VOILA! A NEW MEASURE OF OIL VULNERABILITY FOR CITIES

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ABSTRACT

Oil price shocks and supply disruptions have the potential to adversely affect automobile-dependent personal transport systems. This places users at risk if they are unable to access their activities without economic or transport hardship. This research develops a new measure of oil vulnerability, combining spatial data of vehicle fuel use with a novel transport energy-accessibility metric, the Minimum Energy Transport Activity Access characterisation (METAA), overcoming many of the limitations seen in previous studies. The Vulnerability to Oil: Income, Land-Use and Accessibility (VOILA) assessment identifies vulnerable areas as those where residents might lose access to activities during oil price rises as they can neither afford to spend more on fuel nor adapt their travel patterns to reduce consumption. This new metric allows planners to analyse where, how and why residents are vulnerable. Assessing the oil vulnerability of Christchurch, New Zealand, indicated that although the majority of areas are adaptable, residents in most areas are already spending over 10% of their income on transport, leaving the less adaptable areas vulnerable. A comparative mapping exercise highlighted the distribution of vulnerability and identified potential mitigation strategies. The research has important implications for urban and transport planning.

INTRODUCTION

Peak oil, and the ensuing global decline in oil supplies, will drive change in automobile-dependent personal transport systems. Consequences for the transportation sector, and particularly private transport, are likely to be significant and will be exacerbated by two factors as analysed by Krumdieck, Page & Dantas (2010):

- transport systems are highly dependent on crude oil, and there are no other energy sources currently available that possess the ability to fill the gap between the amount of energy available into the future and the amount of energy that transport systems require;
- private transport is the most discretionary and most easily reduced of all the uses that society has for oil. It is thus likely to be subject to greater supply reductions than those seen in the overall system.
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The risk of fuel price rises and supply shortfalls to automobile dependent residents in sprawled urban forms is that the ability to travel to activities, such as employment, education and shopping, might be lost. Areas in which residents are vulnerable are those where there are few available alternatives to car use for reaching activities, and where the residents cannot afford to continue current levels of vehicle use.

The growing number of oil vulnerability studies are an indication of the shift in attention to the issue as a result of the 2007-2008 oil price spike. The well-known VIPER study by Dodson and Sipe (2007), aimed to stimulate international scholarly debate about oil vulnerability. The authors noted that data limitations were a particular impediment in the VIPER study, forcing the use of simple proxies and area-ranking methods to account for multiple vulnerability variables. Some of the studies that followed have made use of more advanced datasets, but are still constrained by some or all of the following:

- Area-rank and/or indexing methods, which hide real trends in the data and prevent different study areas being compared to one another.
- Assessing only work travel, when other activities such as education, shopping and social visits can attract as many trips employment; see Rendall (2012).
- Using proxies to represent the underlying factors that influence vulnerability.

All but one of the current studies assume that the only viable option available to travellers during a fuel price rise is to spend a greater amount of their income on travel. However, it is also possible to respond by shifting to less fuel-intense modes of travel and selecting activity destinations that may require less travel. Krumdieck et al. (2012) describe the extent to which the travellers in an area can shift modes and change destinations, termed *adaptive capacity*, is a property of the traveller, the land-use pattern and the available transport alternatives. Other than the Krumdieck group, only Runting et al. (2011) take into account the ability of travellers to offset price rises by walking or cycling to public transport. However, they do not consider what destinations might be accessible by the public transport service once accessed, nor accessing activities by active modes.

The objective of this research is to develop an oil vulnerability assessment method that directly compares vulnerability variables, rather than using area-rank or indexes. The method assesses travel for all purposes, minimises the use of proxy variables and accounts for traveller adaptability. We propose a new measure of oil vulnerability, the Vulnerability to Oil: Income, Land-Use and Accessibility (VOILA) assessment. It combines spatial data of household transport energy consumption and fuel cost with a novel transport energy-accessibility metric, the Minimum Energy Transport Activity Access characterisation (METAA) developed by Rendall et al. (2011). VOILA can be used to understand the potential strain due to oil price rise or fuel supply disruption on activity systems for populations in different areas of the urban form, and for organizations and businesses as a function of location and accessibility. VOILA can also be used to investigate how different development options may result in the improved ability to respond to oil supply and price pressures without economic or activity loss.

METHOD

Overview of META Method

The Minimum Energy Travel Activity Access model (METAA) characterizes of the minimum transport energy required by households to meet their day-to-day activity requirements. The method combines an energy-weighted accessibility analysis with aspects of activity modelling. The METAA model includes the properties of resident population; the ability of people to use different modes and chain trips together and the frequency with which activities are accessed, all of which are functions of age. The method is spatial, and uses a range of geographical information systems (GIS) data, including the layout of land uses and the design and performance of transport systems. METAA uses data derived from national household travel survey results. The New Zealand Household Travel Survey collects trip mode, purpose and duration information over a two-day period as described by Milne et al. (2011). Mode ability is defined as a travel time limit by age group, incorporating the speed at which travellers of different ages are able to travel by each mode. Trip chaining represents the current level of trip chaining undertaken by various age groups. Activity frequency represents the annual trips made by each age group to different activities, such as shopping, employment or education. All activity destination classes contained in the household travel survey are used in the analysis. For each activity the method locates a user-defined critical number of opportunities, representing the effects of activity classification as used by household travel surveys. For example, the geographical locations for the activity category *shopping* includes grocery stores, book stores, clothing stores, and so on. Each non-employment facility represents one opportunity. For employment the number of opportunities is represented by the number of employed persons at the facility.

