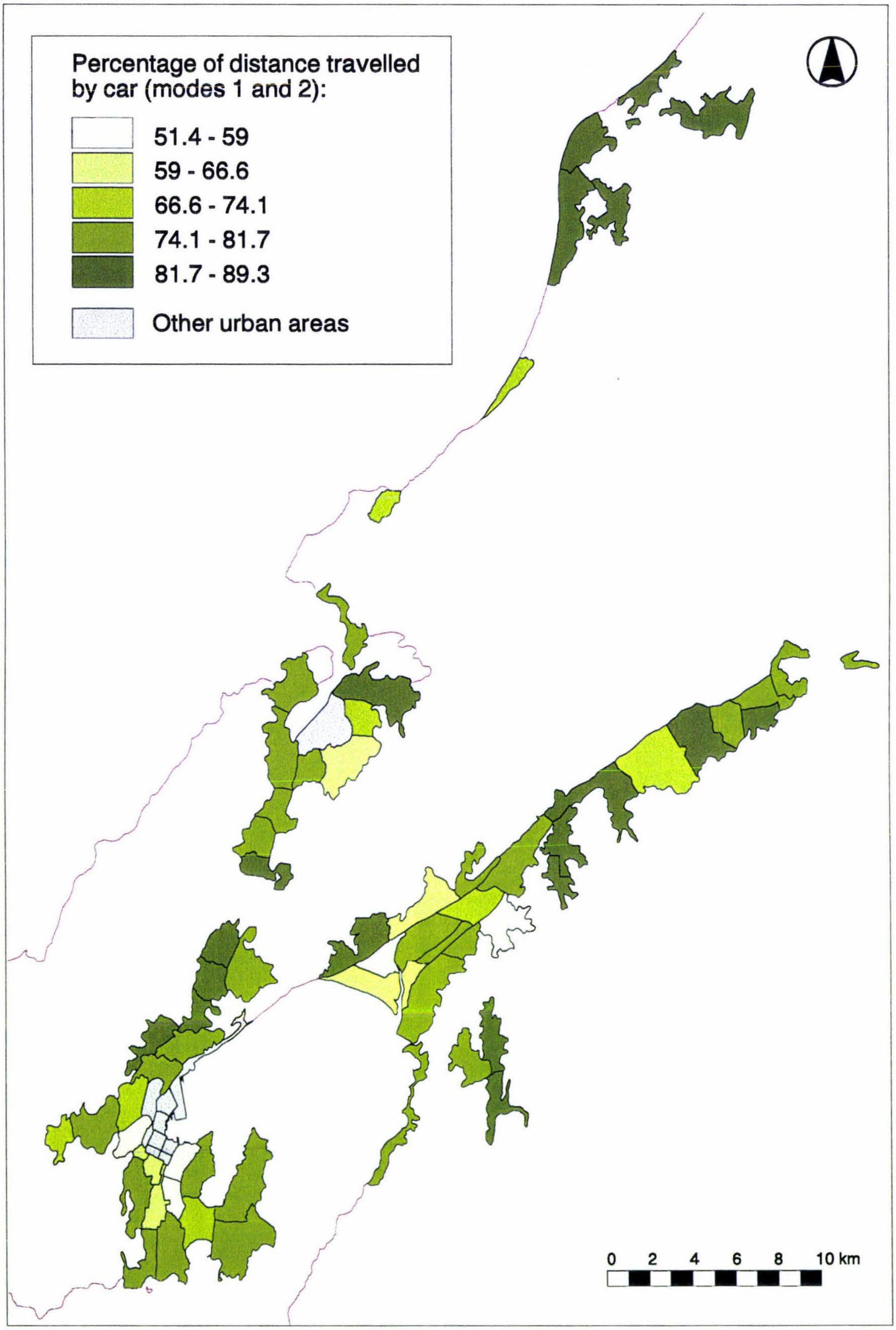
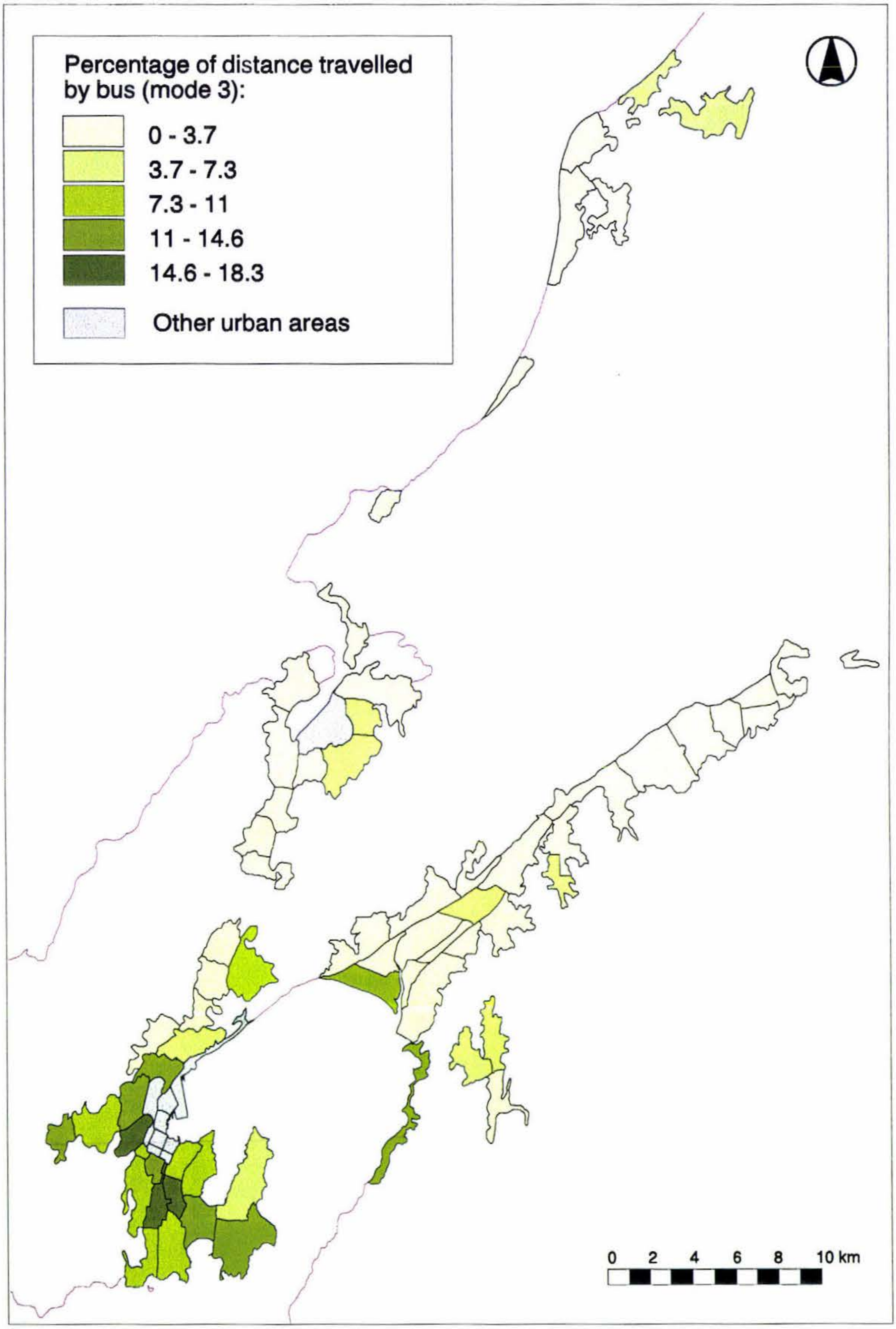


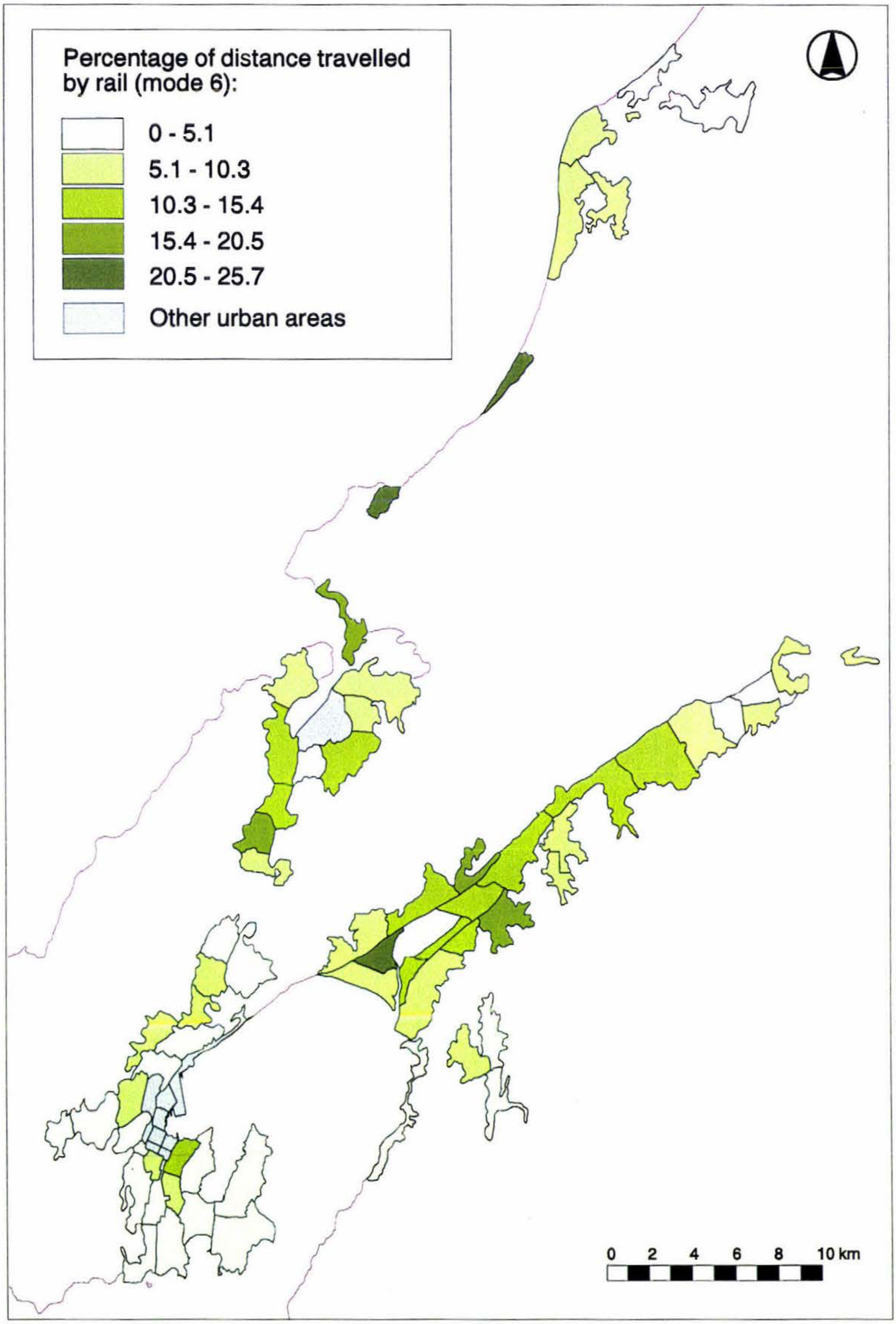
Figure 6.17: Plot for submodels 12 (c) and (d); effect of population and dwelling densities on mean household emissions (g/CO_2 equivalent) for homezone.



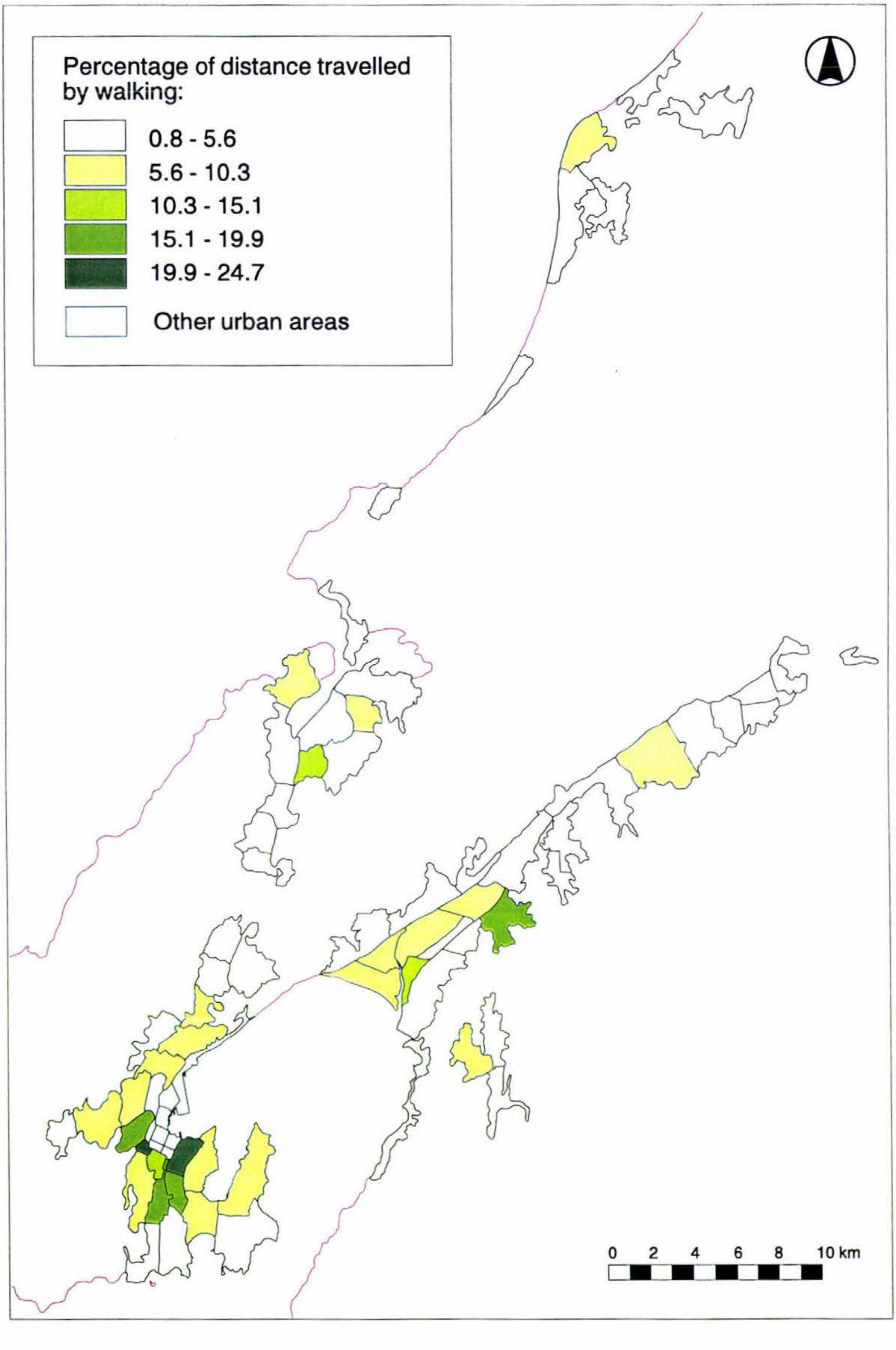
Map 5: **Car use as a proportion of total distance travelled for residential areas in the Wellington region; Homezone modal split from 1988 survey.**



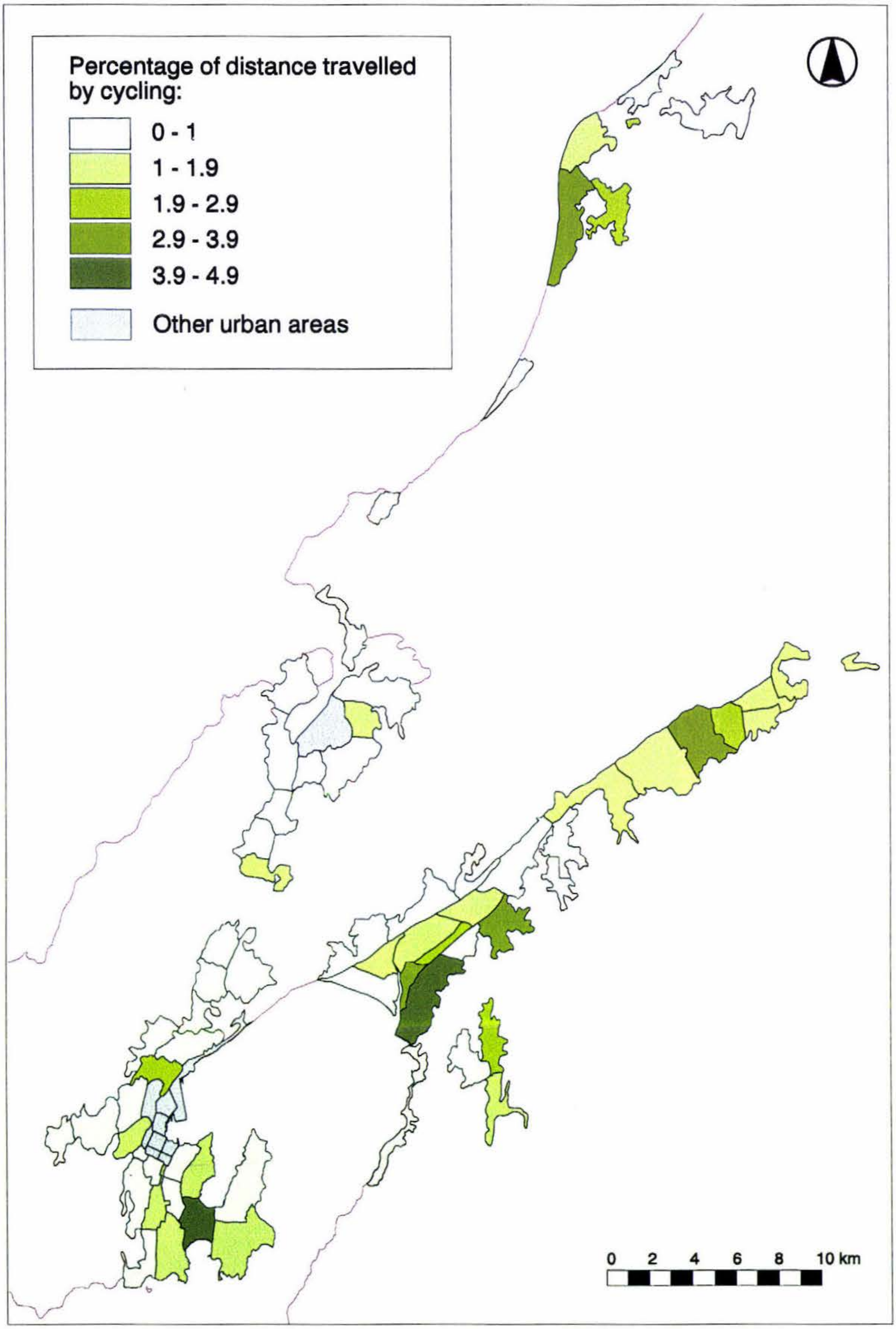
Map 6: Public bus use as a proportion of total distance travelled for residential areas in the Wellington region; Homezone modal split from 1988 survey.



