Evaluating Urban Transport Oil Vulnerability of Asia Pacific Cities

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Submitted in fulfilment of the requirements of the degree of Doctor of Philosophy (PhD)

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Abstract

The purpose of this thesis is to advance understanding of oil vulnerability\(^1\) of transport in Asia Pacific cities. This is achieved by the development of a multi-scalar methodology which leads to nine published/submitted papers. This thesis is motivated by the concern of uncertain oil prices and the uneven dependence of oil in transport due to different urban designs and available modes to transport users. To achieve this purpose, a literature review (Chapter 2) is conducted, revealing prior oil vulnerability studies can be distinguished as being inter-city, intra-urban and disaggregate (household or personal) based. A conceptual framework based on prevailing vulnerability components is developed, defining oil vulnerability with the tripartite components of exposure, sensitivity and adaptive capacity. This conceptual framework helps to interpret previous and current research methodologies and approaches. The methodological approach of this thesis is based on these conceptualisations, as outlined in Chapter 3.

A broad international comparison study is first presented in Chapter 4. Eleven major cities across the Asia Pacific are analysed, showing that compact cities like Hong Kong and Singapore are the least vulnerable. Australasian cities are highly vulnerable due to high car use, yet this vulnerability is offset by the relatively high income and wealth of their populations. New ways to research oil vulnerability are introduced. Data Envelopment Analysis (DEA) method is first used to benchmark the level of fuel stress, which refers to the proportion of fuel expenditure to disposable income. This is a direct measure of oil vulnerability, instead of proxy measures that were largely used in previous efforts. Oil resilience is also measured by how fuel stress could be offset by public and active transport

\(^1\) Oil vulnerability broadly refers the potential of being impacted by increased fuel prices.
usage. Chapter 5 used this method to examine Australian major cities, and Chapter 6 takes the DEA method to an international level, which internal divisions between Australia and Taiwan are compared. The thesis then narrows down to areas within cities (intra-urban). Presented in Chapter 7 is an improved vulnerability mapping method covering South-East Queensland (SEQ). This involves the use of previously unused adaptive capacity measures. The resultant spatial analysis provides a more nuanced socio-spatial understanding of oil vulnerability across urban spaces. Chapter 8 takes this approach and uses it in what is likely to be the first international spatial mapping comparison of intra-urban oil vulnerability - Hong Kong is compared with Brisbane. The results show stark contrast of oil vulnerability of Hong Kong and Brisbane, where in the latter, the car is the dominant mode in most parts of the city. A comparative study of urban transport policy follows in Chapter 9. This involves a discursive analysis of urban transport policy of both Hong Kong and Brisbane and revealed the different levels of interest in oil vulnerability and the associated policy responses. Lastly, an analysis of Gold Coast’s recent light rail commencement is provided in Chapter 10 demonstrating the effect on vehicle travel distance on households between 2009 and 2015.

The thesis contributes to transport and urban policy research by presenting likely the first international comparison of multi-level oil vulnerability, both quantitatively and qualitatively, inter-city and intra-urban. Insights drawn from the results will help to shape the debates on preparing for post-petroleum cities and to reduce automobile dependence for a more sustainable future.
Statement of Originality and Ethical Clearance

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

The research reported upon in this dissertation was conducted with ethical clearance for human research as approved by the Griffith University Human Research Ethics Committee (GU Protocol Number ENV/06/15/HREC) under the supervision of A/Prof Matthew Burke and Dr Jenny Cui.

________________________ (Date: 24 June, 2017)
Abraham Chik-Keung Leung

_________________________ (Date: 24 June, 2017)
A/Prof Matthew Burke
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Specific terms and definitions in this thesis

*adaptive capacity* represents the ability of an urban system to change in a way that makes it better equipped to manage its future exposure and/or sensitivity to oil price influences. Adaptive capacity can be short term or long term.

*Asia Pacific* this study adopts the definition of Asia Pacific region used by the International Monetary Fund, which includes the countries and territories in East Asia and Oceania, See: https://www.imf.org/external/oap/about.htm

*car dependence* A self-reinforcing macro-social process with systemic properties, resulting in continually increasing levels of car ownership (Mattioli 2013, p. 5)

*energiearmut* energy poverty in German

*Exposure* to what extent energy-related events are able to affect the urban system

*forced car ownership* no alternatives to cars that can provide the same level of mobility (Currie and Senbergs, 2007)

*G:Link* The branding for the City of Gold Coast light rail

*Inter-city* a comparison between two or more cities

*intra-urban* a comparison within a city boundary

*oil vulnerability* the degree to which an urban system (e.g., city) is susceptible to, or unable to cope with, adverse effects of oil price variability and extremes

*précarité énergétique* energy precarity in French

*Sensitivity* the degree to which an urban system are affected by both energy and non-energy drivers. It is focused on the internal aspect of cities.

*transport disadvantage* the inability to travel when and where one needs without difficulty (Denmark 1998, p. 234)

*z-score* Standard score, the standard deviations level of the difference, above or lower from the mean value
<table>
<thead>
<tr>
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<th>Description</th>
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<tbody>
<tr>
<td>ABS</td>
<td>Australian Bureau of Statistics</td>
</tr>
<tr>
<td>AC</td>
<td>Adaptive Capacity</td>
</tr>
<tr>
<td>ACT</td>
<td>Australian Capital Territory (Territory in Australia)</td>
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<td>AIP</td>
<td>Australian Institute of Petroleum</td>
</tr>
<tr>
<td>AREA</td>
<td>Australian Renewable Energy Agency</td>
</tr>
<tr>
<td>APVI</td>
<td>Australian Photovoltaic Institute</td>
</tr>
<tr>
<td>ASI</td>
<td>Avoid-Shift-Improve approach</td>
</tr>
<tr>
<td>ASEAN</td>
<td>Association of South-East Asian Nations</td>
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<tr>
<td>ASGS</td>
<td>Australian Statistical Geography Standard</td>
</tr>
<tr>
<td>AU</td>
<td>Australia</td>
</tr>
<tr>
<td>BITRE</td>
<td>Bureau of Infrastructure, Transport and Regional Economics</td>
</tr>
<tr>
<td>BNE</td>
<td>Brisbane</td>
</tr>
<tr>
<td>CBD</td>
<td>Central Business District</td>
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<tr>
<td>CCR</td>
<td>Charnes, Cooper and Rhodes (the classic DEA model)</td>
</tr>
<tr>
<td>CNG</td>
<td>Compressed Natural Gas</td>
</tr>
<tr>
<td>cpl</td>
<td>Cent(s) per litre</td>
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<tr>
<td>DEA</td>
<td>Data Envelopment Analysis</td>
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<tr>
<td>DMU</td>
<td>Decision Making Unit (a DEA terminology)</td>
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<tr>
<td>EMT</td>
<td>Electric Mass Transit</td>
</tr>
<tr>
<td>EROI</td>
<td>Energy Return On (energy) Invested</td>
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<tr>
<td>DTMR</td>
<td>Department of Transport and Main Roads (Queensland)</td>
</tr>
<tr>
<td>EIA</td>
<td>Energy Information Administration (an US Government Department)</td>
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<tr>
<td>EV</td>
<td>Electric Vehicle(s)</td>
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<td>GCCSA</td>
<td>Greater Capital City Statistical Area</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GIS</td>
<td>Geographic Information Systems</td>
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<tr>
<td>GTFS</td>
<td>General Transit Feed Specification</td>
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<tr>
<td>GUHREC</td>
<td>Griffith University Human Research Ethics Committee</td>
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<tr>
<td>HOV</td>
<td>High Occupancy Vehicle(s)</td>
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<td>HKG</td>
<td>Hong Kong</td>
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<tr>
<td>HTS</td>
<td>Household Travel Survey</td>
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<tr>
<td>ICC</td>
<td>intra-class correlation</td>
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<tr>
<td>ICT</td>
<td>Information Communication Technology</td>
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<tr>
<td>IEA</td>
<td>International Energy Agency</td>
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<tr>
<td>IRSAD</td>
<td>Index of Relative Socio-economic Advantage and Disadvantage (one of the SEIFA indices)</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>JTW</td>
<td>Journey-To-Work</td>
</tr>
<tr>
<td>LAC</td>
<td>Lack of Adaptive Capacity</td>
</tr>
<tr>
<td>LGA</td>
<td>Local Government Area (Australia)</td>
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<tr>
<td>LPG</td>
<td>Liquefied Petroleum Gas</td>
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<tr>
<td>LOV</td>
<td>Low-Occupancy Vehicle(s)</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>MQ</td>
<td>Meta-question(s)</td>
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<tr>
<td>MLM</td>
<td>Multi-Level (regression) Model(ing)</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales (State in Australia)</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation and Development</td>
</tr>
<tr>
<td>OLS</td>
<td>Ordinary Least Square</td>
</tr>
<tr>
<td>OR-DEA</td>
<td>Oil Resilience Data Envelopment Analysis</td>
</tr>
<tr>
<td>OV-DEA</td>
<td>Oil Vulnerability Data Envelopment Analysis</td>
</tr>
<tr>
<td>PT</td>
<td>Public Transport</td>
</tr>
<tr>
<td>PTLOS</td>
<td>Public Transport Level of Service</td>
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<tr>
<td>PWD</td>
<td>Population-Weighted Density</td>
</tr>
<tr>
<td>PV</td>
<td>photovoltaic</td>
</tr>
<tr>
<td>QGSO</td>
<td>Queensland Government Statistician’s Office</td>
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<tr>
<td>Qld</td>
<td>Queensland (State in Australia)</td>
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<tr>
<td>RQ</td>
<td>Research Question</td>
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<tr>
<td>R+P</td>
<td>Rail plus Property</td>
</tr>
<tr>
<td>SA(number)</td>
<td>Statistical Area (level number) (ABS Geographic Unit)</td>
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<tr>
<td>SEIFA</td>
<td>Socio-Economic Indexes for Areas (developed by ABS)</td>
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<tr>
<td>SEQ</td>
<td>South-East Queensland</td>
</tr>
<tr>
<td>SFA</td>
<td>Stochastic Frontier Analysis</td>
</tr>
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<td>SM</td>
<td>Special Municipalities (直轄市) in Taiwan</td>
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<tr>
<td>Tas</td>
<td>Tasmania (State in Australia)</td>
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<tr>
<td>TW</td>
<td>Taiwan</td>
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<tr>
<td>TZ</td>
<td>Travel Zone</td>
</tr>
<tr>
<td>UITP</td>
<td>Union Internationale des Transports Publics</td>
</tr>
<tr>
<td>URP</td>
<td>Usual Resident Population (ABS population term)</td>
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<tr>
<td>VAMPIRE</td>
<td>Vulnerability Assessment for Mortgage, Petrol and Inflation Risks and Expenditure (an oil vulnerability index by Dodson and Sipe (2008))</td>
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<tr>
<td>Vic</td>
<td>Victoria (State in Australia)</td>
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<tr>
<td>VIPER</td>
<td>Vulnerability Index for Petroleum Energy Rises (an oil vulnerability index by (2007))</td>
</tr>
<tr>
<td>VOILA</td>
<td>Vulnerability to Oil: Income, Land-Use and Accessibility (an oil vulnerability index by Rendall et al. (2014))</td>
</tr>
<tr>
<td>VKT</td>
<td>Vehicle Kilometres Travelled</td>
</tr>
<tr>
<td>WA</td>
<td>West Australia (State in Australia)</td>
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Acknowledgements

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Abraham Leung
Brisbane 24th June, 2017
List of publications by candidate

This thesis includes published papers that were co-authored with other researchers. It also includes papers that have been submitted and are currently under peer review. These papers were produced during PhD candidature only and comprise the thesis by publication. The bibliographic details (if published or accepted for publication)/status (if prepared or submitted for publication) for these papers including all authors are:

Published Papers


Leung, A., Chiou, Y.-C., Yen, B.T.H., Burke, M., 2016. Comparative data envelopment analysis of oil vulnerability of urban transport in Taiwan and Australia. Presented at the 2016 International Conference and Annual Meeting of the Chinese (Taiwan) Institute of Transportation, Hualien, Taiwan.

Leung, A., Burke, M., Cui, J., Perl, A., 2015. New approaches to oil vulnerability mapping for Australian cities: The case of South-East Queensland, the 200km city. Presented at the State of Australian Cities National Conference (SOAC) 2015, Gold Coast, Australia.

Leung, A., Burke, M., Cui, J., 2016. The tale of two (very different) cities - Mapping Urban Transport Oil Vulnerability of Brisbane and Hong Kong. Presented at the 14th World Conference on Transport Research 2016, Shanghai, China.


**Accepted Papers**


Leung, A., Burke, M., Cui, J., (Accepted). The tale of two (very different) cities - Mapping the urban transport oil vulnerability of Brisbane and Hong Kong. Transportation Research Part D: Transport and Environment. Accepted for inclusion in the Transportation Research Part D: Transport and Environment on 23/10/2017.

**Papers in Review**

Leung, A., Burke, M., Cui, J., (Accepted subject to revisions). The emergence of urban transport oil vulnerability research: a review. Transport Reviews. First submission on 22/6/2017.

**Other papers produced during candidature**


Acknowledgement of Papers included in this Thesis

All papers included are co-authored

Section 9.1 of the Griffith University Code for the Responsible Conduct of Research ("Criteria for Authorship"), in accordance with Section 5 of the Australian Code for the Responsible Conduct of Research, states:

To be named as an author, a researcher must have made a substantial scholarly contribution to the creative or scholarly work that constitutes the research output, and be able to take public responsibility for at least that part of the work they contributed. Attribution of authorship depends to some extent on the discipline and publisher policies, but in all cases, authorship must be based on substantial contributions in a combination of one or more of:

• conception and design of the research project
• analysis and interpretation of research data
• drafting or making significant parts of the creative or scholarly work or critically revising it so as to contribute significantly to the final output.

Section 9.3 of the Griffith University Code ("Responsibilities of Researchers"), in accordance with Section 5 of the Australian Code, states:

Researchers are expected to:

• Offer authorship to all people, including research trainees, who meet the criteria for authorship listed above, but only those people.
• Accept or decline offers of authorship promptly in writing.
• Include in the list of authors only those who have accepted authorship.
• Appoint one author to be the executive author to record authorship and manage correspondence about the work with the publisher and other interested parties.
• Acknowledge all those who have contributed to the research, facilities or materials but who do not qualify as authors, such as research assistants, technical staff, and advisors on cultural or community knowledge. Obtain written consent to name individuals.

Included in this thesis are papers in Chapters 2, 4, 5, 6, 7, 8, 9 and 10 which are co-authored with other researchers. My contribution to each co-authored paper is outlined at the front of the relevant chapter.

Appropriate acknowledgements of those who contributed to the research but did not qualify as authors are included in each paper.

The bibliographic details (if published or accepted for publication)/status (if prepared or submitted for publication) for these papers including all authors, are:

**Chapter 2:**

**Leung, A., Burke, M., Cui, J.**, (Accepted subject to revisions). The emergence of urban transport oil vulnerability research: a review. *Transport Reviews.*

First submission on 22/6/2017.

(Signed) ________________ (Date) 24 June, 2017

Name of Student: Abraham Leung

(Countersigned) ________________________ (Date) 24 June, 2017

Supervisor: A/Prof Matthew Burke
Chapter 4:
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Chapter 6:
Leung, A., Chiou, Y.-C., Yen, B.T.H., Burke, M., 2016. Comparative data envelopment analysis of oil vulnerability of urban transport in Taiwan and Australia. Presented at the 2016 International Conference and Annual Meeting of the Chinese (Taiwan) Institute of Transportation, Hualien, Taiwan.

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Chapter 7:
Leung, A., Burke, M., Cui, J., Perl, A., 2015. New approaches to oil vulnerability mapping for Australian cities: The case of South-East Queensland, the 200km city. Presented at the State of Australian Cities National Conference (SOAC) 2015, Gold Coast, Australia.

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Chapter 8:
Leung, A., Burke, M., Cui, J., 2016. The tale of two (very different) cities - Mapping urban transport oil vulnerability of Brisbane and Hong Kong. Presented at the 14th World Conference on Transport Research 2016, Shanghai, China.

Leung, A., Burke, M., Cui, J., (Accepted). The tale of two (very different) cities - Mapping the urban transport oil vulnerability of Brisbane and Hong Kong. Transportation Research Part D: Transport and Environment. Accepted for inclusion in the Transportation Research Part D: Transport and Environment on 23/10/2017.

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Chapter 9:

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Chapter 10:

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Supervisor: A/Prof Matthew Burke
1. Introduction

This thesis is concerned with the threat of oil vulnerability posed to urban settlements, in particular, mobility and transportation. This chapter provides an overview of the research agenda of this thesis. Firstly, the research background is introduced, followed by the rationale for conducting the research. The research activities are briefly outlined, and the research contributions are then discussed. Finally, an outline of the dissertation structure and concluding remarks are provided.

1.1 Research background

In car dependent areas, where households depend on the use of internal combustion engine (ICE) vehicles to access services and opportunities, increases in fuel prices can have negative consequences on their well-being. Oil vulnerability typically refers to the impact caused by the reliance on oil, in particular, fuel price levels and the affordability of transport (Dodson and Sipe 2007, Fishman and Brennan 2010, Runting et al. 2011, Akbari and Nurul Habib 2014, Lovelace and Philips 2014, Rendall et al. 2014). This is an issue for developed countries due to high levels of motorisation at a time when car-based mobility has become an established practice (Mattioli et al. 2016). Car dependence is the main cause of this vulnerability. The 20th century can be referred as the “automobile century”, as oil became a feasible source of energy, utilised by ICEs in the form of affordable automobiles as a product of industrialisation and mass production. Yet the geographic distribution of oil reserves is highly uneven – most are concentrated in geopolitically less stable regions. The problem of oil vulnerability was first demonstrated during the Oil Crises of the 1970s. Automobiles have become cheaper and faster - providing freedom from the
tyranny of distance – as the frictional impedance of distance has greatly declined (Knowles 2006). Nevertheless, the promotion of mass motorisation has led to the creation of socio-technical systems of oil-based transport (Geels 2012). As shown in the literature review in Chapter 2, there are a strong and broad conceptual basis for oil vulnerability research – 1) the critical one is the social equity argument – which focuses on comparing those with and without easy access to activities/employment/goods due to disparities in transport time and costs from access to different modes (Dupuy 1999); 2) the health argument is also significant, which refers to the ability of non-motorised active travel, which is virtually oil-free and has significant health benefits; and 3) is addressing oil vulnerability being urban planning and design objective, which suggests attractive cities have high levels of walking, cycling and public transport. These broader framings are deliberately used, as this will in turn be applicable when electric, or even automated vehicles could become a solution for meeting personal mobility needs without (or less) oil. However, the narrower arguments of oil vulnerability – 4) oil depletion, pollution (environmental) or 5) energy security remain valid and important.

1.2 Car dependence and social equity

Car dependence is often seen as a symptom of unsustainable transport (Banister et al. 1997). In this thesis, I adopt the comprehensive definition of car dependence as defined by Mattioli (2013, p. 5), which is a self-reinforcing macro-social process with systemic properties, resulting in continually increasing levels of car ownership and use. We put greater emphasis on the issue of greater inequity has also arisen. As observed by Illich (1974), the ability to travel at high velocities is unequal in nature. Whereas the speed of walking is the same no matter rich or poor. In a car
dependent society, only those who can afford to own cars and to pay for the fuel have greater accessibility than others. In other words, relative disparities in transport time and cost have widened between areas, creating a “mobility-gap” (Dupuy 1999). This relates to the concern of social equity and justice in terms of energy use and transport. The ultimate purpose of transport is to provide access to the goods, jobs and services people need (Martens 2012, Dodson et al. 2016). This forms the conceptual basis of oil vulnerability, as oil remains a dominant fuel in transport. Sudden increases in fuel prices are theorised to have a negative effect on livelihoods. This might be reflected by the fuel protests when oil prices are heightened in the early 2010s (Ortiz et al. 2013, Channel NewsAsia 2014, CNN 2014, International Business Times 2014).

Research has been undertaken into a wide range of issues from reliance on imported oils (Newman 1991, Sovacool 2007, OCED Joint Transport Research Centre 2008) to health and environmental impacts of car related pollution (Shabbir and Ahmad 2010, Hart et al. 2013, Yang and He 2016), to road trauma and safety (de Blaeij et al. 2003, Pucher and Dijkstra 2003), and to inactivity and obesity (Jacobson et al. 2011, Li et al. 2011) and many other concerns. Energy related concerns about transport have focused mainly on potential oil depletion, popularly known as peak oil (Hubbert 1956, Krumdieck et al. 2010, Aftabuzzaman and Mazloumi 2011), and climate change mitigation as petroleum-based fuel for vehicles is a significant contributor of carbon emissions, with the need to keep fossil fuels unburned (Leather 2009, Schipper 2011, Hickman and Banister 2014, McGlade and Ekins 2015).
Social and equity issues in transport have been given less attention as transport planning has been a field more dominated by modelling and traffic, which focuses on revealed demand rather than latent demand (Martens and Hurvitz 2011). This favours car owners and those who can afford to drive. The technocratic engineering approach to urbanisation based on meeting car-based transport needs has been increasingly questioned (Jacobs 1961, Curtis et al. 2010), which in turn gives rise to research into the disadvantages associated with the inequity of transport and access. Denmark (1998, pp.234) defined transport disadvantage as “the inability to travel when and where one needs without difficulty”. Isolation and exclusion from opportunities such as employment, services and social connections intensify social polarisation and injustice (Hine and Mitchell 2001, Buchanan et al. 2005), and one of the most damaging impacts of transport disadvantage is indeed isolation and exclusion. Studies have identified transport disadvantage as a barrier to employment and limiting access to services (Hine & Mitchell, 2003; Currie et al., 2005). These effects are collectively termed “social exclusion”, which refers to a condition in which socio-economic circumstances prevent individuals or households from accessing employment, adequate housing, and other social and community services (Social Exclusion Unit (SEU) 2003, Johnson and Herath 2004, Dodson et al. 2006, 2007, Grant-Smith and Johnson 2012, Lucas 2012). It has been shown that well-accessed and job-concentrated city centres are increasingly unaffordable for the less advantaged, which is a combined housing and transport costs problem (Dodson 2005, Gleeson 2006). In car dependent societies, car ownership is found to be “forced” as there are no alternatives to cars that can provide the same level of accessibility (Currie and Senbergs 2007). On the other hand, even in cities with highly developed public transport networks such as Hong Kong, transport
disadvantage caused by higher travel costs is also noted in certain social groups and in districts further from city centres (Law et al. 2009, Wong 2011, Lam 2012). From a land use point of view, these impacts are exacerbated by the spatial mismatch of transport infrastructure, housing affordability and employment locations.

Meanwhile, there are some emerging trends which could further exacerbate transport disadvantage. Some have suggested that the ageing population will intensify transport disadvantage as more people become less able to drive (Denmark, 1998; Alsnih & Hensher, 2003; Schmöcker et al., 2007). This, however, can be compounded by the threat of higher oil prices. The social perspective of transport energy in cities has received increasing attention. Scholars are increasingly interested in the implications of car dependent societies on oil price increases (Mattioli 2014, Berry et al. 2016, Dubois and Meier 2016). During the recent oil price spike in the 2000s, a new notion, oil vulnerability was used to denote the potential socio-economic impact on cities, in particular on households (Dodson and Sipe 2007). In other jurisdictions, terms such as energy precarity (précarité énergétique) (Rosales-Montano et al. 2009) from France and energy poverty (energiearmut) (Gertz et al. 2015) from Germany, and car/energy-related economic stress from the UK (Mattioli and Colleoni 2016) also emerged. Chapter 2 of this thesis provides a more detailed literature review of the emergence of these energy-related notions of urban transport affordability issues.
1.3 The research rationale

As will be shown in greater depth in Chapter 2, there are serious gaps in terms of our understanding of oil vulnerability. The key gaps, as summarised here are listed below:

1.3.1 Conceptual and methodological issues of “oil vulnerability”

Despite recent studies into urban oil vulnerability (Dodson and Sipe 2005, 2007, 2008), the concept of vulnerability is merely implicitly defined but without reference to other more established vulnerability fields, such as development studies or climate change. It is possible that vulnerability can be used as a multidisciplinary and integrative approach to understand and explain the uncertainty of future threats (Cutter 2003). The sets of research included in this thesis provide a unified definition of oil vulnerability. This also helps to provide new methodological directions for oil vulnerability research. For instance, a greater focus on adaptive capacity - the ability to use modes other than cars, and direct indicators such as fuel stress (fuel expenditure as a proportion of disposable income). These advancements in research are covered in Chapter 3 to 10.

1.3.2 Socio-spatial oil vulnerability

Previous concepts of vulnerability in cities see suburbanisation as a result of economic growth (Figure 1-1). More recent economic thinking started a post-Marxist refocus on social inequity, as increasing evidence shows that overall economic growth does not imply equity (Piketty and Goldhammer 2014). This adds another dimension of inequity in regions and cities, with the notions ranging from leftover suburban poverty “sinkholes” in Australia (Baum and
Gleeson 2010, Randolph and Tice 2014) to the “city of misery” of Tin Shui Wai, an outer new town in Hong Kong (Law et al. 2009, Monkkonen and Zhang 2011). These communities are found to be increasingly disadvantaged in terms of transport, essential services and availability of jobs. Analysis of inter-city urban comparisons in transport and urban density (Newman and Kenworthy 1989, Kenworthy et al. 1999, Union Internationale des Transports Publics (UITP) 2005, p. 201) rarely acknowledge inequity as a socio-spatial disadvantage in terms of economic turbulence, for instance, caused by fluctuating fuel prices.

![Diagram showing the processes of urban development explained with key mechanisms](image)

**Figure 1: The processes of urban development explained with key mechanisms**

*(Adapted from Hayashi 1996)*

The viability of suburban areas depends on infrastructure (Addie 2016), but funding for such is highly political and is often contested. The future of suburbanisation is increasingly challenged by recent trends of reversal in urban fortunes. In a number of Western nations, previously derelict inner urban centres
have become desirable places, or have been gentrified (Smith 1996). While deindustrialisation played a role, most importantly these inner urban areas well connected and are close to jobs, services and amenities. Residences in these inner urban centres are becoming well sought after by the “creative-class”, who are likely to be important ratepayers with greater political clout (Glaeser 2012). In the literature of transport disadvantage, the interactions of these urban trends are increasingly drawn upon (Kahn 2007, Motte-Baumvol et al. 2009, Burke et al. 2010), but they are by no means well understood.

1.3.3 A dimension of Asia Pacific cities
Recently, inter-city urban comparisons have become more internationally focused, and have often used the examples of compact, dense and public transport dominant Asian (developed) cities, (Newman and Kenworthy 1989, Kenworthy et al. 1999) to promote such developmental styles in car dependent Western cities. While there are some examples of transport disadvantage studies in Asian cities (Wong 2011, Herwangi et al. 2015), research into these areas is less plentiful than that in Western counterparts, in particular in relation to oil vulnerability. The literature review in Chapter 2 offers a more detailed analysis of the research coverage of fuel price related research in urban transport. Asian transport research tends to focus more on rapid urbanisation, motorisation, environmental impacts and infrastructure (Hook and Replogle 1996, Barter 2000, Ieda 2010, Hayashi et al. 2011).

1.3.4 Oil vulnerability policies and the issue of equity
Oil vulnerability is a “wicked” issue related to car dependence and socio-spatial disadvantage, which involves complex policy areas which is not easy to resolve.
Inequality is one of the biggest challenges to society now with the rise of populist movements globally (Toly 2017). Much of that debate has focused on the inequality of income and wealth; much less attention has been paid to inequality of opportunity to accessing energy efficient and affordable transport. To deal with the car dependence and transport disadvantage problem, improvements in public transport and spatially matching the location of residences and activities are preferred over other policy options on inter and intra generational equity grounds. This will be discussed further in Chapter 11 after presenting the body of research in Chapters 2 to 10. However, regional variations of policy suitability (due to economy, geography and governance) need to be acknowledged. This study is focused on the Asia-Pacific region. One thing in common is the time lag before structural changes to address car dependence can be very long. The car-dependent resident may demand subsidies for car use to resolve the inequity problem (e.g., freezing fuel tax and car registration fees, or generous tax benefits for business car use in Australia), but this causes environmental impact and continues car dependence. Further research is needed to understand what policies can be enacted. Inter-city studies or comparisons may help foster learning between cities and policy transfer (Marsden et al., 2011), but caveats and pitfalls to successful policy transfer should be acknowledged, which warrants further research.
1.4 Research aims and questions

In response to the issue outlined in the research rationale, this thesis sought to achieve the following aims (A) and the research questions:

<table>
<thead>
<tr>
<th>A1</th>
<th>To further develop the concept of oil vulnerability;</th>
<th>MQ1</th>
<th>What is the concept of oil vulnerability? How is it measured? What does it mean?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>To explore new approaches for understanding, measuring and mapping oil vulnerability;</td>
<td>RQ1</td>
<td>What is the level of oil vulnerability of different cities in Asia Pacific cities?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RQ2</td>
<td>Do fuel use and income levels differ in different cities in relation to adaptive capacity?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RQ3</td>
<td>How do oil price change impacts vary spatially, internally in an urban area?</td>
</tr>
<tr>
<td>A3</td>
<td>To study oil vulnerability in areas, or unit of analysis that has not been assessed before</td>
<td>RQ4</td>
<td>How are policies are developed to respond to increasing oil prices in selected Asia Pacific cities (Hong Kong and Brisbane)?</td>
</tr>
<tr>
<td>A4</td>
<td>To raise awareness of the socio-spatial distribution of oil vulnerability by identifying areas of concern; and</td>
<td>RQ5</td>
<td>Does new public transport help reduce oil vulnerability in Asia Pacific cities</td>
</tr>
<tr>
<td>A5</td>
<td>By applying A4, to inform urban and transport policy making with better information and knowledge of oil vulnerability in the Asia Pacific.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The first question is a “meta-question” (MQ) of oil vulnerability, which concerns the meaning of oil vulnerability itself. This is followed by more practical research questions (RQs). These research questions are answered in Chapter 2 by a literature review and the development of a conceptual framework. This allows the development of methods, as outlined in Chapter 3, to answer the research questions listed in Table 1.
1.5 Research activities and methods

To answer the stated research questions, this thesis consists of the following major research activities:

1. A literature review of oil vulnerability (fuel-price related urban transport studies).
2. The development of new methods to assess oil vulnerability at multiple scales in various areas
3. Comparing oil vulnerability levels at the following spatial scales:
   a. Inter-urban
   b. Intra-urban
   c. Disaggregate level (households/personal)
4. Gaining an understanding of policy responses to oil vulnerability, and its obstacles in Asia Pacific cities

A more detailed description of the research methodology is provided in Chapter 3.