Residents within statistical areas are assigned randomly to households using statistical data, this process has two steps:

1. Randomly draw the number of residents for each household in each area without replacement from the data
2. Randomly draw age values for each resident in each area without replacement from the data, assigning to households until the assigned number of residents is matched

The minimum energy calculation is described below and illustrated in Figure 1:

3. Calculate travel distance and time by each mode from every origin to the critical number of opportunities for each activity
4. Randomly assign household sizes and resident demography in each area
5. For each household resident determine the minimum energy travel mode for each trip, until the critical number of opportunities is attained, and calculate the specific minimum energy in reaching the activity
6. Sum minimum energy, accounting for opportunities at the destination, activity frequency and trip chaining, for all residents in the household

Modes are assigned through a minimum energy hierarchy, this means that for any destination the resident is able to walk to, walking is the selected mode for that destination. If they are unable to walk, but are able to cycle to the destination, then cycling is the selected mode, and so on. It is assumed that any trip that cannot be made by other modes can be made by car. The random population assignment and minimum energy calculation is repeated and the results are averaged. The METAA model calculates a value per household, representing the minimum possible transport energy consumption in Megajoules. The METAA output does not represent behaviour, but the minimum transport energy that might be consumed by residents in the area as a function of demography, land-uses and transport systems. The difference between current and minimum transport energy consumption can be thought of as the capacity of residents to adapt that is inherent within the urban form. This research used the odometer database and vehicle address information from the Ministry of Transport (2013) to develop a spatial database of private vehicle fuel and energy consumption over 10 years for New Zealand urban areas, at the statistical-unit level. The database can be combined with fuel and travel cost information to estimate overall travel costs.

Development of VIOLA

In an unconstrained situation people will make choices about the modes they use and which particular set of facilities they travel to. This travel behaviour results in some level of energy consumption. During an oil crisis, which might include price rises or supply shortfalls, travellers will be faced with three choices:

- **Maintain** current travel by spending more on fuel
- **Adapt** by changing modes or selecting closer facilities for conducting activities
- **Forgo** activities

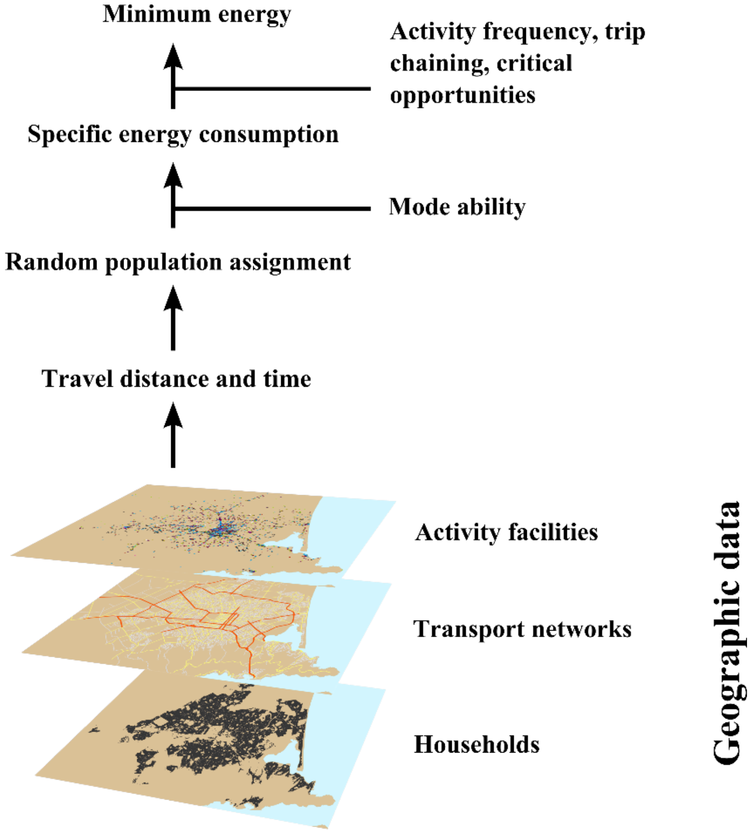

Figure 1. METAA minimum energy calculation

Adaptations for extended fuel crises can include purchasing a more efficient vehicle or moving residential location to be closer to activity facilities, although the ability to afford such measures during a fuel crisis may be limited. The VOILA assessment specifically considers vulnerability to short term fuel price rises. However, long-term development alternatives can also be evaluated and compared using the VOILA assessment of potential land use, public transport, and development options.

Activity participation is considered to be essential for all activities, not only for subsistence activities such as employment, education and shopping. This represents the requirement of humans to interact socially and engage in other maintenance activities. Consequently, travellers being forced to forgo any activities during an oil crisis is considered to be a failure of the transport-activity system.