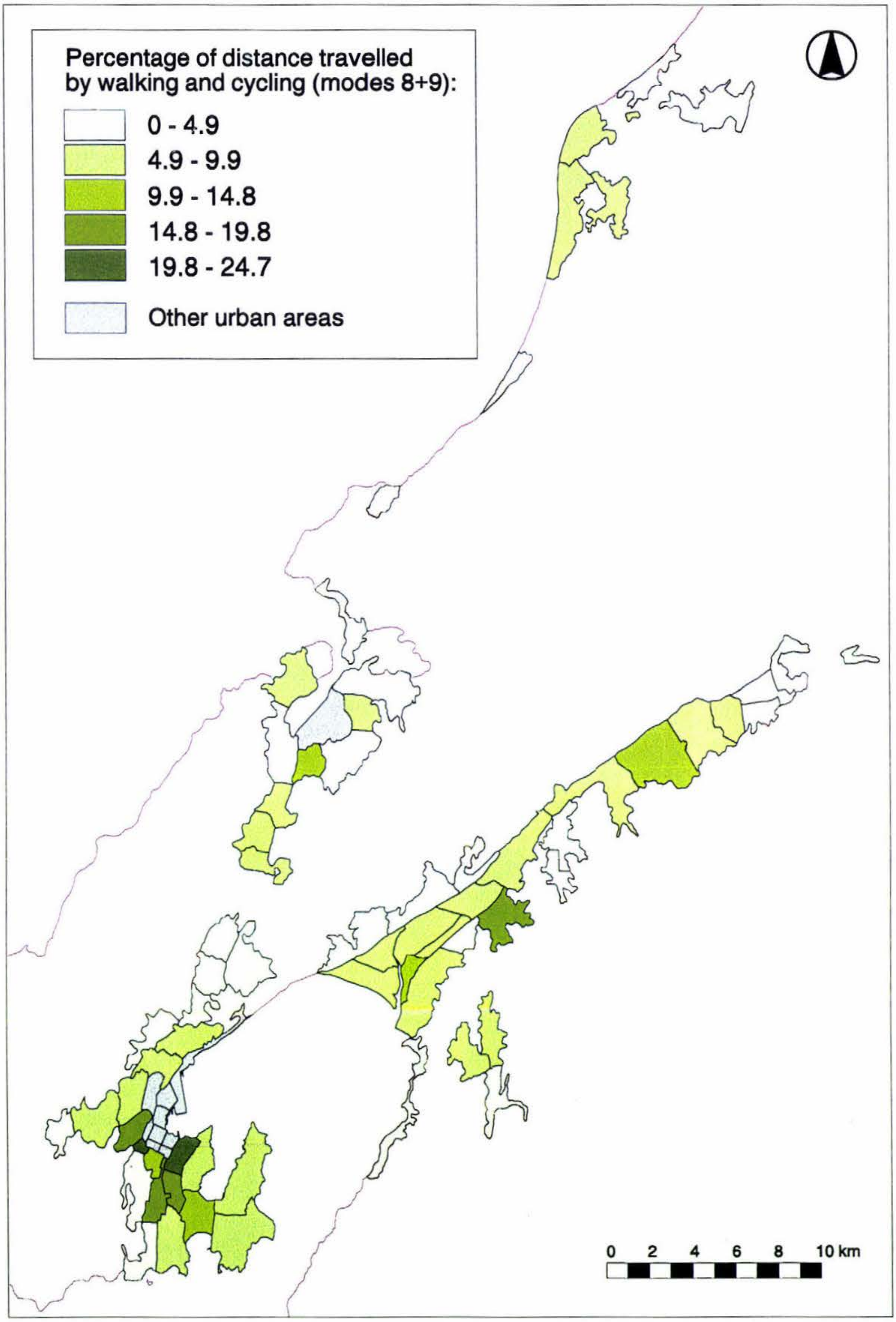
Map 7: Suburban rail use as a proportion of total distance travelled for residential areas in the Wellington region; Homezone modal split from 1988 survey.



Map 8: Walking as a proportion of total distance travelled for residential areas in the Wellington region; Homezone modal split from 1988 survey.



Map 9: Cycling as a proportion of total distance travelled for residential areas in the Wellington region; Homezone modal split from 1988 survey.



Map 10: Walking and cycling (combined total) as a proportion of distance travelled for residential areas in the Wellington region; Homezone modal split from 1988 survey.

Additional analyses on rail and bus travel:

The modal split analyses of Model 12 produced some unexpected results in regard to the influence of public transport on energy use and emissions. While distance travelled by bus has some effect on the dependent variables, rail appears to have none at all. In view of the environmental advantages often cited for rail transport, some additional analysis of this mode was warranted. The program written to produce this model was easily modified to analyse bus travel as well and this was used for further analysis in Model 14.

As model split for rail offered nothing to the overall analysis at the homezone level, these models return to analysing energy use for individual household. Modal split at this level. One submodel in Model 13 considers modal split for individuals.

Analyses of distance to railway station; Model 13:

Several analyses were performed on distance to rail station as an influence on energy use by individual households.

All of these submodels show clearly that inter-relationships between the various **x** and **y** variables are negligible or almost non existent. Although it was anticipated that proximity to rail would influence choice of that mode, it appears that the factors such as high car ownership in most of the zones where railway stations are located outweighs the availability of this form of transport. The limited choice of destinations for trips by rail must also weigh against its popularity. While it is used by thousands of people for trips to and from work, particularly by those who work in central Wellington, there are few areas where day-to-day needs such as shopping for food at supermarkets are adequately served by rail. For these purposes local buses often appear to better serve the majority of people.

Analyses of distance to nearest bus stop; Model 14:

Similar analyses to the Model 13 submodels were performed on a subset of Wellington city households. As accurate location of all bus-stops was only known for parts of the city the analysis was limited to households resident in those zones, 910 to 917, as even a few missing bus-stops would result in quite different home to bus-stop distances for some households.

Some 190 home to bus-stop distances were derived from complete addresses recorded in the uncoded survey data, from a total of 342 household resident in these eight zones.

As with the distance to rail analyses, the sub-models run here showed no relationship between distance to bus, modal split and energy use. Three of the four submodels failed to meet the 5% confidence level. Thus while Model 11 shows us that bus use as a proportion of all travel accounts for a moderate proportion of variation in energy use, Model 14 tells us nothing more about this mode of transport at the level of each household.

Table 6.23: Analyses of relationships between energy use for household against distance to railway station and modal split for rail use.

	Adjusted R-square:	Level of significance:
13 a: Models HH energy use against distance to railway station:	0.0044	0.0020
13 b: Models household energy use against mode split 6:	0.0038	0.0038
13 c: Models mode split 6 for household against distance to rail:	0.0359	0.0001
13 d: Models household rail use for trips to Wellington CBD only, against distance to rail:	0.0713	0.0001

Table 6.24: Analyses of relationships between nearest bus-stop, modal split for bus and energy use at household level.

	Adjusted R-square:	Level of significance:
14 a: Models HH energy use against distance to nearest bus stop:	0.0049	0.8377
14 b: Models household energy use against modal split for bus:	0.0152	0.0461
14 c: Models mode split 3 for household against distance to nearest bus stop:	0.0007	0.2862
14 d: Models household bus use for trips to Wellington CBD only, against distance to rail:	0.0006	0.2956

Stepwise regression for selection of key variables; Model 15:

This model searches through variables used in several of the homezone level analyses to produce multiple regression models. Stepwise regression has been used widely in analysis of relationships between energy use and urban form, as seen in the reviews in Chapter Four, and this procedure is used here as well. In essence, this is an automated method which selects explanatory variables on the basis of "goodness of fit" to produce a range of multivariate models. Several model selection procedures are available in SAS, and the stepwise option incorporates three of those which are most commonly used. Running the stepwise procedure invokes these procedures **forward selection**, **backward selection** and **maximum R-square improvement**, in that order. Forward selection begins by selecting the single x variable which gives the highest value for F (refer analyses: page 73). SAS then searches through all possible models with two explanatory variables to find the one which will is the next best in terms of explaining the dependent variable. This continues until no more models reach the level of significance nominated for the program. Backward selection begins by running a model with all the independent variables, and then eliminates the variable which contributes least to the fit of the model. A model is then run with all the remaining variables, and the next least significant variable is then eliminated, and so on until all remaining variables meet a specified minimum significance level. The maximum R-squared improvement (MAXR) begins with the single variable which has the highest R-squared value, and selects further explanatory variables rather like the forward selection procedure but on the basis of the maximum improvement that each additional variable gives to this statistic (Pledger 1997, 137; SAS Institute, undated 818-819).

Model 17 was run at the default significance levels. This is 50% for the forward procedure which is clearly a totally unrealistic level of significance. The MAXR procedure continues to generate models until the maximum R-square is reached, regardless of significance level, while the backward procedure is set at a somewhat more realistic default of 10%. Running the procedure without setting maximum acceptable levels of significance results in many models being generated with variables which have virtually no explanatory value. While this could have been avoided by resetting these levels of significance the alternative which was used here is to visually search through the output find the point at which the forward and MAXR procedures begin to include variables which do not meet an acceptable significance level and at which elimination of variables in the backward procedure reaches a point where all variables are significant at the desired level (if indeed this point is reached). Extracts from the print-out have been included in Appendix Four. These portions of output include the steps at which each procedures for both submodels, 15(a) for energy use and 15(b) for emissions, begin to include variables which fail to meet the 5% level in the case of forward and MAXR procedures and eliminate all the variables which do not meet this level (15 (a) only). In the case of the backward procedure, all of the variables include in the final model for energy use actually meet the 5% level, while for the final emissions model only one of the variables incorporated fail to meet this level.

This analysis used most of the variables which were shown to meet 5% confidence levels in Models 8 to 12. Two groups of variables from the univariate regression analyses were omitted however. This was the continuous household variables of Model 7, which could have been used to create proportional variables in the same way that the class variables run in Models 1 to 5 were converted into "proportional" variables for Model 8. The "trip purpose" variables of Model 10 were also excluded from this analysis. While it would have been desirable to run some of these variables in a step-wise regression, the evidence from that model is nevertheless quite clear that mean distance of work trips has one of the strongest relationships to mean energy use and emissions found through these analyses.

The variables included here were:

(i) "proportion" variables for:
  age groups 2, 4, 6;
  "need car at work" 1, 2;
  occupation group 2;
  income groups 1, 4;
  household categories 1, 11, 14 and 20;
  car ownership 0, 1, 2, 3 or more (all in this group);

(ii) all five distance to central Wellington zone variables;

(iii) mode split variables 1, 3, 8, c, wabi;

(iv) population density, dwelling density.

Given that several of these variables are not independent, some additional selection would have been advisable rather than entering this whole set of variables into the procedure. The various car ownership variables, for example, are not independent of each other as together they add up to 100 percent. Some of the other groups such as household category and modal split, there are probably sufficient groups in total for the few which have been selected to be considered reasonably independent of each other.

Another general rule of thumb with multiple regression analyses is that the number of observations should not be less than about ten times the number of variables. Observing this "rule" would limit us to six variables. (Table 6.25, page 126) summarizes the variables selected by the stepwise procedures. While these are not necessarily the "best" possible models, even given the absence of the important "trip distance" variables, repeated selection of a variable is an indication of its strength as an explanatory variable. All the variables included in the models summarised here were significant at the 5% level, except for the backward elimination procedure for mean emissions. Two of the seven variables included there failed to meet this level of significance but did however meet the 10% level. Disregarding the number of vehicles involved, one or other of the car ownership variables is significant in each of these analyses.

Inclusion of more than one variable in each submodel which is derived from a common classification variable should be treated with considerable caution. For example, inclusion of two variables related to car ownership for example indicates that this is an important factor but it would be unwise to attach a great deal of significance to whether the number owned is two, or three or more as the case may be. Given that the plots of individual analyses for these variables showed an inverse relationship between energy use and ownership of one or no vehicle, but a positive relationship with owning two or more vehicles, it may be that these should be grouped into "below average" and "above average" vehicle numbers.

Table 6.25: Summary of variables selected by stepwise regression analysis.

	15(a) mean energy use			**15(b) mean emissions**		
Procedure:	Forward (step 5)	Backward (step 25)	MAXR (step 6)	Forward (step 5)	Backward (step 24)	MAXR (step 7)
Proportion age group 6	**YES**	**YES**	**YES**	**YES**	**YES**	**YES**
Own no vehicles	**no**	**no**	**no**	**no**	**YES**	**no**
Own one vehicle	**no**	**YES**	**no**	**no**	**YES**	**no**
Own two vehicles	**YES**	**no**	**YES**	**YES**	**no**	**YES**
Own three or more vehicles	**YES**	**no**	**YES**	**YES**	**no**	**YES**
Distance to C4	**YES**	**no**	**YES**	**YES**	**no**	**YES**
Distance to C2	**no**	**YES**	**no**	**no**	**YES**	**no**
Distance to C1	**no**	**no**	**no**	**no**	**YES**	**no**
Modal split for bus	**no**	**YES**	**no**	**no**	**no**	**YES**

	15(a) mean energy use			15(b) mean emissions		
Procedure:	Forward (step 5)	Backward (step 25)	MAXR (step 6)	Forward (step 5)	Backward (step 24)	MAXR (step 7)
Modal split for walking	**YES**	**YES**	**YES**	**YES**	***YES* - *10%***	**YES**
Income group 1	**no**	**YES**	**no**	**no**	**no**	**no**
Household category 11	**no**	**YES**	**no**	**no**	***YES* - *10%***	**no**

Distance to central Wellington, also disregarding just which zone is selected, appears in all of the analyses, as does modal split for walking. Proportion of people aged 65 or over is the other variable which consistently appears in all of the analyses. Model 11 demonstrates that the mean distance of trips to work is a particularly strong influence on the two dependent variables. If six variables was considered to be a maximum for the number of observations (homezones) entered into the overall analysis, it would be necessary also to enter the **mean trip distance** variables for various purposes into a stepwise regression to confirm the position of the sixth variable. In the absence of the information which a further analysis would provide, modal split for scheduled bus services appears to be the sixth major influence on energy use and emissions.

The various models generated by the stepwise regression procedure all yield R-square values in the 0.79 to 0.82 range. This may be interpreted as showing that taken together the variables in these models explain about 80% of the variation in mean household energy use or emissions for between homezones.

Conclusion for regression analyses:

Some of the findings of the overall analysis agree with those identified by studies reviewed in Chapter Four. Modal split for walking, the level of car ownership and the mean distance to work for each homezone emerged as the strongest influences on energy use and emissions. Distance to central Wellington is also important, confirming the dominance of the CBD in the regional economy. However the appearance of some homezones with a high modal split for walking in other cities of the region, notably Lower Hutt and Porirua, along with the low energy use in these zones, suggests that these zones are relatively self-contained in respect of most of the day-to-day needs of those who live there. This could be taken as an indication of weak multicentricity in the overall region. This is also very much commonsense however, as experience tells us that people ***tend*** to go shopping, to school and so on, closer to home rather than further away. What the results tell us however is the degree to which this is the case; in some zones this general rule appears to apply much more so than others. At the same time, the effect of mean journey to work distance obviously has an effect at the homezone level beyond that of other activities.

While mode share of scheduled bus services had a moderate influence on the dependent variables tested in the univariate analyses, no relationship could be found between rail travel and energy use. This appears to be because the zones which have high levels of rail use also make considerable use of private motor vehicles. For example Zones 925 (Central Tawa), 933 (Plimmerton/Cambourne) and 949 (Kelson/Belmont) are in the second highest brackets for both car and rail use in Maps 5 and 7. They are all in different bracket for energy use and emissions however (Map 2, page 70). Longer trips by car appears to cancel out the gains from rail use in zone 933 at least, and perhaps 949 also.

We turn now to some planning implications for these findings.

Chapter Seven : Implications for local urban planning:

What conclusions can be drawn from the analyses in Chapter Six?

To reiterate the themes in the literature reviewed in Chapter Four, dense residential development and monocentric organisation of cities were common themes identified by many researchers as crucial to establishing and maintaining "energy efficient" urban forms. The effects of these two factors find only moderate support in the analyses performed here however.

Options for high density and pedestrian oriented mixed-use developments:

While residential density has some explanatory value as shown in Model 12, the relationships with energy use and emissions were not particularly strong. The importance of the proportion of total distance travelled by walking, mean distance of the journey to work and car ownership levels, show that increasing densities ***in the favoured locations*** can in fact result in low energy use and emissions for households which are located there. Policies which encourage of residential development in Wellington's central city area illustrates this very well. The ability to fulfil many different daily activities within walking distance of each other, along with proximity to work for many people, are likely to contribute strongly to lowered fossil fuel use for those living in there, but high residential densities appear to be incidental to this. While it is an obvious effect of converting, for example, a vacant office building to apartments, higher density is not necessarily the cause of the environmental improvements which result. In the unlikely event of a high density, high rise development being built in the zone which is Wellington's highest energy user, Churton Park (zone 923) it is highly likely that the households located there would use their cars as much as anyone else living there, if car ownership levels were in fact similar to the type of households which are located there now.

A further spin-off of central city apartment development is the effect of car-parking provision on energy use. While this has not been considered up until this point, availability of car-parking at trip destinations is naturally enough likely to be a strong influence in whether to drive there or travel by some other means. In the case of central Wellington housing, however, limited availability of car parking at peoples *homes* is likely to limit the number of vehicles owned by inner city dwellers. Model 11 showed that the proportion of households which owned one vehicle and of those that owned no vehicles, had an inverse relationship with energy use, whereas in the case of the proportion of those owning two (or more) the relationship was positive. Of the many hundred townhouses and apartments developed in central Wellington in the last two years, few have more than one car park. (The writer has spent two years in 1995 and 1996 processing resource consent applications for Wellington City Council.) A few developers have sought to subdivide unit titled car parks but these are not common. Owning more than one car in this area is therefore likely to necessitate renting an additional car-park. While it is of course possible that this could occur on a reasonably wide scale, it is likely to act a disincentive to owning a second car, and it is probably that many households would find it unnecessary in this location.

The analyses therefore offer considerable support to WCC policies which have aided this interest in inner city housing. Most of this has occurred since the 1988 survey was undertaken, and consequently there were very few respondents who lived in the central area. It is likely however that energy use and emissions here would be similar to that of suburbs closest to the city centre such as zones 905 (Mt Victoria) and 917 (Aro Street-Upper Willis Street), perhaps less.