1.6 Contributions

This thesis makes three main contributions to transport and planning scholarship and practice. This will be explained in greater detail in Chapter 11 after the presentation of the results (Chapter 4-10):

- Conceptual and methodological development of the term “oil vulnerability”
- Improved understanding of oil vulnerability at inter-city (Asian-Pacific cities), intra-urban (Brisbane and Hong Kong) and household levels (Gold Coast)
• A policy analysis of oil vulnerability, in relation to the recent oil price increase, covering Hong Kong and Brisbane

**Theoretical and Conceptual:**
A key theoretical and conceptual development is the application of the prevailing vulnerability conceptual framework to the study of oil vulnerability. This research sets to expands a vulnerability based conceptual framework based in part on prevailing adopted practice in climate change vulnerability research, and it operates in multiple areas and scales. The notions of oil vulnerability are researched further, with a stronger focus on socio-spatial inequity. Advances in oil vulnerability research offer scope for a wide application, for instance, in urban planning and design, in health and wellbeing based on active transport, and in social inequity. In doing so this thesis will contribute to future transport and planning, with great emphasis on social aspects.

**Applied:**
This research endeavours to be ambitious as it aims to explore the comparative experiences of oil vulnerability in different urban settings across cities and areas in the Asia Pacific region. This study is venturing into previously uncharted territory – oil vulnerability in Asian cities. Furthermore, there is currently a lack of empirical and scholarly investigation and in particular, qualitative research into the views of stakeholders regarding this topic. Previous research in oil vulnerability has been largely quantitative. This research will incorporate qualitative research methods to connect with stakeholders’ experience. The mixed method approach will help to reduce gaps and to validate research findings in both quantitative and qualitative methods.
Practical, Empirical and Policy

There are a number of deliverables in this proposed research, ranging from vulnerability mapping, inter-city/intra-urban comparisons, qualitative perceptions and policy understanding. It has been recognised that the key product of this research, vulnerability mapping, is a powerful tool in identifying areas that require urgent attention and intervention (Reid et al. 2009, Preston et al. 2011). The impact of Dodson’s and Sipe’s (2007, 2008, 2013) research, which spurred government attention on oil vulnerability, demonstrates the value of mapping based research. With a specific focus on the Asia Pacific region and on energy related issues, the aggregate comparative study of oil vulnerability will help fill the gap in Newman’s and Kenworthy’s (1989, 1999) sourcebook style research. Stakeholder interviews and policy comparison will help scholarly understanding of the urban transport debates about urban form (compact vs dispersed), density (high vs. low) or even cultural values (western vs. eastern). The practical know-how obtained from the case studies made of cities should help improve understanding of the role of energy in the transport and planning fields. It is also hoped that the research outcomes will stimulate further understanding, collaboration and cooperation between cities in dealing with the challenges of urban inequity, energy transition and climate change.

1.7 Dissertation structure

This thesis consists of eleven chapters including an introduction and background, literature review, methodology, seven results chapters and conclusion. The results chapters are in the form of published and in review manuscripts formatted to meet the requirements of the peer-reviewed academic journals that they have been submitted to. There are also detailed literature reviews at the start
of each results chapter in accordance with the requirements of journal manuscripts. There is some repetition among the results chapters, including in the descriptions of study sites and reference lists. The separate reference list for each chapter is included at the end of each chapter. The thesis was prepared in accordance with Griffith University’s policy of including research papers in a thesis. For reference, this policy has been provided in Appendix B.

This chapter laid the foundations for the entire thesis. It introduced the research problem, aims, and the corresponding questions. Then the research was justified, definitions were presented, the research activities were briefly described, the thesis structure was outlined, and the limitations were given. On these foundations, the next Chapter proceeds with a detailed literature review focusing on previous oil vulnerability studies and the proposing of a new conceptual framework.
2. The emergence of oil vulnerability research: a review

The work presenting here in Chapter 2 has been submitted as Leung, A., Burke, M., Cui, J. (Accepted subject to revisions). The emergence of urban transport oil vulnerability research: a review. Transport Reviews.

First submission on 22/6/2017.

A literature review is based on the meta-questions of this research - What is the concept of oil vulnerability? What does it mean? And how is it measured? The scope of the study is restricted to urban transport research that involves fuel price related impacts. The review shows the number of published works in Web of Science on fuel price related impacts in urban transport roughly follows the trends of global crude oil prices. For geographic focus, Western countries (Europe, North America and Australasia) remain dominant in this field of research, but a trend of moving out to non-Western countries is observed. The definitions, concepts, key methods and applied findings of fuel price related research in urban transport are reviewed.

In order to help understand fuel price related impacts and to better understand the meaning of oil vulnerability, a new concept of oil vulnerability is introduced. The emerging studies which are reviewed in this paper are analysed in terms of “oil vulnerability”, and which is defined by the authors as consisting of three components – Exposure, Sensitivity and Adaptive Capacity. Regarding the research question on how to measure oil vulnerability, the methods of the key oil vulnerability papers are analysed in tables based on this conceptual framework. The variables and methods used in more recent oil vulnerability research are
examined in greater detail with the aid of this oil vulnerability conceptual framework. Typically, there are three main units of analyses in oil vulnerability studies – *inter-city, intra-urban* and *disaggregated*. The implications and meaning of the term are further explored in the discussion section, which suggests a greater focus on inequity as it is still relevant when oil price reduces. This review helps to define the research aims and questions that will be covered in the next chapter and to allow the reader to better understand existing concepts, knowledge and methodologies of the proposed research to be undertaken the subsequent result chapters of this thesis.

**Research questions addressed in this paper and contributions**

**Primary “meta” research questions**
- What is oil vulnerability?
- What does it mean?
- How is oil vulnerability measured?

**Summary of contributions**
- A first systematic review of oil vulnerability, methods and offered a conceptual framework for oil vulnerability research
2.1 Statement of contribution to co-authored published paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:

**Leung, A., Burke, M., Cui, J.** (Accepted subject to revisions). The emergence of urban transport oil vulnerability research: a review. *Transport Reviews.*

The authors listed below have certified that:

1. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. they agree to the use of the publication in the student's thesis and its publication on the Griffith University database consistent with any limitations set by publisher requirements.

<table>
<thead>
<tr>
<th>Contributors</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abraham Leung</td>
<td>Conceiving, planning and the writing of the manuscript, literature collection and analysis, and the preparation of tables and figures.</td>
</tr>
<tr>
<td>Matthew Burke</td>
<td>Provided assistance in the theoretical framing of the research and provided editing revisions in the initial and the reviewed manuscript.</td>
</tr>
<tr>
<td>Jianqiang Cui</td>
<td>Provided editorial suggestions in the initial and the reviewed manuscript.</td>
</tr>
</tbody>
</table>

Supervisor Confirmation: I have sighted email or other correspondence from all co-authors confirming their certifying authorship.

(Signed) ___________________________ (Date) 24, June, 2017

Co-principal Supervisor: A/Prof Matthew Burke
The emergence of urban transport oil vulnerability research: a review

Abstract: The academic and policy research on fuel price related impacts expanded considerably when oil prices increased significantly in the last decade. While there is growing awareness of this research and its implications, with the emergence of ‘oil vulnerability’, there has not been a systematic review of this notion. We focus this study in urban areas due to increasing global urbanisation, its complexity, and a higher potential reduction of oil use. However, many cities, particularly those in developed western countries, remain automobile dependent. This paper quantitatively and qualitatively reviews the emerging literature in this area, its historical evolution, geographical trends and research approaches. The analysis shows that research into fuel price impacts on urban transport correlates closely with global crude oil price levels, with research being over-represented in Europe, North America and Australasia. The analysis is aided by a bibliometric network approach, which identifies key influential research clusters. Early fuel price impact studies in urban transport tended to be national or city-wide comparisons, which then became more spatially disaggregated. We propose to borrow the framework based on mainstream vulnerability conceptualisations of exposure, sensitivity and adaptive capacity. Future research directions should encompass energy, transport and inequity issues arising from oil vulnerability.

Keywords: oil vulnerability; urban transport; transport inequity; automobile dependence; bibliometric analysis

1. Introduction

Academic interest concerning the society’s dependence on oil has grown in the heyday of oil age, in particular when Hubbert (1956) first coined the term – Peak Oil. Studies about the impacts of oil price increase mushroomed during the oil crises of the 1970s but receded during the oil glut of the 1990s. Prediction of oil (and other resources) depletion was featured in the ‘Limits of Growth’ also (Meadows and Club of Rome 1972). Not until the recent oil price increase during the 2000s has public, academic and policy
attention focused on the problem of oil dependence, seeking measures to address these issues. Very high oil prices during the period of 2005 to 2015 attracted heightened interest about the potential impacts on the economy (Hamilton 2013, Kerschner et al. 2013), transport (Shepherd et al. 2008) and political stability (Colgan 2014). This also reignited the interest about the idea of peak oil (Krumdieck et al. 2010, Murphy and Hall 2011).

While developed economies (e.g., OECD members) were more able to reduce energy intensity by better fuel efficiency and alternative fuel sources for transport (e.g., electric vehicle (EV) or biofuel), but in some cases, travel demand continues to grow. This leads to continued increase in total energy use. For emerging economies with rapid economic and population growth, they are likely to sustain current motorisation trends and oil use increases (Pojani 2016). The middle scenario of recent energy forecasts shows global oil use in transport will remain at 88% in 2040 (currently it is at 93%) (U.S. Energy Information Administration 2016). The long term future trend of oil use is uncertain. This depends on how quick EVs are replacing internal combustion engines (ICE) vehicles.

There is still a high likelihood of large numbers of pure ICE or hybrid vehicles remain in global vehicle fleet in 2040 or beyond, especially in remote areas where petroleum powered ICE vehicles remain competitive (Coffman et al. 2017).

Despite recent falls in oil price, future scenarios have never been as uncertain, as shown in Figure 1. Lower oil prices might have led to reduced oil production investment, at the same time, cheap oil might prolong the use of internal combustion technologies (Khan 2017).
The periods of higher oil prices have nevertheless attracted the attention of many studies into the potential impacts of rising or volatile oil prices on transport. This research is reviewed in greater detail in later sections. A particular concern found linked heightened oil prices to the problem of automobile dependence and transport disadvantage.

**1.1 Energy-related transport disadvantage, with a focus on urban areas**

Despite some signs of “peak” of automobile growth which are recently found in a number of developed economies (Newman & Kenworthy, 2015), automobile use remains dominant, in particular North American and Australian cities (Union Internationale des Transports Publics (UITP) 2015). Alternative fuel vehicles (such as EVs) are still a novelty (Egbue and Long 2012). In areas without transport alternatives to
automobiles (e.g.: public transport or walking/cycling), people are more impacted by fuel prices increases. This is related to the notion of transport disadvantage, which is defined by Denmark (1998, pp.234) as “the inability to travel when and where one needs without difficulty”. Isolation and exclusion from opportunities such as employment, services and social connections intensify social polarisation and injustice (Hine and Mitchell 2001, Martens et al. 2012). Transport disadvantage can also be a barrier to employment, limiting access to services and contributing to “social exclusion” (Dodson et al. 2007). If there is a lack of alternatives that can provide the same level of mobility of automobiles, forced automobile ownership may occur (Currie and Senbergs 2007). When these are amplified by oil price increases, the potential impacts caused by higher motor fuel prices can be referred as “oil vulnerability” (Dodson and Sipe 2007). While there has been increasing research being published in this area, there is a lack of in-depth understanding about what this vulnerability actually means, and there has been no systematic review of research into this issue to date. This paper aims to respond to this research gap by systematically reviewing the literature, and conceptualise the findings, in relation to urban transport oil vulnerability.

This paper consists of seven sections. Section 2 outlines the methodology of the literature review. Section 3 analyses four decades of oil vulnerability research in both quantitative and qualitative methods. A conceptual framework for oil vulnerability is proposed in Section 4. The major methodological approaches of oil vulnerability research are analysed in Section 5, followed by a discussion of policy implications in Section 6. Section 7 explores the future research directions. Section 8 concludes the paper, with a brief outline of the contributions and limitations.
2. Methodology

The key methodology of this paper draws from the approach developed by Pickering et al. (2015), and augmented by bibliographic citation analysis. This review targets oil vulnerability literature from 1970 to 2017, when oil price increases first became a serious issue following the First Oil Crisis in 1973. Since then oil prices have fluctuated greatly. Fuel price impacts of transport are found to be more acute in outer urban areas due to higher levels of automobile dependence and lower incomes (Dodson and Sipe 2007, Lovelace and Philips 2014, Chatterton et al. 2017). We focus on urban areas, as they warrant special attention. Urbanisation remains a global trend, with a growing share of the population living in cities. Urban areas are becoming more important, both economically and socially (Fuller and Romer 2014) and have the potential to reduce energy oil and oil vulnerability with better opportunities for alternatives to automobiles, or co-location of activities (Gilbert and Perl 2012). Therefore, this paper’s scope is limited to urban transport. The papers selected for this study had to fit the criteria listed in Table 1:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Keyword combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impacts caused by an increase, or fluctuation of the price of petroleum derived fuel (gasoline/petrol)</td>
<td>fuel, petrol, gasoline, oil, price, impact, vulnerability</td>
</tr>
<tr>
<td>Concerning transport</td>
<td>transport, travel, commute, journey, mobility</td>
</tr>
<tr>
<td>Focus is in urban areas but excludes remote or rural settlements</td>
<td>urban, city/cities, town(s), suburb, peri-urban</td>
</tr>
</tbody>
</table>

Based on this criteria, the initial round of database keywords search in academic databases, including Transport Research International Documentation (TRID), Google Scholar, Scopus and Thompson Reuters Web of Science (WoS), was conducted in April 2017. The initial search resulted in up to 2,000 matching records. By reading the abstracts and the keywords of these records, 776 were selected and downloaded for further study.
Upon reading the contents, only 433 publications were found to fit all of the criteria included in this study. A further bibliographical citation analysis was based on 291 of the 433 publications that were identified in WoS. WoS was used because of its ability to download complete citation records and better archiving of papers prior to the 1990s. One of its limitations is that WoS predominately contains journal articles only, but this can be seen as a filter to identify more developed research. The key bibliographic method used in this paper is weighted-direct citation, as illustrated in Figure 2. Direct citation can show the information flow between two articles but misses out linkage with a third article that cited both articles. An improved solution is weighted-direct citation, which calculates these relationships by assigning the frequency of both direct and co-citations. This has been increasingly seen as a more accurate way to conduct citation analysis (Persson 2010, Newell and Cousins 2015), which is adopted in this paper.

In co-citation analysis, the papers that are cited more are deemed to be more influential, and this is used to visualise a discipline and its intellectual interconnections by co-citation network mapping (Small 1973, Yu et al. 2014). An open-source software Bibexcel developed by Persson (2009) was used to develop co-citation metrics based on the WoS collection of oil vulnerability papers. Citation network visualisation and analysis was assisted by Gephi (Bastian et al. 2009), an open-source software increasingly used in network analysis. Publications gathered from other sources (TRIP, Google Scholar and Scopus), including policy papers, conferences and other grey literature that are not included in the WOS-only citation analysis (in Section 3) will also be used in the rest of the paper (from Sections 4 to 7) in a more conventional review format.
3. Historical trends in fuel price related urban transport research

Figure 3 shows the change of fuel price and the number of papers from 1970 to 2016 based on the WoS subset. Fuel price impact research papers on urban transport follow the fuel price changes and the historical events of the several oil crises since the 1970s. With oil prices stabilised from the late 1980s to the early 2000s, the number of papers dropped, with no publications in some years. After 2005, oil prices began to rise and this led to renewed attention on fuel price related impacts. 2014 was the peak year of these publications (29 papers), but the oil price had lowered soon after. Even with lowered price, 2016 still had the second highest number of publications (23 papers).
Figure 3: Publications of fuel price related studies in urban transport compared with oil price

The geographic distribution of fuel price related urban transport research is illustrated in Table 2. The counts are based on fractional counts - if a paper is covering two areas, each area would be given a score of 0.5. Papers covering more than five areas are treated as “global”. Research that did not have a specific study area (e.g., literature review) are treated as “non-geographical”. Before 2000, most of the publications concentrated in countries that are more likely to use English in academic outputs. Coinciding with the globalisation of academic research and increased use of English (Short et al. 2001), the number of publications is more evenly spread-out after 2000, with greater coverage in Europe, Asia and Africa. This can be visualised in Figure 4. A limitation of this study is that non-English sources are not considered. South America does not appear in these counts, probably because the WoS caters for English language
outlets only. Nevertheless, the trend of English-written research on fuel impacts moving beyond Anglosphere centres is evident.

Table 2: World distribution of fuel price related urban transport studies

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>Share (%)</td>
<td>Count</td>
<td>Share (%)</td>
<td>Count</td>
<td>Share (%)</td>
</tr>
<tr>
<td>North America</td>
<td>35</td>
<td>47.95</td>
<td>47</td>
<td>35.07</td>
<td>82</td>
<td>39.61</td>
</tr>
<tr>
<td>Europe</td>
<td>13.5</td>
<td>18.49</td>
<td>35.5</td>
<td>26.49</td>
<td>49</td>
<td>23.67</td>
</tr>
<tr>
<td>Oceania</td>
<td>11</td>
<td>15.07</td>
<td>22.5</td>
<td>16.79</td>
<td>33.5</td>
<td>16.18</td>
</tr>
<tr>
<td>Asia</td>
<td>4.5</td>
<td>6.16</td>
<td>17</td>
<td>12.69</td>
<td>21.5</td>
<td>10.39</td>
</tr>
<tr>
<td>Africa</td>
<td>0</td>
<td>0.00</td>
<td>6</td>
<td>4.48</td>
<td>6</td>
<td>2.90</td>
</tr>
<tr>
<td>Global</td>
<td>9</td>
<td>12.33</td>
<td>6</td>
<td>4.48</td>
<td>15</td>
<td>7.25</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>73</td>
<td>100.00</td>
<td>134</td>
<td>100.00</td>
<td>207</td>
<td>100.00</td>
</tr>
<tr>
<td>All Geographical</td>
<td>73</td>
<td>62.93</td>
<td>134</td>
<td>76.57</td>
<td>207</td>
<td>71.13</td>
</tr>
<tr>
<td>Not Geographical</td>
<td>43</td>
<td>37.07</td>
<td>41</td>
<td>23.43</td>
<td>84</td>
<td>28.87</td>
</tr>
<tr>
<td>Total</td>
<td>116</td>
<td>100.00</td>
<td>175</td>
<td>100.00</td>
<td>291</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Figure 4: Distribution of the number of publications by country – a comparison of before and after 2000
3.1 Bibliographic analysis of fuel price related urban transport research

A more detailed bibliographic citation analysis is carried out next. Figure 5 shows the “landscape” of fuel price related urban transport research since 1970. The size of the circle (or node) is determined by the value of the weighted direct citation score, which means it has been directly cited and co-cited more often. Uncited papers are not shown as there is no linkage to the citation network. The arrow refers to the citation flow made between two publications with the arrowhead indicating the source. The colour refers to the clusters of publication types. Six major groups and with two lesser groups are identified. Small or isolated clusters are indicated in grey. The position of the nodes is based on the Forced Atlas Algorithm by the Gephi software (Hu 2005, Bastian et al. 2009), which pushes the nodes that are more related to each other more closely. The following subsection briefly describes these clusters.

The green cluster at the top refers to the early research into fuel price impacts circa 1970s and 1980s. A number of papers involved in a debate on whether centralisation or decentralisation of urban forms might happen in response to fuel price increase (Zucchetto 1983). Based on citation network analysis, Romanos’ (1978) paper is the most influential, which theorises a form of polycentric development. The papers in this cluster mostly propose theoretical urban models, like many of the studies at that time. Most papers here theorise these urban forms’ ability to reduce long distance automobile travel (Gilbert and Dajani 1974, Waymire and Waymire 1980, Haines 1986). Empirical research based on motor vehicle fuel sales figures (Stewart and Bennett 1975, Zelinsky and Sly 1984) and modelling (Sharpe 1980, 1982) were found. The linkage of energy, and transport and land use were beginning to be recognised, with some authors calling for the development of “energy efficiency standards” in land use planning (Owens 1986, 1992).
Figure 5: The “landscape” of the literature of fuel price related urban transport studies (Only the nodes with a degree-centrality over 6 are labelled, first author’s name only)

The research then diverged into several other clusters. The light purple cluster on the right denotes elasticity-based studies that are mainly focused the response of travel behaviour to fuel price. This is in fact a large research area in transport studies, but our paper’s review criteria only include research that is related to urban transport. For urban-related studies, this research cluster focuses on drivers’ response to fuel price increase in
terms of vehicle distance travelled (Chao et al. 2015), public transport ridership (Wang and Skinner 1984) or both (Becker et al. 1976). There were also examples of using urban land use variables to model personal vehicle fuel use (Keyes 1982). This cluster tends to focus on improving fuel efficiency as a solution. Social equity and spatial disadvantage caused by different levels of transport services provision were generally not their foremost concern.

Then, the most influential publication of fuel price related urban transport study is Newman’s and Kenworthy’s (1989) international study, which belongs to the orange coloured cluster on the top left corner. This study was the first global empirical study (with 32 cities across Asia, North America, Europe and Oceania) to collect land use and transport data, which was developed from their earlier paper (Newman and Kenworthy 1980) which has citation links to Romanos’ (1978) study. The same authors later expanded their work with more detailed analysis (Newman and Kenworthy 1991) and more cities were included (Kenworthy et al. 1999). This paper has influenced land use and transport planning policy with the recommendation for compact cities - as high density Asian cities (e.g., Hong Kong and Singapore) are found to have much lower fuel use per capita. Their work has been widely cited but has been contested by many (Gordon and Richardson 1989, Mindali et al. 2004, Mees 2009). Further examination of Newman’s and Kenworthy’s datasets is reflected in the brown cluster in the middle of Figure 5, with improved methods and better data. Mindali et al. (2004) re-examined Newman’s and Kenworthy’s database by co-plot statistics, which became the most influential in this (brown) cluster. Brownstone and Golob (2009), Karathodorou et al. (2010), Su (2011), Marique and Reiter (2012), Ahmad and Puppim de Oliveira (2016)
added more land use variables, and Boussauw and Witlox (2012) used GIS mapping with fine-grained census tracts.

Another type of study, as indicated by the teal coloured cluster on the left, is focused on automobile mobility. They tend not to be focused on cities, but national or worldwide statistics. This was begun by Pucher (1988) and focused on the determinants of automobile ownership or usage, using national comparisons (Schafer and Victor 2000, Giuliano and Narayan 2003, Buehler 2011). Moriarty & Honnery (2013) reviewed a number of these studies and suggested that a reduction in passenger tasks should be the focus rather than energy efficiency gains from technical solutions.

The light blue cluster in the bottom of the figure is largely influenced by the oil vulnerability study of Australian’s three largest cities (Sydney, Melbourne and Brisbane) by Dodson and Sipe (2007). Oil vulnerability is first conceptualised as a term to describe “socioeconomic impacts of increasing oil price on households in relation to transport” by mapping the “potential exposure of households to adverse socioeconomic outcomes arising from increased fuel costs” based on census datasets (Dodson and Sipe 2007, pp. 38, 46). This approach was extended in later studies, and was applied to the UK (Lovelace and Philips 2014, Mattioli 2014) and New Zealand (Krumdieck et al. 2010). Another approach used in this cluster are “energy requirement” studies in Australia, which typically used input and output tables to assess the estimated need of domestic energy use, including transport (Lenzen et al. 2004, Rickwood et al. 2008, Wiedenhofer et al. 2013). Many of these studies are mapping studies, looking at spatial variations of areas within cities. The field is continuing to develop – recent papers looked at the combined impact of increased housing and transport costs (Cao and Hickman 2017, Li, Dodson, et

The remaining minor pink clusters identified early studies regarding policy responses to oil price increase (Mazur and Rosa 1974) and more recent studies with further in-depth research into urban energy use (Mörtberg et al. 2017). These clusters are also linked with the literature in other major clusters and are hence scattered throughout the citation network. This section has summarised the major work on fuel price impacts in urban transport, based on bibliographic citation network analysis. Recent studies have been found using notions such as “oil vulnerability” and “energy resilience” as conceptualisations of the risk of reducing transport affordability due to higher fuel prices in urban areas.

4. Conceptualising oil vulnerability

This section provides an overview of the term “vulnerability” and discusses its applicability to energy and urban transport. A qualitative approach, drawing on the 433 publications mentioned in Section 2 is used, in addition to those identified by the citation network analysis in Section 3. Grey literature, such as government policy and conference papers, are also considered. Early government documents in the USA suggested cities’ “vulnerability to energy supply disruptions” (U.S. General Accounting Office 1979). Perhaps the first use of “oil vulnerability” was in the analytical report to the US Secretary of Energy titled “Reducing U.S. oil vulnerability: energy policy for the 1980’s” (US Department of Energy 1980), outlining the areas of risk in the US and policy recommendations such as fuel standards and greater uptake of public transport. Since then, governments around the world have mandated energy efficiency standards and
phased out the use of oil in heating and power generation. Despite energy efficiency does not necessarily and usually does not lead to a reduction in total energy demand, these policies have helped to provide market signals that helped suppress oil price and may have led to the “oil glut” which took place from the mid-1980s to the 1990s. Research into the energy use of urban transport then shifted to increased liveability, by dealing with air pollution, climate protection and overall sustainability (Blanco et al. 2009).

During this time, the widely cited global cities comparison by Newman and Kenworthy (1989) was also published, with a stated objective to study the “vulnerability of a city to oil supply disruptions, transportation related inflation and increased balance of payments problems from imported oil” (ibid, p. 6). Also, “oil dependence” and “oil depletion vulnerability” were mentioned in Newman’s (1991a, 1991b). Until the 2000s, Dodson and Sipe (2007) were the first to adopt the term for the more recent period heightened oil prices in the wake of the 2007-2010 global financial crisis. They implicitly define oil vulnerability as the “potential exposure of households to adverse socioeconomic outcomes arising from increased fuel costs” (Dodson and Sipe 2007, p. 46). The use of “vulnerability” for fuel price impacts is inspired by broader vulnerability studies, which can be broadly defined as “the degree to which a system/unit is likely to experience harm due to exposure to perturbations or stress” (Turner et al. 2003, p. 8074). There are two major streams of vulnerability research traditions, namely climate change (Adger 1999, Füssel 2007), and disaster studies (Chambers 1989, Watts and Bohle 1993). The former tends to operate in a “contextual” (or starting point) view, which focuses on the ability to withstand and recover from shocks. Typical measures of this vulnerability are socioeconomic status. The later sees vulnerability as an “outcome” (or end point), which represents an integrated vulnerability concept that combines information on
potential impacts and on the socio-economic capacity to cope and adapt (Füssel 2007). Whilst the literature on vulnerability is growing, the definitions or terms vary in different contexts which contributed to the debate on the meaning and methods to measure vulnerability (Adger 2006, Gallopín 2006, Smit and Wandel 2006). Alternatively, there is a growing recognition of resilience as the opposite, or a more positive view (Cutter et al. 2008, Aldunce et al. 2015, Meerow et al. 2016), which can be defined as a “measure of the persistence of systems and of their ability to absorb change and disturbance” (Holling 1973, p. 14).

Oil vulnerability studies tend to adapt Adger/Gallopin vulnerability approach instead of the Holling’s resilience approach, perhaps due to the ease to work with and with limited data. In addition to Dodson and Sipe’s original notion of oil vulnerability, Lovelace and Phillips (2014) interpret oil vulnerability as “a combined probability and magnitude of negative effects resulting from high oil price or shortage scenarios” (pp. 171). Whereas Rendall et al. (2014) see it comprised of dual components of the dependence on oil for transport, and the inability to pay more for transport (pp. 3). However, these concepts did not specify adaptive capacity as seen in the prevailing vulnerability fields. Based on these shortcomings, we propose to borrow the commonly used, outcome-based framework by the Intergovernmental Panel on Climate Change (IPCC) (2001) as a framework for further oil vulnerability research. Thus, oil vulnerability can be defined as “the degree to which an urban system is susceptible to, or unable to cope with, adverse effects of oil price variability and extremes”. The major components of climate change vulnerability are borrowed for oil vulnerability (Figure 6).
Figure 6: A proposed framework for future oil vulnerability research (Adapted from (Marshall et al. 2010))

The detailed explanation of these components (E-S-AC) is as follows:

- **Exposure (E)** represents to what extent energy related events are able to affect the urban system. Possible indicators include the level of oil imports, automobile ownership or mode share of personal and low occupancy transport.