We propose that the term *oil dependence*, as used in earlier studies, actually represents *current oil use*. Oil dependence is the condition of oil use coupled with an inability to adapt, which was not comprehensively assessed by any of the previous studies. VOILA proposes two complementary measures that combine to represent oil vulnerability, *adaptability* and *maintainability*, as described in the following sections. They represent the ability of travellers to either adapt or maintain travel during fuel price rises.

The variable of adaptability is a comparison between current energy consumption and minimum energy consumption. *Low adaptability* areas are those in which both current and minimum energy consumption are high; *adaptable* areas have low minimum energy; while areas of *low current energy consumption* do not need to adapt, as presented in Figure 2. The adaptability space is represented by a triangle, as it is not possible to have greater minimum energy consumption than current energy consumption. Although adaptability is a positive attribute, there is still some level of risk associated with adaptation, hence adaptable households are more vulnerable than households with low energy requirements.

The variable of maintainability represents the extent to which travellers are able to spend more on transport. It would ideally be a measure of the amount of money available to the traveller that could be used to maintain travel during a crisis. However, such a value is dependent on a wide range of factors, including the presence of dependents and mortgage or rental status, and could not be determined without a large number of assumptions. To reduce complexity maintainability is considered to be a comparison between transport spend and income. The maintainability space is presented in Figure 2 indicating decreased maintainability for areas with higher transport spend and lower income.

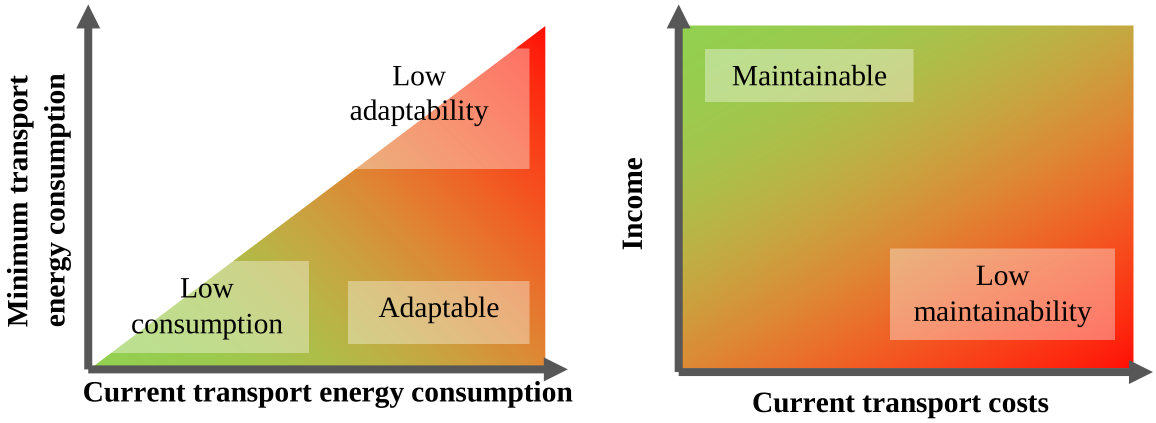

Figure 2. Adaptability and maintainability spaces

The VOILA method is based upon the idea that a resilient transport system is one in which residents can continue to participate in their activities regardless of constraints upon the system. The method by which activity participation is maintained is less important than the fact that it is maintained. VOILA does not account for the fact that it may not be possible to maintain current travel patterns during an actual supply shortfall at the pump. The most vulnerable areas are those in which residents can neither adapt nor maintain their current energy consumption, as presented in Figure 3. Although it is intuitive that decreasing adaptability and maintainability will make travellers more vulnerable, it is currently not known how these two variables combine or offset one another, nor the extent to which changes in either will quantitatively affect the ability of residents to endure oil shocks. Future work on the VOILA method will examine these aspects in greater detail and focus on developing a combined quantitative output. For analysis in this paper, maps of the two variables were visually combined to allow identification of vulnerable areas as those with both low adaptability and maintainability.

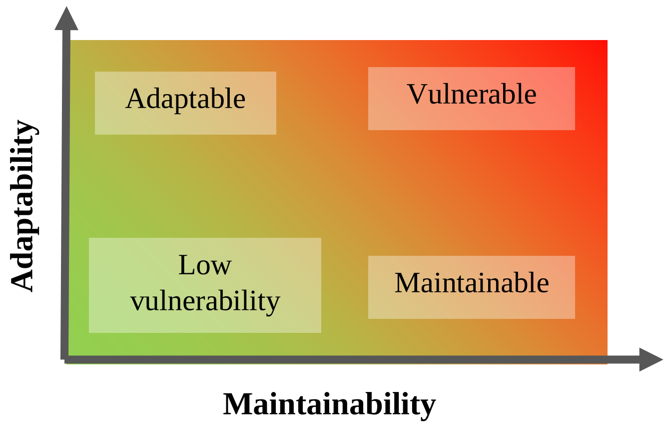

Figure 3. Vulnerability space

To produce a figure suitable for visual comparison, values for energy adaptability and economic maintainability were calculated based on the following definitions:

Energy adaptability = minimum energy / current energy

Economic maintainability = transport costs / income

Census units in the study area were then partitioned into three categories for each variable, representing high, medium and low, such that each category contained an equal number of areas. These variables were then simultaneously plotted for all areas, allowing assessment of the relative performance over both variables compared to other areas.