Infill housing in the outer residential area, on the other hand, may be less successful at minimising energy use. It is here that strategies such as the "pedestrian pocket" proposals outlined in the last section of Chapter Four may be successful. Encouraging higher densities around suburban centres which are well served by public transport could extend the energy efficiencies of the central area into the suburbs to a greater extent than has occurred up until now, whereas the evidence suggests that infill housing in areas which do not have a good pedestrian environment may be little different in terms of travel behaviour to locating housing further out on the edge of the urban area. The main difference for energy use will be in the length of trips made, and as discussed in Chapter Five, a high proportion of short car trips is not at all efficient in terms of engine warming.

The "best performing" areas for pedestrian orientated development in Wellington city may therefore by close to existing shopping centres which are on existing trolley bus routes or the Johnsonville suburban railway line.

The presence of areas in Lower Hutt and Porirua which have good energy and emissions characteristics offers some support that denser, mixed use areas in the suburbs could share some of the environmental benefits of the central city. Selective redevelopment of run-down areas has some potential to provide good access to transport services as well as to daily needs such as shopping schools and perhaps employment opportunities. The last factor however is more open to the vagaries of economic cycles, and while attracting employers has been high on many local bodies' list of priorities in the last ten to fifteen years it has seldom been easily achieved. Redevelopment of pockets of land in declining shopping and industrial areas may offer some incentives to employers to locate there however, given a level of ambience which much recent inner city redevelopment has sought to achieve.

Two examples of areas in decline which offer opportunities for redevelopment are the Naenae shopping centre in Lower Hutt and industrial land adjacent to the Upper Hutt city centre. Naenae was one of the better performing areas at the time of the 1988 survey. Since then the shopping centre has lost business to new retail developments in the centre of Lower Hutt, and a fairly high proportion of shops there are vacant. Large areas of vacant land are not readily available, so the options for new development are limited. However proximity to rail services, a hospital, and a core suburban shopping centre offers potential for apartment type development within the existing shopping area.

In Upper Hutt, a larger area of land is available close to the city centre and railway station in the Goodshed Road area. Most of the land here is currently occupied by under-utilised warehouses and factories with several hectare of land which has never been developed. Advantages include some older railway "character" housing, a large reasonably attractive park, and a local marae. Possible uses include extensions to the existing retail area, should any developer be interested in this option, new housing and possibly conversion of some of the office buildings associated with warehouses and factories to apartment type housing.

While proposals such as these are necessarily small in scale, they are likely to fit well with smaller household sizes including both young families and retired people, offering alternatives to living in car-oriented suburbs further from the city centres.

For local bodies, preparation of District Plans which have yet become operative offers some opportunity to introduce policies which encourage this type of selective redevelopment. Wellington City's Proposed District Plan was notified in 1994 and at the time of writing this chapter hearing of submissions has been completed. Other local governments in the area are at different stages of preparing their Plans; Porirua's has been notified while Upper Hutt expects to notifies its Plan early in 1998. The submissions process offer an opportunity for new policies and planning rules to be introduced.

Support for the "monocentric" hypothesis":

The analysis lends considerable support to the hypothesis that Wellington is a strongly core-oriented city. However this is not the same as showing that this is an energy efficient form. Both mean work trip distance and the distance from each zone to central Wellington have a strong bearing on energy consumption, and the fact that large numbers of people travel from Kapiti and Upper Hutt to work in the central city obviously contributes to the high energy use of many of the zones in those areas. It appears therefore that the assertion by researchers such as Giuliano and Small (1993), that the development of polycentric urban forms leads to some efficiencies in urban travel, may have some merit. Most of the cities discussed in this context were large American cities which have poorly developed public transport systems. As proposed by both Schneider and Beck (1973) and Clark (1974) in their studies of Seattle, more even distribution of jobs and housing could result in lower energy use. This would be particularly true if associated with a good public transport system, with an attractive pedestrian environments as already discussed in this chapter. A greater proportion of work being performed at homes could achieve something similar. This could involve, for example, office workers staying home to work for one or two days a week, and is already seen in some flexible working environments although generally this is limited to higher income bracket professionals and also to low paid out-workers in some countries. Such changes are however more in the realm of deeply rooted social changes rather than likely outcomes of planning measures.

Transport options:

Unexpectedly, the analyses did not find any evidence for suburbs with good access to rail being more energy efficient. This is probably largely due to the mean distances travelled by people in suburbs which have a high proportion of rail users. Car use almost always exceeds use of any other transport mode, so areas close to railway stations tend to have quite high car use as well. Given a more even distribution of urban activities, it is possible that this would change if activities could be induced to cluster around railway stations. The cities would then tend more towards the linear forms proposed by some of the studies of hypothetical urban layouts which were undertaken in the 1960s and '70s.

Bus use emerges as having a stronger influence on overall transport use, and this could possibly be encouraged by introducing a finer grained bus-network. Steadily improving telecommunications offer a number of innovations which could improve services dramatically. Vehicle tracking equipment make it quite feasible to allow people to communicate with sensor networks to track expected bus arrival and departure times from their homes, avoiding time wasted at uncomfortable bus stops waiting for buses which do not always run to schedule. Utilising currently unused suburban shapes for bus-shelters offers some improvement for the latter feature of some bus services, and this could perhaps be encouraged by offering rate rebates to property owners who make vacant shops available for this purpose. This could also make some business activities viable there, by bringing people into the dual purpose shop / stops to wait for buses.

The inverse relationship between low levels of car ownership (submodels 8 (53) and 8 (54)) and energy use, as opposed to the positive relationship for the proportion of respondent household owning two or more cars (submodels 8 (55) and 8 (56)) also suggests that any strategies which encourage people to own only one car may be successful at slowing growth in energy use and emissions from transport sources. As discussed above, where restricted availability of parking exists in conjunction with good pedestrian access this already appears to be happening. Some options for flexible, responsive public transport systems may encourage lower car ownership as well. While light-rail has been promoted by some proponents, it appears that to appeal to a wide range of people any public transport improvements need to be much finer-grained in their coverage. Smaller buses, perhaps taxi-vans, could offer some potential here.

Some final thoughts:

While this thesis does not deal with possible public transport improvements in depth, it appears that a combination of transport and land use approaches offer scope for ameliorating the worst effects of high fossil fuel reliance in urban transport. The analysis in Chapter Six throws some light on some of the issues involved.

Chapter Eight - Conclusion:

It is clear from the analyses carried out in this thesis that residential location has a strong influence on energy used in urban transport and the greenhouse gas emissions which result. Most of the models run in Chapter Six sought to explain differences in energy use and emissions between the various zones, using mean household measures for the homezone as the two dependent variables. Although many of these models were modified to run with each dependent variable in turn, the differences between the two proved to be minor. Zones where emissions and energy use were highest were shown in Chapter Five to use about six times as much energy and produce six times the quantities of emissions of the "best performing" zones. While these low energy users were mainly located close to Wellington's CBD, a few were also located in Porirua and Lower Hutt, indicating a degree of self containment in those zones which is suggestive of a very weak multicentricism.

The main explanatory variables were found to be mean distance to work, car ownership levels and the proportion of daily travel undertaken by walking. Modal split for bus use, population and dwelling densities, and the distance to central Wellington were identified as moderate influences on these areas of interest, whereas modal split for rail and cycling had little influence on the relative performance of the different areas surveyed. The implications for urban planning include support for several tenets which have received widespread support in the planning literature in recent years. Increased mixing of land uses and clustering of urban activities is one outcome which is already being put into action in many western countries, and the analyses confirm that this changing approach to urban planning is every bit as applicable in Wellington as it is in larger cities in Australia, Canada and the United States.

These suggestions have come to form something of a new paradigm in urban planning. The survey of literature shows that this came about over a period of many years, having its roots in the energy crises of the 1970s. Proposals were put forward then to increase urban densities and encourage alternatives to the private car, and these ideas have gained currency amongst planners and others with interests in the built environment, to the point where they have gained widespread acceptance in planning and related disciplines such as urban design and architecture. For some commentators, this contrast with the suburbanisation of the early post-war decades seems as different as the flexible industrial production regimes of the 1990s are from the mass production methods of the 1950s and '60s. The parallel with mass production in the housing and road building sectors is a pertinent one, and the urbanisation which is becoming typical of the so-called "post-modern" era is increasingly one of consolidation of existing areas, infill and redevelopment of older parts of the city.

The environmental effects of this reurbanisation appear to be largely positive. The analyses here have shown that advantages accrue to urban areas which have high levels of pedestrian activity and a high proportion of residents working in close proximity to their homes. Sympathetic planning measures can only encourage this trend.

Appendix One

Number of participating household and persons per homezone:

HOME ZONE	Housholds / homezone	Persons / homezone		HOME ZONE	Housholds /homezone	Persons / homezone
901	81	232		933	35	125
902	79	257		934	43	112
903	61	189		935	47	140
904	65	200		936	44	128
905	44	109		937	49	116
906	63	188		938	58	134
907	27	88		939	40	142
908	56	156		940	51	169
909	70	170		941	33	110
910	33	81		942	32	94
911	33	76		943	60	168
912	38	109		944	59	172
913	77	212		945	61	187
914	45	103		946	44	151
915	52	133		947	36	114
916	34	109		948	46	123
917	30	91		949	33	85
918	56	164		950	60	149
919	46	154		951	41	116
920	30	72		952	31	86
921	32	82		953	50	166
922	88	259		954	43	129
923	39	119		955	44	117
924	30	106		956	32	76
925	44	149		957	42	110
926	37	119		958	34	76
927	32	111		959	41	118
928	68	205		960	42	119
929	30	99		961	56	180
930	93	352		962	74	228
931	73	294		963	41	119
932	54	174		964	38	115

Mean daily energy use for homezones (MJ) sorted in ascending order:

Homezone	Energy Use		Homezone	Energy Use
905	46.612		949	142.779
910	47.452		902	144.134
906	56.686		963	148.578
911	64.742		908	150.706
951	65.063		943	153.975
915	75.779		962	155.027
917	78.023		919	160.999
916	80.789		935	161.764
914	85.53		922	166.075
927	89.07		953	166.379
954	93.9		931	166.57
913	94.052		940	175.138
955	95.068		961	175.631
907	95.189		942	177.592
903	96.862		938	178.766
948	99.429		928	178.992
920	103.632		921	179.749
912	107.695		960	180.021
950	108.401		947	181.123
957	110.894		926	189.58
904	111.015		924	192.458
958	111.236		952	202.625
909	111.312		936	203.644
930	119.328		945	205.123
929	121.31		946	205.36
956	123.346		933	212.868
944	126.467		939	214.227
925	128.378		923	218.038
959	131.819		934	218.82
937	134.985		964	220.936
901	141.055		941	231.438
918	142.227		932	274.497

Mean daily energy use for individuals by homezone (MJ) sorted in ascending order:

Homezone	Energy Use		Homezone	Energy Use
905	18.816		958	49.7634
906	18.9957		953	50.1141
910	19.3322		962	50.3158
951	22.9966		963	51.1907
916	25.2003		956	51.9351
927	25.6777		940	52.8524
917	25.722		908	54.0996
911	28.1115		935	54.3064
907	29.2056		924	54.4693
915	29.6278		961	54.6407
903	31.2624		943	54.9912
954	31.2999		949	55.4318
930	31.527		922	56.4271
913	34.1603		937	57.0196
955	35.752		947	57.1967
904	36.08		926	58.945
929	36.7607		928	59.3728
948	37.185		933	59.603
914	37.3676		946	59.8401
912	37.5449		939	60.3457
925	37.9103		942	60.4569
931	41.3592		960	63.5368
957	42.3414		945	66.9118
920	43.1799		941	69.4315
944	43.3813		936	70.0026
950	43.6514		921	70.146
902	44.3058		923	71.4579
959	45.8016		964	73.0049
909	45.8344		952	73.0392
919	48.0905		938	77.3762
918	48.5655		934	84.0114
901	49.2477		932	85.1888

Mean daily emissions for homezones (g/CO_2 equivalent) sorted in ascending order:

Homezone			Homezone	
905	3272.19		949	10102.51
910	3369.73		902	10289.89
906	4001.08		963	10658.4
951	4562.47		908	10801.99
911	4611.54		943	10931.94
915	5506.93		962	11147.29
917	5578.36		935	11526.88
916	5772.08		919	11554.5
914	6055.27		953	11893.04
927	6311.5		931	11941.78
955	6665.17		922	12018.38
913	6732.37		940	12569.78
954	6784.15		961	12596.18
907	6838.68		942	12674.37
903	6907.11		921	12774.27
948	7089.81		928	12806.43
920	7376.58		960	12812.85
950	7703.12		938	12945.8
912	7779.04		947	13021.28
957	7861.15		926	13477.37
958	7871.11		924	13703.58
904	7944.88		952	14453.11
909	7949.08		936	14532.21
930	8480.12		945	14590.63
929	8669.39		946	14686.7
956	8852.2		933	15006.91
944	8979.37		939	15297.79
925	9058.99		934	15311.12
959	9333.3		923	15616.76
937	9647.81		964	16078.42
918	10048.26		941	16492.87
901	10099.16		932	19570.24

Dwelling density of homezones, descending order:

Homezone	Dwellings / hectare	Homezone	Dwellings / hectare
906	20.8953	920	7.4497
916	20.7599	943	7.4056
911	18.7352	932	6.9177
910	16.7996	934	6.6002
904	14.6562	948	6.5496
909	13.6493	918	6.5173
954	13.4512	951	6.0487
908	12.8312	963	5.9969
905	12.7031	926	5.9037
950	12.2886	929	5.6842
917	11.6843	933	5.4557
915	11.5301	947	5.0222
960	11.3545	962	5.0218
942	11.119	961	4.9602
944	11.0047	925	4.895
955	10.4775	953	4.7542
957	10.3341	937	4.6402
921	10.0886	958	4.6277
903	10.0121	935	4.6064
940	9.9578	941	3.5149
901	9.7195	913	3.3648
914	9.4678	946	2.9563
959	9.2724	912	2.8623
956	8.9488	923	2.0142
930	8.8371	952	1.995
922	8.1145	927	1.6709
907	7.8941	938	1.6398
919	7.8878	964	1.551
931	7.8106	936	1.3923
928	7.7385	945	1.3043
902	7.6239	939	1.2939
924	7.5577	949	0.6483

APPENDIX TWO

A - ANOVA PROCEDURE OUTPUTS:

MODEL 1(a): EFFECT OF AGE ON ENERGY USE BY INDIVIDUALS.

Analysis of Variance Procedure

Dependent Variable: TLENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	5183280.0634	1036656.0127	186.91	0.0001
Error	7637	42357340.3326	5546.3324		
Corrected Total	7642	47540620.3961			

R-Square	C.V.	Root MSE	TLENERGY Mean
0.109028	129.6006	74.473703	57.464014

MODEL 1(b): EFFECT OF AGE ON TRAVEL EMISSIONS FOR INDIVIDUALS.

Analysis of Variance Procedure

Dependent Variable: TLEMISNS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	26254599171	5250919834	183.45	0.0001
Error	7637	218596240911	28623313		
Corrected Total	7642	244850840082			

R-Square	C.V.	Root MSE	TLEMISNS Mean
0.107227	130.4028	5350.0760	4102.7316

Duncan's Multiple Range Test for variable: TLEMISNS

Alpha= 0.05 df= 7637 MSE= 28623313
Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	PERSNAGE
	A	5457.8	2036	5
	A			
	A	5333.9	2966	4
	B	3038.9	439	6
	B			
C	B	2476.6	811	3
C				
C	D	1227.2	20	1
	D			
	D	771.5	1371	2

MODEL 1(c): EFFECT OF EMPLOYMENT STATUS ON ENERGY USE BY INDIVIDUALS.

Analysis of Variance Procedure

Dependent Variable: TLENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	6256594.8218	1251318.9644	231.51	0.0001
Error	7639	41288165.2645	5404.9176		
Corrected Total	7644	47544760.0863			

R-Square	C.V.	Root MSE	TLENERGY Mean
0.131594	127.9640	73.518144	57.452223

MODEL 1(d): EFFECT OF EMPLOYMENT STATUS ON TRAVEL EMISSIONS FOR INDIVIDUALS.

Analysis of Variance Procedure

Dependent Variable: TLEMISNS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	31607857208	6321571442	226.43	0.0001
Error	7639	213267149861	27918203		
Corrected Total	7644	244875007068			

	R-Square	C.V.	Root MSE	TLEMISNS Mean
	0.129078	128.8151	5283.7678	4101.8235

Duncan's Multiple Range Test for variable: TLEMISNS

Alpha= 0.05 df= 7639 MSE= 27918203

Duncan Grouping	Mean	N	PERSNEMP
A	5925.6	3713	1
B	4845.4	620	2
C	3142.8	576	5
C			
C	3102.6	548	9
C			
C	2967.9	210	4
D	1121.7	1978	3

MODEL 1(e): EFFECT OF NEED FOR CAR AT WORK ON ENERGY USE BY INDIVIDUALS.

Analysis of Variance Procedure

Dependent Variable: TLENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3411193.6981	3411193.6981	461.23	0.0001
Error	4438	32823043.1629	7395.9088		
Corrected Total	4439	36234236.8610			

	R-Square	C.V.	Root MSE	TLENERGY Mean
	0.094143	107.1660	85.999470	80.248803

MODEL 1(f): EFFECT OF NEED FOR CAR AT WORK ON TRAVEL EMISSIONS FOR INDIVIDUAL.

Analysis of Variance Procedure

Dependent Variable: TLEMISNS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	17857381119	17857381119	468.35	0.0001
Error	4438	169214407101	38128528		
Corrected Total	4439	187071788221			

	R-Square	C.V.	Root MSE	TLEMISNS Mean
	0.095457	107.9074	6174.8302	5722.3418

MODEL 1(g): EFFECT OF OCCUPATION GROUP ON ENERGY USE BY INDIVIDUALS.

Analysis of Variance Procedure

Dependent Variable: TLENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	858430.85551	107303.85694	13.31	0.0001
Error	4345	35037093.09466	8063.77286		
Corrected Total	4353	35895523.95017			

R-Square	C.V.	Root MSE	TLENERGY Mean
0.023915	110.9878	89.798513	80.908433

MODEL 1(h): EFFECT OF OCCUPATION GROUP ON TRAVEL EMISSIONS FOR INDIVIDUALS.

Analysis of Variance Procedure

Dependent Variable: TLEMISNS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	4491697299.3	561462162.4	13.49	0.0001
Error	4345	180849963254.2	41622546.2		
Corrected Total	4353	185341660553.5			

R-Square	C.V.	Root MSE	TLEMISNS Mean
0.024235	111.8296	6451.5538	5769.0939

Duncan's Multiple Range Test for variable: TLEMISNS

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 4345 MSE= 41622546
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 28.73165

Number of Means	2	3	4	5	6	7	8	9
Critical Range	3337	3514	3632	3719	3788	3844	3891	3931

Means with the same letter are not significantly different.