- **Sensitivity (S)** represents the degree to which an urban system is affected by both energy and non-energy drivers. It is focused on the internal aspect of cities. In the case of oil vulnerability, the ability to pay could reflect this component. It could be measured by such as income or socio-economic wellbeing.

- **Adaptive capacity (AC)** represents the ability of an urban system to change in a way that makes it better equipped to manage its future exposure and/or sensitivity to oil price influences. Adaptive capacity can be short term or long term. Short term measures are more like the extent of coping measures that could be reflected by the ability of a city to use less oil dependent modes of transport, such as the mode share of active or public transport. However, a limitation of short-term
measures is it portrays vulnerability with a static representation of current vulnerability. While longer term resilience is an important aspect of this component, it is more difficult to measure as it entails longer-term adaptation in urban systems that structurally reduce oil use in transport (e.g., policy and infrastructure changes).

This conceptualisation is then used for analysing previous works on oil vulnerability in the next section.

5. Spatial differences in oil vulnerability research in urban transport

The major methodological approaches to oil vulnerability research are analysed in this section. The units of analysis level of previous vulnerability or fuel-related impact studies are largely operating in the spatial scales of inter-city, intra-urban and household level, which the details are listed below.

1. Inter-city studies can be compared internationally and make use of aggregate data, such as city-wide vehicle distance travelled/fuel use to derive per capita indicators of fuel use.

2. Intra-urban studies usually use census data to create composite indicators for spatial analysis.

3. Household level studies are best to explore the issue at its core, and to calculate exact indicators that can measure actual transport affordability impacts caused by increasing fuel costs.

Using the vulnerability conceptual framework as specified in Section 4, previous urban transport oil vulnerability studies are analysed according to different spatial scales,
as shown in Tables 3 and 4, referring to inter-urban and intra-urban studies respectively. The E-S-AC classification of vulnerability is also used to separate the variables used.

Table 3 shows inter-city comparisons, in which the earlier studies tend to investigate the relationship of land use intensity (e.g., population/road network density) to automobile or fuel use. While some of the inter-city studies have a certain intra-urban component by separating “CBD, inner and outer” parts of the cities in their analyses, their analyses are still largely inter-city based. These analyses tend to employ energy use as the exposure component of oil vulnerability, whereas intra-urban analyses usually resorted to using proxy variables such as car ownership or mode share. This is probably because energy data is easier to obtain when the unit of analysis is the whole city. A large number of these studies also used regression (Zelinsky and Sly 1984, Næss et al. 1996) or correlation (Banister et al. 1997) analyses to demonstrate the statistical relationship between transport energy consumption and urban characteristics.

Newman’s and Kenworthy’s landmark inter-city study actually had its beginnings in an earlier intra-urban study of Perth, Australia, (Newman et al. 1985), in which they estimated exposure by suburban VKT based on household travel survey and modal energy consumption data. Post-2005 studies started to use the notion of oil vulnerability, which was pioneered by Dodson and Sipe’s census data based composite indicator. This method has been adopted in Toronto (Akbari and Nurul Habib 2014) and in some US cities (Sipe and Dodson 2013). Newman et al.’s (1985) method of using household travel survey data to obtain VKT and fuel use variables reappeared in Fishman and Brennan’s (2010) assessment of Melbourne. Fishman and Brennan’s (2010) also
Table 3: Selected studies considering oil vulnerability in urban transport with inter-urban comparison

<table>
<thead>
<tr>
<th>Source</th>
<th>Area</th>
<th>Approach</th>
<th>Exposure</th>
<th>Adaptive Capacity</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Zelinsky and Sly 1984)</td>
<td>864-county level areas in USA</td>
<td>Multivariate analysis</td>
<td>Vehicle fuel sales (per capita)</td>
<td>Not specified</td>
<td>Not specified</td>
</tr>
<tr>
<td>(Banister et al. 1997)</td>
<td>5 UK cities and 1 Dutch city</td>
<td>Correlation</td>
<td>1. Energy use per trip 2. Energy use per household 3. Trip distance and trips made 4. Private vehicle ownership</td>
<td>1. PT and non-motorised mode mode share</td>
<td>1. Socioeconomic groups (young, unemployed)</td>
</tr>
</tbody>
</table>
Table 4: Selected spatial-geographical urban transport oil vulnerability studies at intra-urban scale

<table>
<thead>
<tr>
<th>Source</th>
<th>Location</th>
<th>Approach</th>
<th>Exposure</th>
<th>Adaptive Capacity</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Newman et al. 1985)</td>
<td>Perth, Australia</td>
<td>Mapping, correlations, bivariate and multivariate regression</td>
<td>1. Estimated annual transport energy use (based on VKT, trip length/speed data and modal energy consumption data)</td>
<td>1. % of journey to work trips by non-private vehicle modes</td>
<td>1. Household income</td>
</tr>
<tr>
<td>(Dodson and Sipe 2007)</td>
<td>Brisbane, Sydney, Melbourne</td>
<td>Composite index with mapping</td>
<td>1. Proportion of households with two or more motor vehicles; 2. Mode share of journey to work by private vehicle</td>
<td>Not specified</td>
<td>1. Socio-economic status (SEIFA index)</td>
</tr>
<tr>
<td>(Dodson and Sipe 2008)</td>
<td>Brisbane, Sydney, Melbourne</td>
<td>Composite index with mapping</td>
<td>1. Proportion of households with two or more motor vehicles; 2. Journey to work car modal share</td>
<td>Not specified</td>
<td>1. Mortgage 2. Median weekly household income</td>
</tr>
<tr>
<td>(Fishman and Brennan 2010)</td>
<td>Melbourne</td>
<td>Composite index with mapping</td>
<td>1. Average weekly fuel use 2. Percentage of non-automobile weekday travel (all trips)</td>
<td>1. Mode share including public and active transport</td>
<td>1. Average personal income</td>
</tr>
<tr>
<td>(Rutting et al. 2011)</td>
<td>Southeast Queensland</td>
<td>Composite index with mapping and dimension table</td>
<td>1. Weighted average JTW distance on road network 2. Car ownership (≥ 2) 3. JTW by car 4. Weighted average JTW distance</td>
<td>1. Proportion of non-motorised access to public transport</td>
<td>1. Socio-economic status (by SEIFA index)</td>
</tr>
<tr>
<td>(Lovelace and Philips 2014)</td>
<td>Yorkshire and Humber</td>
<td>Spatial microsimulation and mapping</td>
<td>1. Average proportion of individual’s energy budget spent on commuting</td>
<td>1. Distance to employment centre; 2. Proportion of work trips made by private vehicle</td>
<td>Not specified</td>
</tr>
<tr>
<td>(Rendall et al. 2014)</td>
<td>Christchurch</td>
<td>Activity modelling and mapping</td>
<td>1. Average household vehicle ownership energy consumption costs (by odometer)</td>
<td>1. Estimation of average minimum required transport energy consumption</td>
<td>1. Median income</td>
</tr>
</tbody>
</table>
included public and active transport mode share as an indicator, showing the consideration of adaptive capacity. Soon after, Runting et al. (2011) included the coverage of a public transport buffer in their indicator, and Rendall et al. (2011, 2014) developed more advanced activity modelling, which is an accessibility modelling to estimate the minimum distance required to reach a jobs/goods/services by walking or cycling. Due to lack of fuel use data, another approach generated synthetic populations by spatial microsimulation (Lovelace and Philips 2014). With improving fuel efficiency and electrification of vehicle fleets, automobile dependence may not equal oil dependence. Fuel efficiency was also considered in Li et al.’s (2013) work by matching model and make of vehicles based on the postcodes of vehicle registration data.

More recently, oil vulnerability studies have begun to look directly at disaggregate household datasets for expenditure variables as expenditure data are often available in national household expenditure surveys. A brief outline of oil vulnerability related works done in this area is described below. Instead of a traditional cut-off line approach (e.g. “10% of fuel expenditure in relation to income (Hills 2011), more recent mobility fuel use stress studies use a Low-Income-High-Costs (LIHC) approach (Berry et al. 2016, Mattioli et al. 2016, Mayer et al. 2014). In household studies of fuel stress, vulnerability components became blurred as the fuel-stress (income-cost) approach combines exposure, sensitivity and adaptive capacity measures. However, studies using the LIHC approach were not as adept as other census-based intra-urban studies in dealing with the spatial geography of urban form, often due to coarser spatial resolution of data due to confidentiality issues. Household/personal based studies are still better for allowing more tacit understanding of fuel stress. Berry et al. (2016) illustrated an alternative way to view oil vulnerability, which comprises of dimensions and factors that cause fuel poverty in
transport at household level. In Table 5, Barry et al.’s conceptualisation is cross-compared with the oil vulnerability components as proposed in this paper. While most of the oil vulnerability components can match with Berry et al.’s dimensions and factors, it might miss out those disadvantaged households without any vehicle, which needed to drive to work/services due to lack of alternative transport. They might be erroneously considered by Dodson and Sipe’s (2007) approaches, to be indicated as less exposed to fuel price increase due to lower car ownership, and are depicted as less oil vulnerable. The inclusion of adaptive capacity variables in analysis, such as public or active transport use, may help address this shortcoming.

Table 5: Comparing the household level transport fuel poverty dimensions and factors by Berry et al. (2016) and the oil vulnerability components used in this paper

<table>
<thead>
<tr>
<th>Fuel poverty studies at household or personal level</th>
<th>Inter-city or Intra-urban studies by area aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions</strong></td>
<td><strong>Factors / Situations</strong></td>
</tr>
<tr>
<td>Financial Resources</td>
<td>Low income</td>
</tr>
<tr>
<td>Mobility Practices</td>
<td>High fuel spending</td>
</tr>
<tr>
<td></td>
<td>Extra travel time</td>
</tr>
<tr>
<td></td>
<td>Automobile use restriction (Could not afford the fuel to drive despite ones’ preference/suitability)</td>
</tr>
<tr>
<td>Conditions of Mobility</td>
<td>Poor spatial matching (Located far from jobs with long distance of travel)</td>
</tr>
<tr>
<td></td>
<td>No alternative (without/poor public transport)</td>
</tr>
<tr>
<td></td>
<td>Low vehicle performance (Fuel efficient vehicles are expensive to obtain but cheap to run)</td>
</tr>
<tr>
<td></td>
<td>No vehicle (Could not afford it)</td>
</tr>
</tbody>
</table>

This section has discussed the emerging literature of oil vulnerability, establishing clearer conceptualisations of exposure, sensitivity and adaptive capacity based on
different units of analysis. The next section discusses the policy implications and the relevance of oil vulnerability research.

6. Research which has discussed policy implications: is oil vulnerability still relevant if oil prices are lowered?

Dependence on oil remains a concern, and calls for a shift to alternative fuels are not new (Greene *et al.* 1988, Millans *et al.* 1988). However, lower oil prices might prolong import dependence and a vulnerability to supply interruptions and price shocks. Urban transport oil vulnerability research is still relevant, with the arguments of social equity, health, urban planning arguments still remain. Oil vulnerability studies sit within the broader energy study areas of energy and the environment, which uses a similar term “energy security” with the three perspectives of “sovereignty” (political sciences), “resilience” (economics) and “robustness” (natural science and engineering). Security is often the more used term in energy policy studies (Sovacool and Brown 2010, Hughes 2015), but it is essentially analogous to vulnerability (i.e., the lack of security). The possible responses to energy security are outlined in Cherp and Jewell’s (2014) theoretical synthesis of various fields in “energy security”. They consider the most preferred “no-regrets” responses which are accepted by all three perspectives but which are also relatively difficult to implement, needing substantial technological advancement or societal adaptations (Moriarty and Honnery 2013). Many of the policy responses (e.g.: national level energy policies or foreign affairs and trade) are beyond the reach of local authorities. However, the role of local authorities in reducing energy intensity is well placed, such as by the means of better transport and urban planning (Hodson *et al.* 2017) and social practices that are less energy consumptive (Shove 2004). However, the issue of transport (in)equity is often overlooked in wider transport policy consideration and in
project appraisal (Di Ciommo and Shiftan 2017). One reason could be varied price effects at different levels. For other research areas, the notion of vulnerability is apparently referred specifically to household impacts, which are at the mercy of external factors. Households prefer lower prices, but for energy providers, higher prices would mean more profit and investment (Cherp and Jewell 2014). This conflict of pricing is often only mediated by governments to ensure affordable fuel prices to the masses whom require energy.

6.1 Transport inequity and automobile dependence practices

Apart from environmental impacts (Chester and Horvath 2009) and congestion (Parry et al. 2007), another key concern of automobile dependence is the inequity of transport cost burden across areas, which most oil vulnerability studies are attempting to show. Other similar notions are “transport poverty” (Lucas et al. 2016, Ortar 2016), “energy poverty” (González-Eguino 2015) and “transport affordability” (Litman 2017). A more specific term of “energy-related economic stress” and “car-related economic stress” also reappeared in more recent research (Mattioli 2014, 2015, Mattioli et al. 2016). Such diversity of notions shows a concern of urban scholars about social disadvantage related to transport, urban form and energy price increases or uncertainty. In sprawling cities, suburban areas often incur greater mortgage debt and longer commuting distances with higher transport costs (Dodson and Sipe 2008, Cadus 2013, Vidyattama et al. 2013), implying a wider urban planning and transport issue. However, driving remains desirable and is associated with freedom and status (Jeekel 2014, Kent 2015, Wells and Xenias 2015). In a time-use travel study in the UK, Mattioli (2016a) demonstrated that automobile use is already an established practice. Policy responses to oil vulnerability are needed to address the widespread preference of car usage, especially in areas with poor public transport (Sheller and Urry 2000, Kent 2015). From an equity perspective, “energy
justice” has been proposed as an ideal policy goal, aimed to reshape the debate of pro-car policies in many jurisdictions (Sovacool and Dworkin 2014, Mullen and Marsden 2016). Simply raising the costs of automobile travel to a sufficiently high level (e.g., congestion charges, fuel taxes) might be effective, but it is likely to be inequitable due to current dependence on the car (Moriarty 2016). A minimum standard of energy allowance in society, based on necessary energy uses has been proposed by Walker et al. (2016). Urban energy planning should also be the key policy response (Madlener and Sunak 2011). The challenge remains for urban areas to anticipate and implement energy efficient public transport systems before automobile dependence practices become entrenched (Steemers 2003).

7. Future research directions

From the findings in this literature review as presented in the earlier sections, we propose that future research should move towards these directions.

7.1 Adapting the “oil vulnerability” conceptual framework

Previous attempts to research oil vulnerability had no underlying conceptual framework that defined and classified the variables. The conceptual framework proposed in this paper could help to unify the definitional and operational issues constraining current oil vulnerability research. Adaptive capacity could be seen as a dimension that helps to reduce exposure and sensitivity, which is currently less used as a variable in measuring oil vulnerability. It is imperative to include this dimension, because it can be a solution to oil vulnerability, rather than merely a discussion of the risk components.
7.2 Unit of analysis issues of oil vulnerability studies

In previous studies, data availability constrained the choice of the unit of analysis. The mobility database originally developed by Newman and Kenworthy (1989) and now maintained by the UITP (2015) can be considered to be the best effort. Inter-city datasets or studies using aggregated urban data are useful for comparing different cities, but are not as useful for investigating internal differences. Conversely, the more bottom-up intra-city studies are well-placed to reveal internal and spatial differences within a city. But to date, no international comparison of intra-urban areas has been made. Studies regarding oil vulnerability have also been predominately Western-based (in particular Anglosphere) scholarship. This raises questions about whether other regions, for instance, the Asia Pacific, have different insights or experiences of oil vulnerability. Hence, international oil vulnerability should be subjected to further analysis and evaluation.

Disaggregated units of analysis often contain national statistical agency surveys which contain expenditure data, but are usually limited by data confidentiality issues. Tailor made oil vulnerability or fuel use surveys (Watcharasukarn et al. 2012, Allard et al. 2014) and interviews (Gray et al. 2001) have been undertaken, but are very localised in nature and may not give generalised findings. Future research could consider “multi-scale” or “hybrid” studies. For instance, intra-urban studies should be developed in a way that is comparable in an inter-city, or even international, way. This could shed light on why and how cities are developed, and whether the levels of oil vulnerability differ from city to city.
7.3 New trends that may affect oil vulnerability measures

Current oil vulnerability studies still largely measure automobile dependence. The “disruptive” developments occurring in the transport field may soon render these measures obsolete, if research is not adjusted to match these changes. Fuel efficiency is rapidly improving due to the uptake of hybrid (Vyas et al. 2009) or “oil free” EV (Weiss et al. 2015). The simple vehicle ownership or mode share variable used in a number of oil vulnerability studies may gradually become less relevant unless fuel efficiency or EV variables are included. This has already been observed in more recent oil vulnerability studies (Li et al. 2013). Higher fuel prices may encourage the uptake of fuel efficient vehicles but this is not certain now as oil prices have plummeted (Burke and Nishitateno 2013). The pace and timing of when energy transition will occur remain uncertain (Rutherford and Coutard 2014).

Nevertheless, “EV-ability” of households, such as the ease of obtaining EV, availability of renewable energy (e.g., solar panels) has so far not been well assessed. E-bikes, or e-scooters, are a much cheaper alternative to full-sized EVs, should also be considered in urban transport policy as well (Weinert et al. 2007, Hwang 2010). The current trend of “peak car” may affect some of the oil vulnerability metrics used (Newman and Kenworthy 2011, Metz 2013). Future vehicle ownership may not be essential as similar mobility can be offered by car-sharing (Shaheen and Cohen 2013, Sheller and Urry 2016) and more recently “ride-sharing” services (Çetin 2017). How these developments could be reflected in oil vulnerability is not known. On a more futuristic note, the fuel use and social impact which will arise with autonomous vehicles should also be anticipated (Mersky and Samaras 2016, Miller and Heard 2016, Ohnemus and Perl 2016). However, some scepticism is also developing from the point of view that cars
of whatever fuel mix are not that useful in cities – it does not help solve the issue of car dependence and causes negative impacts on the urban environment (e.g.: safety, congestion and parking) (Wells 2012, Newman 2013).

8. Concluding Remarks

This paper is a first systematic review of fuel price impacts in urban transport. We have so far outlined four decades of fuel price related urban transport impacts and the emerging oil vulnerability research. It is hoped this study will provide a better theoretical basis and useful guidance for upcoming oil vulnerability studies. There are some of the limitations to this study: Firstly, we are not able to consider non-English sources due to language barriers. A wider consideration of multilingual literature could reveal other global viewpoints of this issue. Moreover, our bibliographic analysis only considered journal articles due to database limitations. Future literature reviews might be able to tackle these limitations better. With great uncertainty in future oil prices, further research should consider the role of energy transition and the potential equity impacts. Those with fewer socio-economic resources are more likely to be left out in adopting the latest technology, which tends to be more expensive. Yet their social practices are likely to be more energy frugal, due to the necessity to reduce costs. This consideration in oil vulnerability is not exactly clear. On a more optimistic note, the current lowered oil price might be caused by alternative fuel sources (renewables for EVs or biofuels) are expected to be increasingly able to compete with oil’s current dominance in private transport, and also climate change concerns that calls for reducing fossil fuel use (Khan 2017). However, the issue of transport equity caused by fuel use and price increase remains, as cities remain spatially unequal in terms of housing location and access to energy efficient modes such as public and active transport.
References


Cadus, S., 2013. A Housing and Mobility Cost Calculator for the Province of Salzburg. Salzburg, Austria.


3. Methodology

Building on the literature review in Chapter 2 and the conceptual oil vulnerability framework provided therein, this chapter outlines the research methodology and activities of this thesis. First, the chosen research approach paradigm is described, followed by the research questions. Then the delimitations of research are defined, and justification for the key case study areas is given. The research activities are then outlined and summarised, followed by the description of research ethics requirements and how they are being met.

3.1 Research approach and paradigm

Transport planning has been generally based on positivist paradigms (Banister 2002) which focus on representation and prediction of travel behaviour. Increasing attention is given to alternative approaches, such as critical realism, in conducting research (Næss and Jensen 2002). The issue of oil vulnerability is a complex issue as it deals with multiple dimensions, not only from an energy use intensity standpoint but also because of the possible social impacts caused by rising and more volatile oil prices.

Fitting this thesis’ research questions into only one purist paradigm as outlined by Guba and Lincoln (1984) is less preferable. The thesis in its entity takes neither a purely positivist or critical theory research paradigm, as summarised in Table 2. Instead, the author adopts a pragmatic research approach underpinned by post-positivism and critical realism paradigms. In a pragmatic research approach, no strict loyalty to a system of philosophy or reality is associated. What matters to a researcher should be the “research problem” and all approaches can be applied
to understanding the problem and the results of the research (Creswell 2003). The rise of the pragmatic approach is a response to early methodological debates in social science research in general, and also in the fields of transport planning, which tend to emphasise the dualism of quantitative and qualitative methods (Guba and Lincoln 1984, Banister 2002, Denzin and Lincoln 2005). In particular, positivism and post-positivism, which they believe, take an objective, value-free stance to reality and knowledge, are often associated with quantitative methods. In contrast, critical theory and constructivism, which view the world and knowledge production as subjective and mediated by values, are seen as linked to qualitative methods (Guba and Lincoln, 1984; Lincoln and Guba, 2011). This dichotomy has led to a paradigm contest between advocates of quantitative versus qualitative methods in research. In recent years, there have been attempts to reconcile or negotiate this contest through the use of mixed methods (Johnson and Onwuegbuzie 2004, Venkatesh et al. 2013). A pragmatic approach supports the use of mixed methods which refers to research mixing quantitative and qualitative research methods (Creswell 2003).

### Table 2: Key aspects of the major research approaches and paradigms
*(Adapted from Perry 1998)*

<table>
<thead>
<tr>
<th></th>
<th>Quantitative Research</th>
<th>Qualitative Research</th>
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</thead>
<tbody>
<tr>
<td>Research Problem:</td>
<td>Research Problem:</td>
<td></td>
</tr>
<tr>
<td>Research Nature:</td>
<td>Research Nature:</td>
<td></td>
</tr>
<tr>
<td>Explanatory – What are</td>
<td>Exploratory – What are the variables involved?</td>
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<tr>
<td>the relationships between</td>
<td>Constructs are messy</td>
<td></td>
</tr>
<tr>
<td>the variables which have</td>
<td>Research issues are developed</td>
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<tr>
<td>been previously measured?</td>
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<tr>
<td>Hypotheses are developed</td>
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<tr>
<td>Paradigm:</td>
<td>Paradigm:</td>
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</tr>
<tr>
<td>Positivist / Post-positivist</td>
<td></td>
<td>Critical realist / Constructivist</td>
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<tr>
<td>Methodology commonly used:</td>
<td>Survey, experiments, statistical analysis</td>
<td>Methodology commonly used:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Case studies, surveys, action research</td>
</tr>
</tbody>
</table>
One of the advantages of the mixed method approach is that it draws from several approaches of research, which offset the weaknesses of either a singular quantitative or qualitative research (Creswell and Clark 2011). This is especially useful, as qualitative study, especially perspectives of oil vulnerability, has been less thoroughly examined in previous studies. Quantitative empirical research is more post-positivist; whereas qualitative dialogue with stakeholders is more of a critical realist approach. By interpreting evidence from quantitative data and qualitative views together, various sources of evidence can strengthen empirical findings (Creswell and Clark 2007). Transport studies are increasingly multi-disciplinary, embracing research that could offer an explanation of phenomena from different perspectives in order to form a comprehensive understanding of people or phenomena (Goulias 2002). This view aligns with methodological pragmatism, which argues that methods can be separated from the epistemology out of which they emerged (Gale and Rescher 1979, Morgan 2007). The methodological orthodoxy is thus rejected and is replaced by methodology appropriate to the specific study.

3.2 Research questions

This thesis is based on the following key questions, with a number of related sub-questions that help apportion the study into smaller manageable activities, as shown in Table 3. These questions seek understanding of transport and urban forms in view of energy uncertainty and social inequity.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Research Questions</th>
<th>Background Studies</th>
<th>Methods</th>
<th>Publications / Chapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Literature Review and Methodology</td>
<td><strong>Primary Questions:</strong> MQs: What is oil vulnerability? What does it mean? How is oil vulnerability measured? Secondary Questions: How was oil vulnerability (or fuel price related urban transport impacts) research been conducted?</td>
<td>(See Chapter 2)</td>
<td>Qualitative and Quantitative Literature Review</td>
<td>Chapter 2; Chapter 3</td>
</tr>
<tr>
<td>Benchmarking inter-city oil vulnerability – many cities</td>
<td><strong>Primary Question:</strong> RQ1: What is the level of oil vulnerability in different Asia Pacific cities? Secondary Questions: • What indicators can be used to assess oil vulnerability in urban transport in a wider region? • What is the relationship of key urban characteristics (e.g., density) to oil vulnerability?</td>
<td>(Newman and Kenworthy 1989); (Newman and Kenworthy 1999)</td>
<td>Quantitative analysis</td>
<td>Chapter 4 (Newman, Burke, Yen, et al. 2017)</td>
</tr>
<tr>
<td>Benchmarking inter-city oil vulnerability with new data – local study</td>
<td><strong>Primary Question:</strong> RQ2: Do fuel use and income levels differ in different cities in relation to adaptive capacity? Secondary Questions: • How to assess oil vulnerability in a way that allows inter-city comparison? • What indicators can be used to assess oil vulnerability in urban transport? • What is the level of fuel stress in major Australian cities? • What is the level of resilience to fuel price changes in major Australian cities?</td>
<td>(Zhu 2001); (Zou and Wei 2009); (Yen et al. 2014)</td>
<td>Quantitative analysis using DEA</td>
<td>Chapter 5 (Leung, Burke, Yen, et al. 2016)</td>
</tr>
<tr>
<td>Benchmarking inter-city oil vulnerability with new data – international study</td>
<td><strong>Primary Question:</strong> RQ2: Do fuel use and income levels differ in different areas in relation to adaptive capacity? Secondary Questions: • How can oil vulnerability be assessed in a way that allows inter-city comparison? • What indicators can be used to assess oil vulnerability in urban transport? • What is the level of fuel stress in Taiwanese and Australian areas? • What is the level of resilience to fuel price changes in Taiwanese and Australian areas?</td>
<td>(Zhu 2001); (Zou and Wei 2009); (Yen et al. 2014); (Leung, Burke, Yen, et al. 2016)</td>
<td>Quantitative analysis using DEA</td>
<td>Chapter 6 (Leung, Chiou, et al. 2016)</td>
</tr>
<tr>
<td>Developing new methods to assess oil vulnerability in intra-urban areas</td>
<td><strong>Primary Question:</strong> RQ3: How do oil price change impacts vary spatially internally in an urban area? Secondary Question: • What indicators can be used to assess oil vulnerability in urban transport? • How does the spatial distribution of the oil vulnerability components differ in a regional urban setting?</td>
<td>(Dodson et al. 2007)</td>
<td>Quantitative analysis and mapping</td>
<td>Chapter 7 (Leung et al. 2015)</td>
</tr>
</tbody>
</table>
Table 3: Research Questions and the Associated Research Activities in this Thesis (Continued)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Research Questions</th>
<th>Background Studies</th>
<th>Methods</th>
<th>Publications / Chapter</th>
</tr>
</thead>
</table>
| Comparing intra-urban oil vulnerability between cities | **Primary Question:** RQ3: How do oil price change impacts vary spatially internally in an urban area?  
**Secondary Questions:**  
• What indicators can be used to assess oil vulnerability in urban transport?  
• How does the spatial distribution of the oil vulnerability components differ in internationally? | (Dodson et al. 2007) (Leung et al. 2015) | Quantitative analysis and mapping | Chapter 8 (Leung, Burke, and Cui 2016) |
| Understanding policy responses to oil vulnerability | **Primary Question:** RQ4: How are policies developed to respond to increasing oil prices?  
**Secondary Questions:**  
• Is oil vulnerability, or other energy factors, being considered in the current transport and urban planning policy making processes?  
• Was peak oil an instrumental discourse in promoting policy changes?  
• What are the obstacles to reducing oil vulnerability? | (Kingdon 1984) (Hajer 1995) | Qualitative interviews | Chapter 9 (Leung, Burke, Perl, et al. 2017) |
| Using disaggregated data to study oil vulnerability | **Primary Question:** RQ5: Do new public transport improvements help reduce oil vulnerability (measured by VKT per capita)?  
**Secondary Questions:**  
• Can disaggregated time series data be used to analyse oil vulnerability?  
• Did Gold Coast’s VKT reduce after the commencement of light rail?  
• What are the determinants of VKT on the Gold Coast? | (Corpuz et al. 2006, Mulley and Tanner 2009) | Quantitative analysis and modelling | Chapter 10 (Leung, Burke, Eccarius, et al. 2017) |

3.3 Scope

As briefly mentioned in Chapter 2, the main focus of this thesis is urban areas. The following section describes the scope of this research in greater detail, and why only domestic passenger transport is considered.