CASE STUDY

The VOILA method has been applied to the New Zealand city of Christchurch, using data from 2006 with the urban form presented in Figure 4. Although Christchurch has a comprehensive bus network, ridership levels are low on most routes and it represents only 4% of the mode share for all trips. Annual transport costs, input to the VOILA method, are calculated as the sum of fuel costs and include road user charges for diesel vehicles. Statistical level data of public transport use in Christchurch, which would allow public transport costs to be calculated, are unavailable. The prices of fuel and road user charges in 2006 are outlined in Table 1 along with the energy content of each fuel. In the year of 2006 there were no electric vehicles in Christchurch.

The model inputs are presented as a series of maps in Figure 5, all of which are averages over all households in the area, apart from income, which represents the median value. The distribution of income indicates lower income areas to the south and east of the CBD, with highest income areas to the northwest of the CBD, and on the southern fringes of the city. Annual transport costs and energy consumption largely increase with increasing distance from the CBD, with some exceptions. The METAA minimum energy results for Christchurch indicate residents near the CBD could access all of their activities without travel, as they have a minimum energy of zero. The highest minimum transport energy values are seen on the fringes of the city.

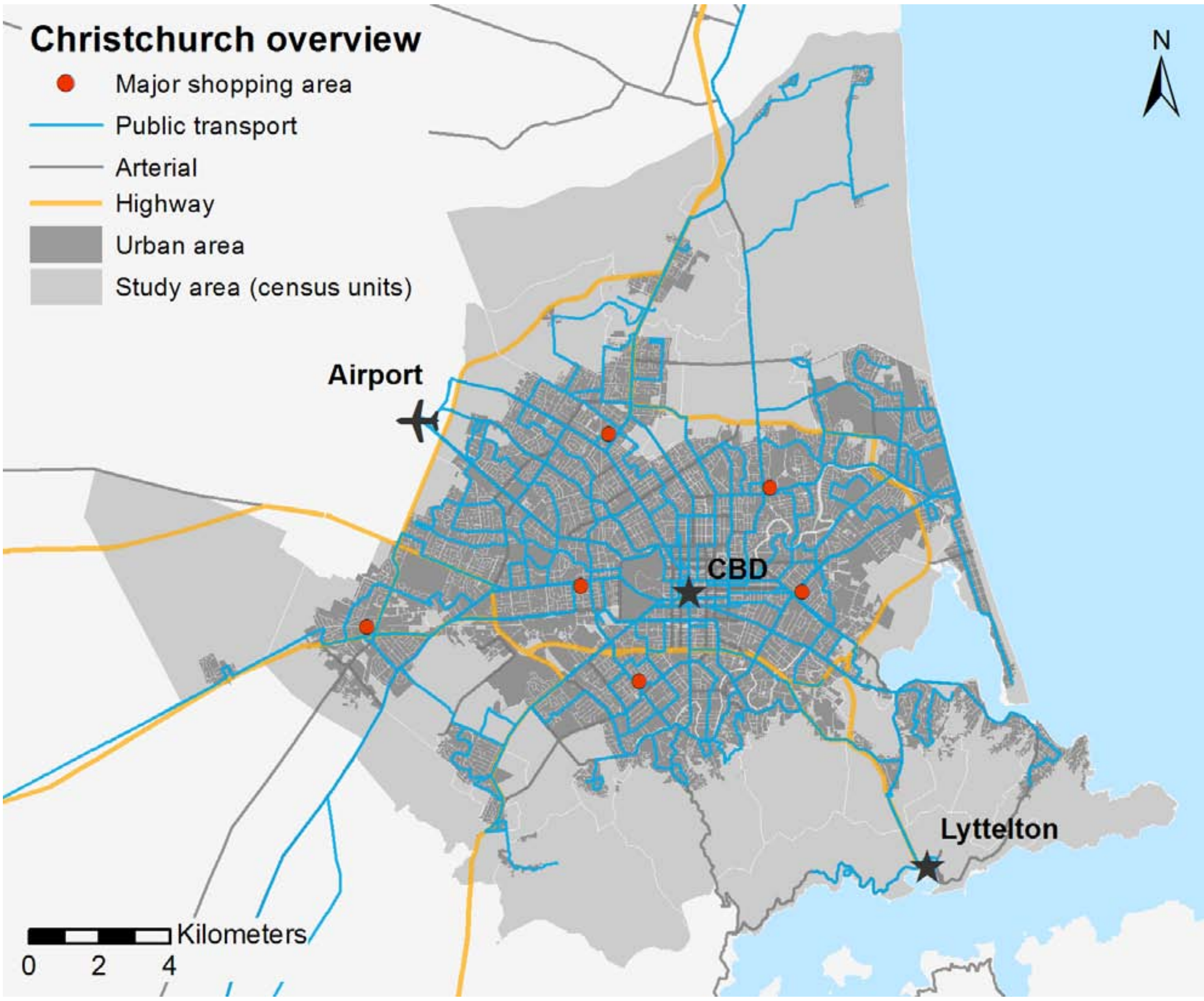

Figure 4. Overview map of Christchurch

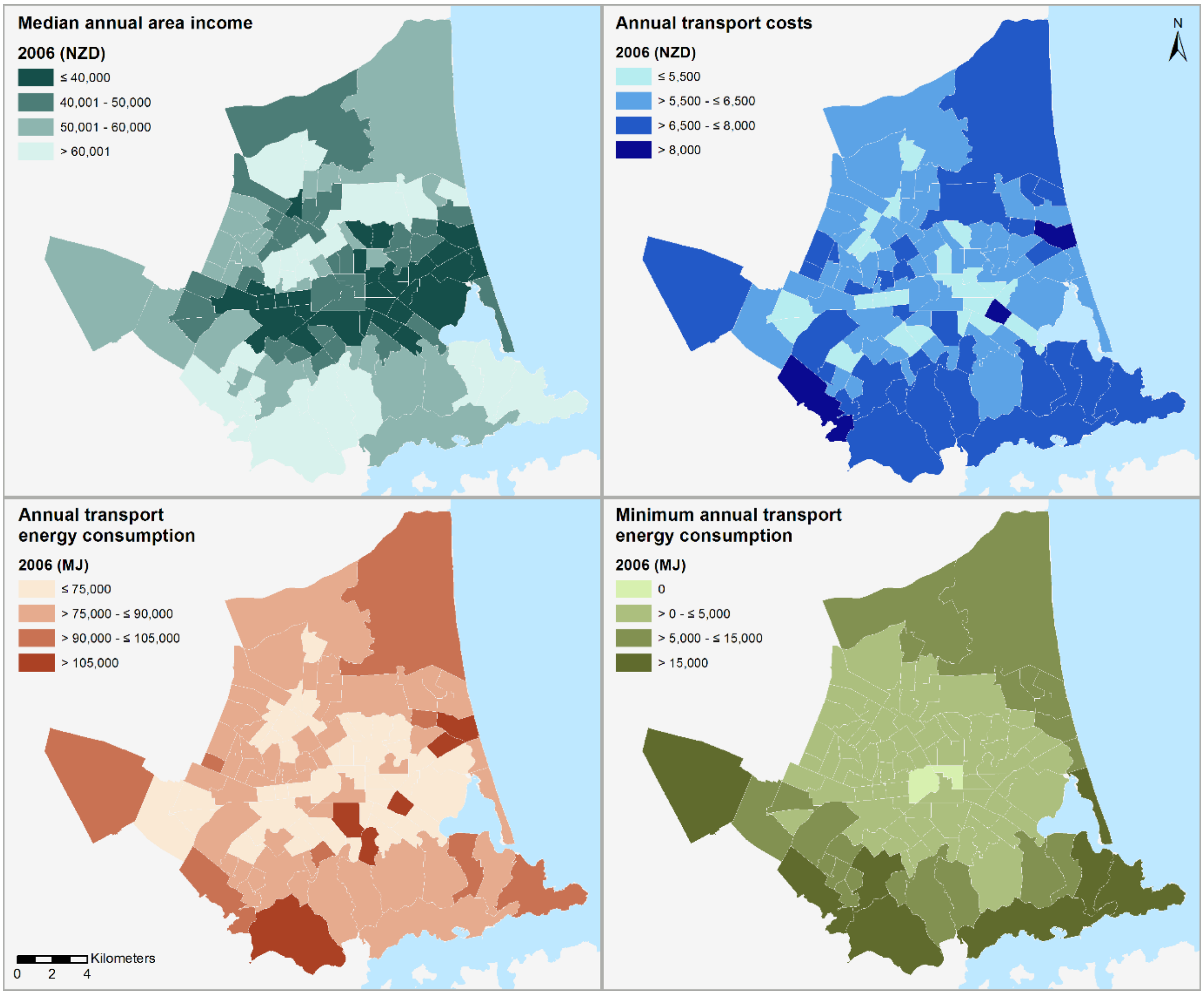

Figure 5. Inputs to the VOILA analysis for Christchurch from NZ data and the META model.

Table 1. Travel costs in 2006 and fuel energy content values used in the model

Fuel	Cost	Energy content (MJ/L)
Petrol	1.59 $/L[1]	35
Diesel (Road User Charges)	1.13 $/L[2] (+ 0.31 $/km)[3]	38
Liquid Propane Gas (LPG)	1.00 $/L	26

The Christchurch energy adaptability is presented in Figure 6 with the line of equal current and minimum energy highlighted. The figure indicates many areas in Christchurch are highly adaptable: the lowest value of current energy consumption is over 55 GJ/yr, but most areas have a minimum energy near zero. A few areas with current energy around 180 GJ/yr have possible minimum energy under 10 GJ/yr. Most areas are clustered around 55-100 GJ/yr current energy, however there is a large spread of minimum energy for some areas, with some areas at 20-30 GJ/yr and one area as high as 45 GJ/yr.