Duncan Grouping			Mean	N	PJOBTYPE
	A		8340	25	6
	A				
B	A		7481	242	4
B	A				
B	A		7142	619	2
B	A				
B	A		6246	640	7
B	A				
B	A		5830	1486	1
B	A				
B	A	C	4734	442	5
B		C			
B		C	4434	85	8
B		C			
B		C	4369	811	3
		C			
		C	1155	4	9

MODEL 2(a): EFFECT OF PERSON-AGE ON MEAN PERSON-ENERGY USE / HZ.

Analysis of Variance Procedure

Dependent Variable: EPERS_HZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	10090.776272	2018.155254	8.58	0.0001
Error	9128	2147061.751465	235.217107		
Corrected Total	9133	2157152.527737			

R-Square	C.V.	Root MSE	EPERS_HZ Mean
0.004678	31.89723	15.336789	48.081878

MODEL 2(b): EFFECT OF PERSON-AGE ON MEAN PERSON-EMISSIONS / HZ.

Analysis of Variance Procedure

Dependent Variable: EMMN_PHZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	51529706.888	10305941.378	8.55	0.0001
Error	9128	10997008282.63	1204755.509		
Corrected Total	9133	11048537989.52			

R-Square	C.V.	Root MSE	EMMN_PHZ Mean
0.004664	31.97402	1097.6136	3432.8292

Duncan's Multiple Range Test for variable: EMMN_PHZ

Duncan Grouping	Mean	N	PERSNAGE
A	3550.86	2250	5
B	3449.80	1452	2
B			
B	3428.79	880	3
B			
B	3414.96	642	1
B			
B	3377.66	650	6
B			
B	3359.42	3260	4

MODEL 2(c): EFFECT OF PERSON-EMPLOYMENT STATUS ON MEAN PERSON-ENERGY USE / HZ.

Analysis of Variance Procedure

Dependent Variable: EPERS_HZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	2340.0097566	468.0019513	1.98	0.0780
Error	9130	2156268.015860	236.1739338		
Corrected Total	9135	2158608.025616			

R-Square	C.V.	Root MSE	EPERS_HZ Mean
0.001084	31.96596	15.367952	48.075985

MODEL 2(d): EFFECT OF PERSON-EMPLOYMENT STATUS ON MEAN PERSON-EMISSIONS/ HZ.

Analysis of Variance Procedure

Dependent Variable: EMMN_PHZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	11913645.761	2382729.152	1.97	0.0797
Error	9130	11044179444.14	1209658.209		
Corrected Total	9135	11056093089.90			

R-Square	C.V.	Root MSE	EMMN_PHZ Mean
0.001078	32.04298	1099.8446	3432.4044

Duncan's Multiple Range Test for variable: EMMN_PHZ

Alpha= 0.05 df= 9130 MSE= 1209658

Duncan Grouping	Mean	N	PERSNEMP
A	3481.74	661	2
A			
A	3450.34	854	5
A			
A	3447.13	3889	1
A			
A	3427.51	1322	9
A			
A	3408.67	2114	3
B	3268.38	296	4

MODEL 2(e): EFFECT OF PERSON-NEED FOR CAR AT WORK ON MEAN PERSON-ENERGY USE / HZ.

Analysis of Variance Procedure

Dependent Variable: EPERS_HZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	14463.972639	14463.972639	60.26	0.0001
Error	4694	1126597.945064	240.008084		
Corrected Total	4695	1141061.917703			

R-Square	C.V.	Root MSE	EPERS_HZ Mean
0.012676	31.96145	15.492194	48.471500

MODEL 2(f): EFFECT OF PERSON-NEED FOR CAR AT WORK ON MEAN PERSON-EMISSIONS / HZ.

Analysis of Variance Procedure

Dependent Variable: EMMN_PHZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	74157741.925	74157741.925	60.41	0.0001
Error	4694	5762445846.383	1227619.482		
Corrected Total	4695	5836603588.307			

R-Square	C.V.	Root MSE	EMMN_PHZ Mean
0.012706	32.01569	1107.9799	3460.7404

MODEL 2(g): EFFECT OF PERSON-OCCUPATION GROUP ON MEAN PERSON-ENERGY USE / HZ.

Analysis of Variance Procedure

Dependent Variable: EPERS_HZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	8911.5139663	1113.9392458	4.60	0.0001
Error	4567	1105031.634290	241.9600688		
Corrected Total	4575	1113943.148256			

R-Square	C.V.	Root MSE	EPERS_HZ Mean
0.008000	32.14989	15.555066	48.382946

MODEL 2(h): EFFECT OF PERSON-OCCUPATION GROUP ON MEAN PERSON-EMISSIONS / HZ.

Analysis of Variance Procedure

Dependent Variable: EMMN_PHZ

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	44644794.175	5580599.272	4.51	0.0001
Error	4567	5653112270.609	1237817.445		
Corrected Total	4575	5697757064.784			

R-Square	C.V.	Root MSE	EMMN_PHZ Mean
0.007836	32.20715	1112.5724	3454.4265

Duncan's Multiple Range Test for variable: EMMN_PHZ

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 4567 MSE= 1237817
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 29.28966

Number of Means	2	3	4	5	6	7	8	9
Critical Range	570.0	600.2	620.3	635.3	647.0	656.5	664.6	671.4

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	PJOBTYPE
	A	4097.6	4	9
	A			
B	A	3862.4	28	6
B	A			
B	A	3664.9	93	8
B	A			
B	A	3615.1	648	2
B	A			
B	A	3519.3	262	4
B	A			
B	A	3466.4	847	3
B				
B		3421.2	661	7
B				
B		3412.8	1560	1
B				
B		3289.8	473	5

MODEL 3(a): EFFECT OF PERSON-AGE ON MEAN HH ENERGY USE / HZ.

Analysis of Variance Procedure

Dependent Variable: ENGYMEAN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	150215.10831	30043.02166	12.93	0.0001
Error	9128	21214291.77643	2324.08981		
Corrected Total	9133	21364506.88473			

R-Square	C.V.	Root MSE	ENGYMEAN Mean
0.007031	33.27609	48.208815	144.87524

MODEL 3(b): EFFECT OF PERSON-AGE ON MEAN HH EMISSIONS / HZ.

Analysis of Variance Procedure

Dependent Variable: EMISSNMN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	770978664.90	154195732.98	12.96	0.0001
Error	9128	108631165459.6	11900872.64		
Corrected Total	9133	109402144124.5			

R-Square	C.V.	Root MSE	EMISSNMN Mean
0.007047	33.35064	3449.7641	10343.921

MODEL 3(c): EFFECT OF PERSON-EMPLOYMENT STATUS ON MEAN HH ENERGY USE / HZ.

Analysis of Variance Procedure

Dependent Variable: ENGYMEAN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	82985.358870	16597.071774	7.12	0.0001
Error	9130	21297379.37048	2332.681202		
Corrected Total	9135	21380364.72935			

R-Square	C.V.	Root MSE	ENGYMEAN Mean
0.003881	33.34200	48.297838	144.85584

MODEL 3(d): EFFECT OF PERSON-EMPLOYMENT STATUS ON MEAN HH EMISSIONS / HZ.

Analysis of Variance Procedure

Dependent Variable: EMISSNMN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	429416365.84	85883273.17	7.19	0.0001
Error	9130	109054774460.2	11944663.14		
Corrected Total	9135	109484190826.0			

R-Square	C.V.	Root MSE	EMISSNMN Mean
0.003922	33.41646	3456.1052	10342.525

MODEL 3(e): EFFECT OF PERSON-NEED FOR CAR AT WORK ON MEAN HH ENERGY USE / HZ.

Analysis of Variance Procedure

Dependent Variable: ENGYMEAN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	98260.094553	98260.094553	40.25	0.0001
Error	4694	11457910.88893	2440.969512		
Corrected Total	4695	11556170.98348			

R-Square	C.V.	Root MSE	ENGYMEAN Mean
0.008503	33.98854	49.406169	145.36124

MODEL 3(f): EFFECT OF PERSON-NEED FOR CAR AT WORK ON MEAN HH EMISSIONS / HZ.

Analysis of Variance Procedure

Dependent Variable: EMISSNMN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	503753292.19	503753292.19	40.32	0.0001
Error	4694	58645434069.48	12493701.34		
Corrected Total	4695	59149187361.67			

R-Square	C.V.	Root MSE	EMISSNMN Mean
0.008517	34.05492	3534.6430	10379.243

MODEL 3(g): EFFECT OF PERSON-OCCUPATION GROUP ON MEAN HH ENERGY USE / HZ.

Analysis of Variance Procedure

Dependent Variable: ENGYMEAN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	81887.276056	10235.909507	4.18	0.0001
Error	4567	11179690.26240	2447.928676		
Corrected Total	4575	11261577.53846			

R-Square	C.V.	Root MSE	ENGYMEAN Mean
0.007271	34.08860	49.476547	145.14104

MODEL 3(h): EFFECT OF PERSON-OCCUPATION GROUP ON MEAN HH EMISSIONS / HZ.

Analysis of Variance Procedure

Dependent Variable: EMISSNMN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	415501264.22	51937658.03	4.14	0.0001
Error	4567	57225585371.53	12530235.47		

Corrected Total	4575	57641086635.75			
	R-Square	C.V.	Root MSE		EMISSNMN Mean
	0.007208	34.15636	3539.8073		10363.538

MODEL 4(a): SIGNIFICANCE OF HOUSEHOLD INCOME ON HOUSEHOLD ENERGY USE:

Analysis of Variance Procedure

Dependent Variable: TLENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	6914090.8842	987727.2692	51.30	0.0001
Error	2880	55446020.5216	19252.0905		
Corrected Total	2887	62360111.4058			
	R-Square	C.V.	Root MSE		TLENERGY Mean
	0.110874	93.54865	138.75190		148.32059

MODEL 4(b): SIGNIFICANCE OF HOUSEHOLD INCOME ON HOUSEHOLD EMISSIONS.

Analysis of Variance Procedure

Dependent Variable: TLEMISNS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	35098123710	5014017673	50.55	0.0001
Error	2879	285585433118	99196052		
Corrected Total	2886	320683556828			
	R-Square	C.V.	Root MSE		TLEMISNS Mean
	0.109448	94.05982	9959.7215		10588.710

Duncan's Multiple Range Test for variable: TLEMISNS

NOTE: This test controls the type I comparisonwise error rate, not the experimentwise error rate

Alpha= 0.05 df= 2879 MSE= 99196052
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 257.6445

Number of Means	2	3	4	5	6	7	8
Critical Range	1721	1812	1873	1918	1953	1982	2006

Means with the same letter are not significantly different.

Duncan Grouping		Mean	N	HHINCOME
	A	15061.3	490	7
	A			
	A	14279.1	403	6
	B	12140.4	401	5
	C	10230.5	473	4
	C			
D	C	8645.0	447	3
D				
D		8204.2	78	9
	E	6382.4	340	2
	F	4131.1	255	1

MODEL 4(c): SIGNIFICANCE OF SURVEY DATE ON HOUSEHOLD ENERGY USE:

Analysis of Variance Procedure

Dependent Variable: TLENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F

Model	51	1719357.3255	33712.8887	1.57	0.0063
Error	2902	62307862.5671	21470.6625		
Corrected Total	2953	64027219.8926			

R-Square	C.V.	Root MSE	TLENERGY Mean
0.026854	98.54037	146.52871	148.69917

MODEL 4(d): SIGNIFICANCE OF SURVEY DATE ON HOUSEHOLD EMISSIONS:

Analysis of Variance Procedure

Dependent Variable: TLEMISNS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	51	8904176934.7	174591704.6	1.58	0.0056
Error	2901	320374869806.0	110436011.7		
Corrected Total	2952	329279046740.8			

R-Square	C.V.	Root MSE	TLEMISNS Mean
0.027041	98.99025	10508.854	10616.049

Duncan's Multiple Range Test for variable: TLEMISNS

Duncan Grouping		Mean	N	SURVDATE
	A	52308	1	2110
	B	21880	2	2810
C	B	18212	2	411
C	B	14283	1	2511
C	B	13584	2	2711
C	B	13226	115	2610
C	B	13199	1	1811
C	B	13124	115	1810
C	B	12995	36	2709
C	B	12291	64	1310
C	B	12152	103	1210
C	B	12139	90	2010
C	B	12005	43	2909
C	B	11778	137	2510
C	B	11700	121	1710
C	B	11451	111	1010
C	B	11156	2	210
C	B	11150	1	710
C	B	11089	110	1110
C	B	11002	54	2809
C	B	10884	133	211
C	B	10861	129	1910
C	B	10659	71	410
C	B	10457	65	1411
C	B	10409	145	111
C	B	10299	85	610
C	B	10283	62	310
C	B	10255	87	2710
C	B			

C	B	9957	74	510
C	B			
C	B	9838	147	711
C	B			
C	B	9819	143	3110
C	B			
C	B	9766	100	811
C	B			
C	B	9610	30	1711
C	B			
C	B	9341	2	2011
C	B			
C	B	9069	104	911
C	B			
C	B	9015	116	311
C	B			
C	B	8900	75	1511
C	B			
C	B	8622	34	2609
C	B			
C	B	8586	75	1611
C	B			
C	B	8514	85	1011
C	B			
C	B	8431	5	1111
C	B			
C	B	7659	1	3111
C	B			
C	B	7635	12	3011
C	B			
C	B	7537	4	611
C	B			
C	B	7313	1	1410
C	B			
C	B	7053	12	112
C	B			
C	B	6865	14	2811
C	B			
C	B	4536	10	2111
C	B			
C	B	4098	15	2911
C				
C		3013	3	511
C				
C		2887	2	2410
C				
C		501	1	3010

MODEL 4(e): SIGNIFICANCE OF HOUSEHOLD CATEGORY ON HOUSEHOLD ENERGY USE:

Analysis of Variance Procedure

Dependent Variable: TLENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	23	9751491.7408	423977.9018	22.90	0.0001
Error	2933	54310807.4483	18517.1522		
Corrected Total	2956	64062299.1891			

	R-Square	C.V.	Root MSE	TLENERGY Mean
	0.152219	91.57795	136.07774	148.59226

MODEL 4(f): SIGNIFICANCE OF HOUSEHOLD CATEGORY ON HOUSEHOLD EMISSIONS:

Analysis of Variance Procedure

Dependent Variable: TLEMISNS

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	23	49409178865	2148225168	22.49	0.0001
Error	2932	280049053517	95514684		
Corrected Total	2955	329458232382			

	R-Square	C.V.	Root MSE	TLEMISNS Mean
	0.149971	92.12660	9773.1614	10608.403

Duncan's Multiple Range Test for variable: TLEMISNS

```
Alpha= 0.05  df= 2932  MSE= 95514684
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 24.52988

Number of Means     2    3    4    5    6    7    8    9   10   11   12   13
Critical Range   5472 5762 5955 6099 6211 6303 6380 6445 6502 6553 6597 6638

Number of Means    14   15   16   17   18   19   20   21   22   23   24
Critical Range   6674 6707 6738 6766 6792 6816 6839 6860 6879 6898 6916

Means with the same letter are not significantly different.

Duncan Grouping              Mean      N  HHCATGRY

                  A         18200    342  17
                  A
          B       A         13818     18  18
          B       A
          B       A   C     13428    329  19
          B           C
          B       D   C     12149    695  11
          B       D   C
          B       D   C     11904     24  20
          B       D   C
          B   E   D   C     11558     96  21
          B   E   D   C
      F   B   E   D   C     10812    140  12
      F   B   E   D   C
      F   B   E   D   C G    9828    294  13
      F   B   E   D   C G
      F   B   E   D H C G    9036    216  14
      F   B   E   D H C G
      F   B   E   D H C G    8407      4  5
      F   B   E   D H C G
      F   B   E   D H C G    8184     21  23
      F   B   E   D H C G
      F   B   E   D H C G    7817     17  22
      F   B   E   D H C G
      F   B   E   D H C G    7333     33  4
      F       E   D H C G
      F       E   D H C G    7169     56  6
      F       E   D H   G
      F       E   D H   G    6456     40  10
      F       E   D H   G
      F       E   D H   G    6142    195  3
      F       E   D H   G
      F       E   D H   G    5493     69  15
      F       E   D H   G
      F       E   D H   G    5482    130  2
      F       E     H   G
      F       E     H   G    5167      5  24
      F             H   G
      F             H   G    4258     23  8
                    H   G
                    H   G    3702     49  7
                    H   G
                    H   G    3464     12  16
                    H
                    H        2741    120  1
                    H
                    H        2465     28  9
```

MODEL 4(g): SIGNIFICANCE OF CAR OWNERSHIP ON HOUSEHOLD ENERGY USE:

Analysis of Variance Procedure

Dependent Variable: TLENERGY

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	13568356.512	4522785.504	264.50	0.0001
Error	2953	50493942.677	17099.202		
Corrected Total	2956	64062299.189			

R-Square	C.V.	Root MSE	TLENERGY Mean
0.211799	88.00183	130.76392	148.59226

MODEL 4(h): SIGNIFICANCE OF CAR OWNERSHIP ON HOUSEHOLD EMISSIONS:

Analysis of Variance Procedure

Dependent Variable: TLEMISNS

Sum of Mean

Source	DF	Squares	Square	F Value	Pr > F
Model	3	69943756182	23314585394	265.21	0.0001
Error	2952	259514476200	87911408		
Corrected Total	2955	329458232382			

	R-Square	C.V.	Root MSE	TLEMISNS Mean
	0.212299	88.38378	9376.1084	10608.403

Source	DF	Anova SS	Mean Square	F Value	Pr > F
CAROWNNO	3	69943756182	23314585394	265.21	0.0001

Duncan's Multiple Range Test for variable: TLEMISNS

Alpha= 0.05 df= 2952 MSE= 87911408
WARNING: Cell sizes are not equal.
Harmonic Mean of cell sizes= 524.2517

Number of Means	2	3	4
Critical Range	1136	1196	1236

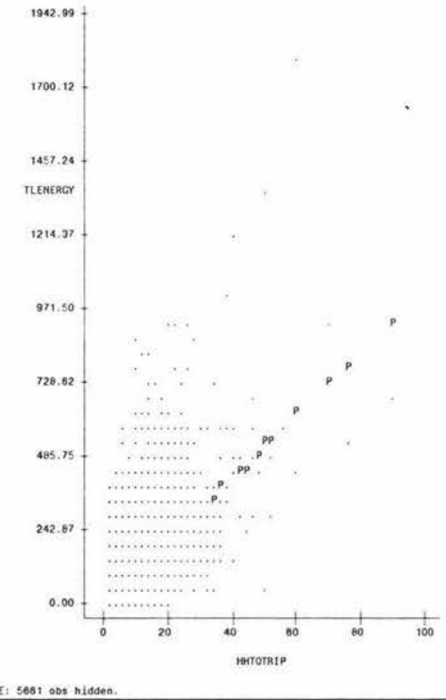
Means with the same letter are not significantly different.