Urban Areas

As outlined in Chapter 2, the main reason for focusing on urban areas is due to cities’ role in providing adaptive capacity against oil vulnerability - reducing per capita oil use by more energy efficient transport arrangements (e.g.: public or active transport). Non-urban areas are not considered within the key scope of
research is that those areas are difficult for public transport provision due to lack of critical mass, and hence should be treated differently. Definitions of “urban area” differ, ranging from population size, density, administrative or political boundaries or economic function (Cohen 2006). In a transport study context, Newman and Kenworthy’s (1989, 1999) international city comparison study defined an urban area as “large, fairly contiguous built-up area”. In more recent studies, with better improvements in geographic datasets, Mees (2009) was able to reconstruct urban areas based on smaller census tracts to allow more accurate interurban comparisons. Mees (2009) argued that the administrative boundary of a city is less suitable for international urban comparisons of key transport and land use questions due to the inclusion of non-urban areas and distortion of actual density. However, in many cases, administrative boundaries remain important due to data collection practices are often confined by them. For the spatial mapping, only the administrative areas that are within the extent of urban areas are included in the scope of this research. The urban-only scope is not applied in Chapter 8, and this is due to the recent mergers of a number of municipal areas in Taiwan, making an urban-rural demarcation less feasible. In that chapter, Australia is organised by Greater Capital City Statistical Areas (GCCSAs) and “Rest of Capital” areas within a State.

**Passenger and freight transport**

The impacts of increasing oil prices do not discriminate between passenger and freight transport. The potential reduction of oil vulnerability in passenger transport can be achieved by organising public transport trips collectively or by reduction of motorised trips through telecommuting or active transport if these policies can be implemented (Kingdon 1984, Khayesi and Amekudzi 2011, Krohn
2011). For freight, the impacts of using information communication technology in freight transport are however mixed and uncertain (Cullinane 2009). The examination of oil vulnerability of freight transport will be useful for future research but is beyond the scope of this doctoral research. A key consideration is a practical one – public data collection and dissimilation of transport data is more difficult for urban freight transport, when compared to the urban passenger counterpart (Woudsma 2001. Cui et al. 2015).

3.4 Selection of the key case study cities

The selection of the cities covered in this study was mainly decided by the availability of data and potential contact with local institutions. Due to data limitations, different indicators are used for different scales as aggregated indicators are useful for inter-city comparisons but are not useful for internal local investigation. In the detailed analysis, the choice of key case study cities is limited to Greater Brisbane (including the local government areas of Brisbane, Moreton Bay, Logan and Ipswich) and Hong Kong. Selection of these two cities provides a contrasting comparison of different urban forms (compact vs dispersed), transport systems (public transport based vs car based) and planning approaches. For a further international comparison, Taiwan is included, as the author was awarded the Endeavour Research Fellowship in 2016. With a supported trip to Taiwan, an inter-city comparison of Australia’s and Taiwan’s cities and urban areas is researched, and the results are presented in Chapter 6. The inclusion of Taiwan allows a better understanding of urban areas with high motorcycle use, contrasting to car dominant Australia. However, this is based on aggregated data with household fuel expenditure, and is not directly comparable to the intra-urban study of Hong Kong and Brisbane in Chapter 7 and 8.
3.5 Outline of key research activities

The methodology is structured in five key activities, which resulted in nine peer-reviewed academic publications. Several empirical investigations, involving both quantitative and qualitative methods, are included in this research project.

1. Literature review and the development of new methods to study oil vulnerability.
2. An extensive, but less thorough, study of 11 Asia Pacific cities based on aggregated urban data.
3. Comparison of wider urban areas, by using fuel related data which has not been used in prior research in Taiwan and Australia.
4. An in-depth case study of Brisbane and Hong Kong covering vulnerability mapping and statistical spatial variations of different localities within the cities.
5. Interviews with stakeholders in Brisbane and Hong Kong to understand perceptions and awareness of oil vulnerability and the associated policy responses.

The abovementioned research activities can be summarised in Figure 2, where the operational definitions closely align with the oil vulnerability conceptual framework proposed in Chapter 2.
3.6 Ethics

Within Australia, the ethical and legal responsibilities for academic researchers in relation to research participants have been outlined in the National Statement for Ethical Conduct in Research Involving Humans (NHMRC 1992). This ethical framework emphasises that research must be designed to ensure that “respect for the dignity and wellbeing of the participants takes precedence over the expected benefits to knowledge” (NHMRC 1992, p23). Three areas are identified within the report for particular note: 1) the need for informed consent, research merit and safety and ethical review and conduct; 2) that participants must be able to withdraw at any time without reason or justification and; 3) researchers must ensure that the privacy, confidentiality and cultural sensitivities of the participants are respected and that the results must be made publicly available.
This research conformed to all Griffith University ethical requirements as specified in the Griffith University Code for the Responsible Conduct of Research.

Ethical clearance for human research was approved by the Griffith University Human Research Ethics Committee (GUHREC) on the 17th March, 2015 under Protocol Number ENV/06/15/HREC. After the successful completion of interviews in Hong Kong and Brisbane, a Final Ethical Conduct Report has been submitted to the GUHREC. The GUHREC considers this protocol has been recorded as completed on the 13th July, 2016.

3.7 Summary of research methodology

The research aims, questions, approach and key research activities have been summarised in this chapter. Figure 3 outlines the research activities. These interrelated activities cover all three units of analyses as identified in Chapter 2. From the next section, the results of this research are presented in seven publications. The conclusion in Chapter 11 outlines the contributions, limitations and future research directions.
Figure 3: Thesis structure and outline

1: Introduction
2: Literature Review
3: Methodology

Research Activities

International
Inter-city (Across cities)

Chapter 4:
Benchmarking oil vulnerability in 11 Asian Pacific Cities

Chapter 5:
Using DEA to benchmark oil vulnerability across Australian major cities

Chapter 6:
Using DEA to benchmark oil vulnerability between Taiwan and Australian urban areas

Chapter 7:
A new method to map and analyse intra-urban oil vulnerability in South-East Queensland, Australia

Chapter 8:
A first international intra-urban study of oil vulnerability comparing Hong Kong and Brisbane, Australia

Chapter 9:
A qualitative analysis of peak oil and oil vulnerability discourse in transport policy in Hong Kong and Brisbane, Australia

Chapter 10:
Using disaggregated data to analyse oil vulnerability changes on Gold Coast, Australia

11. Conclusion
4. Benchmarking Urban Transport Oil Vulnerability in 11 Asia-Pacific Cities


Following prior research findings in the literature review (Chapter 2) and methodology (Chapter 3), this chapter applies the proposed conceptual framework of oil vulnerability to actual research. This paper presents a scoreboard approach to benchmark oil vulnerability internationally with a diverse set of cities. Eleven major cities in the Asia Pacific region are included. These include East Asian, South-East Asian and Australasian cities.

The conceptual framework of oil vulnerability used in this thesis is applied to organise the variables used. This study provides a detailed inter-city analysis of oil vulnerability, for which some variables have not been considered in earlier inter-city transport studies, such as GDP per capita and Gini coefficient. In this current study, a weighting and scoring criteria is used, based on the relative importance of the variables to oil vulnerability. Private vehicles and motorcycles are measured separately, which is an innovation in oil vulnerability studies, as previous methods did not usually distinguish between them, despite their difference in fuel efficiency per distance. The results show that compact cities such as Hong Kong and Singapore are the least oil vulnerable, followed by the
capital cities of Japan (Tokyo) and Korean (Seoul). South-East Asian and Australian cities are found to be the most oil vulnerable, but in different ways. Australian cities are vulnerable due to high car mode share and ownership levels, but this is compensated for by higher incomes. South-East Asian cities are highly vulnerable due to low public transport mode share, high motorcycle use/ownership and lower incomes. Chinese and Taiwanese cities are located in the middle in terms of oil vulnerability. Shanghai has a rapidly developing public transport system and middle ranged income. Taipei is a developed economy, has a decent public transport but with a relatively large scooter fleet. This study’s methods can be further improved if “bottom-up” intra-urban variables are used to understand the social spatial differences in within the cities.

Research questions addressed in this paper and contributions

Primary question
What is the level of oil vulnerability in different Asia Pacific cities?

Summary of contributions
Developed method to benchmark oil vulnerability in a number of Asia Pacific cities
4.1 Statement of contribution to co-authored published paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:


The authors listed below have certified that:

1. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. they agree to the use of the publication in the student's thesis and its publication on the Griffith University database consistent with any limitations set by publisher requirements.

<table>
<thead>
<tr>
<th>Contributors</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abraham Leung (Signed)</td>
<td>Conceiving, planning and the writing of the manuscript, data collection, and the preparation of tables and figures. The candidate was also responsible for the revision made at the suggestion of the conference reviewers and the presentation of the paper during the conference.</td>
</tr>
<tr>
<td>24, June, 2017</td>
<td></td>
</tr>
<tr>
<td>Matthew Burke</td>
<td>Provided assistance in the theoretical framing of the research and provided editing revisions in the initial and the reviewed manuscript.</td>
</tr>
<tr>
<td>Barbara T.H. Yen</td>
<td>Provided editorial suggestions in the initial manuscript.</td>
</tr>
<tr>
<td>Yu-Chiun Chiou</td>
<td>Provided editorial suggestions in the initial manuscript.</td>
</tr>
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</table>

Supervisor Confirmation: I have sighted email or other correspondence from all co-authors confirming their certifying authorship.

(Signed) ___________________________ (Date) 24, June, 2017

Co-principal Supervisor: A/Prof Matthew Burke
Benchmarking Urban Transport Oil Vulnerability in 11 Asia-Pacific Cities

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Abstract: Oil vulnerability emerged as a transport policy concern during the period of higher oil prices circa 2003 to 2014. This paper assesses and compares 11 Asian Pacific cities of different size regarding their level of oil vulnerability. A scorecard ranking method is developed, building from more established vulnerability concepts of ‘exposure’, ‘sensitivity’ and ‘adaptive capacity’ based on census data, transport agency datasets and previous international studies. The results show city-states such as Hong Kong and Singapore are the least vulnerable despite their complete reliance on imported oil. Conversely, South-East Asia’s growing megacities such as Jakarta, Bangkok and Manila, with increasing motorisation, insufficient public transport supply and lower income levels are likely to be the hardest hit in the event of any oil supply shortfall. Implications of this research include that cities aspiring to be oil-free must curb private motorisation and devote their resources towards public transport.

Keywords: oil vulnerability; benchmarking; Asia Pacific cities; motorisation

1. THE PROBLEM OF OIL VULNERABILITY IN THE ASIA PACIFIC

Transport is highly dependent on oil, with internal combustion engines expected to remain dominant for years to come. This has been dubbed transport’s ‘liquid fuel problem’ (Hirsch, 2008). Oil is the most versatile form of dense energy storage, but it is a finite resource, provides decreasing energy return on investment, and is implicated in a growing proportion of the world’s carbon emissions (Murphy & Hall, 2011). The Asia Pacific region’s oil supply is largely sourced from oil abundant regions, most importantly in the Middle East with even nations such as Indonesia now net-importers of oil products. Geopolitical instability within the large oil producing regions (notably the Middle East and North Africa) and the vulnerability of shipping lanes (i.e. piracy in Somalia and contests of control in the South China Sea) are threats to oil supplies in the Asia Pacific (Blackburn, 2013; Liu & Wu, 2015; Shigeru Kimura, Tetsuo Morikaw, & Siddharth Singh, 2016). The fracking revolution appears to have delivered a short-term boost to oil supply, particularly in North America, but the peak of conventional oil production may well be past us. Despite recent falls in oil prices that offered respite for automobile users and transport operators, the future of oil prices remains uncertain and the risk of increased oil price remains (Alexander, 2016). Further, technology has not advanced yet to the point of replacing oil use. While alternative transport fuels are
often lauded as a solution (Li & Loo, 2014), the suitability and affordability of electric cars have not yet proven feasible, and are especially out of reach to those with lower incomes (Steinhilber, Wells, & Thankappan, 2013). Researchers have increasingly recognised the social cost of oil dependence in Western nations since the oil price shocks of the late 2000s and early 2010s with research on the ‘oil vulnerability’ of transport caused by increasing fuel prices (Dodson & Sipe, 2008; Lovelace & Philips, 2014; Mattioli, Anable, & Vrotsou, 2016; Mayer, Nimal, Nogue, & Sevenet, 2014; Rendall, Page, & Krumdieck, 2014). In the times of high oil price, ‘oil vulnerability’ research attracted significant government attention (Australian Senate, 2007; Lee & Scott, 2007; New Zealand Transport Agency, 2008; Oxford Economics, 2011). Yet such scholarly attention on ‘oil vulnerability’ has been largely focused on Western cities with high automobile use.

Cities in the Asia Pacific, including wealthy and less developed cities, should similarly be concerned due to increased oil consumption caused by rapid growth, coupled with limited of domestic oil supply and long distances to oil producing regions (Brandt, Millard-Ball, Ganser, & Gorelick, 2013; Phoumin & Kimura, 2014). In the period 2006-2013 high fuel and energy prices spurred protests across Asia (Ortiz, Burke, Berrada, & Cortés, 2013). Any future oil supply shocks will have potentially significant impacts. Policy-makers need to consider oil vulnerability, including in the transport sector. Strategies such as limiting urban sprawl, encouraging transit-oriented development and investing in sustainable transport are regularly used to reduce private motorised travel (da Silva, Costa, & Brondino, 2007; Dantas, Krumdieck, & Saunders, 2006; Kim & Brownstone, 2013; McGlynn, Newman, & Kenworthy, 1991; Naess, 2004). These strategies recognise that travel can be minimised and private motoring reduced through better spatial matching of transportation, location and needs (Cervero, 2001). The ‘Avoid - Shift - Improve’ (ASI) approach (German Society for International Cooperation, 2011) harnesses these strategies in ways that avoid travel, shift it to sustainable modes, and improve the performance of what remains on the road. But changing a city’s travel behaviour can be an expensive proposition, requiring monetary and political capital. Mass transit infrastructure is costly to construct. Adjusting transport trajectories is difficult given the rapid pace of urbanisation and motorisation in many developing Asian nations (Koizumi, Nishimiya, & Kaneko, 2013). A strong aspiration to drive has also been fuelled by economic growth – the car portrayed as a symbol of luxury and wealth currently enjoyed by developed Western nations (Sheller & Urry, 2000; Van & Fujii, 2011; Zhu, Zhu, Lu, He, & Xia, 2012) and car restraint policies such as car registration plate auctions have only been possible in heavy-handed ways. It is timely to consider how cities across the Asia Pacific might fare in an oil shock. There is limited systematic research comparing the oil vulnerability of cities internationally. Previous efforts developing comparative transport indicators (Kenworthy, 2013; Kenworthy, Laube, Newman, & Barter, 1999) covering the Asia Pacific region are helpful, but most focus on car dependence and do not address the social impacts of higher motor fuel explicitly. Improving on these methods may assist in revealing greater differentiation between cities in their oil vulnerability. Exploring social issues may be advantageous as areas in cities with less public transport accessibility tend to be those with higher socio-economic advantage (Martin & Goodman, 2016). It is also important to understand the recent trajectory of Asia Pacific cities.

Asia Pacific cities in the late 20th and early 21st Century witnessed rapid motorisation, with the exception of certain cities such as Hong Kong or Singapore using strict demand management measures and efficient public transport networks (Cullinane, 2003; Han, 2010). Based on regression modelling of statistics at the national level from a panel of 92 countries
during 1975-2005, a 1% increase in urbanisation raised national road energy use in the low, middle and high income countries by 0.81%, 0.37% and 1.33%, respectively. (Poumanyvong, Kaneko, & Dhakal, 2012). Figure 1 shows the gasoline consumption of a set of Asia Pacific cities’ gasoline consumption from 1995 to 2009. Figure 2 shows the same data weighted by each city’s gross regional product. The differences are stark and we, therefore, presume significant variation in oil vulnerability across the Asia Pacific, though there are many additional considerations beyond total gasoline consumption.

Figure 1. Comparisons of gasoline consumption per 1,000 persons in Asian cities (Economic Research Institute for ASEAN and East Asia, 2013)

Figure 2. Comparisons of gasoline consumption per 1,000 persons normalised by per capita Gross Regional Product in Asian cities (Economic Research Institute for ASEAN and East Asia, 2013)
This paper aims to show how vulnerable Asia Pacific cities are to an event of reduced oil supply. The primary research question is - What is the level of oil vulnerability in different Asia Pacific cities? This is then expanded to secondary questions of – 1) What indicators can be used to assess oil vulnerability in urban transport in a wider region? and 2) What is the relationship of key urban characteristics (e.g., density) to oil vulnerability?

To answer these research questions, we developed a benchmarking approach to compare cities in terms of oil vulnerability, which includes a scoring scheme to rank the level of oil vulnerability in cities. This is then applied to 11 selected cities in the Asia Pacific region for which there was ready data availability. The contributions of this paper are both methodological, providing improved approaches to measuring oil vulnerability at this scale, and applied, in helping to establish relative performance for these cities. The results may assist policy makers, government agencies, key industries and communities in these cities understand the differentiated nature of oil vulnerability and to devise better transport and land use policies in response.

The following Section 2 explains the conceptual framing of oil vulnerability in this study. Section 3 provides the approach and methods. The results are then outlined at Section 4, then the implications of this study are discussed in Section 5, alongside with the limitations, potential future research directions and concluding remarks.

2. CONCEPTUAL FRAMEWORK AND METHODOLOGY

2.1 The origins of the term of oil vulnerability

Oil vulnerability is related to transport disadvantage, which has its roots in transport geography, recognising the inequities in transport provision and accessibility (Healey, 1977; Rimmer, 1978). Transport disadvantage has not always been well defined despite a burgeoning research literature in the field (Dodson, Gleeson, Sipe, & Program, 2004; Lucas, 2004; Murray & Davis, 2001). Currie & Delbosc (2011, p. 15) suggest transport disadvantage may be defined as:

“the lack of access to services and opportunities arising from the interaction of three sets of factors: land-use patterns, the transport system and individual characteristics”.

This definition is closely related to the ‘equity turn’ in transport (Altshuler, 2010; Litman, 2002) as measures of transport have evolved from traffic/mobility-based measures to accessibility, defined as “the ability to reach desired goods, services, activities and destinations” (Litman, 2005, p. 5). For the case of Australia, increased oil prices have been shown to be a likely cause of transport disadvantage (Dodson & Sipe, 2007) with real social impact reported from welfare advocacy groups (Baker, 2004). So it is important to consider social dimensions. Mattioli (2017) summarised the recent oil vulnerability literature, showing there are two main types of analysis. The first kind operates at a micro scale – at a household or individual level. This level is able to analyse the percentage of income spent in travel and transport stress (Lovelace & Philips, 2014; Mattioli, Wadud, & Lucas, 2016). The second kind looks at the meso-scale, which is usually at intra-urban level, exploring the internal spatial
divisions within a city. This level is able to reveal the spatial pattern of oil vulnerability and has garnered the most attention.

The term ‘oil vulnerability’ has advanced from the implied term of Dodson and Sipe’s pioneering study (2007) into a more developed conceptualisation, drawing upon the notion of ‘social vulnerability’ from the well-established fields of hazards (Adger, 2006) and climate change (Brooks, 2003). This paper follows the definition of oil vulnerability first proposed by Leung et al. (Leung, Burke, Cui, & Perl, 2015, pp. 2–3; 2016, pp. 4–5) which drew on a definition of socio-economic vulnerability caused by climate change (Intergovernmental Panel on Climate Change, 2001). Oil vulnerability is defined as ‘the degree to which an urban system is susceptible to, or unable to cope with, adverse effects of oil price variability and extremes’. The subcomponents of this vulnerability comprise of three components, namely exposure, sensitivity and adaptive capacity, as shown in Figure 3.

The detailed explanation of these components is:

- **Exposure (E)** refers to what extent energy-related factors are able to affect the population of a city. It is useful for risk identification. Possible indicators include the level of oil imports, car ownership or mode share of personal and low occupancy transport.

- **Sensitivity (S)** represents the degree cities are affected by both energy and non-energy drivers. It is focused on the internal aspect of cities. For the case of oil vulnerability, the ability to pay could reflect this component. It could be measured by wealth or socio-economic wellbeing.

- **Adaptive capacity (AC)** represents the ability to adapt to change in a way that makes it better equipped to manage its future exposure and/or sensitivity to oil price influences. Adaptive capacity can be short term or long term. Short term measures could be reflected by the ability of a city to use less oil dependent modes of transport, such as the mode
share of active or public transport. While longer term adaptive capacity is important aspects of this component, it is more difficult to measure.

This more developed conceptualisation has advanced from the oil vulnerability conception of Dodson and Sipe (2005) and allows evolution from simple measures into more sophisticated analysis and data modelling.

3. APPROACH AND METHOD

We borrow the approach of vulnerability benchmarking, which is commonly used in the disaster or hazard reduction literature as a way to measure the potential impact of an event. By comparing different entities, cities or countries it can allow policy makers to better understand how vulnerable they are and to address the problem (Birkmann, 2006; Davidson, 1997; Fekete, 2009; Yuan et al., 2015). In the field of transport and planning, benchmarking is also a practice widely adopted to understand the efficiency of public transport systems (Hilmola, 2011) of freight transport (McKinnon, 2009) the sustainability in cities (Boyko et al., 2012) and the ‘smartness’ of transport (Debnath, Chin, Haque, & Yuen, 2014) via different methods.

Based on the conceptual framework with a set of directly comparable metrics, this research uses available aggregated urban and local statistics data, focusing on domestic passenger transport only, given freight data is generally not available. Direct measures of fuel use and of transport accessibility are often difficult to obtain, especially at local scale and within developing countries. A work-around is to reduce the spatial resolution of data, such as using an entire city-region as the unit of analysis. A recent Australian study (Leung et al., 2016) used data envelope analysis to compare the level of oil vulnerability across Australian state and territory capital cities at this scale.

While the data from the (Union Internationale des Transports Publics (UITP), 2001, 2015) database has been used in a number of public transport sustainability cities, boundary definitions remain an issue. Some cities include data on their broader city-region, others like Taipei include data only for the smaller local government area for Taipei City. More importantly, UITP database has a large number of missing variables as noted by De Gruyter et al (2016, p. 11).

Table 1 shows the cities selected for this study. They are mainly selected as key examples of major urban typologies in the Asia Pacific region. Tokyo, Seoul, Bangkok, Manila and Jakarta are key examples of mega-cities, covering multiple local government boundaries. Shanghai, Hong Kong, Singapore represent mega-cities with one major administrative region. Sydney and Auckland represent Australasian cities. All of these cities are important economic centres and all bar Shanghai have primacy of population and GDP share for their nations.
Table 1. City area definition used in this study (Ordered from north to south of location)

<table>
<thead>
<tr>
<th>City Area</th>
<th>Areas covered</th>
<th>Population</th>
<th>Area (km²)</th>
<th>Population Density</th>
<th>Data Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tokyo</td>
<td>Tokyo with Kanagawa, Saitama, Ibaraki (southern part) and Chiba Prefectures</td>
<td>34,620,000</td>
<td>15,940.5</td>
<td>2171.8</td>
<td>2010</td>
</tr>
<tr>
<td>Seoul</td>
<td>Seoul Special City with Incheon City and Gyeonggi Province</td>
<td>23,459,570</td>
<td>11,704.0</td>
<td>2004.4</td>
<td>2010</td>
</tr>
<tr>
<td>Shanghai</td>
<td>Shanghai Municipality</td>
<td>23,019,196</td>
<td>6,340.5</td>
<td>3630.5</td>
<td>2010</td>
</tr>
<tr>
<td>Taipei</td>
<td>Taipei City with New Taipei and Keelung Cities</td>
<td>7,091,791</td>
<td>2,457.1</td>
<td>2886.2</td>
<td>2010</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>Hong Kong Special Administration Region</td>
<td>7,071,576</td>
<td>1,104.4</td>
<td>6403.0</td>
<td>2011</td>
</tr>
<tr>
<td>Manila</td>
<td>Metro Manila with parts of Bulacan, Cavite, Rizal and Laguna Provinces</td>
<td>18,300,393</td>
<td>3,874.8</td>
<td>4722.9</td>
<td>2012</td>
</tr>
<tr>
<td>Bangkok</td>
<td>Bangkok with the adjacent provinces of Nakhon Pathom, Samut Prakan, Pathum Thani, Samut Sakhon and Nonthaburi</td>
<td>14,626,000</td>
<td>7,761.6</td>
<td>1884.4</td>
<td>2010</td>
</tr>
<tr>
<td>Singapore</td>
<td>Republic of Singapore</td>
<td>5,076,732</td>
<td>712.4</td>
<td>7126.24</td>
<td>2010</td>
</tr>
<tr>
<td>Jakarta</td>
<td>DKI Jakarta with the surrounding cities and regencies of Bogor, Depok, Tangerang, and Bekasi (Often referred as Jabodetabek)</td>
<td>27,936,000</td>
<td>6,581.0</td>
<td>4244.95</td>
<td>2010</td>
</tr>
<tr>
<td>Sydney</td>
<td>City of Sydney with surrounding local councils (Greater Sydney Capital Region defined by the Australian Bureau of Statistics)</td>
<td>4,537,000</td>
<td>12136.8</td>
<td>373.8</td>
<td>2011</td>
</tr>
<tr>
<td>Auckland</td>
<td>Auckland Council (merged from 7 former local councils in 2010)</td>
<td>1,415,550</td>
<td>4,894</td>
<td>289.2</td>
<td>2013</td>
</tr>
</tbody>
</table>

3.1 Context of case study cities

Data in the study are mostly obtained from official statistics and relevant studies that encompass physical, social and economic variables. The collected metrics will be examined thoroughly for their reliability and validity. The aim of this activity is to achieve a region-wide understanding of oil vulnerability in the Asia Pacific. As this research involves more than one study area, with data collected from a number of jurisdictions, it is difficult to ensure the data collected are completely compatible with each other. Noting from previous international comparative transport studies (Kenworthy et al., 1999; Næ ss, Sandberg, & Roe, 1996; Newman & Kenworthy, 1989), rigour in ensuring data validity must be applied prior to analysing data collected.

While the data from the UITP database has been used in a number of urban public transport studies (Kenworthy, 2014; Koizumi et al., 2013; McIntosh, Trubka, Kenworthy, & Newman, 2014), boundary definition remained an issue (For example, Taipei was only included as city proper without included surrounding areas in the UITP database). More importantly, UITP database remained with a large number of missing variables as evidenced in De Gruyter (2016) et al.’s global analysis of sustainable transport. The data in this study are collected from publicly available sources with greater consideration on data reliability and comparability. Table 2 shows the cities selected in this study. They are mainly selected for
representing key examples of major urban typologies in the Asia Pacific region. For the delimitation of each city, the availability of statistics is a key consideration. Reflecting the ‘mega-city’ phenomenon, some large cities with a coordinating authority in transport have collected key transport indicators, such as mode share across political administrative boundaries. Tokyo, Seoul, Bangkok, Manila and Jakarta are key examples of such arrangement. For some other cities like Shanghai, Hong Kong, Singapore, the existing administrative borders are used. For Sydney, the State Government of New South Wales has conducted transport studies with a focus of Greater Sydney Area. Auckland is an example of a city region with a recent formal merger of former smaller local entities. Many of these cities are important economic centres and have a primacy in population and significant GDP share for the whole nation.

3.2 Developing international city comparisons indicators of oil vulnerability

To allow comparability of cities of different size, only per capita values are used. To construct a combined index of oil vulnerability we used a method of weighting derived from De Gruyter et al. (2016). Table 2 shows the list of indicators, scoring and weighting criteria. Scoring and weights were determined subjectively based on a review of the literature with higher priority given to adaptive capacity (40%), then exposure (30%), then sensitivity (20%). The raw values of indicators are transformed into percentage value, ranging from 0 to 5. These are then weighted based on its relative importance as supported by the judgement of the authors and relevant literature and explained further in Section 3.3. This study covers are rather large (11) samples of cities, which does not have previous assessment on inter-city oil vulnerability. The aim of this paper to provide an overall benchmarking in a qualitative way, rather than statistically driven modelling. Hence, a more formal multi-criteria analysis is not carried out but this could a possible future research endeavour. The following subsection describes how these weights were developed.

**Exposure:** Oil importation dependence (E1) and percentage of private personal mode share (E4) are given the same weighting of 1.5 as they are deemed to be moderately important (Brandt et al., 2013; Harvey, 2013). As mode share for motorcycles is not available in some countries, an aggregated measure of both private vehicles and motorcycles are used. Vehicle and motorcycle ownership are also included separately as two indicators. This separately is necessary as fuel use intensity is lower for motorcycles. Also, this is to reflect the phenomenon of high motorcycle ownership in some Asia Pacific countries (Wilson, Stimpson, & Hilsenrath, 2009). Car ownership (E2) is deemed to have a higher impact on oil vulnerability and is given a weighting of 3. Motorcycle ownership (E3) is given a weighting of 1 as motorcycles typically consume less oil than cars per km travelled.

**Sensitivity:** The key sensitivity variables relate to income and equity. City area with better economic fundamentals tends to be less sensitive to higher oil prices as individuals will be able to afford higher prices, at least in the short/medium-term. GDP (S2) is deemed as a more important indicator, with a weighting of 4. Income inequality in the form of Gini coefficient (S1) is included as inequity in an oil shock may induce greater social impacts, with a lesser weighting of 1.