[1] Assuming 30% premium grade and 70% regular grade petrol. Source: http://www.transport.govt.nz/ourwork/tmif/transportpriceindices/ti005/
[2] Source: http://www.transport.govt.nz/ourwork/tmif/transportpriceindices/ti006/
[3] Source: http://www.transport.govt.nz/ourwork/tmif/transportpriceindices/ti010/

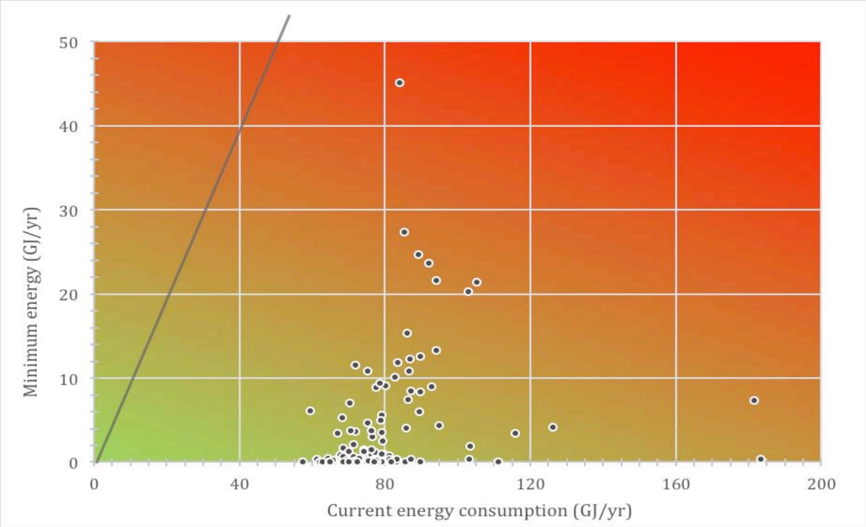

Figure 6. Christchurch energy adaptability (2006)

The Christchurch financial maintainability is presented in Figure 7, annotated with a line showing transport costs equal to 10% of income, which is commonly used as a definition of commuter fuel poverty. The figure indicates a spread in median incomes from $30,000 to $100,000 and fuel costs ranging from $4,000 to $10,000. Two areas with the greatest current fuel costs are also near the lowest income. The majority of areas have transport costs greater than 10% of income, and hence might be considered to be in fuel poverty.

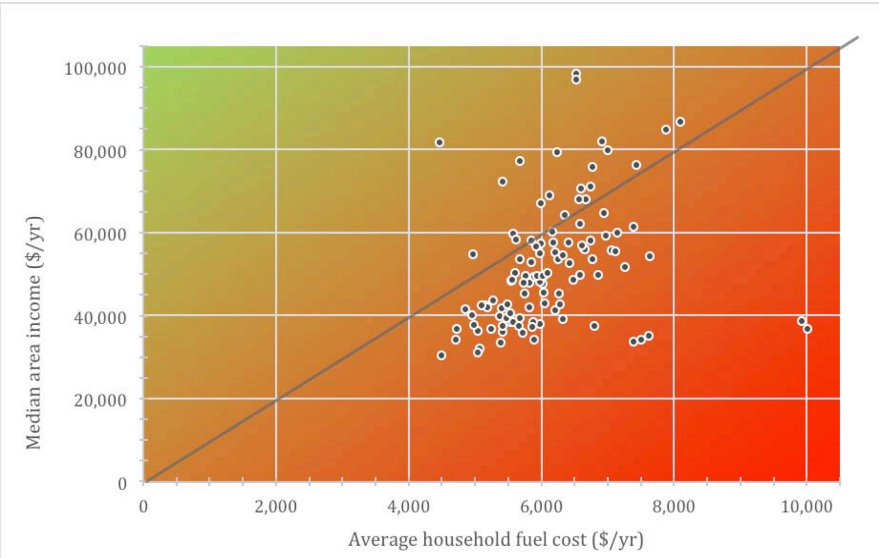

Figure 7. Christchurch economic maintainability (2006)

A comparative analysis of the VOILA outputs is presented in Figure 8. The output shows the interactions between energy adaptability and economic maintainability in areas, and provides some indication of the relative vulnerability compared to other areas. The lowest vulnerability areas are found 2-4km to the north west of the CBD, where high accessibility provides adaptability and incomes are much greater than fuel costs. Other areas proximate to the CBD feature similar levels of adaptability, with lower levels of maintainability as incomes decrease relative to fuel costs. Outlying areas suffer from lower adaptability, although for many higher income areas this is offset by greater maintainability. Only three areas fall into the most vulnerable category of lowest maintainability and adaptability. These areas are all located on the eastern periphery of the city. Two types of area fall into the second highest vulnerability category, those with medium adaptability and low maintainability, and those with low adaptability and medium maintainability. Of the first group, most areas are located in a ring about the CBD, approximately 4km out. Areas in the second group are scattered predominantly around the edges of the city.