Duncan Grouping	Mean	N	CAROWNNO
A	18370.6	509	3
B	13086.6	950	2
C	7386.4	1234	1
D	1751.6	263	0

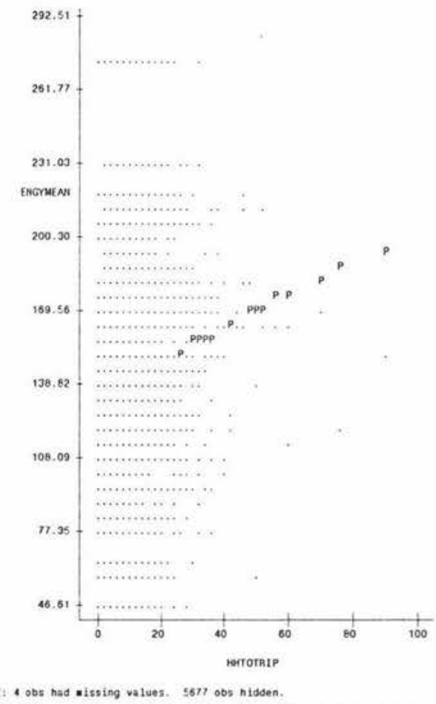
APPENDIX TWO

PART B - TABLES OF PLOTS:

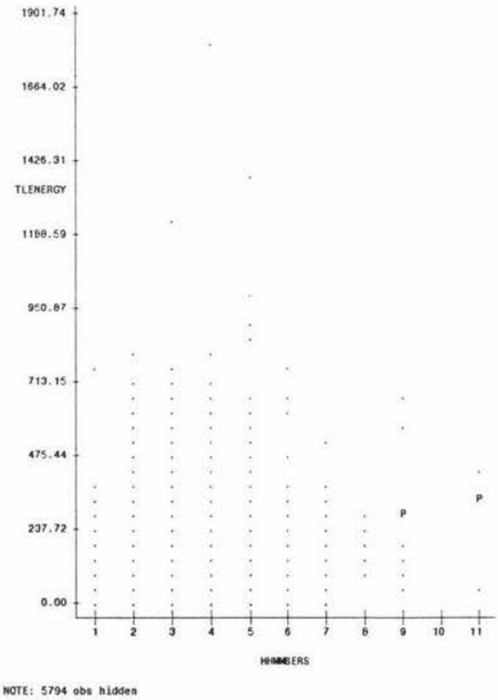
MODEL 6(a): Models energy use against total number of trips by HH:



MODEL 7(a): Models mean HH energy use against total number of trips by HH:



MODEL 6(b): Models energy use against number of people in HH:



MODEL 7(b): Models mean HH energy use against number of people in HH:

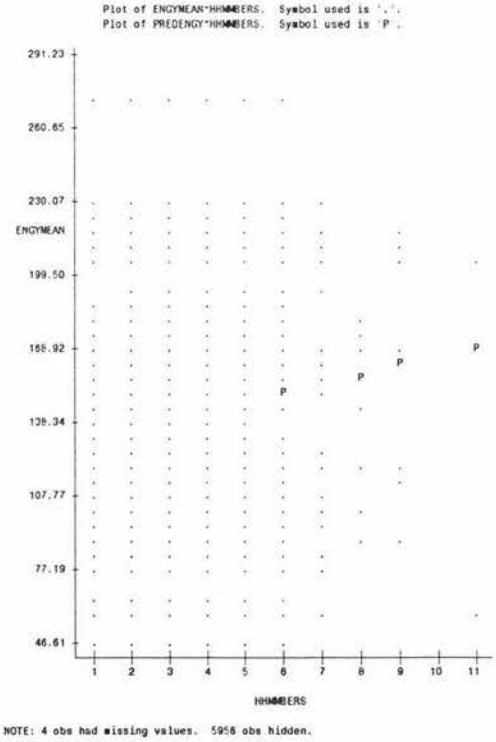
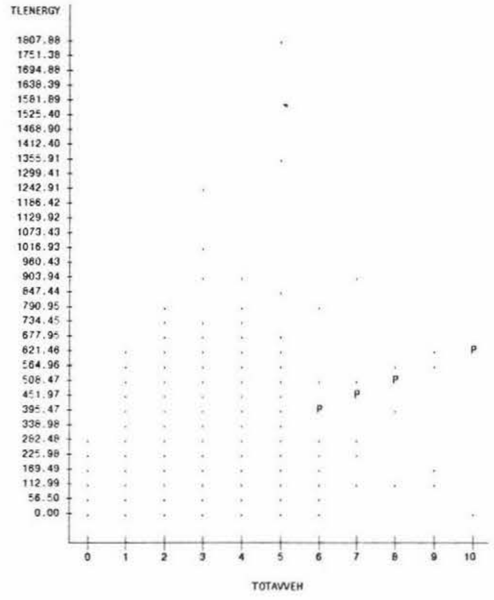


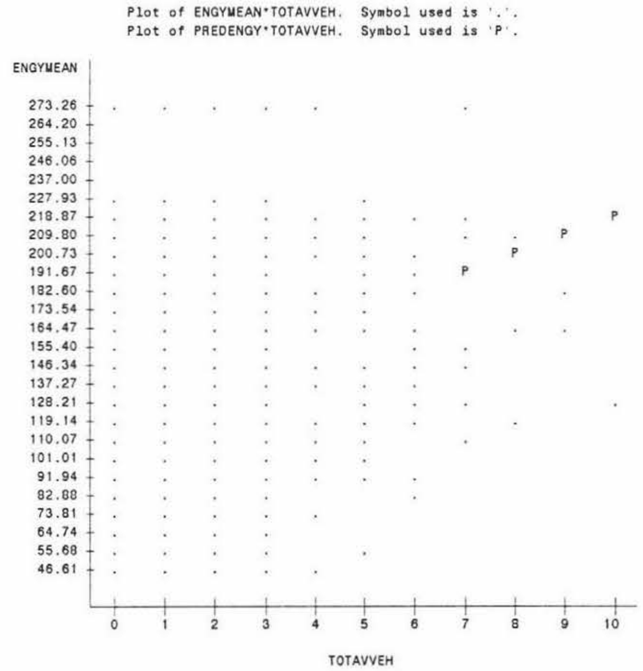
TABLE OF PLOTS 1

MODEL 6(c): Models HH energy use against total available vehicles:



NOTE: 5807 obs hidden.

MODEL 7(c): Models mean HH energy use against total available vehicles:

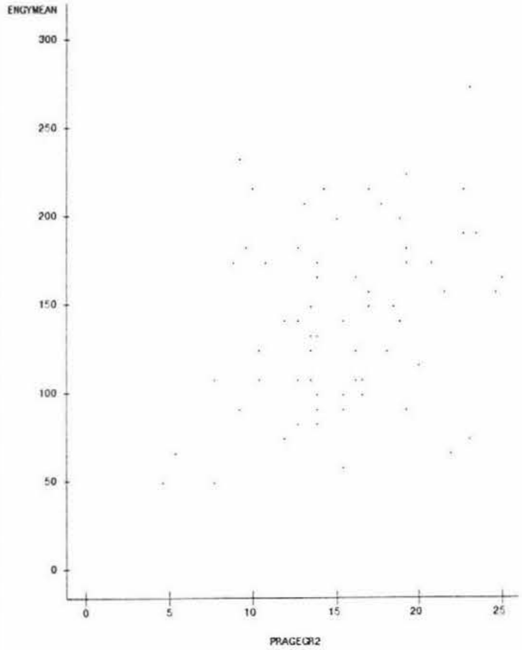


NOTE: 4 obs had missing values. 6016 obs hidden.

TABLE OF PLOTS 2

MODEL 8 (2): Models HH energy use against proportion in age group "2":

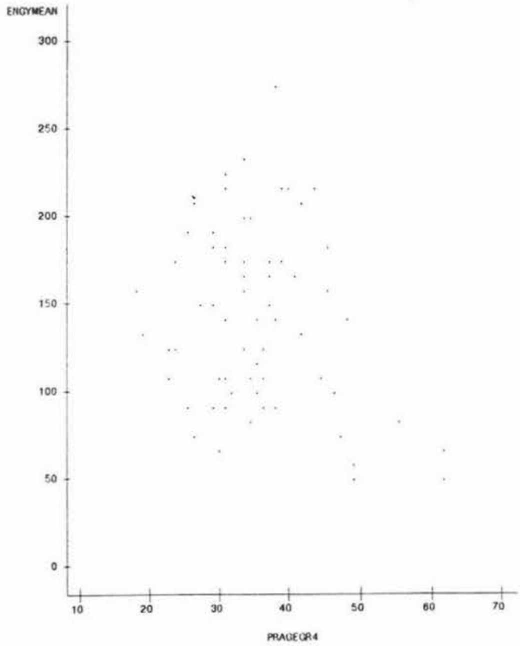
Plot of ENGYMEAN*PRAGEGR2. Symbol used is '.'.



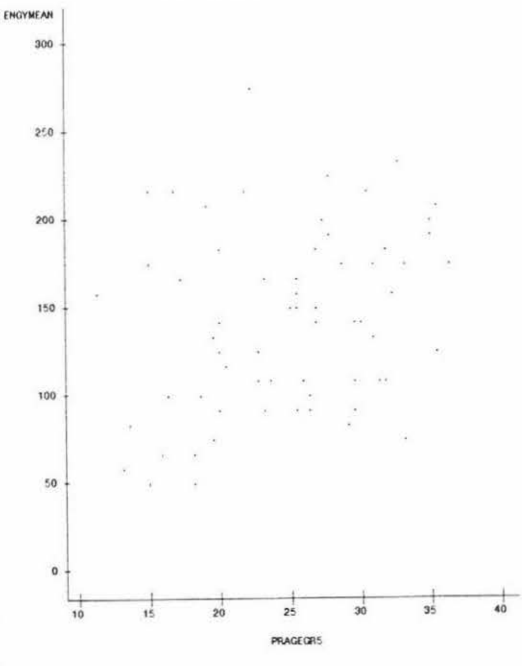
NOTE: 1 obs hidden.

MODEL 8 (4): Models HH energy use against proportion in age group "4":

Plot of ENGYMEAN*PRAGEGR4. Symbol used is '.'.



Plot of ENGYMEAN*PRAGEGR5. Symbol used is '.'.



MODEL 8 (6): Models HH energy use against proportion in age group "6":

Plot of ENGYMEAN*PRAGEGR6. Symbol used is '.'.

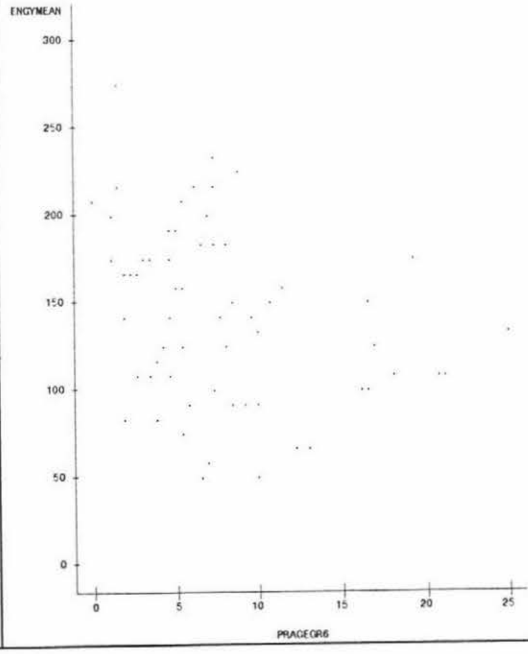


TABLE OF PLOTS 3

MODEL 8 (16): Models HH energy use against proportion in occupation group 2:

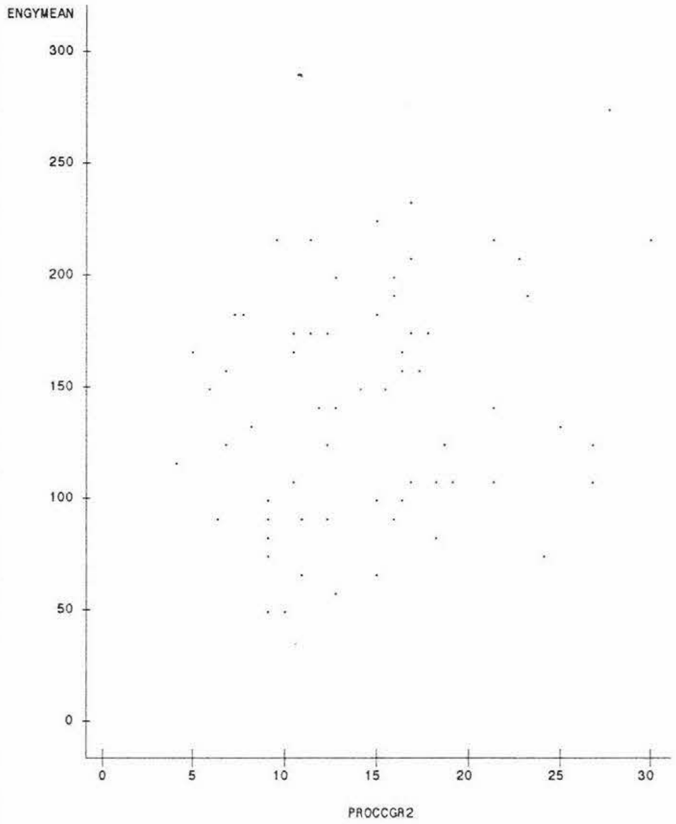
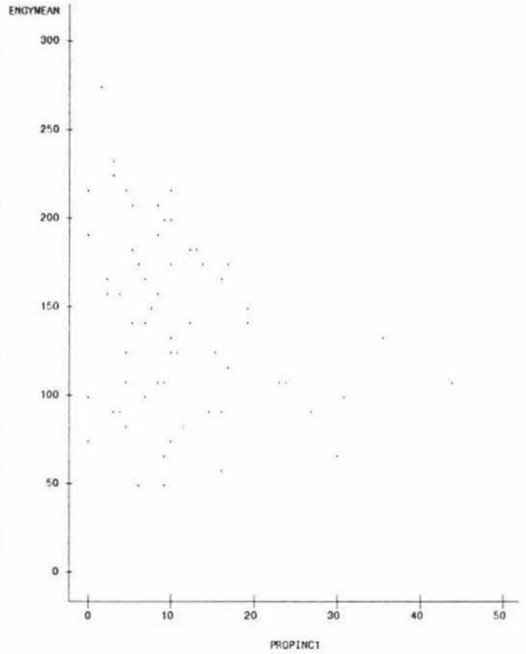


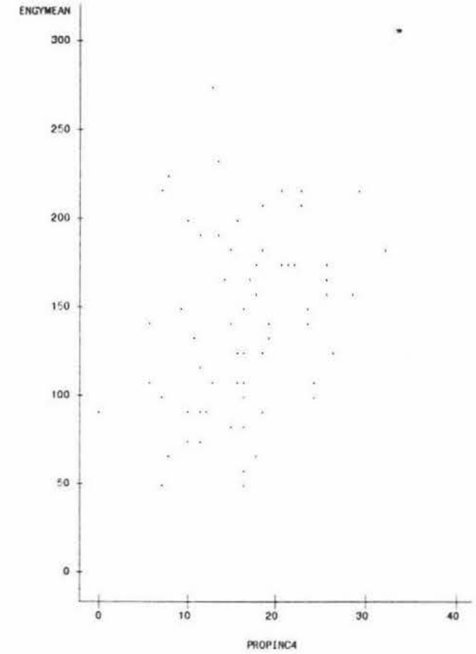
TABLE OF PLOTS 4

MODEL 8 (22): Models HH energy use against % HH in Income Group 1 in HZ:

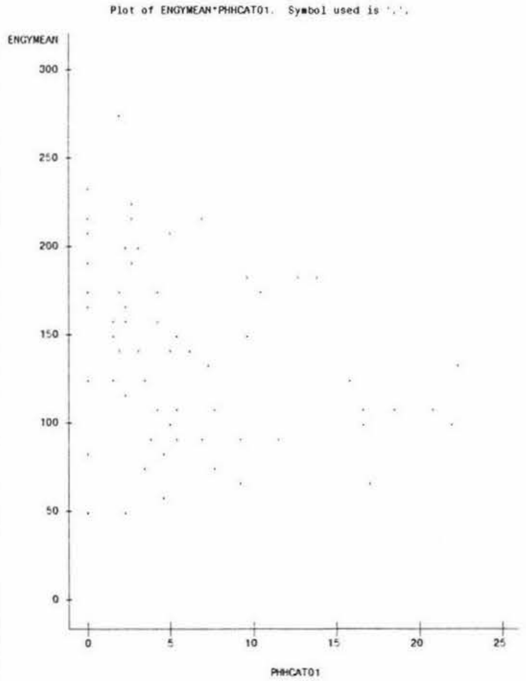


NOTE: 3 obs hidden.

MODEL 8 (25): Models HH energy use against % HH in Income Group 4 in HZ:

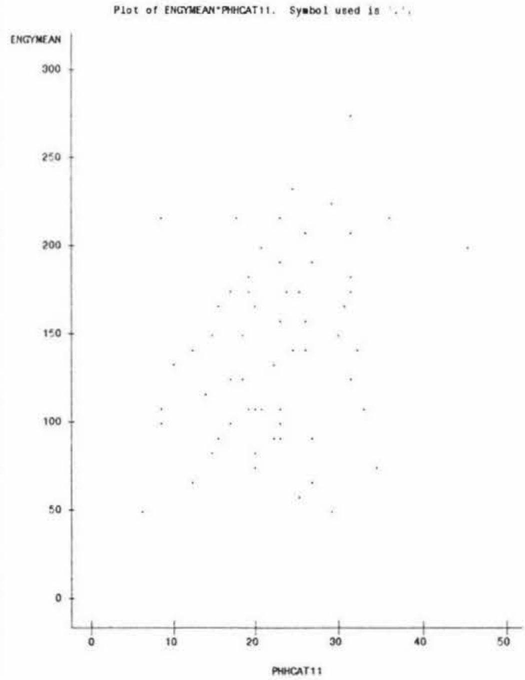


MODEL 8 (29): Models HH energy use against % HH-category 1 in HZ:



NOTE: 3 obs hidden.