**Lack of Adaptive Capacity:** is the ‘inverted’ view of adaptive capacity, which helps create the measure with the same relationship as exposure and sensitivity for better visualisation.
<table>
<thead>
<tr>
<th>Code</th>
<th>Indicators</th>
<th>Transformation Scoring (by percentage ratio)</th>
<th>Weight</th>
<th>Max Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Imported oil dependence = Ratio of domestic oil production to consumption per capita</td>
<td>0 = Low 5 = High</td>
<td>1.5</td>
<td>7.5</td>
</tr>
<tr>
<td>E2</td>
<td>Vehicle ownership = Low occupancy personal vehicles per 1000 persons (cars, taxis)</td>
<td>0 = Low 5 = High</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>E3</td>
<td>Motorcycle ownership = Motorcycles per 1000 persons</td>
<td>0 = Low 5 = High</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>E4</td>
<td>Private transport use = Mode share of low occupancy vehicles and motorcycles</td>
<td>0 = Low 5 = High</td>
<td>1.5</td>
<td>7.5</td>
</tr>
<tr>
<td>S1</td>
<td>Income inequality = Gini coefficient</td>
<td>0 = Low 5 = High</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>S2</td>
<td>Economic strength GDP of PPP per capita</td>
<td>0 = High 5 = Low</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>LAC1</td>
<td>Mode share of public transport</td>
<td>0 = High 5 = Low</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>LAC2</td>
<td>Mode share of active transport</td>
<td>0 = High 5 = Low</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>LAC3</td>
<td>Electric mass transit stops per 1,000,000 persons</td>
<td>0 = High 5 = Low</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>LAC4</td>
<td>Electric mass transit system length per 1,000,000 persons</td>
<td>0 = High 5 = Low</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>LAC5</td>
<td>Ridership of electric mass transit per 1000 persons</td>
<td>0 = High 5 = Low</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

| Maximum Possible Score | 100 |

(The source of data of the indicators are listed in the Appendix)

This approach differs slightly to previous approaches (Leung et al., 2015; Mattioli et al., 2017) that view adaptive capacity as a remedying or counter-acting component against exposure and sensitivity. The key measures of this component include low mode share of all forms of public transport (LAC1) which is given the same weighting of 3. Mode share of active transport, such as cycling and walking (LAC2) is also included but with a weighting of 1, given the much smaller catchments afforded by these modes. Lack of electric mass transit (EMT), which refers to the lack of ability to provide less oil intensive transport for the inhabitants of a city (Gilbert & Perl, 2012; Litman, 2012). A number of variables are used for this: Firstly is the EMT stops per capita (LAC3). Station stops are counted at line level and interchanges are repeated if they intersect to each line. One reason for this is to make calculation easier as some EMT systems such as Tokyo have over 2000 stations. While this may inflate the actual station count, it can reflect the network effect of public transport and reflect the higher accessibility of better-connected mass transport systems. For some commuter rail designs with multiple lines sharing the same railroad, as found in Sydney, Auckland and Jakarta, the duplications are shown on the system line map are not treated as interchanges. The rationale is that such ‘line sharing’ does not give frequency and accessibility advantages for a mass transit system. The system length per capita (LAC4) is used as a proxy measure of EMT coverage. Stops (LAC3) and system length (LAC4) per capita are only given a weighting of 1 as they are similar in nature and only reflect a potential ability to use EMT. One limitation is that future EMT networks under construction or planned are not considered in LAC2 and LAC3 as there is a lack of reliable data on when these will be completed. Meanwhile, EMT Ridership per capita (LAC5) is given a higher weight of 2 as this reveals the actual ability for the population in a city to use EMT and reflects the service quality and the attainable capacity of an EMT system.)
**Combined Score:** can be derived by simply adding up the score of all the weighted oil vulnerability indicators of their respective components as detailed above. For the purpose of this paper, the combined vulnerability is expressed as:

\[ \text{OV} = \text{Exposure (E)} + \text{Sensitivity (S)} + \text{Lack of Adaptive Capacity (LAC)} \]

By applying this approach, the following section presents the results and followed up by the discussion of the implication of the findings.

4. RESULTS

4.1 Overall scores

The unweighted scores are the raw values without treatment, as listed in Table 2 earlier. The pre-transformed benchmarking values are provided in Table 3, followed by the results of the benchmarking in Table 4. Figure 4 outlines the benchmarking results based on the scoring scheme, which clearly distinguishes the oil vulnerability components of exposure, sensitivity and the lack of adaptive capacity.

### Table 3: Original indicator values before transforming into benchmarking scores

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Original Indicator Values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposure</strong></td>
<td>Tokyo</td>
</tr>
<tr>
<td>E1 Oil Import Dependency</td>
<td>-35.7</td>
</tr>
<tr>
<td>E2 Vehicle ownership</td>
<td>304.4</td>
</tr>
<tr>
<td>E3 Motorcycle ownership</td>
<td>34.9</td>
</tr>
<tr>
<td>E4 Private Transport Use</td>
<td>31.0</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td></td>
</tr>
<tr>
<td>S1 Income inequality</td>
<td>0.3</td>
</tr>
<tr>
<td>S2 Economic Strength</td>
<td>43064</td>
</tr>
<tr>
<td><strong>Lack of Adaptive Capability</strong></td>
<td></td>
</tr>
<tr>
<td>LAC1 Public Transport Use</td>
<td>33.0</td>
</tr>
<tr>
<td>LAC2 Active Transport Use</td>
<td>36.0</td>
</tr>
<tr>
<td>LAC3 EMT Length</td>
<td>98.7</td>
</tr>
<tr>
<td>LAC4 EMT Usage</td>
<td>93.1</td>
</tr>
<tr>
<td>LAC5 EMT Stops</td>
<td>1074.9</td>
</tr>
</tbody>
</table>

### Table 4: Transformed benchmarking scores

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Weighted Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposure (E)</strong></td>
<td>Tokyo</td>
</tr>
<tr>
<td>E1 Oil Import Dependency</td>
<td>6</td>
</tr>
<tr>
<td>E2 Vehicle ownership</td>
<td>9</td>
</tr>
<tr>
<td>E3 Motorcycle ownership</td>
<td>3</td>
</tr>
<tr>
<td>E4 Private Transport Use</td>
<td>3</td>
</tr>
<tr>
<td>Sub-total</td>
<td>21</td>
</tr>
<tr>
<td>% of maximum attainable</td>
<td>60%</td>
</tr>
<tr>
<td><strong>Sensitivity (S)</strong></td>
<td></td>
</tr>
<tr>
<td>S1 Income inequality</td>
<td>1</td>
</tr>
<tr>
<td>S2 Economic Strength</td>
<td>12</td>
</tr>
<tr>
<td>Sub-total</td>
<td>13</td>
</tr>
<tr>
<td>% of maximum attainable</td>
<td>65%</td>
</tr>
<tr>
<td><strong>Lack of Adaptive Capability (LAC)</strong></td>
<td></td>
</tr>
<tr>
<td>LAC1 Public Transport Use</td>
<td>9</td>
</tr>
<tr>
<td>LAC2 Active Transport Use</td>
<td>1</td>
</tr>
<tr>
<td>LAC3 EMT Length</td>
<td>0</td>
</tr>
<tr>
<td>LAC4 EMT Usage</td>
<td>0</td>
</tr>
<tr>
<td>LAC5 EMT Stops</td>
<td>0</td>
</tr>
<tr>
<td>Sub-total</td>
<td>10</td>
</tr>
<tr>
<td>% of maximum attainable</td>
<td>65%</td>
</tr>
</tbody>
</table>

**Combined (Total)** | | | | | | | | | | | |
| 44 | 48.5 | 48.5 | 61.5 | 27.5 | 69.5 | 75.5 | 36 | 68.5 | 68.5 | 67.5 |

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Figure 4. Benchmarking results for oil vulnerability in the selected Asia Pacific cities

From the benchmarking results, Bangkok is found to be the most oil vulnerable city with an overall vulnerability score of 75.5 out of 100, followed by its South-East Asian counterparts of Manila (69.5) and Jakarta (68.5). The Australasian cities of Sydney (68.5) and Auckland (67.5) are also highly oil vulnerable.

4.2 Oil vulnerability components

The underlying components of combined oil vulnerability vary greatly amongst these cities. To show this, Figure 5, 6 and 7 shows the relative value (percentage of the city’s score to maximum possible value) of exposure, sensitivity and lack of adaptive capacity respectively.

**Exposure:** From Figure 5, E1 is an imported oil dependency measure measured by the net consumption of oil per capita. Hong Kong, Korea, Japan, Australia and Singapore are highly dependent on oil imports. For E2, vehicle ownership per capita is extremely high in Sydney and Auckland, followed by Tokyo and Seoul. South East Asian and Taiwan cities are found to be having high rates of E3 (motorcycle ownership). For the private transport mode share (E4), Auckland is ranked the highest, followed by Sydney, Jakarta, Bangkok and Taipei. In contrast, Hong Kong and Singapore have the lowest rates of vehicle ownership and usage.
**Sensitivity:** From Figure 6, the ‘city-states’ of Hong Kong and Singapore top the economic performance and income measure (S2) but they also have high levels of inequity (S1). Australasian cities are better able to withstand possible increases in oil price with high GDP per capita and reasonable equity, and are better placed to pay for increased fuel expenses than the South-East Asian cities. Bangkok and Manila have the highest scores for sensitivity, being low income and highly inequitable, compared to the others, whilst Jakarta is more equitable as measured by its Gini coefficient.

**Lack of Adaptive Capacity:** From Figure 7, South-East Asian cities are also characterised by a lack of adaptive capacity due to low public transport uptake (LAC1). Active transport use (LAC2) is mixed across the cities, with Sydney and Bangkok having the lowest mode share, followed by Seoul, Auckland and Hong Kong. For the EMT indicators (LAC3 and 4) and ridership (LAC5) Jakarta has the poorest performance, followed by Bangkok. Conversely, Hong Kong and Singapore have highly developed public transport systems, resulting in strong adaptive capacity. Shanghai is rapidly catching up, seeing the completion of an enviable public transport network, mostly based around metro lines, in recent years, approaching the proportion of stops provided per capita in Seoul. Japan is rated best in terms of EMT system
size and ridership per capita with relatively good active transport uptake. Sydney and Auckland have relatively decent EMT coverage but their ridership and mode share is much less, reflecting their commuter rail systems with lower frequencies, servicing low-density suburbia.

Figure 7. Relative values of lack of adaptive capacity indicators

4.2 Relationship of oil vulnerability and density

Newman’s and Kenworthy’s (1989) early study explored the relationship of urban density and per capita fuel comparison. In this study, we are also interested in looking at whether denser cities are less oil vulnerable, which is a combined measure including possible social impacts of higher oil prices. To this end, density and the benchmarking scores are plotted as shown in Figure 8. The combined oil vulnerability benchmark score is found to be somewhat related to population density (R = 0.599). In detail, Hong Kong and Singapore are highly dense transit-based ‘city-states’ and are the least oil vulnerable. The Northeast Asian mega capitals of Tokyo and Seoul (with over 20 million population) are located in the middle with moderate density and oil vulnerability. China’s premier city Shanghai is having higher density but also lower oil vulnerability due to local oil production and lower rates of motorisation at least for now. Taipei is similarly dense with the East Asian counterparts, but is having higher oil vulnerability due to high rates of motorcycle ownership and usage. South-East Asian megacities are overall having high oil vulnerability, largely due to underdeveloped public transport and increasing rates of motorisation with low income. Australasian car-dependent cities (Sydney and Auckland) are nearly as oil vulnerable as South-East Asian megacities. They are having the highest rate of motorisation, yet only offset by their high income.
5. DISCUSSION AND CONCLUDING REMARKS

The benchmarking results reveal the components of oil vulnerability for these cities in a novel and comprehensive manner for these cities. The scorecard method used in this paper can also be adapted for other issues, such as energy transition readiness and transport equity. The contributions of this study can be viewed as methodological, applied and empirical. Methodologically, this research developed method to benchmark oil vulnerability in a number of Asia Pacific cities. This is then applied by analysing the relationship of key urban characteristics (e.g., density) to oil vulnerability. Empirically, this study assessed the common characteristics of less oil vulnerable cities, e.g., public transport development and car restraint policies. This paper is also an advance on previous inter-city studies that either focused on indicators of car dependence (Kenworthy et al., 1999) or public transport (De Gruyter, Currie, & Rose, 2016). The rankings appear to be able to measure oil vulnerability of cities in a comprehensive way. The applied contributions are in showing how each of these particular cities assessed, other than Hong Kong and Singapore, may be vulnerable to an oil shock, in particular ways.

The implications of the research are many. In terms of car ownership levels, the pathways for
Car dependence in Asian cities identified by Barter (2000) remain in place, albeit there is growing investment in mass transit in many of the South-East Asian cities, and a shift towards more inner-urban housing development. The South-East Asian cities with higher exposure (due to high private vehicle use), higher sensitivity (due to lower incomes and high inequality) and lack of adaptive capacity (due to the lack of EMT options) are likely to be the most affected by an oil price shock. Australasian major cities have high car ownership and policies supportive of motorisation, such as low fuel taxes, which makes them vulnerable despite their wealth. Conversely Hong Kong and Singapore, and more recently Shanghai, have been the cities with the most stringent car restraint policies, such as high fuel taxes and plate auctions, and have invested heavily in EMT systems (Lo, Tang, & Wang, 2008). Hong Kong and Singapore’s land development has also been tightly constrained, creating an enviable transport and land use combination supporting mass transportation. Tokyo and Seoul developed earlier, are dense and have extensive EMT networks, enabling them to offset some of the effects of moderate car ownership. Shanghai and other Chinese cities are also notable in high e-bike uptake, which could offer a form of energy efficient personalised transport with limited occupation of road space. Taiwanese cities followed a trajectory into high motorcycle use with dedicated road infrastructure to facilitate its use. Taipei’s EMT systems are also moderately developed.

Several limitations of our study could be addressed in future research. The subjective weightings used in this study could be improved through surveys and data analysis. However, data regarding city level fuel consumption and monies spent on fuel are not available to estimate fuel price impacts over time. For LAC, future EMT networks under construction or planned are not considered in LAC2 and LAC3 as there is a lack of reliable data on when these will be completed. The benchmarking analysis could be improved by the incorporation of bottom-up GIS analysis and perhaps the testing of indicator significance between cities. A more rigorous and data-based approach could be used to derive weights or normalise the data for benchmarking. For example, DEA has been used for public transport efficiency benchmarking (Chiou, Lan, & Yen, 2012; Hilmola, 2011) and even oil vulnerability (Leung et al., 2016). There may be some over-reliance on variables such as mode share and ridership, as a proxy for transport energy use. Boundary issues remain a concern including in locations like Hong Kong and Singapore that have extensive travel into the neighbouring cities of Shenzhen and Johor. Tourism and freight aspects are not included in this study due to data limitation concerns. Accessibility measures are not used at this scale but could potentially be adapted. One approach might be to map public transport networks and their quality of service based on frequency and proximity to employment locations (Curtis & Scheurer, 2010). Further improvement of this methodology should also consider better weighting (e.g.: principal component analysis) and incorporate sensitivity analysis. Additional qualitative indicators of policy settings for transport, such as pricing controls or car restraint measures, might also be considered, to complement the quantitative measures used. Qualitative measures have been used in previous benchmarking studies (Gudmundsson, Wyatt, & Gordon, 2005). Other areas for future study include how the more vulnerable cities of Auckland, Sydney, Jakarta, Manila and Bangkok might best respond to their lack of adaptive capacity to oil vulnerability.
APPENDIX

<table>
<thead>
<tr>
<th>Code</th>
<th>Indicators</th>
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<tbody>
<tr>
<td>S1</td>
<td>Income inequality = Gini coefficient</td>
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<tr>
<td></td>
<td>UN Habitat, Global Report on Human Settlements (2009)</td>
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<td></td>
<td>Australian Bureau of Statistics and Statistics New Zealand</td>
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<tr>
<td>S2</td>
<td>Economic strength GDP of PPP per capita</td>
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<tr>
<td>E1</td>
<td>Imported oil dependence = Ratio of domestic oil production to consumption per capita</td>
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<tr>
<td></td>
<td>Source: US EIA international energy statistics</td>
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<td></td>
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<tr>
<td>E2 &amp; 3</td>
<td>Vehicle/Motorcycle ownership = Low occupancy personal vehicles per 1000 persons (cars, taxies)</td>
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<td></td>
<td>Source: City/national transportation statistics</td>
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<td></td>
<td>Tokyo: Kanto District Transport Bureau - Number of vehicles owned by municipality (2009)</td>
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<td>Singapore: Land and Transport Authority - Annual Vehicle Statistics (2011)</td>
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<td>Jakarta: Statistical Yearbook of Indonesia and Jakarta Police data (2011)</td>
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<td>Sydney: NSW Roads and Maritime Services (2011)</td>
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<tr>
<td>E4, LAC1 &amp; LAC2</td>
<td>Mode shares</td>
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<td></td>
<td>Source: City/national transportation statistics</td>
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<td>Shanghai: The Fifth Travel Survey of Residents in Shanghai</td>
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<td>Census and Statistics Department – 2011 Population Census</td>
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<td>Manila: Japan International Cooperation Agency (JICA) and Department of Transportation and Communications (DOTC)</td>
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<td>Transportation Demand Characteristics based on MUCEP Person Trip Survey</td>
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<td>Jakarta: Economic Research Institute of ASEAN and East Asia</td>
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<td></td>
<td>Sydney – Household Travel Survey (2011/2012)</td>
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<td>Auckland - Household Travel Survey (2012-2014)</td>
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### Detailed data source of indicators (continued)

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<th>Indicators</th>
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Leung, A., Burke, M., Cui, J., & Perl, A. (2015). New Approaches to Oil Vulnerability Mapping for Australian Cities: The Case of South-East Queensland, the 200km City. Presented at the State of Australian Cities National Conference (SOAC) 2015, Gold Coast, Qld, Australia.


5. Oil vulnerability of Australian capital cities: A pilot study using Data Envelopment Analysis (DEA) for vulnerability benchmarking

The work presenting here in Chapter 5 was previously published as Leung, A., Burke, M., Yen, B.T.H., Cui, J., 2016. Oil vulnerability of Australian capital cities: A pilot study using Data Envelopment Analysis (DEA) for vulnerability benchmarking. Presented at the Australasian Transport Research Forum 2016, Melbourne, Australia.

This chapter uses the data obtained from the income and expenditure survey of the Australian Bureau of Statistics (ABS). This data provides a “fuel stress” (the proportion of fuel expenditure to disposable income) measurement. However, this data is only available for an entire city, as the exact spatial location of the surveyed households is not disclosed for confidentiality reasons. The oil vulnerability framework of exposure, sensitivity and adaptive capacity outlined in Chapter 2 is not easily applicable in this case due to a limited number of variables. Hence, using a linear optimisation modelling method, known as data envelopment analysis (DEA), the oil vulnerability of major Australia cities can be benchmarked based on the actual fuel stress and vehicle kilometre travelled (VKT). Another new measure, which is coined as “oil resilience”, reflects the level of adaptive capacity measured by mode share in relation to fuel stress, is also created by DEA. In this case, the “OV-DEA” and “OR-DEA” values can be seen as two dimensions that can co-exist, and are represented as perpendicular axes.
The results show that Sydney is the least oil vulnerable city in Australia due to high mode shares of active and public transport, and a lower fuel stress overall. This research is the first that uses DEA to analyse oil vulnerability. Using fuel stress as a measure is also novel in Australia as previous studies usually used proxy measures (e.g., car mode share or ownership and income). This inter-city assessment is useful for providing insights into how cities perform in terms of oil vulnerability and transport energy sustainability, and could help higher levels of government in deciding transport priorities.

For the interested reader, the detailed explanation of DEA method used in this chapter can be found in Emrouznejad (2012) and Zhu (2015).

**Research questions addressed in this paper and contributions**

**Primary question**
Do fuel use and income levels differ in different cities in relation to adaptive capacity?

**Summary of contributions**
Proposed a new method and the usage of new data to conduct inter-city oil vulnerability assessment in Australia
5.1 Statement of contribution to co-authored published paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:


The authors listed below have certified that:

1. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. they agree to the use of the publication in the student's thesis and its publication on the Griffith University database consistent with any limitations set by publisher requirements.

<table>
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<th>Statement of contribution</th>
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<tr>
<td>Abraham Leung</td>
<td>Conceiving, planning and the writing of the manuscript, collected data and conducted DEA analysis, and the preparation of tables and figures. The candidate was also responsible for the revision made at the suggestion of the conference reviewers and the presentation of the paper during the conference.</td>
</tr>
<tr>
<td>Matthew Burke</td>
<td>Provided assistance in the theoretical framing of the research and provided editing revisions in the initial and the reviewed manuscript.</td>
</tr>
<tr>
<td>Barbara T.H. Yen</td>
<td>Provided the theoretical and methodological advice as an expert in the transport applications of DEA.</td>
</tr>
<tr>
<td>Jianqiang Cui</td>
<td>Provided editorial suggestions in the initial manuscript.</td>
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Supervisor Confirmation: I have sighted email or other correspondence from all co-authors confirming their certifying authorship.

(Signed) ________________________________ (Date) 24, June, 2017

Co-principal Supervisor: A/Prof Matthew Burke
Oil vulnerability of Australian capital cities: A pilot study using Data Envelopment Analysis (DEA) for vulnerability benchmarking

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²Griffith School of Environment, Griffith University

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Abstract

Skyrocketing oil prices in the mid-2000s have prompted increased academic and policy attention on oil vulnerability. Concerns remain about the continued use of oil due to energy, security and environmental grounds. High per-capita transport energy use remains an issue. Urban transport has been seen as highly oil vulnerable due to urban forms that promote automobile dependence. Due to reduced refinery capacity, risks in main oil supply chains are increasing, suggesting oil vulnerability remains an important research area for transport. Recent studies in Australia have been focused on mapping intra-urban household oil vulnerability by car ownership using journey-to-work data. Yet few studies have looked at the overall fuel use of transport at the metropolitan level. Datasets used in this paper include census, household energy consumption surveys and energy datasets. This paper aims to develop a new methodological framework which integrates a wider range of urban transport data, including average household fuel expenditure at the city level. The intent is to help facilitate policy transfer between cities and to identify best practices to help improve energy efficiency and sustainability in urban transport. The new approach involves the adaptation of data envelopment analysis (DEA) to benchmark the ‘efficiency’ of cities in causing oil-related impacts and also the resilience thanks to less oil intensive modes (public and active transport). The results show the differences across the largest cities in Australia, with particular vulnerabilities are affected by local conditions of fuel price, socio-economic condition and the usage of sustainable modes. This framework should assist in showing the different levels of oil vulnerability of Australian capital cities. The DEA method has the potential to be expanded to consider more variables and/or applied to a wider set of global cities for comparative purposes.

Keywords: oil vulnerability, oil resilience, DEA, benchmarking

1. Background and Introduction

Despite recent decreases in oil prices due to global overproduction and the economic slowdown, cities with high car ownership and car usage should remain vigilant in preventing the potential impacts of sudden oil supply shortfall and oil price increases. Currently, Australia has modest (but declining) domestic crude oil production, alongside plentiful reserves of other energy resources ranging from coal, gas, uranium, solar and wind. However, these are unlikely to help address the ‘liquid-fuel problem’ in the short-term as the majority of the automobile fleet remains petroleum based. Australia still imports up to 80% of crude oil and about half of its refined petroleum products to meet its liquid fuel demand (Australian Commonwealth Government, Department of Industry and Science, 2015). Figure 1 describes Australia’s petroleum energy flows in 2012-13. Most of the petroleum demand in
Australia is used in transport. This makes Australia’s transport system highly vulnerable to global oil supply chain disruptions, with the nation exposed to geopolitical, natural disaster and price volatility threats. Recent closures of domestic refineries are leading to higher dependence on imported refined oil products. As Australia has no mandated government strategic liquid fuel stockholding requirement and with limited retail fuel stockholdings, oil supply shortfalls may cause wide ranging effects. Oil fuels are not only used for passenger transport, but also for distribution of vital supplies such as food and pharmaceutical products to end-users (Blackburn, 2013).

During the period of the historically higher levels of oil prices in 2008 and 2011-2014, concern about ‘Peak Oil’ and higher fuel costs have sparked debate and attention in Australasian transport policy and research. Higher oil prices have also been a social issue that has attracted widespread attention due to increased fuel expenditure to households. The notion of transport disadvantage has been raised, concerning the lack of transport options at outer or impoverished suburbs or districts of a city due to the impacts of increased fuel price. Research are drawing connections between transport disadvantage and fuel prices, for example, fuel price increases are likely to cause greater impact on those who are forced to drive more due to lack of transport alternatives and with less financial resources (Currie et al., 2010; Dodson et al., 2004; Murray et al., 1998). The term ‘oil vulnerability’ emerged after a method was developed to use census variables to map small areas of

![Figure 1: Australia’s oil flows (in petajoules), 2012–13](image-url)
census tracts within a city (Dodson and Sipe, 2007, 2008) (the Vulnerability Assessment for Mortgage, Petrol and Inflation Risks and Expenditure (VAMPIRE) approach). This method remained popular in assessing oil vulnerability due to relative ease and availability of data. It has been adapted by a number of other researchers, within and outside Australasian jurisdictions, showing oil vulnerability mapping results for Melbourne (Fishman and Brennan, 2009), South-East Queensland (Leung et al., 2015), New Zealand (Smith et al., 2012) and North American cities (Akbari and Habib, 2014; Sipe and Dodson, 2013). Oil vulnerability, however, is not the only concept used to denote energy-related transport stress. While the term varies in the European context, with similar terms such as terms such as ‘transport poverty’ (Lucas, 2012) from the UK, ‘energy precarity (précarité énergétique)’ from France and ‘energy poverty (energiearmut)’ from Germany. Mattioli (2014, 2015) suggests a more encompassing term of ‘energy-related economic stress’ instead. Such diversity of terms shows the concern of urban scholars on social disadvantage related to transport, urban form and energy price increases or uncertainty.

In this paper, we use the term ‘oil vulnerability’ as it is the more widely used in the Australasian region to describe energy-related economic stress in transport. In terms of methodology, European researchers have been able to assess the actual energy costs of households due to detailed data collected from statistical authorities in both household travel and energy surveys (Mayer et al., 2014; Motte-Baumvol et al., 2009). Australasian researchers often resort to using proxy variables from the census to depict fuel expenditure, such as car ownership, the mode of journey-to-work (JTW) and commuting distance. Yet detailed investigation on vehicle fuel-efficiency and socio-spatial dimension has also been explored by matching motor vehicle registration data and the Commonwealth Government’s “Green Vehicle Guide” (Li et al., 2015). While this can give reasonable estimates of essential fuel use, the actual fuel cost of motor vehicles for non-work commuting remains inadequately represented. Another issue of oil vulnerability research is the limited focus of geographical extent. Most studies look at a particular city alone, such as the VAMPIRE-inspired studies. Limited work has been done to meaningfully compare the situation of oil vulnerability across different cities. This is possibly due to the difficulty to establish comparable datasets as the typical census data based methods are only internally comparing smaller areas within the same city. To address these research gaps, this research intends to ‘stocktake’ all the available data in Australia and propose to use the city-region as a unit of analysis.

The paper is structured as follows: Section 2 outlines the data available for researchers to conduct transport and energy-expenditure stress research at a city-wide level. Section 3 proposes and reviews the use of data envelope analysis (DEA) as a method to measure vulnerability in other fields, such as hazards and disaster reduction. Section 4 describes the methodology of DEA in measuring oil vulnerability and resilience. Section 5 shows the results and discusses the findings and limitations. Section 6 concludes the paper and outlines some limitations and the possible future research directions.

### 2. Oil Vulnerability and Energy Transition in Urban Transport of Australian capital cities

Capital city areas are defined by the Australian Bureau of Statistics (ABS) (2010) as the Greater Capital City Statistical Area (GCCSA) classification. The advantage of this is that the areas defined for capital cities provide a larger range of available data, including fuel expenditure and price, a variable that has been neglected. The GCCSA area allows a wider range of oil vulnerability variables to be used. It is also possible to aggregate smaller spatial scales to fit in the ABS-defined GCCSA structure. Table 1 lists the data source of the variables used in this paper. The majority of the data used in this study is obtained from the ABS. The Energy Consumption Survey data provides fuel expenditure data of each capital that has not been explored in previous oil vulnerability research. Due to privacy and
confidentiality concerns, ABS has not been providing this dataset with a geographic scale smaller than the GCCSA. Unless using micro-simulation techniques, as demonstrated by Lovelace and Philips (2014), it would not be possible to estimate fuel expenditure in Australia at sub-city level in the meantime. It should be noted that State governments have conducted household travel surveys for capital cities. While comparing Australia’s diverse household travel surveys may produce a more accurate mode share or fuel use estimation, especially including non-work related trips, the issue of inconsistent methodologies and survey timing would cause some problems for inter-city comparison. The ABS’s motor vehicle registration data and the roof-top photovoltaic (PV) installation data are at postcode level which can be aggregated into GCCSA geography. As postcodes are not ABS maintained geographies, some boundaries do not provide an exact fit. For the borders of postcodes that are inconsistent with GCCSA, the differences were approximated by the proportion of area size. Most of the inconsistent areas are located on the outer fringes of GCCSA and the data losses caused by approximation are expected to be small. In addition to conventional governmental datasets, the electrical vehicle (EV) charging point counts are obtained by crowd-sourced information from an online application PlugShare™ that allows users to share the location charging points (Recargo, Inc., 2016).