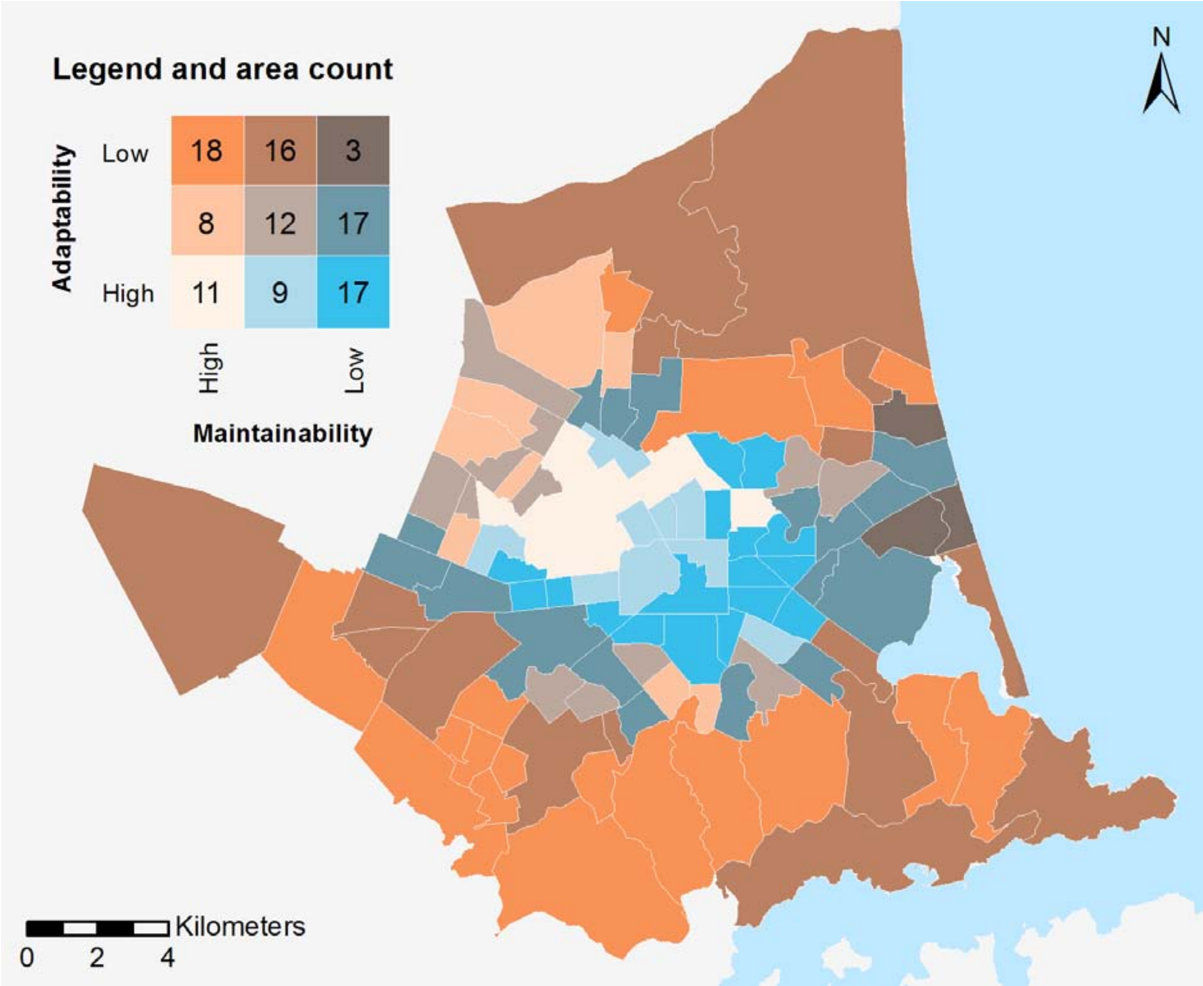

Figure 8. Comparative VOILA analysis of Christchurch

DISCUSSION

The VOILA energy adaptability and economic maintainability shown in Figures 6 and 7 indicate that high levels of adaptability for many Christchurch travellers will reduce vulnerability, although many areas are already considered to be in fuel poverty, spending more than 10% of their income on fuel. However, during fuel price rises it is likely that these travellers will be able to adapt.

The comparative analysis indicated a less linear pattern of vulnerability than was exhibited in earlier studies, such as VAMPIRE, of other cities. VOILA showed the outlying parts of Christchurch feature a number of higher-income areas where economic maintainability is high, despite lower energy adaptability. This is in contrast to other cities where the cheapest housing is typically seen on the fringes, attracting lower income residents. Comparatively, this indicates Christchurch may be less vulnerable to fuel price shocks, as lower-income residents may be nearer their activities, and thus able to preserve access to their activities through adaptation. The analysis does indicate three areas in which both adaptability and maintainability are low; these are closely grouped, raising the possibility that targeted public transport improvements could be used to reduce vulnerability in these areas. The distribution of areas with medium adaptability and low maintainability, which form a ring about 4km from the CBD, indicate that public transport and active mode network improvements may also assist residents in these areas. Fortunately most outlying areas in Christchurch are able to trade adaptability for maintainability, however this suggests that fringe developments attracting low income residents should be avoided, as the inherently low adaptability of these areas would leave travellers unable to maintain their travel particularly vulnerable.

Applying the method to cities with higher public transport ridership would require inclusion of public transport cost. Developing a method for accounting for this, where specific data is unavailable, will be part of the future work for this research. Compared to other oil vulnerability assessments the VOILA method is not as transferrable, given its reliance on area-level fuel consumption and cost data. To some extent this information may be available in other countries, for example, Li, Sipe, & Dodson (2013) calculated employment travel energy consumption using results of the Australian census, which collects employment destination information as well as mode of travel to work, and the registered vehicles database. The METAA characterisation can be applied to other areas, as it uses data that can be obtained from local government bodies, but it is computationally intensive.