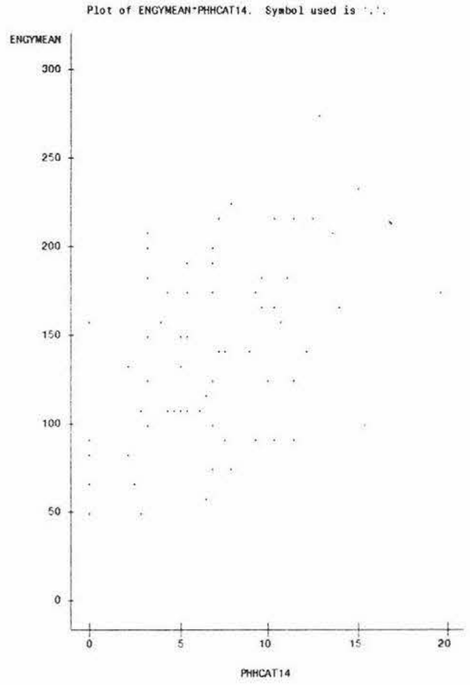
MODEL 8 (39): Models HH energy use against % HH-category 11 in HZ:



NOTE: 4 obs hidden.

TABLE OF PLOTS 5

MODEL 8 (42): Models HH energy use against % HH-category 14 in HZ:



MODEL 8 (48): Models HH energy use against % HH-category 20 in HZ:

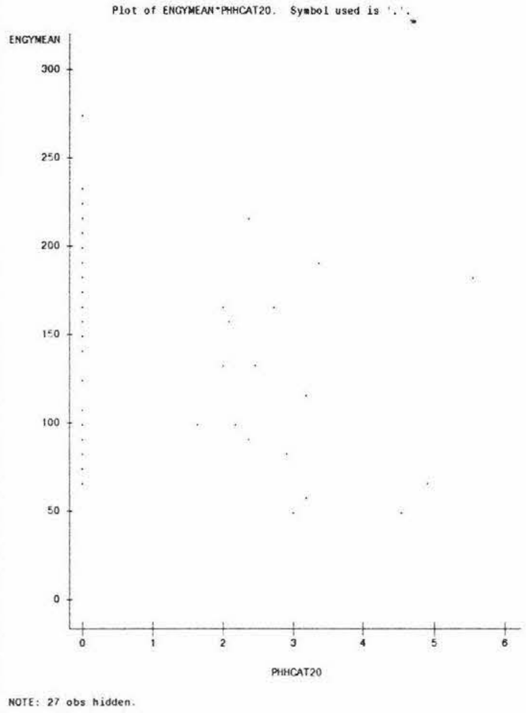


TABLE OF PLOTS 6

APPENDIX THREE

AVERAGE TRIP LENGTH BY TRIP PURPOSE.

Single leg trips only are recorded here, except for walking and cycling. This results in a severe "under-observation" of rail travel, as most trips are recorded as combined wit other modes (often walking). Multi-leg trips were however recorded in modal split totals for Model 11.

AVERAGE LENGTH OF SINGLE LEG (mode 1) CAR DRIVER TRIPS.

Analysis Variable : DISTANCE

N	Mean
16411	7.5612132

AVERAGE LENGTH OF SINGLE LEG (mode 2) CAR PASSENGER TRIPS.

Analysis Variable : DISTANCE

N	Mean
5877	7.3397856

AVERAGE LENGTH OF SINGLE LEG (mode 3) BUS TRIPS.

Analysis Variable : DISTANCE

N	Mean
698	5.9414900

AVERAGE LENGTH OF SINGLE LEG (mode 4) TRIPS BY "EMPLOYERS TRANSPORT":

Analysis Variable : DISTANCE

N	Mean
303	9.7931683

AVERAGE LENGTH OF SINGLE LEG SCHOOL BUS TRIPS (mode 5).

Analysis Variable : DISTANCE

N	Mean
212	6.5841509

AVERAGE LENGTH OF SINGLE LEG RAIL TRIPS (mode 6).

Analysis Variable : DISTANCE

N	Mean
75	14.8664000

AVERAGE LENGTH OF SINGLE LEG "OTHER MOTORISED" TRIPS (mode 7).

Analysis Variable : DISTANCE

N	Mean
350	6.7153143

AVERAGE LENGTH OF ALL WALKING TRIPS (mode 8).

Analysis Variable : DISTANCE

N	Mean
7846	1.5725261

AVERAGE LENGTH OF SINGLE LEG WALKING TRIPS (mode 8).

Analysis Variable : DISTANCE

N	Mean
5082	1.6579418

AVERAGE LENGTH OF ALL CYCLING TRIPS (mode 9).

Analysis Variable : DISTANCE

N	Mean
742	3.3503774

AVERAGE LENGTH OF SINGLE LEG CYCLING TRIPS (mode 9).

Analysis Variable : DISTANCE

N	Mean
733	3.3354297

APPENDIX FOUR

EXTRACTS FROM STEPWISE REGRESSION OUTPUT:

Step 5 Variable PRAGEGR6 Entered R-square = 0.79256946C(p) = -0.02339219

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	5	131002.00697133	26200.40139427	44.32	0.0001
Error	58	34285.72387361	591.13317023		
Total	63	165287.73084494			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	68.31980841	23.27828961	5091.86024457	8.61	0.0048
PRAGEGR6	-2.16237345	0.66918625	6172.38086822	10.44	0.0020
MNCARON2	1.48203612	0.41945156	7379.70986628	12.48	0.0008
MNCARON3	1.90842034	0.50745854	8360.50048917	14.14	0.0004
DISTZN28	1.39661738	0.26883676	15953.75514282	26.99	0.0001
MODSPLT8	-2.23102293	0.94597725	3288.00156228	5.56	0.0217

Bounds on condition number: 2.200394, 42.21625

Model 15 (a).sas: STEPWISE REGRESSION ANALYSIS of MEAN ENERGY USE for HOMEZONE:

Step 6 Variable MODSPLT3 Entered R-square = 0.80451325C(p) = -1.01619130

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	6	132976.16973544	22162.69495591	39.10	0.0001
Error	57	32311.56110950	566.86949315		
Total	63	165287.73084494			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	79.64558309	23.58960984	6461.97036086	11.40	0.0013
PRAGEGR6	-2.14830979	0.65535196	6091.54834789	10.75	0.0018
MNCARON2	1.44280118	0.41129066	6975.86980953	12.31	0.0009
MNCARON3	1.91518753	0.49694806	8419.44934778	14.85	0.0003
DISTZN28	1.14842971	0.29494734	8594.15058076	15.16	0.0003
MODSPLT3	-1.48051857	0.79334835	1974.16276410	3.48	0.0672
MODSPLT8	-1.87155412	0.94617447	2217.91766552	3.91	0.0528

Bounds on condition number: 2.295534, 63.68808

Model 15(a) Mean household energy use for homezone: **Forward selection procedure**.

All variables are within 5% significance level at Step 5, but from Step 6 onwards increasing numbers of variables fall outside this level, for example MODSPLT3 (modal split for bus).

Step24 Variable MOSPWABI Removed R-square = 0.82625972 C(p) = -2.46528109

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	8	136570.59414589	17071.32426824	32.70	0.0001
Error	55	28717.13669905	522.12975816		
Total	63	165287.73084494			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	209.43397824	20.68457228	53527.83041803	102.52	0.0001
PRAGEGR6	-2.95502646	0.95621029	4986.48331661	9.55	0.0031
MEANINC1	-1.41739464	0.53210685	3704.77915161	7.10	0.0101
MNHHCAT1	1.42723553	1.01888925	1024.50901625	1.96	0.1669
MNHHCA11	1.01802181	0.46105494	2545.58295758	4.88	0.0314
MNCARON1	-1.60458165	0.34347154	11395.16407572	21.82	0.0001
DISTZN31	1.71602482	0.31962356	15050.39925899	28.83	0.0001
MODSPLT3	-1.85766640	0.76270736	3097.40521944	5.93	0.0181
MODSPLT8	-2.35558111	0.84071898	4098.95236872	7.85	0.0070

Bounds on condition number: 4.409447, 152.6782

Step25 Variable MNHHCAT1 Removed R-square = 0.82006138 C(p) = -2.91214184

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	7	135546.08512964	19363.72644709	36.46	0.0001
Error	56	29741.64571530	531.10081634		
Total	63	165287.73084494			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	207.55946148	20.81780937	52794.90160279	99.41	0.0001
PRAGEGR6	-2.04528095	0.70781690	4434.46329177	8.35	0.0055
MEANINC1	-1.00500309	0.44703537	2684.28107731	5.05	0.0285
MNHHCA11	1.06845315	0.46357906	2821.24182743	5.31	0.0249
MNCARON1	-1.51821470	0.34078266	10541.15920026	19.85	0.0001
DISTZN31	1.54221027	0.29707403	14313.13533951	26.95	0.0001
MODSPLT3	-2.00494311	0.76188795	3677.89105066	6.93	0.0110
MODSPLT8	-2.64350657	0.82217821	5490.42335383	10.34	0.0022

Bounds on condition number: 1.853625, 82.26484

All variables left in the model are significant at the 0.1000 level.

Model 15(a) Mean household energy use for homezone: **Backward elimination procedure**.

All variables are within the 5% significance level at Step 25, but up to Step 24 one or more variables fall well outside this level (e.g. in Step 24, MNHHCAT1 - proportion of households in homezone in household category 1).

Step 6 Variable MODSPLT8 Entered R-square = 0.79256946C(p) = -0.02339219

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	5	131002.00697133	26200.40139427	44.32	0.0001
Error	58	34285.72387361	591.13317023		
Total	63	165287.73084494			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	68.31980841	23.27828961	5091.86024457	8.61	0.0048
PRAGEGR6	-2.16237345	0.66918625	6172.38086822	10.44	0.0020
MNCARON2	1.48203612	0.41945156	7379.70986628	12.48	0.0008
MNCARON3	1.90842034	0.50745854	8360.50048917	14.14	0.0004
DISTZN28	1.39661738	0.26883676	15953.75514282	26.99	0.0001
MODSPLT8	-2.23102293	0.94597725	3288.00156228	5.56	0.0217

Bounds on condition number: 2.200394, 42.21625

The above model is the best 5-variable model found.

Step 7 Variable MODSPLT3 Entered R-square = 0.80451325C(p) = -1.01619130

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	6	132976.16973544	22162.69495591	39.10	0.0001
Error	57	32311.56110950	566.86949315		
Total	63	165287.73084494			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	79.64558309	23.58960984	6461.97036086	11.40	0.0013
PRAGEGR6	-2.14830979	0.65535196	6091.54834789	10.75	0.0018
MNCARON2	1.44280118	0.41129066	6975.86980953	12.31	0.0009
MNCARON3	1.91518753	0.49694806	8419.44934778	14.85	0.0003
DISTZN28	1.14842971	0.29494734	8594.15058076	15.16	0.0003
MODSPLT3	-1.48051857	0.79334835	1974.16276410	3.48	0.0672
MODSPLT8	-1.87155412	0.94617447	2217.91766552	3.91	0.0528

Bounds on condition number: 2.295534, 63.68808

The above model is the best 6-variable model found.

Model 15(a) Mean household energy use for homezone: **MAXR procedure**.

All variables are within 5% significance level at Step 6, but from Step 7 onwards increasing numbers of variables fall outside this level. MODSPLT3 (modal split for bus) is outside the 5% level of significance in this step.

Step 3 Variable MNCARON2 Entered R-square = 0.68794038 C(p) = 21.67850263

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	3	581527760.20400	193842586.73467	44.09	0.0001
Error	60	263789331.83244	4396488.8638740		
Total	63	845317092.03645			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	4525.02404453	1564.20047973	36792807.688290	8.37	0.0053
MNCARON2	131.87221885	34.51634654	64174569.410265	14.60	0.0003
MNCARON3	184.57743391	39.47932249	96100091.918837	21.86	0.0001
MODSPLT8	-233.57543849	72.49489796	45639979.149682	10.38	0.0021

Bounds on condition number: 1.737534, 13.63896

Step 4 Variable DISTZN28 Entered R-square = 0.75582470 C(p) = 6.78060104

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	4	638911541.02857	159727885.25714	45.66	0.0001
Error	59	206405551.00787	3498399.1696250		
Total	63	845317092.03645			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	2035.51886448	1524.71604996	6235074.9824467	1.78	0.1870
MNCARON2	135.84951165	30.80543180	68034770.326723	19.45	0.0001
MNCARON3	186.55309151	35.22029932	98149519.384589	28.06	0.0001
DISTZN28	79.27920146	19.57489171	57383780.824569	16.40	0.0002
MODSPLT8	-113.84059038	71.10530556	8967257.1880556	2.56	0.1147

Bounds on condition number: 2.100676, 24.9711

Step 5 Variable PRAGEGR6 Entered R-square = 0.79296461 C(p) = -0.46433907

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	5	670306540.82735	134061308.16547	44.43	0.0001
Error	58	175010551.20910	3017423.2967085		
Total	63	845317092.03645			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	4849.14193962	1663.13124156	25651513.151542	8.50	0.0050
PRAGEGR6	-154.21782889	47.81040934	31394999.798778	10.40	0.0021
MNCARON2	107.07573124	29.96796586	38521554.678961	12.77	0.0007
MNCARON3	136.11066393	36.25567690	42527368.284710	14.09	0.0004
DISTZN28	99.27306755	19.20720192	80606658.576391	26.71	0.0001
MODSPLT8	-160.24989544	67.58590704	16963655.940555	5.62	0.0211

Bounds on condition number: 2.200394, 42.21625

Step 6 Variable MODSPLT3 Entered R-square = 0.80215978 C(p) = -0.75321795

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	6	678079371.27802	113013228.54634	38.52	0.0001
Error	57	167237720.75843	2933995.1010251		
Total	63	845317092.03645			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	5559.80875527	1697.10575998	31489174.502850	10.73	0.0018
PRAGEGR6	-153.33536558	47.14794314	31032627.478181	10.58	0.0019
MNCARON2	104.61382708	29.58945719	36674446.514876	12.50	0.0008
MNCARON3	136.53528984	35.75190217	42790849.761707	14.58	0.0003
DISTZN28	83.69985067	21.21937712	45650284.434482	15.56	0.0002
MODSPLT3	-92.89920073	57.07580853	7772830.4506655	2.65	0.1091
MODSPLT8	-137.69403835	68.07056778	12005241.830024	4.09	0.0478

Bounds on condition number: 2.295534, 63.68808

Model 15(b) Mean household emissions for homezone: **Forward selection procedure** (see next page for notes).

MODSPLT8 (modal split for walking) is entered at Step 4 of the forward selection procedure, but is outside the 5% level of significance in this step. However in the Step 5 all variables are within the 5% significance level. From Step Step 7 onwards increasing numbers of variables fall outside this level.

Step24 Variable MNHHCAT1 RemovedR-square = 0.82143287 C(p) = -1.55071519

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	8	694371248.03455	86796406.004318	31.63	0.0001
Error	55	150945844.00190	2744469.8909436		
Total	63	845317092.03645			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	14340.32033672	1582.18887922	225454818.10048	82.15	0.0001
PRAGEGR6	-132.29307876	52.06708134	17717655.391182	6.46	0.0139
MEANINC1	-40.64359982	36.77058375	3353063.3183448	1.22	0.2738
MNHHCA11	75.03773480	34.37499805	13077735.118476	4.77	0.0333
MNCARON0	-57.77873721	38.07701784	6319296.1286988	2.30	0.1349
MNCARON1	-121.27022305	26.24213959	58609543.767185	21.36	0.0001
DISTZN31	2097.08875636	970.78009516	12807087.247139	4.67	0.0351
DISTZN32	-1988.37997270	976.44972898	11380398.050027	4.15	0.0465
MODSPLT8	-131.01521800	69.41431615	9776960.4688123	3.56	0.0644

Bounds on condition number: 3810.478, 60694.07

Step25 Variable MEANINC1 Removed R-square = 0.81746624 C(p) = -2.56333281

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	7	691018184.71620	98716883.530886	35.83	0.0001
Error	56	154298907.32024	2755337.6307187		
Total	63	845317092.03645			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	14579.41257820	1570.43298861	237473994.10488	86.19	0.0001
PRAGEGR6	-151.23709391	49.26270886	25968980.029367	9.42	0.0033
MNHHCA11	76.29167015	34.42422940	13533203.551261	4.91	0.0308
MNCARON0	-78.42015868	33.24882384	15327724.404418	5.56	0.0219
MNCARON1	-127.43145417	25.69402788	67774093.846410	24.60	0.0001
DISTZN31	1947.49473749	963.20126868	11264017.519680	4.09	0.0480
DISTZN32	-1844.46723954	969.64463849	9969916.3513839	3.62	0.0623
MODSPLT8	-126.28943663	69.41956092	9118956.6358985	3.31	0.0742

Bounds on condition number: 3736.418, 52096.55

All variables left in the model are significant at the 0.1000 level.

Model 15(b) Mean household energy use for homezone: **Backward elimination procedure**.

Step 25 is the final step of the backward elimination procedure for this submodel. Two variables remain outside the 5% significance level, although they are well within 10% which would be considered acceptable by many researchers.

Step 6 Variable MODSPLT8 Entered R-square = 0.79296461 C(p) = -0.46433907

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	5	670306540.82735	134061308.16547	44.43	0.0001
Error	58	175010551.20910	3017423.2967085		
Total	63	845317092.03645			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	4849.14193962	1663.13124156	25651513.151542	8.50	0.0050
PRAGEGR6	-154.21782889	47.81040934	31394999.798778	10.40	0.0021
MNCARON2	107.07573124	29.96796586	38521554.678961	12.77	0.0007
MNCARON3	136.11066393	36.25567690	42527368.284710	14.09	0.0004
DISTZN28	99.27306755	19.20720192	80606658.576391	26.71	0.0001
MODSPLT8	-160.24989544	67.58590704	16963655.940555	5.62	0.0211

Bounds on condition number: 2.200394, 42.21625

The above model is the best 5-variable model found.

Step 7 Variable MODSPLT3 Entered R-square = 0.80215978 C(p) = -0.75321795

	DF	Sum of Squares	Mean Square	F	Prob>F
Regression	6	678079371.27802	113013228.54634	38.52	0.0001
Error	57	167237720.75843	2933995.1010251		
Total	63	845317092.03645			

Variable	Parameter Estimate	Standard Error	Type II Sum of Squares	F	Prob>F
INTERCEP	5559.80875527	1697.10575998	31489174.502850	10.73	0.0018
PRAGEGR6	-153.33536558	47.14794314	31032627.478181	10.58	0.0019
MNCARON2	104.61382708	29.58945719	36674446.514876	12.50	0.0008
MNCARON3	136.53528984	35.75190217	42790849.761707	14.58	0.0003
DISTZN28	83.69985067	21.21937712	45650284.434482	15.56	0.0002
MODSPLT3	-92.89920073	57.07580853	7772830.4506655	2.65	0.1091
MODSPLT8	-137.69403835	68.07056778	12005241.830024	4.09	0.0478

Bounds on condition number: 2.295534, 63.68808

The above model is the best 6-variable model found.