Using the oil vulnerability conceptual framework proposed by Leung et al. (2015), these variables are classified according to three oil vulnerability components namely exposure, sensitivity and adaptive capacity. The full list of variables is provided in Table 2 for an overall view of the Australian capital cities of all states except the Northern Territory. Darwin is not included because of its small population and being similar to Canberra as a city with a disproportionately larger public service sector and also with higher incomes, social advantage levels and also automobile use. For population density, we used the data of a more recent concept - population-weighted density (PWD), which is measured by aggregating smaller blocks in a city instead of a gross divided population to the total area. The PWD shown in here is obtained from Loader (2013) based on ABS kilometre population grids from the 2011 census. It should be noted the GCCSA often includes a larger area beyond prevailing urban administrative boundaries of Australian capital cities. Therefore, the PWD deemed to be more accurate and appropriate.

A brief observation of the data is provided in the following section based on the oil vulnerability components.

**Exposure**

Exposure refers to what extent energy-related factors that are able to affect the population of a city. Car ownership, usage and fuel price data are listed in this section. For car ownership, generally the larger the PWD, the lower the car ownership and passenger VKT, which is generally consistent with Newman & Kenworthy et al’s (1989; 1999) global observation of cities that lower population density is correlated with higher car VKT per capita. This is not the case for Adelaide which has modest PWD (18.2 persons by km²) with lowest VKT per capita. This shows higher PWD does not necessarily resulting in less car use. Urban size also shows mixed correlation with VKT per capita. Adelaide and Hobart both are observed with the lowest passenger VKT per capita in Australian cities, while Canberra with similar size, has the highest VKT per capita. Such high VKT in Canberra is possibly due to better socio-economic standing. In contrast, Adelaide and Hobart are relatively disadvantaged due to their weaker economic performance and a higher incidence of older or populations that ‘require assistance for core activity’ (an indicator of disability), which is a sensitivity variable that is explained in the following section. Another issue that affects oil vulnerability is the variation in fuel prices between the capital cities. Adelaide (141.77 cents per litre (cpl)) and Sydney (142.82cpl) being the lowest while Canberra (146.95cpl) and Brisbane (146.68cpl) being the most expensive. Further work to investigate this disparity of fuel prices might be able to help to understand the underlying factors of oil vulnerability. For the journey-to-work mode share, Adelaide appears to be the city with highest private-owned LOV mode share,
followed by Hobart and Canberra. This relates to public transport usage or active travel, which will be covered in the Adaptive Capacity section.

**Sensitivity**

Sensitivity represents the degree cities are affected by both energy and non-energy drivers. It is often measured by social variables, such as income or socio-economic wellbeing. Canberra has the highest average weekly household disposable income, followed by Sydney, Melbourne and Perth; Hobart has the lowest. Conversely for social disadvantage indicators, it is largely opposite with subtle differences for the rankings in between. Hobart and Adelaide are the most socio-economically disadvantaged capital cities. Yet the level of socio-economic wellbeing alone could not provide an estimate of the potential impact of oil price increase. These sensitivity indicators need to work with other oil vulnerability components in order to estimate oil vulnerability.

**Adaptive Capacity**

Adaptive capacity represents the ability to adapt to change in a way that makes it better equipped to manage its future exposure and/or sensitivity to oil price influences. The mode share of journey to work by HOV, which is predominately public transport, and activity are compared across the capital cities. Sydney has the highest public transport mode share to work, followed by Melbourne and then Brisbane while Hobart and Canberra are the lowest. This measure is also consistent with the share of public transport VKT. Yet, public transport usage rates do not necessarily show the maximum capacity of the urban transport system in an event of a sudden oil supply shortfall, causing fuel price hikes and a possible upsurge of public transport use (Stone and Mees, 2010). Hence, the consideration that active transport (cycle or walk) is important. Conversely, Hobart and Canberra have a significantly higher share of active mode shares to work. This is probably due to their smaller urban footprint, with shorter commuting distance which makes walking and cycling to work more feasible. Working at home is also tabled for analysis and it should be read in conjunction with the percentage of dwellings having broadband internet connection. It appears despite having the highest penetration of broadband at home, Canberra has the lowest work at home share compared to other capitals. Brisbane has the highest work at home percentage and ranks the second in broadband penetration at home. Still, the relationship between working at home and information communication technology (ICT) remain unclear. This could be related to the nature of jobs as Canberra having very high public sector employment which may not encourage working at home. Moreover, cities with higher time and/or monetary costs of commuting may make working at home more attractive. Despite growing academic attention (Aguiléra et al., 2012; Alizadeh, 2012), further study on working at home and its relation with information communication technology (ICT) is needed to uncover the reasons behind this.

A fresh and comprehensive look at electric vehicles (EV) in Australian capital cities is offered in Table 2. It shows Canberra is having high levels of EVs ownership (4.16 per 1000 persons) while other cities were still under 1 per 1000 persons and with Brisbane being the worst performer (0.06 per 1000 persons). EV ownership does not appear to correlate with the availability of charging points. Perth has the highest EV charging point provision (30.6 per 1 million persons, 56 charging points within the Perth GCCSA area) with initiatives of charger provision by the motoring association and universities since 2012 (Speidel et al., 2012). Yet the EV ownership of Perth in 2015 remains modest (0.29 per 1000 persons). As EV vehicles are still a novelty and are significantly more expensive, perhaps only those with higher incomes can afford them. It should also be noted that Canberra’s EV registration number could be boosted by government-owned cars as the Australian Capital Territory...
(ACT) Government initiated a policy to reduce carbon emissions by acquiring EVs in their fleet (ACT Department of Environment and Sustainable Development, 2012). While EV ownership may not have immediate oil reduction implications, another aspect that might affect electric vehicle uptake is the proliferation of residential photovoltaic solar panels. EVs has been seen as a potential form of electricity storage for solar panels as both could complement each other (Adepetu and Keshav, 2015; CSIRO, 2013). Solar panel registration data from the Australian Government clean energy regulator, the Australian Renewable Energy Agency (AREA) shows Brisbane and Adelaide have the highest uptake of rooftop panels in terms of both dwelling density and capacity. Brisbane’s high uptake could be associated with long sun availability; Adelaide has benefited by South Australian government’s favourable feed-in tariffs being able to outset of costs of installation. This inter-city comparison offers some insights on the performance of energy transition in Australian capitals. It seems residential solar panel uptake patterns not relate well with EV registration at this moment. As solar panels are still relatively new in Australia, further research in this area would be needed as the beneficial synergetic effect with EVs are currently not well understood (Cao et al., 2015). Due to small uptake numbers at the moment, the impact of EVs and solar panels to reduce oil vulnerability, both numbers are not considered in the subsequent section in which a more detailed estimation of oil vulnerability of Australian capitals. In fact, only small number of the variables listed above could be selected for further analysis by a mathematical modelling tool - DEA.

Table 1: Data source for variables used

<table>
<thead>
<tr>
<th>Provider</th>
<th>Data Source</th>
<th>Variable</th>
<th>Remarks/Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Population-Weighted Density (persons/km)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mode Share to Work</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOV (Low Occupancy Vehicles)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Public Transport modes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Non-Motorised (Walking or cycling)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Work at home</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disability (Core assistant needed for activities)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motor vehicle numbers in each dwelling</td>
<td></td>
</tr>
<tr>
<td>Socio-Economic Indexes for Areas (SEIFA) (Derived from Census 2011 data)</td>
<td>Index of Relative Socio-economic Advantage and Disadvantage (IRSAD)</td>
<td>The Decile 1 (Most disadvantaged) is used</td>
<td></td>
</tr>
<tr>
<td>Australian Bureau of Statistics (ABS)</td>
<td>Motor Vehicle Survey 2014</td>
<td>Vehicles registered by fuel type</td>
<td>Postcode-level data aggregated into GCCSA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Petrol</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Diesel</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Dual-fuel (LPG)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Electric</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Other</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy Consumption Survey 2012</td>
<td>Total and Disposable Household Income and Fuel Expenditure</td>
<td>Weekly</td>
</tr>
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</table>
### Table 1: Data Source for Variables (Continued)

<table>
<thead>
<tr>
<th>Provider</th>
<th>Data Source</th>
<th>Variable</th>
<th>Remarks/Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bureau of Infrastructure, Transport and Regional Economics (BITRE)</td>
<td>Traffic and congestion cost trends for Australian capital cities (IS-074)</td>
<td>VKT of different modes</td>
<td>6 weekly average sample points approx. every 2-months to reduce fluctuation effects</td>
</tr>
<tr>
<td>Australian Institute of Petroleum (AIP)</td>
<td>Weekly Price Update 2011-2012</td>
<td>Metropolitan Average Retail Fuel Price</td>
<td></td>
</tr>
<tr>
<td>Compiled by the Australian Photovoltaic Institute (APVI)</td>
<td>Photovoltaic (PV) Installations Mapping data 2016 March</td>
<td>PV installation density and capacity</td>
<td>Postcode-level data aggregated into GCCSA</td>
</tr>
<tr>
<td>Plugshare.com</td>
<td>Crowd-sourced data, 2016 May</td>
<td>Locations and counts for EV charging points</td>
<td></td>
</tr>
</tbody>
</table>

### Table 2: Descriptive statistics and oil vulnerability data of Australian capital cities, [ ] brackets denote ranking, 1 is highest and 7 for the smallest

<table>
<thead>
<tr>
<th></th>
<th>Sydney</th>
<th>Melbourne</th>
<th>Brisbane</th>
<th>Adelaide</th>
<th>Perth</th>
<th>Hobart</th>
<th>Canberra</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usual Resident Population (persons)</td>
<td>4,391,674</td>
<td>3,999,981</td>
<td>2,065,998</td>
<td>1,225,235</td>
<td>1,728,865</td>
<td>211,656</td>
<td>356,586</td>
</tr>
<tr>
<td>Population-Weighted Density (persons/km)</td>
<td>34.40</td>
<td>24.90</td>
<td>18.10</td>
<td>18.20</td>
<td>17.60</td>
<td>12.00</td>
<td>15.70</td>
</tr>
<tr>
<td>Exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Registered Vehicles per capita (per 1000 persons)</td>
<td>692.16</td>
<td>806.08</td>
<td>844.58</td>
<td>902.75</td>
<td>920.66</td>
<td>792.34</td>
<td>833.81</td>
</tr>
<tr>
<td>Dwellings with more than 2 vehicles (%)</td>
<td>41.23</td>
<td>46.43</td>
<td>48.44</td>
<td>45.14</td>
<td>50.37</td>
<td>44.75</td>
<td>49.41</td>
</tr>
<tr>
<td>Proportion of method to work is only by private low occupancy vehicles only (LOVs) (%)</td>
<td>67.04</td>
<td>74.64</td>
<td>75.42</td>
<td>81.34</td>
<td>78.50</td>
<td>81.19</td>
<td>80.92</td>
</tr>
<tr>
<td>Total annual VKT of private vehicles (car and motorcycles) (billions km)</td>
<td>31.22</td>
<td>30.62</td>
<td>14.67</td>
<td>8.19</td>
<td>12.98</td>
<td>1.46</td>
<td>3.06</td>
</tr>
<tr>
<td>Metropolitan Average Retail Fuel Prices (cents per litre, cpl)</td>
<td>142.82</td>
<td>142.87</td>
<td>146.68</td>
<td>141.77</td>
<td>143.65</td>
<td>150.28</td>
<td>146.95</td>
</tr>
<tr>
<td>Mean weekly expenditure for vehicle fuel (AU$)</td>
<td>61.17</td>
<td>63.89</td>
<td>62.54</td>
<td>51.71</td>
<td>64.04</td>
<td>52.98</td>
<td>63.44</td>
</tr>
<tr>
<td>Sensitivity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average weekly disposable household income (AU$)</td>
<td>1,727.52</td>
<td>1,715.6</td>
<td>1,538.6</td>
<td>1,413.84</td>
<td>1,690.15</td>
<td>1,360.24</td>
<td>1,971.09</td>
</tr>
<tr>
<td>Proportion of population, core activity needs assistance (%)</td>
<td>4.38</td>
<td>4.48</td>
<td>4.18</td>
<td>5.37</td>
<td>3.56</td>
<td>5.44</td>
<td>3.35</td>
</tr>
<tr>
<td>Proportion of population with lowest SEIFA decile (%)</td>
<td>8.55</td>
<td>6.52</td>
<td>7.74</td>
<td>11.03</td>
<td>3.14</td>
<td>17.11</td>
<td>0.56</td>
</tr>
</tbody>
</table>
3. Using Data Envelopment Analysis (DEA) to Measure Oil Vulnerability and Resilience

To address the shortcomings of previous oil vulnerability assessment in Australian research, an inter-city oil vulnerability benchmarking method is developed. In this section, the concept of DEA is briefly outlined, followed by a review of DEA methods. The DEA method was originally developed by Charnes, Cooper and Rhodes (1978) (hence is often referred to as the CCR model). DEA is a method to measure the relative efficiency of an organisation, often referred as a Decision Making Unit (DMU) in the DEA literature. The analysis method is based on a mathematical linear programming method to estimate relative efficiency based on a mathematically derived weighted ratio of outputs to inputs with the following simplified equation:

\[
\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}}
\]

This can be visualised as a diagram in Figure 2, for example, the DMUs that are using the least input to produce the most output are the best amongst the peers, which can be seen as located on the ‘best practice frontier’. The CCR is also assuming the return of scale is constant.

The advantage of DEA is that it is completely ‘data-driven’ and does not require prior knowledge or assumption of the relationship between the inputs and outputs. It can also generate ‘slack’ values to predict how optimal efficiency be achieved by adjusting the combination of inputs. Therefore, DEA has been widely used in operations research,
management and economic fields with evolving variations (Seiford, 1996). For transport, there is a wide range of DEA applications worldwide, including public transport (Chiou et al., 2012; Hilmola, 2011; Lan et al., 2014; Pina and Torres, 2001; Sampaio et al., 2008), ports or airport operations (Tongzon, 2001; Yoshida and Fujimoto, 2004) and even property value uplifting effects from public transport (Yen et al., 2014). There are also innovative uses of adapting DEA to measure undesirable outputs such as pollution or CO2 emissions (Daraio et al., 2016; Ha et al., 2011; Lin et al., 2015; Song et al., 2015). This demonstrates DEA is highly adaptive to different situations, a strength as it offers a wide range of variants available for researchers (Chen, 2004; Cook and Seiford, 2009).

In the field of vulnerability research, vulnerability indices were typically based on mean-adjusted ranking, or expert-adjusted weights to determine vulnerability scores as a reference measure of the level, or the risk of a potential impact (Cutter et al., 2008; Dwyer et al., 2004; Esty et al., 2005). However, it is often difficult to ascertain the weights to be given on the indices. To address this, there is a growing trend to treat ‘vulnerability’ as the ‘efficiency of baseline factors in causing damage’ in hazards reduction and vulnerability literature. Whereas the exposure to impacts or background levels can be seen as inputs and the resultant damage or loss as outputs. A societal system, such as a city, can be seen as a DMU. The types of hazards or disasters used this way to assess vulnerability include floods (Rygel et al., 2006; Wei et al., 2004), droughts (Yuan et al., 2015), exposure to pollutants (Ratick and Osleeb, 2013) and war (Benini, 2015). Conversely, DMUs with higher levels of resilience or adaptive capacity could reduce the propensity of loss from hazards or negative effects can be assessed by DEA. Examples of DEA-based resilience studies such as coastal hazards resilience at country level (Zou and Wei, 2009) and earthquake resilience (Üstün, 2016). This paper incorporates both vulnerable and resilience analysis by DEA benchmarking. The following section describes the methodology used in this study.

4. Methodology

This study attempts to adapt DEA approaches from the hazards or vulnerability literature to urban transport oil vulnerability assessment. Two DEA models are used in this paper to measure oil vulnerability and resilience, respectively, as illustrated in Figure 3. The first DEA model (OV-DEA) measures oil vulnerability, which includes city-wide and household exposure and sensitivity components. The capital city area population and mean weekly household income are seen as inputs, whereas VKT and fuel expenditure are treated as
outputs. A more vulnerable city is more ‘efficient’ in having fewer inputs (population and income) to produce more outputs (total VKT of private vehicles and fuel expenditure). The second DEA model (OR-DEA) takes account of resilience to oil price increases. The input is a combined measure of household fuel stress, calculated by the percentage of weekly household fuel expenditure to weekly household income. The output is the mode share of less oil-intensive modes, including public and active transport. This measures how efficient a city adapting to fuel stress by not driving.

![Diagram showing DEA models for assessing oil vulnerability and resilience in urban transport](image)

**Figure 3: Conceptual DEA model for assessing oil vulnerability and resilience in urban transport**

This research appears to be the first in using DEA method to evaluate oil vulnerability and resilience. The proposed DEA structure progresses from previous oil vulnerability assessments (e.g.: the VAMPIRE approach) that used subjective ranking method (i.e.: equal weighting for all variables). The proposed DEA models incorporate not only exposure components, also sensitivity and adaptive capacity. This is an advancement to prevailing oil vulnerability methods, as it considers household fuel expenditure and adaptive capacity at city level. The classical input-oriented CCR DEA model is applied for the OV-DEA. To solve the DEA efficiency model by fractional linear program, it is necessary to convert the “common measure” of efficiency into linear form so that the methods of linear programming can be applied. Based on Charnes, Cooper and Rhodes (1978), the mathematical equation is as follows:

\[ \text{Min } \theta - \varepsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \]
\[
\sum_{j=1}^{n} \lambda_j x_{ij} + s^- = \theta_i x_{io} \quad i = 1, 2, \ldots, m
\]

\[
\sum_{j=1}^{n} \lambda_j y_{rj} - s^+ = y_{ro} \quad r = 1, 2, \ldots, s
\]

\[
\lambda_j \geq 0 \quad j = 1, 2, \ldots, n
\]

Suppose we have a set of \( n \) DMUs. Each DMU \( j \) (\( j = 1, \ldots, n \)), produces \( s \) different outputs \( y_{rj} \) utilising \( m \) different inputs \( x_{ij} \) (\( i = 1, \ldots, m \)). Where \( \theta \) is the vulnerability (efficiency) score (by minimising inputs), \( \varepsilon \) is the non-Archimedean infinitesimal, \( m \) is the number of inputs, and \( n \) is the number of outputs, \( x_{ij} \) and \( y_{rj} \) refers to the \( i^{th} \) input and \( r^{th} \) output of the city, respectively, and, \( s_i^- \), \( s_r^+ \) are the input and output slack value. Slack refers to which the excess input or missing output that exists after the proportional change in the input or the outputs to reach the efficiency frontier. In other words, it is the difference of input levels between the inferior performer and the best performer. The purpose of slacks analysis is to predict how optimal efficiency can be achieved by adjusting the combination of inputs. \( \lambda_j \) refers to the weight given to the DMU \( j \) in an effort to ‘outperform’ DMU \( o \). This weight is used to determine the relative efficiency based on the inputs and outputs values. The classical CCR model limits the efficiency value to be under 1 (or 100%). Likewise, the output-oriented model can be formulated for the OR-DEA as follows, which is similar to the OV-DEA, with vulnerability score represented by maximising output and resilience (efficiency) value \( \eta \):

\[
\text{[CCR-O]} \quad \text{Max } \eta + \varepsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right)
\]

\[
\sum_{j=1}^{n} \lambda_j x_{ij} + s^- = x_{io} \quad i = 1, 2, \ldots, m
\]

\[
\sum_{j=1}^{n} \lambda_j y_{rj} - s^+ = y_{ro} \quad r = 1, 2, \ldots, s
\]

\[
\lambda_j \geq 0 \quad j = 1, 2, \ldots, n
\]

This restriction can be relaxed to allow comparison of scores beyond 1 (i.e.: beyond the efficiency frontier) by the following condition:

\[
s_i^- , s_r^+ \geq 0
\]

\[
\lambda_j \geq 0 \quad j \neq 0 \quad j = 1, 2, \ldots, n
\]

This relaxed model is known as super-efficiency model which permits more precise ranking of the DMUs while the inefficient DMUs remains the same as classical DEA model (Andersen and Petersen, 1993; Wu et al., 2014; Zhu, 2001). Table 3 shows the basic descriptive statistics of the variables used in the DEA models. Table 4 shows the correlation coefficients among input and output variables. Note that the correlation coefficients between input and output variables of the OV-DEA are positive, while the OR-DEA are negative. To
test the relevance of the selected input and output variables, regression analyses are further conducted and Table 5 presents the results. The variables for OV-DEA are statistically significant, but not for OR-DEA. As the aim of this study is to use DEA to create a vulnerability and resilience index, not to identify the actual efficiency of a DMU in typical DEA studies. Hence, a negative correlation and non-significant relationship between inputs and outputs are acceptable.

### Table 3: Descriptive Statistics of the inputs and outputs for the DEA models used

<table>
<thead>
<tr>
<th>Variables</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OV-DEA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population</td>
<td>211,656.00</td>
<td>43,91,674.00</td>
<td>1,997,142.14</td>
<td>1,648,084.00</td>
</tr>
<tr>
<td>Weekly Disposable Income ($)</td>
<td>1360.24</td>
<td>1971.09</td>
<td>1690.15</td>
<td>210.02</td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VKT of private vehicles (billion)</td>
<td>1.46</td>
<td>31.22</td>
<td>14.60</td>
<td>12.13</td>
</tr>
<tr>
<td>Weekly Fuel Expenditure ($)</td>
<td>51.71</td>
<td>64.04</td>
<td>59.97</td>
<td>5.31</td>
</tr>
<tr>
<td><strong>OR-DEA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Stress (%)</td>
<td>2.65</td>
<td>3.41</td>
<td>3.08</td>
<td>0.26</td>
</tr>
<tr>
<td><strong>Output</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public Transport Mode Share (%)</td>
<td>6.64</td>
<td>22.60</td>
<td>12.84</td>
<td>5.45</td>
</tr>
<tr>
<td>Active Transport Mode Share (%)</td>
<td>3.89</td>
<td>7.43</td>
<td>5.39</td>
<td>1.46</td>
</tr>
</tbody>
</table>

### Table 4: Correlation coefficients among input and output variables of the DEA models

#### OV-DEA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Population</th>
<th>Weekly Income</th>
<th>Total VKT of Private Vehicles</th>
<th>Weekly Fuel Expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekly Income</td>
<td>0.23</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total VKT of Private Vehicles</td>
<td>0.99</td>
<td>0.25</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Weekly Fuel Expenditure</td>
<td>0.44</td>
<td>0.80</td>
<td>0.47</td>
<td>1</td>
</tr>
</tbody>
</table>

#### OR-DEA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Household Fuel Stress</th>
<th>Public Transport (PT) Mode Share to Work</th>
<th>Active Transport Mode Share to Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Household Fuel Stress</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT Mode Share</td>
<td>-0.1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Active Transport Mode Share</td>
<td>-0.23</td>
<td>-0.44</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 5: Regression results for input and output variables

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Independent variables</th>
<th>OV-DEA</th>
<th>OR-DEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total VKT of Private Vehicles</td>
<td>Population</td>
<td>0.99</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Weekly Income</td>
<td>0.03</td>
<td>(-0.10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekly Fuel Expenditure</td>
<td></td>
<td>0.27</td>
<td>-0.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.73)</td>
<td>(-0.23)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R² = 0.997</td>
<td></td>
<td>R² = 0.01</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>R² = 0.051</td>
</tr>
</tbody>
</table>

Table 5 (Continued): Regression results for input and output variables

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Independent variables</th>
<th>OR-DEA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Household Fuel Stress</td>
<td>-0.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.23)</td>
</tr>
<tr>
<td></td>
<td>PT Mode Share to Work</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Active Transport Mode Share to Work</td>
<td>-0.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-0.52)</td>
</tr>
</tbody>
</table>

5. Results and Discussion

The two DEA models outlined in Section 4 are used to evaluate the city-level oil vulnerability and resilience. For a classical CCR DEA assessment, a value of 1 means it is the most ‘efficient’ and is located at the ‘efficiency frontier’. To allow more meaningful benchmarking, the super-efficiency model is used in both models. The results of OV-DEA in measuring oil vulnerability is shown in Table 6.

Table 6: Oil Vulnerability Scores calculated from OV-DEA Model
(1 is the most vulnerable; 7 the least vulnerable)

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Capital Cities</th>
<th>Classical CCR Oil Vulnerability (CRS)</th>
<th>Super-efficient Oil Vulnerability (CRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hobart</td>
<td>1</td>
<td>1.407</td>
</tr>
<tr>
<td>2</td>
<td>Canberra</td>
<td>1</td>
<td>1.187</td>
</tr>
<tr>
<td>3</td>
<td>Melbourne</td>
<td>1</td>
<td>1.073</td>
</tr>
<tr>
<td>4</td>
<td>Brisbane</td>
<td>1</td>
<td>1.066</td>
</tr>
<tr>
<td>5</td>
<td>Sydney</td>
<td>1</td>
<td>1.013</td>
</tr>
<tr>
<td>6</td>
<td>Perth</td>
<td>0.990</td>
<td>0.990</td>
</tr>
<tr>
<td>7</td>
<td>Adelaide</td>
<td>0.926</td>
<td>0.926</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>0.988</td>
<td>1.094</td>
</tr>
</tbody>
</table>
The result shows most cities are quite close to the ‘efficient’ frontier of oil vulnerability. It can be said Hobart, Canberra, Melbourne, Brisbane and Sydney, with the oil vulnerable score of 1 in the classical CCR OV-DEA model, are the more oil vulnerable capitals. Conversely, Adelaide achieved the lowest score and it is the least oil vulnerable as it has on average the lowest fuel expenditure and VKT in relation to its population size. The results show Hobart (1.407) and Canberra (1.187) are the most oil vulnerable capitals. For the case of Hobart, this is because of high fuel prices and high private car VKT in relation to its lower income levels and smaller population. For the case of Canberra, it is attributed to very high private car VKT, despite Canberra’s relatively higher income levels that can cushion the impact. Adelaide has the lowest fuel price among the capital cities, whereas Hobart and Canberra has the highest (Table 2). Fuel price in the capital cities could be an external factor explaining oil vulnerability and this could be considered in future studies. The ability to use less oil-intensive modes, such as public or active transport, are also examined in the OR-DEA model and the results are shown in Table 7.

Table 7: Oil resilience calculated from OR-DEA Model (1 is the most resilient; 7 the least resilient)

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Capital Cities</th>
<th>Classical CCR Oil Resilience (CRS)</th>
<th>Super-efficient Oil Resilience (CRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sydney</td>
<td>1</td>
<td>1.498</td>
</tr>
<tr>
<td>2</td>
<td>Canberra</td>
<td>1</td>
<td>1.233</td>
</tr>
<tr>
<td>3</td>
<td>Hobart</td>
<td>0.821</td>
<td>0.821</td>
</tr>
<tr>
<td>4</td>
<td>Melbourne</td>
<td>0.764</td>
<td>0.764</td>
</tr>
<tr>
<td>5</td>
<td>Brisbane</td>
<td>0.668</td>
<td>0.668</td>
</tr>
<tr>
<td>6</td>
<td>Adelaide</td>
<td>0.599</td>
<td>0.599</td>
</tr>
<tr>
<td>7</td>
<td>Perth</td>
<td>0.598</td>
<td>0.598</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td>0.788</td>
<td>0.883</td>
</tr>
</tbody>
</table>

Sydney and Canberra are seen as ‘best practice’ cities in terms of oil resilience with resilience values above 1. It could be useful if both OV-DEA and OR-DEA can be plotted together for comparing both vulnerability and resilience of the capital cities analysed. As shown in Figure 4, the mean value of the score of both DEA models is used as cut-off levels to create four quadrants. Most Australian capitals fall into the quadrant of “Less Vulnerable; Less Resilient”. For the worst case, Adelaide has the lowest OR-DEA efficiency value, which means the city is the least able to utilise public or active transport to reduce oil-related fuel cost impacts and it is also the least oil vulnerable according to the OV-DEA. Melbourne is straddling nearer the mean value of both DEA scores. Hobart is the most vulnerable and close to mean level resilience, whereas Canberra is quite vulnerable but also the most resilient. Sydney is the only city that is less vulnerable and more resilient, which means the capital will be least impacted by higher oil prices in Australia. Fortunately, no cities are falls into the quadrant of ‘More Vulnerable; Less Resilient’ which is an undesirable position. In order to understand how each can improve its efficient, Table 8 demonstrates the slack analysis from OR-DEA model. The slack analysis shows how much each city needs to improve to become more resilient (or the efficiency in using public transport or active transport in relation to fuel stress). For example, it assumes Melbourne can be as oil resilient as its closest peer, Sydney, if it can improve its active transport mode share by 31.94% (i.e., Increasing from its current active transport mode share from 4.79% to 5.41%, to reach the level of Sydney’s). The slack analysis shows except for Hobart, all other non-optimum cities could gain resilience by improving active transport mode share so as to reach the efficiency of the best performer. It should be noted the two input slack values cannot be separated to create the overall improvement. Hence for Hobart, it has to improve both the public transport
and active transport as specified in Table 8 in order to be as ‘resilient’ as Canberra. Larger capital cities such as Melbourne and Brisbane had to improve from 30-40% in active transport to reach ‘best practice’. However, for Adelaide and Perth, even more drastic measures of up to 70% active transport mode share improvements are needed to reach the resilience levels of Sydney or Canberra. These sets of analysis show the importance of evaluating the oil vulnerability and resilience performance for the cities at the same time. It would facilitate the urban transport or land use policy makers to address oil vulnerability of the Australian capital cities evaluated. The proposed DEA models offer an objective and data-driven benchmark ranking method of oil vulnerability and resilience for Australian capital cities. This DEA approach could be useful for Federal level policy makers to determine the priority of public transport infrastructure of Australian cities in relation to oil vulnerability. This method can also be used in conjunction with the other intra-city mapping approaches, if a smaller level data are available.