It is intuitive that decreasing adaptability and maintainability will make travellers more vulnerable, but it is not currently known how these two variables combine or offset one another, nor the extent to which changes in either will quantitatively affect the ability of residents to endure oil shocks. Future work on the VOILA method will examine these aspects in greater detail and focus on developing a combined quantitative output. Currently public transport costs are not included in the transport costs, due to limited availability. Future work will investigate this factor further, aiming to locate or develop a methodology for estimating public transport costs at the household or statistical unit level.

CONCLUSION

The Vulnerability to Oil: Income, Land-Use and Accessibility (VOILA) assessment developed by this research presents a valuable addition to the field of oil vulnerability. It combines spatial data of household transport energy consumption and fuel cost with a novel transport energy-accessibility metric, the METAA characterisation, to develop an improved oil vulnerability metric. The nature of the input datasets means that variables can be directly assessed, without ranking or indexing, for example: current energy versus minimum energy. This means that different cities, areas within cities and areas in different cities can all be directly compared to one another. Most previous methods are able do only one of these, depending on the design of the metric. This also means that changes can be monitored over time. Where other studies might show that a particular area becomes less vulnerable relative to the other areas in the city over time, VOILA might show that the entire city is becoming more vulnerable, but the area is doing so at a slower rate.

Where other studies consider only work travel, VOILA assesses all purposes. This is important as shopping actually attracts a larger share of trips than employment, with social visits a close third, and travel to education might be considered as important as travel to employment for certain age groups. Employment is an important maintenance activity, but focusing solely on it ignores the requirement of humans to interact socially and engage in other maintenance activities.

VOILA reduces the use of proxies by clearly defining the problem: vulnerable areas are those that might lose access to activities during oil price rises as they can neither afford to spend more on fuel nor adapt their travel. Other studies included a variable of oil dependence, represented by various proxies, which typically assumed that travellers currently owning and using vehicles were dependent on oil. VOILA recognises that oil dependent areas are those in which greater amounts of oil are used *and* travellers are unable to adapt. Similar to previous studies, VOILA uses income to represent inability to pay more for fuel. This is due to a lack of alternative specifications and the complexity of fully defining this variable, which would have to account for many factors, including presence of dependents and mortgage or rental status, and would involve a large number assumptions.

VOILA is the first oil vulnerability study to include a comprehensive assessment of transport adaptation as a means of reducing the impacts of fuel price rises. Runting et al. (2011) did consider the ability of travellers to offset price rises by walking or cycling to public transport. However, they do not consider what destinations might be accessible by the public transport service once accessed nor accessing activities by active modes. Combining the METAA characterisation with a fuel use database enables the adaptive capacity of areas to be quantified, and allows this key component of oil resilience to be assessed as part of the vulnerability analysis.

With the long term future of oil supplies uncertain it is imperative that planners and decision makers understand the implications that fuel price rises will have for urban travellers. This research presents an analytical method for quantitatively assessing the vulnerability of residents to oil price rises. The multi-faceted approach of the analysis presents a better understanding of the underlying causes of vulnerability than previous studies, and is a step towards enabling more resilient communities.

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REFERENCES

DODSON, J.; SIPE, N. (2007). Oil Vulnerability in the Australian City: Assessing Socioeconomic Risks from Higher Urban Fuel Prices. *Urban Studies*, 44, p.37–62.

KRUMDIECK, S., S. PAGE, A. DANTAS, (2010). Urban form and long term fuel supply decline: A method to investigate the peak oil risks to essential activities, *Transportation Research Part A:* 44 p.306-322.

KRUMDIECK, S., PAGE, S.,WATCHARASUKARN, M. (2012).*Travel adaptive capacity assessment for particular geographic, demographic and activity cohorts*; New Zealand Transport Agency Research Report: 486. 91pp. Wellington.

LI, T.; SIPE, N.; DODSON, J. (2013). Investigating Private Motorised Travel and Vehicle Fleet Efficiency: Using New Data and Methods to Reveal Socio-Spatial Patterns in Brisbane, Australia. *Geography Research*, 51, p.269–278.

MILNE, A.; RENDALI, S.; ABLEY, S. (2011). *National travel profiles part B: Trips, trends and travel prediction*; New Zealand Transport Agency: Wellington, p. 94.

MINISTRY OF TRANSPORT (2013). New Zealand Vehicle Fleet Statistics.

RENDALL, S. M.; PAGE, S.; REITSMA, F.; VAN HOUTEN, E.; KRUMDIECK, S. (2011). Quantifying Transport Energy Resilience. *Transportation Research Record, Journal of the Transportation Research Board*, 2242, p.72–80.

RENDALL, S. M. (2012). *Minimum Energy Transport Adaptability*. Doctor of Philosophy in Engineering, University of Canterbury: Christchurch, N.Z.

RUNTING, R.; CORCORAN, J.; LEUNG, A.; PULLAR, D. (2011). Oil vulnerability: the effect of non-metropolitan areas and master planned estates in South East Queensland 2001–2006. *Australian Planning Journal,* 48, p.117–130.