Model 15(b) Mean household emissions for homezone: **MAXR procedure**:

As with the maximum R-square improvement procedure for submodel 15 (a), all variables are within 5% significance level at Step 6, but from Step 7 onwards increasing numbers of variables fall outside this level. MODSPLT3 (modal split for bus) is again outside the 5% level of significance in this step.

Bibliography

ACIL 1997 *Barriers to entry to the New Zealand downstream oil market.* Report prepared for NZ Ministry of Commerce by ACIL Economics and Policy Pty Ltd, Canberra.

Albert J D and Banton H S 1978 'Urban spatial analysis adjustments resulting from rising energy costs.' *Annals of Regional Science* 12, 64-71.

Altshuler A., Womack J.P. and Pucher J.R. 1981 *The Urban Transportation System - Politics and Policy Innovation.* Cambridge MA: MIT Press.

Anastasi C, Hudson R and Simpson V J 1990 'Effects of future fossil fuel use on CO2 levels in the atmosphere.' *Energy Policy* 18(10) 936-944.

Anon 1991 'Planned communities.' *Urban Land* 50(3) 40-43.

Atash F 1993 'Mitigating traffic congestion in suburbs: An evaluation of land-use strategies.' *Transportation Quarterly* 47 (4) 597-610.

Atash F 1994 'Redesigning suburbia for walking and transit: emerging concepts.' *Journal of Planning and Development* 120(1) 48-57.

Audirac I, Shermyen A H and Smith M T 1991 'Ideal urban form and visions of the good life: Florida's growth and management dilemma.' *Journal of the American Planning Association* 56(4), 470-482.

Bae C-H C 1993 "Air quality and travel behaviour - Untying the knot.' *Journal of the American Planning Association* 58 (1), 65-74.

Banham J 1991 'Energy and urban regeneration: who decides and what about?' *International Journal of Global Energy Issues* 2 (4), 211-216.

Banks F E 1991 '"Paper" oil, "real" oil, and the price of oil.' Viewpoint, *Energy Policy* 19(6), 517-525.

Beaumont J R and Keys P 1982 *Future cities: Spatial analysis of energy issues.* John Wiley, Chichester U K.

Beca Carter Hollings and Ferner 1977 *Energy in transport; Volume Two: Policies*. Auckland: New Zealand Energy Research and Development Committee, University of Auckland, Report No. 27.

Beca Carter Hollings and Ferner 1984 *Energy use and taxation policy in the New Zealand car fleet*. New Zealand Energy Research and Development Committee, Auckland.

Beca Carter Hollings and Ferner 1986 *Energy use in transport data report.* Auckland: New Zealand Energy Research and Development Committee, University of Auckland, Report No. 131.

Ben Bouanah J and Stein M M 1978 'Urban transportation models: A generalized process for international application.' *Traffic Quarterly* 32, 449-470.

Berry B J L (Ed) 1974 *Land Use, Urban Form and Environmental Quality*. University of Chicago, Chicago.

Berry B J L 1975 *Land use forms and the environment - an executive summary*. Office of Research and Development, United States Environmental Protection Agency.

Blake J 1992 'Living up to the Toronto convention - A strategy for the Wellington region.' Unpublished honours project, Massey University, Palmerston North.

Bleviss D L 1990 'The role of the automobile - future transportation, environmental and energy needs.'*Energy Policy* 18(2) 137-148.

Boulter R 1993 'Misconceptions, flawed assumptions and token treatment.' *Town and Country Planning,* August, 215-217.

Boyle S 1990 'Transport and energy policies: only connect', *Energy Policy* 18(1) 34-41.

Boyle S 1994 'A global fossil free energy scenario: towards climate stabilization?' *Energy Policy* 22(2) 106-109.

Breheny M 1991 'Contradictions of the compact city.' *Town and Country Planning*, January, 21.

Breheny M. 1990 '*Strategic Planning and Urban Sustainability'* Proceedings of the Town and Country Planning Association Annual Conference on Planning for Sustainable Development 9.1-9.28. Town and Country Planning Association, London.

Brindle R 1992 'Toronto - paradigm lost? Toronto as a paradigm for Australian cities.' *Australian Planner*, 30(3), 123-130.

Brittle C., McConnell N. and O'Hare S. 1984 *Traffic mitigation reference guide*. Oakland, CA: Metropolitan Transportation Commission.

Brookes L.G. 1990 'The greenhouse effect: the fallacies in the energy efficiency solution'communication in *Energy Policy* 18(2) 199-201.

Brookes L.G. 1991 'Confusing the issue on energy efficiency', Communication, *Energy Policy* 19(2) 184-186; letter to editor 187.

Brotchie J F, Sharpe R and Rodger A 1990 'Greenhouse implications for urban systems' in in Swaine D J, 369-379.

Bruton M.J. 1975 *Introduction to transportation planning*. London: Hutchinson.

Burchell R W and Listokin D (eds) 1982 *Energy and Land Use.* Rutgers University, New Brunswick N J, USA.

Burchell R W and Listokin D 1982 'The energy-land use interface' in Burchell and Listokin 1982, 1-60.

Bush G 1989 'The revolution of local government restructuring in New Zealand.' *Planning and Administration* 16(2), 88-103.

Button K J and Pearce D W 1989 'Improving the urban environment: how to adjust national and local government policy for sustainable urban growth.' *Progress in Planning* 32(3) 135-184.

Calthorpe P 1989 'Pedestrian pockets: New strategies for suburban growth' in Kelbaugh D (ed) *The pedestrian pocket book: A new suburban design strategy* ; 6-20.

Calthorpe P 1991 'The post-suburban environment.' *Progressive Architecture* 3, 84-85.

Campbell R M and Newman P W G 1989 'Local government and transport energy conservation.' *Planning and Administration* 16(1), 68-75.

Cannell 1996 *personal communication.* Stagecoach, Wellington.

Carmicheal T J and Haley C E 1950 'A study of vehicle, roadway and traffic relationships by means of statistical instruments.' *Highway Research Board Proceedings*. 30, 282-296.

Cervero R 1991 'Land use and travel at suburban activity centres.' *Transportation Quarterly* 45(4) 479-491.

Cervero R 1992 'Future transit and future cities.' *Transportation Quarterly* 46(2) 193-204.

Cervero R. 1986 'Urban transit in Canada: Integration and innovation at its best.' *Transportation Quarterly* 40 (3) 293-316.

Cervero R. 1989 *America's suburban centers: The land use-transportation link.* Boston: Unwin Hyman.

Cervero R 1991 a'Congestion relief: The land use alternative.' *Journal of Planning Education and Research* 10(2) 119-129.

Champion A G 1992 'Urban and regional demographic trends in the developed world.' *Urban Studies* 29(3/4) 461-482 [May].

Chinitz B. 1990 'Growth management: good for the town, bad for the nation?' *Journal of the American Planning Association* 56(1) 3-8.

Chinitz B. 1991 'A framework for speculating about future urban growth in the US.' *Urban Studies* 28 (6), 939-959.

Clark J W 1974 *Defining an urban growth strategy which will achieve maximum travel demand reduction and access opportunity enhancement.* Seattle, Washington USA: Departments of Urban Planning and Civil Engineering, University of Washington.

Clark W A V and Kuijpers-Linde M 1994 'Commuting in restructuring urban regions.' *Urban Studies* 31(3) 465-483

Cockburn D, Efford B, Wood K and Butler G 1992 *Superlink: Wellington Region's Transport Opportunity*. Transport 2000, Wellington.

Cocklin C 1993 'Anatomy of a future energy crisis: Restructuring and the energy sector in New Zealand.' *Energy Policy* 21(8) 881-891

Cody R P 1987 *Applied statistics and the SAS programming language.* Elsevier Science Publishing, New York.

Collie M.J.S. 1990 'The case for urban consolidation.' *Australian Planner*, 28/2, 26-33 (June).

Cristofaro A 1992 '"No regrets" tax reform' in White *et al* 1992, 61-63.

Dasgupta M, Frost M and Spence N 1985 'Interaction between urban form and mode choice for the work journey: Manchester/Sheffield 1971-1981.' *Regional Studies* 19(4) 315-328.

de la Barra T. 1989 Integrated land use and transport modelling; decision chains and hierarchies. Cambridge: Cambridge University Press.*

de la Barra T. and Rickaby P A 1982 'Modelling regional energy use: a land-use, transport and energy evaluation model.' *Environment and Planning B: Planning and Design* 9: 429-443.

de la Barra T. and Rickaby P A 1987 'A hierarchical land-use and transport model for energy evaluation', in Hawkes D, Owens J, Rickaby P and Steadman P (Eds) 1987, 5-28.

Dean A O 1975 'Redesigning an entire town (and its lifestyle) for energy conservation.' *American Institute of Architects Journal* 64, 44-47

Delafons J 1993 'Looking at suburbia.' *Town and Country Planning* 203-204

Diamond D, McLoughlin J and Massam B 1989 'Improving the urban environment: how to adjust national and local government policy for sustainable urban growth.' *Progress in Planning* 32(3) Pergamon, Oxford.

Dimitriou H T 1992 *Urban transport planning: A developmental approach.* Routledge, New York.

Donaldson D M and Betteridge G E 1990 'The relative cost of various measures to ameliorate global warming.' *Energy Policy* 18(6) 563-571.

Douglass M. and Smith M.G. 1981 *Urban transport fuel use evaluation*. New Zealand Energy Research and Development Committee, University of Auckland, Auckland. Report No. 69.

Downs A 1982 'Squeezing spread city - a second look' in Burchell and Listokin 1982, 145-150.

Dynarski M 1986 'Household formation and suburbanization, 1970-80.' *Journal of Urban Economics* 19, 71-87.

Edmonds J A and Reilly J M 1985 'Future global energy and carbon dioxide emissions', Chapter Nine in Trabalka J R (Editor), 215-246.

Edwards J L and Schoper J L 1976 'Relationships between transportation energy consumption and urban structure: Results of simulation studies.' *Transportation Research Record* 599, 53-59.

Electricity Corporation of New Zealand 1994 *Electricity supply and demand in New Zealand: A discussion paper*. Electricity Corporation of New Zealand, Wellington.

Electricity Corporation of New Zealand 1996 (a) *Annual report: Year ended 30 June 1996*. ECNZ, Wellington.

Electricity Corporation of New Zealand 1996 (b) *Environmental report: Year ended 30 June 1996*. ECNZ, Wellington.

Electricity Corporation of New Zealand 1997 *Second annual report for the voluntary agreement between the Electricity Corporation of New Zealand and the Government of New Zealand to reduce carbon dioxide emissions*. ECNZ, Wellington.

Engels F 1980 *The condition of the working class in England*. Reprint of 1845 classic. Progress Publishers, Moscow.

Eno Foundation 1988 'Report of the 20th Annual Joint Conference Eno Foundation Board of Directors and Board of Consultants.' *Transportation Quarterly* 42 (1), 141-154.

European Conference of Ministers of Transport 1990 *Transport Policy and the Environment*. Paris: ECMT/OECD Publications Service.

Fels M F and Munson M J 1975 'Energy thrift in urban transportation: Options for the future', in Williams R H 1975, 7-104

Ferguson E 1990 'Transportation demand management - Planning, development and implementation.' *Journal of the American Planning Association* 56(4), 442-456.

Fergusson M 1994 'The effects of vehicle speeds on emissions.' *Energy Policy* 22(2) 103-106

Fischel W A 1991 'Good for the town, bad for the nation? A comment.' *Journal of the American Planning Association* 57(3), 341-344.

Fitzsimons J 1990 'Urban form and transport fuel in Auckland.' *Planning Quarterly* 98, 12-18 (June).

Florida R and Jonas A 1991 'US urban policy: The postwar state and capitalist regulation.' *Antipode* 23(4) 349-384.

Ford Foundation 1974 *A time to choose: America's energy future*. Ballinger, Cambridge MA USA.

Franklin H M 1974 'Will the new conciousness of energy and environment create an imploding metropolis?' *American Institute of Architects Journal* 63, 28-36.

Freidman R M and Bierbaum R M 1992 'Steps to reduce US carbon dioxide emissions: technical options and the policies to implement them' in White J C, Wagner W R and Beal C N (eds) 1992 *Global Climate Change: Linking energy, environment , economy and equity*. Plenum Press, New York, 13 - 36.

Frey W H 1993 'The new urban revival in the United States.' *Urban Studies* 30 (4/5) 741-774

Frow D 1990 *Implications of electricity for the geenhouse effect.* . Electricty Corporation of New Zealand Ltd, Wellington.

Gammon R H, Trabalka J R and Solomon A M 1985 'History of carbon dioxide in the atmosphere', Chapter 3 in Trabalka J R (Editor), 25-62.

Gilbert G and Dajani J S 1974 'Energy, urban form and transportation policy.' *Transportation Research* 8, 267-276.

Giuliano G 1992 'Transportation demand management - Promise or panacea?' *Journal of the American Planning Association* 58 (3), 327-335.

Giuliano G and Small K A 1993 'Is the journey to work explained by urban structure?' *Urban Studies* 30(9) 1485-1500.

Goldberg M A 1986 *The Myth of the North American City; Continentalism Challenged.* The University of British Columbia Press, Vancouver.

Goldberg M A and Chinloy P 1984 *Urban Land Economics.* John Wiley and Sons, Toronto.

Gomez-Ibanez J A 1991 'A global view of automobile dependence.' *Journal of the American Planning Association* 57 (3), 376-379.

Gordon P and Richardson H W 1989 'Gasoline consumption and cities - a reply'. *Journal of the American Planning Association* 55(3), 342-346.

Gordon P, Richardson H W and Jun M-J 1991 'The communing paradox: Evidence from the top twenty.' *Journal of the American Planning Association* 57(1), 416-420.

Goss W P and McGowan J G 1972 'Transportation and energy - a future confrontation.' *Transportation 1*, 265-289.

Greenhalgh G 1990 'Energy conservation policies.' Communication in *Energy Policy* 18(3) 293-299.

Guest A M and Cluett C 1976 'Analysis of mass transit ridership using 1970 census data.' *Traffic Quarterly* 30, 143-161.

Hall P and Hass-Klau C 1985 *Can rail save the cities? The impacts of rail rapid transit and pedestrianisation on British and American cities.* Gower, London.

Hamburg J R, Guinn C R, Lathrop G T and Hemmens G C 1965 'Linear programming test of journey-to-work minimisation.' *Highway Research Record* 102, 67-75.

Hamilton B W 1982 'Wasteful commuting.' *Journal of Political Economy* 90, 1035-1053.

Hamilton B W 1989 'Wasteful commuting again.' *Journal of Political Economy* 97, 1497-1504.

Hannon B, Herendeen R, Puleo F and Sebald A 1975 'Energy, employment and dollar impacts of alternative transportation options' in Williams R H 1975, 105-130

Hansen W G and Morison I W 1968 *Canberra: A study of land use and transport.* Proceedings: Australian Road Research Board 4(1), 44-63.

Hanson M E 1992 'Automobile subsidies and land use - estimates and policy responses.' *Journal of the American Planning Association* 58 (1), 60-71.

Hart T 1992 'Transport, the Urban Pattern and Regional Change, 1960-2010.' *Urban Studies* 29 (3/4), 483-503.

Hass-Klau C 1988 *New life for city centres: Planning, transport and conservation in British and German cities.* Anglo-German Foundation for the Study of Industrial Society, London.

Hass-Klau C 1990 'Public transport and integrated transport policies in large metropolitan areas of Europe.' *The Planner* 76 (20), 13-20.

Hawkes D, Owens J, Rickaby P and Steadman P (Eds) *1987 Energy and Urban Built Form.* Centre for Configurational Studies, The Open University/ Butterworths, London.

Helwig J T (undated) *SAS introductory guide.* SAS Institute, Cary North Carolina USA.

Hemmens G C 1967 'Experiments in urban form and structure.' *Highway Research Record* 207, 32-41.

Hensher D.A. 1983 *Longitudinal studies in transport: an assessment.* Macquarie University, Sydney.

Hepple 1986 (i) 'Gravity model' in Johnston R J, Gregory and Smith (eds) 1986, 185.

Hepple 1986 (ii) 'Economic base theory' in Johnston R J, Gregory and Smith (eds) 1986, 117.

Herskowitz D S 1992 'The commuting paradox: A reply.' Letter to the editor in *Journal of the American Planning Association* 58 (2) 244.

Hill D R 1992 'Sustainability, Victor Gruen, and the cellular metropolis.' *Journal of the American Planning Association* 58 (3), 312-326.

Hillmann M and Whalley A *1983 Energy and personal travel - obstacles to conservation.* Policy Studies Institute, London.

Hilton A 1992 'Oil, energy and capital: A coming crunch?' *Energy Policy* 20(10) 963-972.

Hodge D C 1992 'Urban congestion: Reshaping urban life'. *Urban Geography* 13(6), 577-588.

Houston L O Jr 1982 'Pro-Development Policies for the Eighties' in Burchell and Listokin 1982, 107-126.

Hughes P 1991 'The role of passenger transport in CO_2 reduction strategies.' *Energy Policy* 19(2) 149-160.

Hunt D 1979 *New Zealand in the future world: resources and technology - sustainability.* Hasselberg - Government Printer, Wellington.

Intergovernmental Panel on Climate Change 1990 *IPPC First Assessment Report.* World Meteorological Organisation/UNEP.

International Association for Travel Behaviour 1989 *Travel Behaviour Research. Fifth International Conference on Travel Behaviour.* Proceedings. Aldershot: Avebury.

International Energy Agency 1993 *IEA Greenhouse Gas R and D Programme.* IEA, (Place of publication not given).

Jacobs B D 1992 *Fractured cities: Capitalism, community and empowerment in Britain and America.* Routledge, Chapman and Hall, Andover UK.

Jamieson G, Mackay W and Latchford J 1967 'Transportation and land use structures.' *Urban Studies* 4, 201-217.

JHK and Associates 1995 *Transportation-related land use strategies to minimize mote vehicle emissions: An indirect source research study.* Report prepared for the California Air Resources Board. Emeryville California.

Jochem E 1991 'Reducing CO2 emissions - the West German plan.' *Energy Policy* 19(2) 119-126.

Johnston R J, Gregory D and Smith D M (eds) 1986 *The Dictionary of Human Geography.* Blackwell, Oxford.

Johnston M 1991 'Planning the urban forest.' *The Planner* 77(39).

Jones P M S 1993 'Paying the full costs of energy consumption'. *ATOM* 428, 41-43.

Joy S 1990 'Light rail's niches and boundaries in Australian and Asian cities.' *Transportation Quarterly* 43(3) 467-476.

Kain J F 1982 'Metropolitan form and increasing fuel prices' in Burchell and Listokin 1982, 151-155.