Figure 4: Cross analysis of OV-DEA and OR-DEA scores of the Australian capital cities
### Table 8: Slack values (Improvements strategies) for the transport mode share of capital cities to be as good as the ‘peers’

<table>
<thead>
<tr>
<th>Code</th>
<th>Capital City</th>
<th>Best Practice Peers</th>
<th>Public Transport</th>
<th>Active Transport</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sydney</td>
<td>-</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>2</td>
<td>Melbourne</td>
<td>Sydney, Canberra</td>
<td>0%</td>
<td>31.94%</td>
</tr>
<tr>
<td>3</td>
<td>Brisbane</td>
<td>Sydney, Canberra</td>
<td>0%</td>
<td>39.07%</td>
</tr>
<tr>
<td>4</td>
<td>Adelaide</td>
<td>Sydney, Canberra</td>
<td>0%</td>
<td>72.55%</td>
</tr>
<tr>
<td>5</td>
<td>Perth</td>
<td>Sydney, Canberra</td>
<td>0%</td>
<td>75.35%</td>
</tr>
<tr>
<td>6</td>
<td>Hobart</td>
<td>Canberra</td>
<td>18.54%</td>
<td>0.71%</td>
</tr>
<tr>
<td>7</td>
<td>Canberra</td>
<td>-</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

### 6. Concluding Remarks and Further Research

Inter-city assessment is useful to provide insights on how cities perform in terms of oil vulnerability and transport energy sustainability. This study proposes two DEA models to measure oil vulnerability (OV-DEA) and oil resilience (OR-DEA). These models adopting a new set of data regarding oil vulnerability and energy transition looking at all major Australian capital cities. The data itself shows exposure, sensitivity and adaptive capacity differs greatly amongst the capitals. Generally speaking, larger cities appear to be better in coping with oil vulnerability due to better public transport systems and driving being less prevalent. However, as oil prices and living standards differ greatly, the actual propensity of the impact caused by higher oil prices also are mixed and complicated. By the use of DEA modelling, it is possible to consider the interplay of factors in a data-driven and objective way. Moreover, slack analysis provides further improvement strategies to understand how to be more resilient.

Further research would be needed to understand this aspect in greater detail. Many DEA studies also incorporate second stage analysis, using Tobit regression models to investigate the contribution of external factors (Chiou et al., 2012; Chiou and Chen, 2006; Hilmola, 2011; Pina and Torres, 2001). It is worthy to add more cities in the proposed DEA approach to examine model applicability. For example, cities beyond Australia in the Asia Pacific region can be included in further analysis. Aggregated city data is widely available in many urban jurisdictions. Alternatively, using sub-city scales of larger areas (e.g.: Statistical Area 4 (SA4) of ABS’s census geography) with State conducted household travel survey with fuel expenditure data with DEA is also feasible if data availability permits. Using DEA in the traditional way, that is, to measure efficiency can also be conducted with the same datasets presented in this paper. For instance, to measure efficiency of public transport or electric vehicle uptake using the same set of data presented here. There are many ways to make use of the DEA method and hence, there is ample opportunity for further research. Future research opportunities could include the housing dimension - as those who live closer to activity centres may spend more on housing whilst having lower transport costs. Further directions for this type of research include active transport (e.g. Dutch cities are having 30% of cycling trips) and even life cycle analysis, examining energy and fuel consumption in transport by source to better reflect the trends of electrification in transport. For EV studies, socio-spatial analysis public/shared charging point location and EV ownership patterns might be useful for future transport and land use planning. It is also hoped the DEA approach can be applied to transport infrastructure priority and fund allocation at a higher governmental level, for instance, at Federal government level.
7. References


Leung, A., Burke, M., Cui, J., Perl, A., 2015. New Approaches to Oil Vulnerability Mapping for Australian Cities: The Case of South-East Queensland, the 200km City. Presented at the State of Australian Cities National Conference, Gold Coast, Australia.


6. Comparative data envelopment analysis of oil vulnerability of urban transport in Taiwan and Australia

The work presenting here Chapter 6 was previously published as Leung, A., Chiou, Y.-C., Yen, B.T.H., Burke, M., 2016. Comparative data envelopment analysis of oil vulnerability of urban transport in Taiwan and Australia. Presented at the 2016 International Conference and Annual Meeting of the Chinese (Taiwan) Institute of Transportation, Hualien, Taiwan.

This paper was undertaken during the author’s Endeavour Scholarship at National Chao Tung University in Taipei, Taiwan. The method applied in Chapter 5 is used in this paper and is expanded to compare Taiwanese geographical divisions (cities and counties) with Australian ones (Greater Capital City Statistical Area (GCCSA) and “Rest of the state”. The results show that, overall, Australia’s oil vulnerability level is lower than that of Taiwan’s, possibly due to higher average incomes to pay for fuel costs, which rendered lower fuel stress levels. Other areas that are found to be less vulnerable and more resilient are Taipei (most resilient), Sydney, Melbourne, Canberra and Keelung. The most vulnerable and non-resilient areas are Taitung, Pingtung and Rest of South Australia (Areas outside Adelaide). DEA-based oil vulnerability/resilience measures provide a relatively objective way to rank areas and have the advantage of being able to apply the method internationally with relative ease.

For the interested reader, the detailed explanation of DEA method used in this chapter can be found in Emrouznejad (2012) and Zhu (2015).
Research questions addressed in this paper and contributions

Primary question
Do fuel use and income levels differ in different cities in relation to adaptive capacity?

Summary of contributions
Using the method and the usage of new data to conduct an inter-city oil vulnerability assessment in Taiwan and Australia
6.1 Statement of contribution to co-authored published paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:

Leung, A., Chiou, Y.-C., Yen, B.T.H., Burke, M., 2016. Comparative data envelopment analysis of oil vulnerability of urban transport in Taiwan and Australia. Presented at the 2016 International Conference and Annual Meeting of the Chinese (Taiwan) Institute of Transportation, Hualien, Taiwan.

The authors listed below have certified that:

1. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. they agree to the use of the publication in the student's thesis and its publication on the Griffith University database consistent with any limitations set by publisher requirements.

<table>
<thead>
<tr>
<th>Contributors</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abraham Leung</td>
<td>Conceiving, planning and the writing of the manuscript, collected data and conducted DEA analysis, and the preparation of tables and figures. The candidate was also responsible for the revision made at the suggestion of the conference reviewers and the presentation of the paper during the conference.</td>
</tr>
<tr>
<td>Matthew Burke</td>
<td>Provided assistance in the theoretical framing of the research and provided editing revisions in the initial and the reviewed manuscript.</td>
</tr>
<tr>
<td>Barbara T.H. Yen</td>
<td>Provided the theoretical and methodological advice as an expert in the transport applications of DEA.</td>
</tr>
<tr>
<td>Yu-Chiun Chiou</td>
<td>Provided guidance in the use of DEA as an expert and editorial suggestions in the initial and revised manuscript.</td>
</tr>
</tbody>
</table>

Supervisor Confirmation: I have sighted email or other correspondence from all co-authors confirming their certifying authorship.

(Signed) ___________________________ (Date) 24, June, 2017

Co-principal Supervisor: A/Prof Matthew Burke
Comparative Data Envelopment Analysis of Oil Vulnerability of Urban Transport in Taiwan and Australia

Abraham Leung¹
Yu-Chiun Chiou²
Barbara T.H. Yen³
Matthew Burke⁴

Abstract

The period of historically high oil prices during the mid-2000s and early 2010s has prompted increased academic and policy attention on oil vulnerability globally. Those countries without significant oil reserves and production, and those cities which are relying on private fossil fuel powered vehicles for transport, are definitely more vulnerable to oil price. Although numerous studies regarding oil vulnerability have been conducted, few have conducted comparisons of oil vulnerability and resilience of cities between different countries. Hence, this paper aims to address this research gap by using Data Envelopment Analysis (DEA) to compare oil vulnerability and resilience among cities in Taiwan and Australia. A methodological framework which integrates a wider range of urban transport data, including average household fuel expenditure at the local area level, is developed. The intent is to help facilitate policy transfer between cities and to identify best practices to help improve energy efficiency and sustainability in urban transport. The new approach involves the adaptation of DEA to benchmark the ‘efficiency’ of cities in causing oil-related impacts and also resilience due to the higher usage of less oil intensive modes (e.g., public and active transport). The results show the differences across the areas of Taiwan and Australia, with particular vulnerabilities attributed to local conditions of fuel price, socio-economic conditions and car dependence. This framework should assist in determining governments’ priorities regarding the level of effort needed to improve oil resilience in public or active transport.

Keywords: Oil vulnerability, oil resilience, urban transport, Data Envelopment Analysis

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1. Introduction

Most countries experienced high levels in oil prices during the periods 2007 to 2009 and 2010 to 2014 (Figure 1). Although price levels have reduced recently, these periods of high oil price have sparked increased attention on the issue of car dependence and the reliance on petroleum fuels. Oil prices are becoming more difficult to predict, due to increased volatility and greater uncertainty in the commodity market, as many previously predicted levels have not materialized. This issue remains important for most countries, including Taiwan and Australia. These countries are experiencing shrinking domestic oil supplies or are solely dependent on imported oil to sustain their transport needs. This presents an energy security risk as most of the oil producing areas, such as the Middle East, are geo-politically unstable.

Figure 1: Global oil fluctuations as reflected in real price at 2010 in US retail price of automobile fuel (Source: (US Energy Information Administration, 2016a)

The issue of energy costs to households, in terms of both transport and domestic fuel, has been developed in a number of worldwide energy related transport research studies. These include ‘oil vulnerability’ from Australia (Dodson and Sipe, 2007), ‘transport poverty’ from the UK (Lucas, 2012), ‘energy precariousness (précarité énergétique)’ from France (Rosales-Montano et al., 2015) and ‘energy poverty (energiearmut)’ from Germany (Bohnet and Gertz, 2011). Some of these terms include household fuel costs from domestic needs (heating or electricity to run appliances). Recently, Mattioli (2014, 2015) advocated for a more encompassing term - ‘energy-related economic stress’. In the transport dimension, these terms also relate to the socio-economic impacts caused by dependence on private vehicles, which are predominantly powered by petroleum fuels. There is increasing recognition that the impacts caused by
fluctuating energy prices are disproportionate in different areas (Currie et al., 2009; Dodson and Sipe, 2012; Mees and Groenhart, 2012). Certain communities are more susceptible due to higher levels of private vehicle usage, urban form that limits public and active transport and. In light of the complex nexus of these issues, in this paper we propose data envelopment analysis (DEA) to benchmark relative levels of vulnerability and resilience of oil usage in households in two oil importing countries – Taiwan and Australia. While the total population in both countries is similar, there are significant differences in terms of geographical size and motorization patterns. The outcomes of this study aim to offer an inter-area and cross country comparison for transport and urban policy practitioners, especially at high levels of government, to address the issue of oil vulnerability. This study has innovated new methods in utilizing fuel use expenditure data and adaptive capacity in relation to oil use in local transport. By looking at both urban and rural communities, this helps in understanding the inter-linked relationships between private, public and active transport in consideration of different levels of fuel price. We also briefly explored the different levels of urbanization and the recent growth of electric vehicles in the study areas.

This paper is structured in the following manner: Section 2 provides an outline of the issue of oil vulnerability in Taiwan and Australia, which is a brief literature review in the field areas of transport, energy use and urban planning. Section 3 describes the background of the case study areas and the methodology used. Section 4 presents the result and discusses the policy implication. Finally, Section 5 summarizes the paper and concludes with a discussion of the limitations of this research and suggestions for opportunities for further research.

2. Oil Vulnerability in Taiwan and Australia

2.1 Dependence on imported oil

Oil is the dominant fuel in transport despite recent calls to expedite energy transition to replace fossil fuels with other more ‘green’ energy sources. However, this transition has not been rapid enough to enable the complete replacement of oil use in transport in the short term (Cherp et al., 2011; Geels, 2012; Hirsch, 2008; Li and Loo, 2014; Renne and Fields, 2013). In a national context, both Taiwan and Australia have seen increasing oil consumption in the last decades, as shown in Figure 2. Taiwan had a higher growth in oil consumption in the past but it is levelling off now, whereas Australia’s oil use has kept rising. Looking at the production side, Australia has modest oil reserves, despite the fact that its domestic production peaked in the year 2000. This does not mean that Australia is less dependent on imports, as 30% of its domestic crude oil supply are exported overseas due to limited local refining capacity (Blackburn, 2013). Instead, Australia imports most of its refined transport fuel directly (Figure 3). Taiwan has only negligible domestic oil production and is completely reliant on imported crude oil. Contrary to Australia, Taiwan refines most of its crude oil locally, as its refining capacity has been expanded to meet its domestic fuel needs. Thus, both
Taiwan and Australia are dependent on oil imports to sustain their transportation needs, albeit in a different manner. Any disruptions in oil supply shipping lines to these countries could have devastating effects on the societies and on the economies.

Figure 2: Total Domestic Crude Oil Production and Total Domestic Consumption of Australia and Taiwan (Source: (US Energy Information Administration, 2016b)

Figure 3: Imports of Refined Petroleum Transport Fuels of Australia and Taiwan (Source: (US Energy Information Administration, 2016b)

2.2 Oil Vulnerability of Urban Transport in Australia and Taiwan – Literature Review

The issue of oil dependence in cities has been a concern of urban studies and transport scholars since the oil crisis in the 1970s, which generated transport research in relation to energy use (Næss et al., 1996; Newman, 1991; Small, 1980; Zelinsky and Sly, 1984). The recent period of high oil prices which occurred between the 2000s and the 2010s has sparked renewed attention about this issue. Australian studies have been focused on the spatial patterning of the impacts of higher oil price using census data mapping, as pioneered by Dodson and Sipe
Australian cities are characterized by high levels of suburbanization and car usage, resulting in outer suburbs which have limited public and active transport opportunities being disproportionately more impacted by higher oil prices (Currie et al., 2009). In Taiwan, the period of higher oil prices attracted attention from both academics and the government. From a household income perspective, the change in transport expenditure was the highest during the time of increased global oil prices (Chang and Cheng, 2008). However, this effect is mixed, as lower income households are more likely to use public transport. Unlike in Australia, the spatial aspect of urban fuel price impacts has not been investigated in Taiwan. In regards to policy in Taiwan, there has been joint government and academic research into higher oil prices and modelling (car ownership and mode choice modelling). A comprehensive decision support system has been created in order to identify policy responses (Chiou et al., 2009), however, research into the geographic dimension of oil use in transport is not as evident.

The issue of the uneven geographic distribution of energy and transport service is gaining scholarly attention globally (Simcock and Mullen, 2016), yet comparative research between countries is lacking as most of the research is focused on western nations, in particular North America (Arico, 2007; Sipe and Dodson, 2013), Europe (Berry et al., 2016; Lovelace and Philips, 2014; Mayer et al., 2014) and Australasia (Dodson and Sipe, 2008; Fishman and Brennan, 2009; Leung et al., 2015; Rendall et al., 2014). There is a dearth in studies into oil vulnerability from an Asian perspective, and the issues are not well understood. This is particularly noteworthy as Taiwan is renowned for its high rates of motorcycle/scooter use and it has a higher overall population density. Australia, however, has a low population density and the main mode of transport used is private cars. Research that compares these differences would offer new insights to oil vulnerability researchers. This paper aims to investigate how differently the elevated fuel price levels in 2011 affected different areas in Taiwan and Australia. New methods and data are explored in order to fulfil this aim.

### 3. Methodology – DEA approach

While it is possible to compare different areas of Australia and Taiwan using a simple statistical comparison, better insight is provided by using more advanced measures for comparison and benchmarking. In this section, the concept of data envelopment analysis (DEA) is introduced. DEA was first developed by Charnes, Cooper and Rhodes (1978) (it is also known as the CCR model). DEA is designed to measure the relative efficiency of a Decision Making Unit (DMU), which can refer to any organizational units such as companies, public organizations or even geographical entities. The DEA method relies on mathematical linear programming to estimate relative efficiency based on a mathematically derived weighted ratio of outputs to inputs with the following simplified equation:

\[
\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}}
\]
The advantage of DEA is that it measures efficiency in an objective manner, as it is completely data-driven without any subjective setting. It does not require prior knowledge or assumption of the relationship between inputs and outputs. Furthermore, slack analysis can be carried out to predict how optimal efficiency can be achieved by adjusting the combination of inputs. ‘Slack’ refers to the difference of a particular input between the worst performer and the best performer. This value is useful in showing how underperforming DMUs can perform as well as the best DMU by adjusting input levels. Because of these advantages, DEA has been widely used in fields of operations research, management and economics, with evolving variations (Seiford, 1996). In the transport field, there is wide range of DEA applications, including public transport (Chiou et al., 2012; Hilmola, 2011; Pina and Torres, 2001; Sampaio et al., 2008), port and airport operations (Tongzon, 2001; Yoshida and Fujimoto, 2004) and also more recently, the property value uplifting effects from public transport (Yen et al., 2014). There are also innovative ways to use DEA to measure undesirable outputs such as emissions (Daraio et al., 2016; Ha et al., 2011). These applications prove that DEA is a versatile and adaptive method for efficient benchmarking purposes (Cook and Seiford, 2009).

Moving beyond efficiency analysis, DEA is also used in vulnerability assessments (Cutter et al., 2008), which have usually been based on the subjective decisions of weights or expert analyses. Both hybrid or solely DEA methods have been used to measure vulnerability, in topics ranging from floods (Rygel et al., 2006; Wei et al., 2004), to droughts (Yuan et al., 2015), exposure to pollutants (Ratick and Osleeb, 2013) and even humanitarian crises caused by conflicts (Benini, 2015). The opposite concept to vulnerability is the level of resilience - the ability to reduce the propensity of loss from hazards or negative effects – and this can also be assessed by the use of DEA. Examples of resilience studies using DEA include coastal hazard resilience (Zou and Wei, 2009) and earthquake resilience (Üstün, 2016). For this study, both the vulnerability and resilience of oil fuel price increase are analyzed and we utilized two DEA models based on an earlier Australian oil vulnerability analysis using DEA (Leung et al., 2016). Figure 4 illustrates the framework of these models. The first DEA model looks at oil vulnerability (named OV-DEA), which includes household exposure and sensitivity components within an area. Population and mean weekly household income are seen as inputs, whereas yearly vehicle kilometers travelled (VKT of private car and motorcycles only) and fuel expenditure are treated as outputs. A higher oil vulnerable area is one which has fewer inputs (population and household disposable income) to produce more outputs (total VKT of private vehicles and household fuel expenditure). Household disposable income (after tax income) is used instead of total household income, as this is a better measure of economic resources available for a household. The second DEA model measures the resilience to oil price increases (named OR-DEA). The input is a combined measure of household fuel stress, which is the proportion of household fuel expenditure to household disposable income. The outputs are the share of transport modes that are more efficient (public transport), or those which do not use oil at all (active transport modes, which includes walking and cycling). The OR-DEA aims to measure how efficiently an area can adapt to fuel stress. This
DEA based method can allow inter-area comparison and it does not use a subjective ranking method (i.e., equal weighting for all variables) as in previous approaches to measuring oil vulnerability, such as the VIPER/VAMPIRE methods first proposed by (Dodson and Sipe, 2007, 2008). The use of DEA is an improvement on previous approaches which used proxy measures of actual fuel impacts on households (e.g., average car ownership per household, or the percentage of journey to work by car). This study is able to use household fuel expenditure data directly, and it also measures adaptive capacity. However, it can only measure on a larger geographical scale due to data limitations (i.e., 2-tier administrative areas instead of smaller census tracts). The analysis did not include regional differences of fuel price and EV ownership rates. This is due to the rather small regional differences and the low numbers of EV currently overall, and the resulting difficulty in building a DEA with these low variables.

To solve the DEA efficiency model by fractional linear program, it is necessary to convert the “common measure” of efficiency into linear form so that the methods of linear programming can be applied. Based on Charnes, Cooper and Rhodes (1978), the classical input-oriented CCR DEA model is adapted for the OV-DEA, which can be expressed as a mathematical equation:

\[
[\text{CCR-I}] \quad \text{Min } \theta - \sum_{i=1}^{m} S_i^+ + \sum_{j=1}^{n} S_j^-
\]
where $\theta$ is the vulnerability score (minimizing function), $\varepsilon$ is the non-Archimedean infinitesimal, $m$ is the number of inputs, and $n$ is the number of outputs, $x_{ij}$ and $y_{ij}$ refers to the $i^{th}$ input and $r^{th}$ output of the city, respectively, and, $s_i^-, s_r^+$ are the input and output slack value. Slack refers to which excess input or missing output exists after the proportional change in the input or the outputs to reach the efficiency frontier. $\lambda_j$ refers to the weight given to the DMU$_j$ in an effort to outperform DMU$_o$, $j = 1, 2, \ldots, n$.

The classical CCR model limits the efficiency value to be under 1 (or 100%). Further, the output-oriented CCR model is used for the OR-DEA, which is similar to the OV-DEA, with vulnerability score represented by maximizing $\eta$:

\[ \text{[CCR-O]} \]

\[ \text{Max } \eta + \varepsilon \left( \sum_{i=1}^{m} s_i^- + \sum_{r=1}^{s} s_r^+ \right) \]

s.t. \[ \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = x_{io}, i = 1, 2, \ldots, m \]

\[ \sum_{j=1}^{n} \lambda_j y_{ij} - s_r^+ = y_{ro}, r = 1, 2, \ldots, s \]

\[ \lambda_j \geq 0 \quad j = 1, 2, \ldots, n \]

Generally, DEA is restricted to a maximum score of 1. It can be relaxed to allow comparison of scores beyond 1 (i.e., beyond the efficiency frontier to rank the performance of efficient DMUs) as the value computed in this analysis exceed this value.

\[ s_i^-, s_r^+ \geq 0 \]

\[ \lambda_j \geq 0 \quad j \neq 0 \quad j = 1, 2, \ldots, n \]

This relaxed model is known as the super-efficiency model, and it allows a more precise ranking of the DMUs, while the inefficient DMUs remains the same as in the classical DEA model (Andersen and Petersen, 1993; Wu et al., 2014; Zhu, 2001). After presenting the method, the area of study and data used are explained in the following sub-section.

### 3.1 Scope of Study and Data

Despite Australia’s vast land mass, most residents live in urban settlements of different sizes, with an urbanization rate of nearly 90% (Australia and Dept. of Infrastructure and Regional Development, 2015). Australia is a three-tier federated country with descending tiers of Commonwealth, states or territories
(consisting of 6 states and 2 territories) and local governments (such as cities or regional councils). The lowest level, local governments, are usually more limited in terms of transport policy and budgetary powers. Hence, the state level is a more useful geographic unit of analysis in Australia. Australia has high levels of primacy, in which the state capitals have the majority share of the population and gross domestic product (GDP). These capitals are often treated differently in state policy and should be viewed as separate DMUs. This can be reflected by the Greater Capital City Statistical Area (GCCSA) classification created by the Australian Bureau of Statistics (ABS) (2010) which largely includes the areas in proximity to, and under the influence of, the capital cities, and usually includes a number of local government entities. Non-capital areas are treated as ‘Rest of the State’ areas.

Figure 5: Map showing the areas in Taiwan and Australia assessed in this study
Taiwan is also highly urbanized (over 80% of the population are living in urban areas) and the country is a unitary political entity (Williams, 2010). There are more second-level divisions with less degree of primacy than in Australia. Since the recent re-organizations in 2010 and 2014, there are 6 special municipalities (直轄市, hereafter known as SM), 3 provincial cities and 13 counties in Taiwan. All of these cities have their own transport budget and policy making powers, and hence can be conveniently treated as DMUs. However, the role of central government in Taiwan remains very strong in making transport policy decisions. Remote areas such as outlying islands (Penghu, Kinmen and Matsu Islands) in Taiwan, and the Northern Territory and external islands in Australia, are excluded due to having very low populations or small area size. The transport situation in these areas is also less representative of the whole country. Figure 5 shows the location of the DMUs considered in this study. Major city areas, including SMs in Taiwan and GCCSAs in Australia, are highlighted with thicker border lines to represent their location.

3.2 Data Collection

Based on the geographical coverage, Table 1 shows the data available for conducting DEA analysis of oil vulnerability and resilience in Taiwan and Australia.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Country</th>
<th>Data Source</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resident Population (persons)</td>
<td>TW</td>
<td>2011 Household Registration Data</td>
<td>Ministry of the Interior</td>
</tr>
<tr>
<td>AU</td>
<td>2011 Census, Usual Residents Population</td>
<td>Australian Bureau of Statistics</td>
<td></td>
</tr>
<tr>
<td>Mode Share to Work, Public and Active Transport (%)</td>
<td>TW</td>
<td>2011 Public Survey of Transport Mode Usage (102 年民眾日常運具調查)</td>
<td>Ministry of Transport and Communications</td>
</tr>
<tr>
<td>AU</td>
<td>2011 Census, Journey to Work</td>
<td>Australian Bureau of Statistics</td>
<td></td>
</tr>
<tr>
<td>Average Fuel Expenditure (Converted to 2011 US$)</td>
<td>TW</td>
<td>2011 Scooter Use Survey / 2012 Car Use Survey (100 年機車/101 年小客車使用狀況調查)</td>
<td>Ministry of Transport and Communications</td>
</tr>
<tr>
<td>AU</td>
<td>2012 Household Energy Consumption Survey</td>
<td>Australian Bureau of Statistics</td>
<td></td>
</tr>
<tr>
<td>Average Income (Converted to 2011 US$)</td>
<td>TW</td>
<td>2011 Household Income and Expenditure Survey (100 年家庭收支調查)</td>
<td>Directorate General of Budget, Accounting and Statistics, Executive Yuan</td>
</tr>
<tr>
<td>AU</td>
<td>2012 Household Energy Consumption Survey</td>
<td>Australian Bureau of Statistics</td>
<td></td>
</tr>
<tr>
<td>Ownership rate of Electric Vehicles (Including private car and motorcycles, excluding others)</td>
<td>TW</td>
<td>(2015 Data) Commonly Used Transportation Statistics</td>
<td>Ministry of Transport and Communications</td>
</tr>
<tr>
<td>AU</td>
<td>2015 Motor Vehicle Survey</td>
<td>Australian Bureau of Statistics</td>
<td></td>
</tr>
</tbody>
</table>

(Note: TW = Taiwan, AU = Australia)
This study only considers local transport, which can be approximated by the mode share of commuting. While inter-city, or long distance travel by air, is also oil-intensive and is vulnerable to increase in oil prices, there is no readily available substitute for oil-based fuel for air travel, and it can be seen as being captive to oil use. This is particularly in the case of Australia, due to its sheer size and because it does not have a conventional railway and high-speed rail network that is as developed as Taiwan’s. It is also more appropriate to measure oil vulnerability and resilience at local transport level, as trips are more likely to be replaced by public transport and active transport. This study collected data available from 2011 to 2012, which matches the timing of the last available full census (2011) completed in Australia. Taiwan’s governmental data collection is less reliant on a census, due to the availability of household registration and administrative records data. In fact, the most recent census (2010) held in Taiwan was only a partial census, and was not a full snapshot as is observed in the Australian counterpart.

A full list of data used is shown in the Appendix. Overall, larger cities are characterized by higher population, VKT and income. Fuel expenditure is also higher in rural areas than in urban areas, however, the reasons for this are different due to varying local conditions. Additional data which are not used in DEA are also present to show a fuller picture of oil vulnerability/resilience. These included fuel price data in 2011 to 20012, electric vehicle (EV) ownership rates in 2015, and land area. For Taiwan, fuel prices are more uniform across its entire territory due to its smaller geographical size and because governmental subsidies are paid for fuel in rural or outlying areas. This is opposite to Australia, where fuel supply companies are free to set the price of petrol and diesel, and because of the country’s large in land mass. This has resulted in higher fuel transport costs and is reflected in fuel prices. Certain rural areas of both Taiwan and Australia, despite its larger area, have higher rates of active transport mode share despite lower public transport mode share and higher VKT in relation to their population. This could be due to these areas being characterized by smaller regional settlements, making active travel feasible for their commuting needs. This complicated pattern means that DEA could be a suitable method to objectively benchmark oil vulnerability and resilience.

EV data are shown in the table for reference only as their effect is not significant enough for DEA to analyze. Despite this, their potential to reduce oil vulnerability and improve resilience should not be dismissed. Only the most recent data is shown to reflect the recent boom in EV ownership. Overall, Taiwan’s level of EV ownership is higher than it is in Australia. This is possibly because of the higher usage of motorcycle/scooters in Taiwan, and because electric motorcycles are cheaper to acquire than cars. The city of Taitung in Taiwan was found to have the highest level of EV ownership (8.75 per 1000 persons) of all DMUs compared, of which most are scooters; whereas in Australia, Canberra has the highest EV ownership all of which are cars, with 4.97 per 1000 persons. It is likely that both areas would benefit from government support. Taitung’s high level of ownership could be due to government subsidies and rental e-scooters for tourism use, as under 50cc models do not require an operating license. Canberra’s ownership
could be due to its exceptionally high income and the government’s policy to acquire a fleet which sets an example to embrace the latest automotive technologies and to reduce carbon emissions (ACT Department of Environment and Sustainable Development, 2012).