Kats G H 1990 'Slowing global warming and sustaining development - the promise of energy efficiency.' *Energy Policy* 18(1) 25-33.

Kelbaugh D (ed) 1989 *The pedestrian pocket book: A new suburban design strategy.* Princeton Architectural Press, New York.

Kent J H and Mudford N R 1979 'Motor vehicle emissions and fuel consumption modelling' *Transportation Research* 13A, 395-406.

Kenworthy J. 1991 'The land use and transit connection in Toronto: Some lessons for Australian cities.' *Australian Planner,* 29(3), 149-154.

Keyes D L 1976 'Energy and land use: An instrument of US conservation policy?' *Energy Policy* 4(3) 225-236.

Khazroom J D, Shelby M and Wolcott R 1990 'The conflicts between energy conservation and environmental policy in the US transportation sector.' *Energy Policy* 18(5) 456-458.

King J 1997 'Road jams driving commuters to trains'. *The Evening Post* 15 September 1997.

Kingston Reynolds Thom and Allardice/Beca Carter Hollings and Ferner 1981 *Energy in Transport : Personal transport energy use*. Auckland: New Zealand Energy Research and Development Committee, University of Auckland, Report No. 65.

Klaassen L H, Bourdrez J A and Volmuller J 1981 *Transport and reurbanisation.* Gower, Aldershot UK.

Klaassen L H, Molle W T M and Paelinck J H P 1981 *Dynamics of urban development.* St Martins, New York.

Knowles R L 1974 *Energy and form: an ecological approach to urban growth,* MIT Press, Cambridge Massachussetts USA.

Knox P 1982 *Urban social geography: An introduction.* Longman and Paul, New York.

Kumar A 1990 'Impact of technological developments on urban form and travel behaviour.' *Regional Studies* 24(2), 137-148.

Labelle S J and Moses D O 1982 *Technology assessment of productive conservation in urban transportation - final report*. Energy and Environment Systems Division, Center for Transporation Research, Argonne National Laboratory, Argonne Illinois USA.

Leggett J. 1991 'Energy and the new politics of the environment.' *Energy Policy* 19(2) 161-171.

Lonergan S C and Cocklin C 1990 'In the aftermath of the energy crisis - New Zealand's energy policy in the 1970s and 1980s.' *Energy Policy* 18(1) 101-116.

Lowry I 1964 *A Model of Metropolis.* Rand Corporation, Santa Monica California.

Lyons T J, Kenworthy J R and Newman P W G 1990 'Urban structure and air pollution'. *Atmospheric Environment* 24B (1), 43-48.

Macauley M K 1985 'Estimation and recent behaviour of urban population and employment density gradients.' *Journal of Urban Economics* 18 251-260.

Maltby D, Monteath I G, Lawler K A 1978 'The U.K. surface transport sector: Energy consumption and options for conservation.' *Energy Policy* 6: 294-313.

Manly B J F 1986 *Multivariate statistical methods: A primer.* Chapman and Hall, London.

Manohar S 1982 'Energy efficient planning' in Burchell and Listokin 1982, 61-106.

Maunsell and Partners Pty. Ltd 1975 *New Structures for Australian Cities.* The Report of the LUTSANC team prepared for the Cities Commission under.

McDonald T.K. 1974 *Urban transportation and land use - a study for the Urban Public Transport Council. Wellington:* New Zealand Institute of Economic Research, Contract Research Paper no. 10.

McKenzie D W (editor) Reed New Zealand Atlas. Reed/ Department of Survey and Land Information, Wellington.

Mills E, Wilson D and Johanssen T B 1991 'Getting started - No-regrets strategies for reducing greenhouse gas emissions.' Communication, *Energy Policy* 19(6) 526-542..

Ministry of Energy 1978 *Goals and guidelines: An energy strategy for New Zealand.* MoE, Wellington.

Monheim R 1992 'Town and transport planning and the development of retail trade in metropolitan areas in West Germany.' *Landscape and Urban Planning* 22, 121-136.

Naiker U 1992 'Sustainable development and human settlements.' *Australian Planner,* 30(4), 207-210.

Narsey and Stevenson C A 1997 *Survey of benzene, aromatics, 1,3-butadiene and lead in air: A report for the Ministry of Health.* Ministry of Health, Wellington.

Netherlands Agency for Energy and the Environment (NOVEM) 1989 *The Netherlands travelling clean: Towards a trend breach in passenger transport.* NOVEM, Utrecht, The Netherlands.

Neuman M 1991 'Utopia, Dystopia, Diaspora'. *Journal of the American Planning Association* 57 (3), 344-347.

Neutze M 1978 *Australian Urban Policy.* George Allen and Unwin, London.

Newman P W G and J R Kenworthy 1989 (a*) Cities and Automobile Dependence: A Sourcebook*. Gower Technical, Aldershot UK and Sydney.

Newman P W G and J R Kenworthy 1989 (b) 'Gasoline consumption and cities.' *Journal of the American Planning Association* 55 (1), 24-37.

Newman P W G, J R Kenworthy and Lyons T J 1985 'Transport energy use in the Perth metropolitan region: some urban policy implications.' *Urban Policy and Research* 3 (2) 4-15.

Nijkamp P and Perrels A 1991 'European cities: means and opportunities'. *International Journal of Global Energy Issues* 2 (4), 231-238.

Nowlan D M and Stewart G 1991 'Downtown population growth and commuting trips - Recent experience in Toronto.' *Journal of the American Planning Association* 57(2), 165-182.

OECD 1979 *Transport services in low density areas*. Paris: OECD Publications.

Okken P. A. 1991 'A case for alternative transport fuels.' Communication, *Energy Policy* 19(4) 400-405.

Olsson R 1992 'Sustaining the city's image - The Adelaide Plan Review exhibition.' *Australian Planner*, 30(4), 180-181.

Orski C K 1990 'Can management of transportation demand help solve our growing traffic congestion and air polution problems?' *Transportation Quarterly* 44(4) 483-498.

Orski C K 1992 'Congestion pricing: Promise and limitations' *Transportation Quarterly* 46(2) 157-167.

Ott L 1993 *An introduction to statistical methods and data analysis.* Wadsworth Publishing, Belmont California.

Owen W 1976 'Transportation energy and community design.' *Futures* 8(2) 94-103.

Owens S 1979 'Energy and settlement patterns.' *Built Environment* 5(4), 282-286.

Owens S 1984 'Energy and spatial structure: a rural example.' *Environment and Planning* A 16: 1319-1337.

Owens S 1985 'Energy demand: Links to land-use and forward planning.' *Built Environment* 11 (1), 33-44.

Owens S 1986 'Strategic planning and energy conservation.' *Town Planning Review* 57(1) 69-85.

Owens S 1986 *Energy, planning and urban form.* Pion, London.

Owens S 1987 'The urban future: Does it really matter?' in Hawkes D, Owers J, Rickaby P and Steadman P (eds), 169-186.

Owens S 1991 'Energy efficiency and sustainable land use patterns.' *Town and Country Planning,* February, 44-45.

Owens S 1992 'Environmental change and land-use planning.' Commentary, *Environment and Planning A* 24, 1671-1678.

Owens S and Rickaby P A 1983 'Energy and the pattern of human settlements.' *Built Environment* 9 (2)150-159.

Patterson M.G. 1987 *A systems approach to energy quality and efficiency.* Auckland: New Zealand Energy Research and Development Committee, University of Auckland, Report No. 143.

Pearmain D and Jones M 1985 *Transport interchanges - Theory and practice summary report.* Oxford Polytechnic, Oxford.

Pickrell D.H. 1992 'A desire named street-car: Fantasy and fact in rail transit planning.' *Journal of the American Planning Association* 58 (2), 158-176.

Pickus J and Gober P 1989 'Urban villages and activity patterns in Phoenix.' *Urban Geography* 9(1) 85-97.

Pivo G 1990 'The net of mixed beads: suburban office development in six metropolitan regions.' *Journal of the American Planning Association* 56(4), 457-469.

Planning Research Centre 1979 *Urban consolidation for Sydney.* University of Sydney, Sydney.

Plawinski V 1983 'Cluster development - an alternative for housing in New Zealand.' *Planning Quarterly* 69, 17-19.

Pledger S 1997 *Design and analysis of experiments.* Lecture notes for undergraduate paper STAT 291, Victoria University of Wellington, Wellington.

Pucher J 1990 'Capitalism, socialism and urban transportation: policies and travel behaviour in the east and west.' *Journal of the American Planning Association* 56(2), 278-296.

Pudup M B 1992 'Industrialization after (de)industrialization: A review essay'. *Urban Geography* 13 (2), 187-200.

Putman S H 1992 *Integrated urban models 2: new research and applications of optimization and dynamics*. Pion, London.

Ramanathan V 1988 'The greenhouse theory of climate change: A test by an inadvertent global experiment.' *Science* 240 no.4850 (15 April), 293-299.

Rasmussen R A and Khalil M A K 1981 *Atmospheric Environment* 15(5) 883-886.

Real Estate Research Corporation 1974 *The costs of sprawl - Environmental and economic cost of alternative residential development patterns at the fringe.* Council on Environmental Quality: Housing and Urban Development and the Office of Planning and Management, United States Environmental Protection Agency.

Reed Rickaby P A 1981 'Six regional settlement patterns: alternative configurations for energy-efficient settlement.' *Environment and Planning B: Planning and Design* 8, 191-212.

Rickaby P A 1987 'Six settlement patterns compared.' *Environment and Planning B: Planning and Design* 14, 193-223.

Rickaby P A 1991 'Energy and urban development in an archetypal English town.' *Environment and Planning B: Planning and Design 18*, 153-175.

Roberts J S 1975 'Energy and land use: analysis of alternative development patterns.' *Environmental Comment* September issue, 2-11.

Rogerson E W 1976 *Cosy homes multiply: A study of suburban expansion in western Auckland, 1918-31.* MA Thesis, Department of History, Auckland University.

Rotty R M and Masters C D 1985 'Carbon Dioxide from fossil fuel combustion: Trends, resources and technological implications', Chapter 4 in Trabalka J R (ed), 63-80.

Schipper L, Figueroa M J, Prices L and Espey M 1993 'Mind the gap: The vicious circle of measuring automobile fuel use.' *Energy Policy* 21(12) 1173-1190

Schneider J B 1992 'A PRT deployment strategy to support regional land use and rail transit objectives.' *Transportation Quarterly* 46(1) 135-153.

Schneider J B and Beck J R 1973 'Reducing the travel requirements of the North American city: An investigation of alternative urban spatial structure.' Presented at the 53rd Annual Meeting of Highway Research Board, Washington D.C..

Schumacher E F 1976 'Patterns of human settlement.' *Ambio* 5(3), 91-97.

Schwartz C., Kuzmyak J.R. and Keefer J. 1986 *Public-private partnerships in transportation: a casebook for elected officials*. Washington D.C.: Department of Transportation.

Sewell W R D and Foster H D 1980 *Analysis of the United States experience in modifying land use to conserve energy*. Lands Directorate, Environment Canada.

Sharpe R 1977 'The effect of urban form on transport energy patterns.' Paper presented to the Urban Meteorology Conference, Macquarie University Sydney; 10-11 February 1977.

Sharpe R 1978 'The effect of urban form on transport energy patterns'. *Urban Ecology* 3, 125-135.

Sharpe R, Roy J R and Taylor M A P 1982 'Optimizing urban futures.' *Environment and Planning B: Planning and Design 9*: 209-220.

Shavelson R J 1981 *Statistical reasoning for the behavioral sciences.* Allyn and Bacon, Needham Heights Massachusetts USA.

Shelton B 1992 'Rethinking our images of the Japanese city.' *Australian Planner* 30(3), 131-135.

Singh M K 1981 *Energy consumption due to local travel by urban households under three alternative policies: 1980-2000.* Argonne Illinois USA: Argonne National Laboratory.

Small K A 1980 'Energy scarcity and urban development patterns.' *International Regional Science Review* 5 (2), 97-117.

Smith 1986 'Market potential model' in Johnston R J, Gregory and Smith (eds) 1986, 281-2

Smith O L 1991 'Computer-assisted flexible routing of mass transit bus systems.' *Transportation Quarterly* 45(4) 581-597.

Snedecor G W and Cochrane W G 1988 *Statistical Methods.* Iowa State University Press, Ames Iowa USA.

Soja E, Morales R and Wolff G 1983 'Urban restructuring: An analysis of social and spatial change in Los Angeles.' *Economic Geography* 59, 159-230.

Solomon A M, Trabalka J R, Reichle D E and Voorhees L D 1985 'The global cycle of carbon', Chapter 1 in Trabalka J R (Editor), 1-14.

Solomon D 1989 'Fixing suburbia' in Kelbaugh D (ed)1989, 21-33.

Soot S and Sen A 1979 'Metropolitan work-trip energy consumption patterns.' *Traffic Quarterly* 33 (2) 275-296.

Sorrell S 1992 'Fuel efficiency in the UK vehicle stock' *Energy Policy* 20(8) 766-780.

Southworth M 1997 'Walkable suburbs? An evaluation of neotraditional communities at the urban edge. *Journal of the American Planning Association* 63 (1), 28-44.

Spector P E 1993 *SAS programming for researchers and social scientists.* Sage Publications, Newbury Park California.

Spreng D 1993 'Possibilities for substitution between energy, time and information.' *Energy Policy* 21(1) 13-23.

Stanback T.M. Jr 1991 *The new suburbanization: challenge to the central city*. Eisenhower Center for the Conservation of Human Resources / Westview Press, Boulder Colorado USA.

Statistics New Zealand 1992 *Supermap 2; The 1991 Census of Population and Dwellings.* CD Rom, Statistics New Zealand, Wellington.

Statistics New Zealand 1997 *Supermap 3; The 1996 Census of Population and Dwellings.* CD Rom, Statistics New Zealand, Wellington.

Statistics New Zealand 1993 *Measuring Up; New Zealanders and the Environment.* Statistics New Zealand Te Tari Tatou, Wellington

Steadman J P 1977 Energy and patterns of land use.' *Journal of Architectural Education* 30(3) 62-67.

Steadman P, Brown F, Rickaby P A 1991 'Studies in the morphology of the English building stock.' *Environment and Planning B: Planning and Design 18*: 85-98.

Sternlieb G and Hughes J W 1982 'Energy constraints and development patterns in the 1980s' in Burchell and Listokin 1982, 127-144.

Sternlieb G and Hughes J W 1988 *America's new market geography: Nation, region and metropolis.* Rutgers, New Jersey.

Stewart C T Jnr, Bennett J T 1975 'Urban size and private expenditure for gasoline in large cities.' *Land Economics* 51, 365-373.

Stutz F P, Parrott R and Kavanagh P 1992 'Charting urban space-time population shifts with trip generation models'. *Urban Geography* 13 (5), 468-474.

Swaine D.J. (Ed) 1990 *Greenhouse and Energy.* CSIRO Australia, East Melbourne.

Toke D 'Increasing energy supply not inevitable', communication in *Energy Policy* 18(7) 671-673.

Tomkins R and Wade J 1989 'Transport energy in Britain: future trends and carbon dioxide emissions.' *International Journal of Ambient Energy* 10(4), 171-193.

Trabalka J R (Ed) 1985 *Atmospheric Carbon Dioxide and the Global Carbon Cycle.* United States Department of Energy, Washington D C.

Trabalka J R, Edmonds J A, Reilly J M, Gardner R H and Voorhees L D 1985 'Human alterations of the global carbon cycle and the projected future', Chapter 10 in Trabalka J R (Ed), 247-288.

Traffic Design Group 1996 *1996 Census Survey: undertaken Census Day, 5 March 1996.* Report for Wellington Regional Council. Traffic Design Group, Lower Hutt.

Transit New Zealand 1991 Proceedings of the New Zealand Land Transport Symposium 1991. Transit New Zealand, Wellington.

Transnet 1990 *Energy, Transport and the Environment.* London Transport Technology Network, London.

Transnet 1990 *Energy, Transport and the Environment.* Transnet, London.

van Kregten H 1988 'National planning in the Netherlands back to the cities.' *Planning Quarterly* 91, 16-18.

Vieira R K 1993 'Forcasted energy savings of reducing the growth rate of Florida household vehicle miles traveled'. *Transportation Quarterly* 47 (4) 597-610.

Voorhees A M and Associates / Ryckman, Edgerley, Tomlinson and Associates 1971 *A guide for reducing automotive air pollution.* Office of Air Programs, United States Environmental Protection Agency.

Waring P and Richards 1994 *Greenhouse Gas emissions from New Zealand energy sources.* Ministry of Commerce, Wellington.

Wearne M and Almond C 1989 *Demographic projections and scenarios.* GATS Technical Report no. 4. Wellington Regional Council, Wellington.

Wellington City Council 1993 *City Profile.* Strategic Planning and Policy Division, WCC, Paper no. 8. Wellington.

Wellington City Council 1994 *Proposed District Plan: Objectives Policies and Rule.* WCC, Wellington.

Wellington Regional Planning Authority 1975 *Wellington Region Land Use and Transportation Study*. Wellington: WRPA.

White J.C., Wagner W.R. and Beal C.N. (Eds) 1992 *Global Climate Change: Linking energy, environment, economy and equity.* Plenum Press, New York.

Willey M, Miller D and Papacostas C S 1991 'A longitudinal comparison of bicycle and moped use by university students.' *Transportation Quarterly* 45(3) 391-408.

Williams R H 1975 *The energy conservation papers*. Ford Foundation/Ballinger, Cambridge Massachussetts USA.

Willis D K 1990 ' IVHS technologies: Promising palliatives or popular poppycock?' *Transportation Quarterly* 44(1) 73-84.

Wilson D 1990 'Quantifying and comparing fuel-cycle greenhouse-gas emissions: Coal, oil and natural gas consumption.' *Energy Policy* 18(6) 550-562.

Wilson DF and Swisher J 1993 'Exploring the gap: Top-down versus bottom-up analyses of the cost of mitigating global warming.' *Energy Policy* 21(3) 249-263

Windheim L S and Wodder R R 1976 'Cities as energy systems.' *Building Systems Design 9-30.*

Windsor D 1979 'A critique of the costs of sprawl' *Journal of the American Planning Association 45 (3) 279-292.*

Wood K 1993 'Transport and city development.' Paper delivered to Civic Trust seminar, Wellington, 30 July 1993.

Wratt D S, Mullan A B, Clarkson T S, Slainger M H, von Daldelszen J, Plume H 1991 *Climate Change; the Consensus and the Debate*. New Zealand Meteorological Service Te Ratonga Tirorangi and Ministry for the Environment Manatu Mo Te Taiao, Wellington.

Wright C L 1991 'Urban transport, health and synergy.' *Transportation Quarterly* 45(3) 455-467.

Zupin S 1988 'The postmodern debate over urban form.' *Theory, Culture and Society* 5, 431-446.