4. Results and Discussion

The following section shows the DEA modelling results. The descriptive statistics of the variables used in the DEA models are shown in Table 3. Testing of the correlation and relationship of the inputs and output variables is performed before running the DEA models as described in Section 3 earlier. Table 4 shows the correlation coefficients among input and output variables. Note that the correlation coefficients between input and output variables are positive, with the exception of the public transport mode share and fuel stress in the OR-DEA model, which is negative. This is probably because higher fuel stress areas are mostly rural areas which have limited public transport opportunities. To test the relevance of the selected input and output variables, regression analyses are further conducted.

<table>
<thead>
<tr>
<th>Table 3: Descriptive Statistics of the inputs and outputs for the DEA models used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>OV-DEA</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>OR-DEA</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4: Correlation coefficients among input and output variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OV-DEA</strong></td>
</tr>
<tr>
<td>Variable</td>
</tr>
<tr>
<td>Population</td>
</tr>
<tr>
<td>Weekly Income</td>
</tr>
<tr>
<td>Total VKT of Private Vehicles</td>
</tr>
<tr>
<td>Weekly Fuel Expenditure</td>
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</table>
### OR-DEA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Input</th>
<th>Outputs</th>
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<tbody>
<tr>
<td></td>
<td>Household Fuel Stress</td>
<td>Public Transport (PT) Mode Share to Work</td>
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<td>Household Fuel Stress</td>
<td>1</td>
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<td>PT Mode Share</td>
<td>-0.21</td>
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<tr>
<td>Active Transport Mode Share</td>
<td>0.59</td>
<td>0.08</td>
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<table>
<thead>
<tr>
<th>Table 5: Regression results for input and output variables</th>
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<td><strong>OV-DEA</strong></td>
</tr>
<tr>
<td><strong>Dependent variables</strong></td>
</tr>
<tr>
<td>Population</td>
</tr>
<tr>
<td>Total VKT of Private Vehicles</td>
</tr>
<tr>
<td>-0.99</td>
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<tr>
<td>(22.61)</td>
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<tr>
<td>Weekly Income</td>
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<tr>
<td>Weekly Fuel Expenditure</td>
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<tr>
<td>-0.19</td>
</tr>
<tr>
<td>(-1.06)</td>
</tr>
<tr>
<td>$R^2 = 0.974$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>OR-DEA</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent variables</strong></td>
</tr>
<tr>
<td>Household Fuel Stress</td>
</tr>
<tr>
<td>-0.21</td>
</tr>
<tr>
<td>(-1.16)</td>
</tr>
<tr>
<td>$R^2 = 0.207$</td>
</tr>
</tbody>
</table>

(Parentheses refers to t-value)

As shown in Table 5, the variables for OV-DEA are statistically significant, but they are not significant for OR-DEA. The aim of this study is, however, to use DEA to create a vulnerability and resilience index, not to identify the actual efficiency of a DMU in typical DEA studies. Hence, a negative correlation and non-significant relationship between inputs and outputs are still considered to be acceptable. After testing the relevance of data, the results of the DEA models are shown in Table 6. For a classical CCR DEA assessment, a value of 1 means it is the most ‘efficient’ and is located at the ‘efficiency frontier’. Viewing the super-efficient OV-DEA, which allows a score over 1, on average, Taiwanese cities have higher oil vulnerability (0.970) than Australian cities (0.799). This is
largely due to the issue of overall higher income in Australia, and also because Taiwan has a higher ratio of fuel expenditure to income. Australian state capital cities are positioned as the least oil vulnerable areas. Rural areas also tend to be more vulnerable than urban areas in both Taiwan and Australia. Taiwanese cities also have higher VKT, which is possibly due to high scooter usage.

Those having a score of 1 in the classical CCR OV-DEA model can be seen as the most oil vulnerable areas. A large number of areas in Taiwan are located on the efficient frontier with a value of 1 in the classical CCR model; this could be due to lower incomes in relation to fuel expenditure, as compared to Australia. To allow more accurate benchmarking, the super-efficiency model results are reported. The results show that Taitung (1.279) and Rest of SA (1.137) are the most oil vulnerable areas in Taiwan and Australia, respectively. This is not surprising, as Taitung is one of the areas of lowest income in Taiwan and this has resulted in a higher burden of fuel expenditure to disposable income. Conversely, the high OV-DEA score for Rest of SA is caused because it is the area with the highest fuel expenditure in the areas compared and has higher VKT in relation to its small population. Unlike Taiwan, fuel prices in Australia are less regulated and rural areas tends to pay more for fuel because transport costs are higher. Fuel price could not be considered in the DEA model directly because it is a price factor. It can be seen to be an external factor explaining oil vulnerability, which could be considered in future studies using other methods. After measuring oil vulnerability, oil resilience is also examined in the OR-DEA model and the results are shown in Table 7. Taipei in Taiwan and Sydney in Australia are the ‘best practice’ cities in terms of oil resilience, especially Taipei City as it has the best results in both public (37.7%) and active (19.9%) transport mode share in comparison to all other areas. Other oil resilient Taiwanese areas include Keelung (mostly due to high public and active transport mode share) and Yilan (mostly due to low fuel stress). The Australian capital cities of Canberra (due to very low fuel stress) and Melbourne (due to higher public transport use) are also found to be more resilient. Most of the other Taiwanese DMUs are ranked low on the resilience scale, due to higher fuel stress and relatively low public and active transport mode share.

As the patterns of OV-DEA and OR-DEA are overlapping, for easier comparison, both values of areas can be plotted together in a quadrant chart (Figure 6). The mean values of the scores of both DEA models are used as cut-off levels to create four quadrants. Most Australian capitals (Sydney, Canberra, Melbourne, Brisbane and Perth) and Taiwanese cities (Keelung and Yilan) fall into the quadrant of ‘Less Vulnerable; More Resilient’ (green area). Areas falling in this quadrant are best positioned to withstand impacts from higher oil prices. Taipei City is an outlier, with exceptionally good oil resilience but with an average oil vulnerability score. The other two quadrants are those with mixed results, namely ‘More Vulnerable; More Resilient’ (blue area) and ‘Less Vulnerable; Less Resilient’ (yellow area). The areas of concern, in the event of higher oil prices, are located in the ‘More Vulnerable; Less Resilient’ (red area). These are the areas with relatively high VKT in relation to population, high fuel stress and less public or active mode share. Taitung is the area that is the most oil vulnerable and also low oil resilience.
Table 6: Oil Vulnerability Scores calculated from OV-DEA Model (The higher the score, the more vulnerable)

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Areas / DMU</th>
<th>(Country)</th>
<th>Classical CCR Oil Vulnerability (CRS)</th>
<th>Super-efficient Oil Vulnerability (CRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Taitung County</td>
<td>TW</td>
<td>1.000</td>
<td>1.279</td>
</tr>
<tr>
<td>2</td>
<td>Pingtung County</td>
<td>TW</td>
<td>1.000</td>
<td>1.162</td>
</tr>
<tr>
<td>3</td>
<td>Kaohsiung City</td>
<td>TW</td>
<td>1.000</td>
<td>1.160</td>
</tr>
<tr>
<td>4</td>
<td>Rest of SA</td>
<td>AU</td>
<td>1.000</td>
<td>1.137</td>
</tr>
<tr>
<td>5</td>
<td>Yunlin County</td>
<td>TW</td>
<td>1.000</td>
<td>1.101</td>
</tr>
<tr>
<td>6</td>
<td>Hobart (Tas.)</td>
<td>AU</td>
<td>1.000</td>
<td>1.090</td>
</tr>
<tr>
<td>7</td>
<td>Taichung City</td>
<td>TW</td>
<td>1.000</td>
<td>1.037</td>
</tr>
<tr>
<td>8</td>
<td>Tainan City</td>
<td>TW</td>
<td>1.000</td>
<td>1.023</td>
</tr>
<tr>
<td>9</td>
<td>Rest of Tasmania</td>
<td>TW</td>
<td>1.000</td>
<td>1.017</td>
</tr>
<tr>
<td>10</td>
<td>New Taipei City</td>
<td>TW</td>
<td>0.994</td>
<td>0.994</td>
</tr>
<tr>
<td>11</td>
<td>Rest of WA</td>
<td>AU</td>
<td>0.959</td>
<td>0.959</td>
</tr>
<tr>
<td>12</td>
<td>Taoyuan City</td>
<td>TW</td>
<td>0.953</td>
<td>0.953</td>
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<tr>
<td>13</td>
<td>Chiayi City</td>
<td>TW</td>
<td>0.951</td>
<td>0.951</td>
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<tr>
<td>14</td>
<td>Hsinchu County</td>
<td>TW</td>
<td>0.947</td>
<td>0.947</td>
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<tr>
<td>15</td>
<td>Chiayi County</td>
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<td>0.943</td>
<td>0.943</td>
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<tr>
<td>16</td>
<td>Rest of Victoria</td>
<td>AU</td>
<td>0.931</td>
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<td>17</td>
<td>Nantou County</td>
<td>TW</td>
<td>0.898</td>
<td>0.898</td>
</tr>
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<td>18</td>
<td>Taipei City</td>
<td>TW</td>
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<td>0.898</td>
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<td>Hualien County</td>
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<td>0.882</td>
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<td>20</td>
<td>Miaoli County</td>
<td>TW</td>
<td>0.863</td>
<td>0.863</td>
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<tr>
<td>21</td>
<td>Keelung City</td>
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<td>0.852</td>
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<td>Changhua County</td>
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<td>0.850</td>
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<td>Hsinchu City</td>
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<tr>
<td>24</td>
<td>Canberra and ACT</td>
<td>AU</td>
<td>0.833</td>
<td>0.833</td>
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<tr>
<td>25</td>
<td>Yilan County</td>
<td>TW</td>
<td>0.801</td>
<td>0.801</td>
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<tr>
<td>26</td>
<td>Rest of NSW</td>
<td>AU</td>
<td>0.709</td>
<td>0.709</td>
</tr>
<tr>
<td>27</td>
<td>Rest of Queensland</td>
<td>AU</td>
<td>0.693</td>
<td>0.693</td>
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<tr>
<td>28</td>
<td>Melbourne (Vic.)</td>
<td>AU</td>
<td>0.650</td>
<td>0.650</td>
</tr>
<tr>
<td>29</td>
<td>Perth (WA)</td>
<td>AU</td>
<td>0.615</td>
<td>0.615</td>
</tr>
<tr>
<td>30</td>
<td>Sydney (NSW)</td>
<td>AU</td>
<td>0.611</td>
<td>0.611</td>
</tr>
<tr>
<td>31</td>
<td>Brisbane (Qld.)</td>
<td>AU</td>
<td>0.581</td>
<td>0.581</td>
</tr>
<tr>
<td>32</td>
<td>Adelaide (SA)</td>
<td>AU</td>
<td>0.556</td>
<td>0.556</td>
</tr>
</tbody>
</table>

Taiwan Average 0.930 0.970
Australia Average 0.780 0.799
Total Average 0.869 0.900
Table 7: Oil Resilience Scores calculated from OR-DEA Model (The higher the score, the more resilient)

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Areas / DMU</th>
<th>(Country)</th>
<th>Classical CCR Oil Resilience (CRS)</th>
<th>Super-efficient Oil Resilience (CRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Taipei City</td>
<td>TW</td>
<td>1.000</td>
<td>1.719</td>
</tr>
<tr>
<td>2</td>
<td>Sydney (NSW)</td>
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<td>0.965</td>
<td>0.965</td>
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<td>3</td>
<td>Canberra and ACT</td>
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<td>4</td>
<td>Melbourne (Vic.)</td>
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<tr>
<td>5</td>
<td>Keelung City</td>
<td>TW</td>
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<td>0.560</td>
</tr>
<tr>
<td>6</td>
<td>Brisbane (Qld.)</td>
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<td>0.546</td>
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<td>7</td>
<td>Hobart (Tas.)</td>
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<td>0.543</td>
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<td>Perth (WA)</td>
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<td>TW</td>
<td>0.364</td>
<td>0.364</td>
</tr>
<tr>
<td>16</td>
<td>Rest of Queensland</td>
<td>AU</td>
<td>0.346</td>
<td>0.346</td>
</tr>
<tr>
<td>17</td>
<td>Chiayi City</td>
<td>TW</td>
<td>0.338</td>
<td>0.338</td>
</tr>
<tr>
<td>18</td>
<td>Hualien County</td>
<td>TW</td>
<td>0.329</td>
<td>0.329</td>
</tr>
<tr>
<td>19</td>
<td>Taitung County</td>
<td>TW</td>
<td>0.327</td>
<td>0.327</td>
</tr>
<tr>
<td>20</td>
<td>Tainan City</td>
<td>TW</td>
<td>0.320</td>
<td>0.320</td>
</tr>
<tr>
<td>21</td>
<td>Rest of SA</td>
<td>AU</td>
<td>0.319</td>
<td>0.319</td>
</tr>
<tr>
<td>22</td>
<td>Rest of NSW</td>
<td>AU</td>
<td>0.304</td>
<td>0.304</td>
</tr>
<tr>
<td>23</td>
<td>Chiayi County</td>
<td>TW</td>
<td>0.300</td>
<td>0.300</td>
</tr>
<tr>
<td>24</td>
<td>Rest of Victoria</td>
<td>AU</td>
<td>0.298</td>
<td>0.298</td>
</tr>
<tr>
<td>25</td>
<td>Rest of Tasmania</td>
<td>AU</td>
<td>0.290</td>
<td>0.290</td>
</tr>
<tr>
<td>26</td>
<td>Nantou County</td>
<td>TW</td>
<td>0.284</td>
<td>0.284</td>
</tr>
<tr>
<td>27</td>
<td>Taoyuan City</td>
<td>TW</td>
<td>0.284</td>
<td>0.284</td>
</tr>
<tr>
<td>28</td>
<td>Pingtung County</td>
<td>TW</td>
<td>0.266</td>
<td>0.266</td>
</tr>
<tr>
<td>29</td>
<td>Miaoli County</td>
<td>TW</td>
<td>0.265</td>
<td>0.265</td>
</tr>
<tr>
<td>30</td>
<td>Changhua County</td>
<td>TW</td>
<td>0.262</td>
<td>0.262</td>
</tr>
<tr>
<td>31</td>
<td>Taichung City</td>
<td>TW</td>
<td>0.241</td>
<td>0.241</td>
</tr>
<tr>
<td>32</td>
<td>Hsinchu County</td>
<td>TW</td>
<td>0.212</td>
<td>0.212</td>
</tr>
</tbody>
</table>

Taiwan Average 0.373 0.411

Australia Average 0.488 0.488

Total Average 0.420 0.442
Figure 6: Cross analysis of OV-DEA and OR-DEA scores of Australian and Taiwanese areas
In order to understand how each can improve its oil resilience, Table 8 demonstrates the slack analysis from the OR-DEA model. The slack analysis shows the level of inputs needed for improvement, in order to be as good as the peers.

Table 8: Slack values (improvements strategies) for the transport mode share of capital cities to be as good as the peers

<table>
<thead>
<tr>
<th>DMU</th>
<th>Public Transport</th>
<th>Active Transport</th>
</tr>
</thead>
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<tr>
<td><strong>Taiwan</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taipei</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>New Taipei</td>
<td>0%</td>
<td>2.82%</td>
</tr>
<tr>
<td>Taoyuan</td>
<td>11.78%</td>
<td>0%</td>
</tr>
<tr>
<td>Taichung</td>
<td>32.87%</td>
<td>0%</td>
</tr>
<tr>
<td>Tainan</td>
<td>49.78%</td>
<td>0%</td>
</tr>
<tr>
<td>Kaohsiung</td>
<td>35.02%</td>
<td>0%</td>
</tr>
<tr>
<td>Keelung</td>
<td>0%</td>
<td>10.72%</td>
</tr>
<tr>
<td>Hsinchu City</td>
<td>27.04%</td>
<td>0%</td>
</tr>
<tr>
<td>Chiayi City</td>
<td>43.78%</td>
<td>0%</td>
</tr>
<tr>
<td>Hsinchu County</td>
<td>16.08%</td>
<td>0%</td>
</tr>
<tr>
<td>Miaoli</td>
<td>35.16%</td>
<td>0%</td>
</tr>
<tr>
<td>Changhua County</td>
<td>46.35%</td>
<td>0%</td>
</tr>
<tr>
<td>Nantou</td>
<td>46.29%</td>
<td>0%</td>
</tr>
<tr>
<td>Yunlin</td>
<td>67.76%</td>
<td>0%</td>
</tr>
<tr>
<td>Chiayi</td>
<td>52.66%</td>
<td>0%</td>
</tr>
<tr>
<td>Pingtung</td>
<td>53.45%</td>
<td>0%</td>
</tr>
<tr>
<td>Yilan</td>
<td>36.97%</td>
<td>0%</td>
</tr>
<tr>
<td>Hualien</td>
<td>50.87%</td>
<td>0%</td>
</tr>
<tr>
<td>Taitung</td>
<td>63.75%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Australia</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sydney</td>
<td>0%</td>
<td>6.74%</td>
</tr>
<tr>
<td>Melbourne</td>
<td>0%</td>
<td>5.54%</td>
</tr>
<tr>
<td>Brisbane</td>
<td>0%</td>
<td>5.63%</td>
</tr>
<tr>
<td>Adelaide</td>
<td>0%</td>
<td>2.77%</td>
</tr>
<tr>
<td>Perth</td>
<td>0%</td>
<td>5.30%</td>
</tr>
<tr>
<td>Hobart</td>
<td>13.50%</td>
<td>0%</td>
</tr>
<tr>
<td>Canberra (ACT)</td>
<td>9.37%</td>
<td>0%</td>
</tr>
<tr>
<td>Rest of NSW</td>
<td>26.45%</td>
<td>0%</td>
</tr>
<tr>
<td>Rest of Vic.</td>
<td>29.99%</td>
<td>0%</td>
</tr>
<tr>
<td>Rest of Qld</td>
<td>24.39%</td>
<td>0%</td>
</tr>
<tr>
<td>Rest of SA</td>
<td>38.63%</td>
<td>0%</td>
</tr>
<tr>
<td>Rest of WA</td>
<td>20.39%</td>
<td>0%</td>
</tr>
<tr>
<td>Rest of Tas.</td>
<td>31.43%</td>
<td>0%</td>
</tr>
</tbody>
</table>

‘Peer’ refers to the best DMUs that that can be achieved by changing input levels. For this study, all other areas treat Taipei as the peer. For example, in Taiwan, New Taipei and Keelung need to improve active transport mode share by 2.82% and 10.72%, respectively. The worst cases in the extreme are Yunlin (67.76%) and Taitung 63.75%, which need massive improvements in public transport mode share. Large cities in Taiwan such as Kaohsiung and Taichung also need
substantial improvements in public transport, as their rates of private transport use (mostly scooters) are high, with relatively low rates of public and active travel rates. Australia shows a clear divide between larger cities and smaller cities or rural areas. Most large state capitals (Sydney, Melbourne, Brisbane and Adelaide) have reasonable rates of public transport compared to other areas, but have even lower active travel mode share than rural areas. It would be best if large Australian cities could improve their active mode share. Possible measures which could be taken include improving cycling networks or pedestrian linkage to improve oil resilience. Conversely, other, mostly rural, areas need to boost public transport ridership as a more effective measure to improve oil resilience.

It should be noted that this analysis only compares various areas taking an overall view. Micro-level considerations and geographic suitability are not able to be revealed. This analysis does not mean that public and active transport improvement should not be implemented together. Polices and measures to improve public or active transport may involve a package of measures, including infrastructure but also urban planning, pricing measures and transport demand management. However, for government agencies overseeing transport policies and with budgetary and resource concerns, this analysis could help to determine funding priorities, especially at high levels of government, such as Federal agencies in Australia or the Central Government of Taiwan.

5. Concluding Remarks and Future Research

The use of DEA modelling allows consideration of oil vulnerability and resilience factors in an objective way without the need for subjective weights, as in other vulnerability assessment or data comparison methods. Previously, international and inter-area assessments of oil vulnerability have not been conducted. This study offers a new perspective on oil vulnerability and transport energy sustainability; in particular, the key differences in the development of public transportation and the popularity of motorcycles, which are the major differences between the two countries investigated in this paper.

The DEA models proposed in this study allow the use of fuel expenditure data, which has not been well utilized in previous household oil price research into local transport. The slack analysis provides an overall guide to mode share improvement in relation to fuel stress levels. The results are quite mixed, as larger cities are not necessarily less oil vulnerable or more oil resilient. Public transport and active transport improvements need not be expensive. Car restraint policies should also be pursued. Future studies could compare more jurisdictions. Subject to data availability, comparison with cities with strong car restraint policies such as Hong Kong or Singapore could test whether car restraint policies can improve OR-DEA scores. An expanded international study looking at the Asia Pacific region could potentially draw a more representative sample of DMUs.

In terms of methodology, DEA suffers from the deficiency of not being able to test its underlying hypothesis. While this is possible for stochastic frontier analysis
(SFA), when used in efficiency evaluation it can provide significance testing results. In this study, we used DEA as DEA has an advantage over SFA at the flexible relationships among input/output variables and applicability at multiple outputs cases. To address this issue in future research, a better approach would be to use two-stage DEA: to evaluate the efficiency and to identify the significant external contributing factors. This has been conducted in a number of transport related DEA studies (Chiou et al., 2012; Chiou and Chen, 2006; Hilmola, 2011; Pina and Torres, 2001). Another limitation of this study is that the DMUs used for comparison are rather large, especially for Australia. This is due to data limitations, as fuel expenditure data are only available at capital city and non-capital city level, delimited by states. Should smaller area statistics be available, for instance, Local Government Areas of Australia, this could greatly improve the usefulness of comparison.

Another possible direction for future research is to start investigating the wider application of ‘green energy’ vehicles, such as electric cars or scooters. As shown in Table 2, Taitung actually has the highest level of electric vehicles despite its poor performance in both OV-DEA and OR-DEA. Electric forms of personal transport, if more widely used, can be a measure to boost oil resilience. Future investigation is needed to ascertain whether the electric vehicles in these areas are actually owned and used by residents for daily use. Overall, the share of EV vehicles remains low at this time. It is not likely to be sufficiently assessed by DEA as the numbers are very small, especially in Australia. New methods and new variables are needed to investigate oil resilience from electricity powered individual transport or even other alternative fuels. Yet while electrification of personal transport might solve the ‘oil problem’, it may also cause new problems, such as increased loads on energy supply and the need to produce renewable energy in order to have truly ‘green energy’ in transport. In view of the scarcity and fragmentation of academic studies and lack of evidence, further research into the nexus of transport, energy and social impacts should be continued.
Appendix: Variables of the areas treated comparing Australia and Taiwan (N=32)
Total VKT of
Private Vehicles
(Billion km)

Mean Weekly
Household Fuel
Expenditure
(US$)

Resident
Population
(persons)

Taipei City (SM)
New Taipei City (SM)
Taoyuan City (SM)
Taichung City (SM)
Tainan City (SM)
Kaohsiung City (SM)
Keelung City
Hsinchu City
Chiayi City
Hsinchu County
Miaoli County
Changhua County
Nantou County
Yunlin County
Chiayi County
Pingtung County
Yilan County
Hualien County
Taitung County
Taiwan (Average)

26.79
29.70
21.69
25.48
20.05
30.09
3.39
3.91
2.56
5.37
4.57
9.78
4.77
6.64
4.44
10.56
4.06
2.84
1.95
11.51

47.48
48.07
53.62
56.22
49.37
45.33
44.82
49.33
48.30
62.51
53.49
50.77
54.67
54.44
53.55
53.22
44.56
48.44
48.13
50.86

2,650,968.00
3,916,451.00
2,013,305.00
2,664,394.00
1,876,960.00
2,774,470.00
379,927.00
420,052.00
271,526.00
517,641.00
562,010.00
1,303,039.00
522,807.00
713,556.00
537,942.00
864,529.00
459,061.00
336,838.00
228,290.00
1,211,250.84

Sydney (NSW)
Melbourne (Vic.)
Brisbane (Qld.)
Adelaide (SA)
Perth (WA)
Hobart (Tas.)
Canberra and ACT
Rest of NSW
Rest of Victoria
Rest of Queensland
Rest of SA
Rest of WA
Rest of Tasmania
Australia (Average)
Overall Average

31.22
30.62
14.67
8.19
12.98
1.46
3.06
21.57
15.31
19.09
3.88
5.38
2.10
13.04
12.13

63.22
66.03
64.63
53.44
66.18
54.75
65.56
68.57
71.50
69.63
80.43
76.67
67.07
66.75
57.31

4,391,674.00
3,999,981.00
2,065,998.00
1,225,235.00
1,728,865.00
211,656.00
356,586.00
2,512,953.00
1,345,718.00
2,253,724.00
368,261.00
502,593.00
282,509.00
1,634,288.69
1,383,109.97

Median Weekly
Disposable
Income
(US$)

Public Transport
Mode Share
(%)

Taiwan
832.11
593.62
655.54
577.19
501.29
582.03
511.94
737.29
592.76
712.05
538.04
515.79
541.46
445.89
486.89
479.22
581.13
495.78
436.15
569.27
Australia
1,785.31
1,772.99
1,590.07
1,461.13
1,746.69
1,405.74
2,037.02
1,328.65
1,207.90
1,380.57
1,223.88
1,595.10
1,170.64
1,515.82
953.81

Active Transport
Mode Share
(%)

Average
Fuel Price
(US$)

Electric Vehicle
(EV) Ownership
(Private car and
motorcycles.
(per 1000 persons)

Land Area
(Square
kilometres)

37.70
26.10
12.00
7.60
4.90
6.60
32.40
6.40
3.40
8.90
8.10
4.90
5.80
4.70
6.00
5.30
6.50
4.50
3.00
10.25

19.90
12.40
8.10
8.20
11.00
10.90
11.10
8.70
9.60
6.50
9.20
9.00
10.00
15.50
11.50
10.30
12.70
11.20
12.60
10.97

5.71
8.10
8.18
9.74
9.85
7.79
8.76
6.69
8.15
8.78
9.94
9.84
10.10
12.21
11.00
11.10
7.67
9.77
11.04
9.18

1.12
1.11
1.11
1.11
1.11
1.11
1.12
1.12
1.11
1.12
1.12
1.11
1.11
1.11
1.11
1.11
1.11
1.11
1.11
1.11

3.46
2.89
4.33
1.57
1.54
2.47
0.73
2.39
2.88
1.36
1.24
1.31
2.27
1.54
1.07
2.15
0.82
3.19
8.75
2.42

271.80
2,052.57
1,220.95
2,214.90
2,191.65
2,947.62
132.76
104.15
60.03
1,427.54
1,820.31
1,074.40
4,106.44
1,290.83
1,903.64
2,775.60
2,143.63
4,628.57
3,515.25
1,888.56

22.57
15.84
14.67
10.00
12.29
6.64
7.87
2.33
2.72
3.09
1.53
5.91
1.87
8.26
9.44

5.41
4.80
4.67
4.13
3.89
7.37
7.43
5.48
6.15
6.08
7.30
8.72
5.80
5.94
8.93

3.54
3.72
4.06
3.66
3.79
3.89
3.22
5.16
5.92
5.04
6.57
4.81
5.73
4.55
7.30

1.48
1.48
1.52
1.47
1.48
1.55
1.52
1.52
1.49
1.50
1.51
1.55
1.55
1.51
1.27

0.17
0.48
0.07
0.14
0.31
0.77
4.97
0.04
0.16
0.04
0.08
0.16
0.46
0.60
1.68

12,367.74
9,990.52
15,825.93
3,257.66
6,417.86
1,695.46
2,357.95
788,441.03
217,505.19
1,714,132.14
980,921.69
2,520,156.34
66,322.73
1,345,034.83
199,227.34

Note: Fuel price, EV ownership and land area listed for reference, SM =Special Municipality (直轄市) of Taiwan

135

Fuel Stress
(Proportion of
weekly fuel
expenditure and
disposable
income)
(US$)


6. References


Leung, A., Burke, M., Cui, J., Perl, A., 2015. New Approaches to Oil Vulnerability Mapping for Australian Cities: The Case of South-East Queensland, the 200km City. Presented at the State of Australian Cities National Conference, Gold Coast, Australia.

Commonwealth of Australia, Melbourne, Australia.


7. New approaches to oil vulnerability mapping for Australian Cities: The case of South-East Queensland, the 200km City

The work presenting here in Chapter 7 was previously published as Leung, A., Burke, M., Cui, J., Perl, A., 2015. New approaches to oil vulnerability mapping for Australian cities: The case of South-East Queensland, the 200km city. Presented at the State of Australian Cities National Conference (SOAC) 2015, Gold Coast, Australia.

Now the research takes on a more in-depth level. This paper aims to study intra-urban oil vulnerability of South-East Queensland (SEQ), a 200km long conurbation. There are several key innovations in this research when compared to the previous Vulnerability Index for Petroleum Energy Rises (VIPER) method developed by Dodson and Sipe (2007). Firstly, a wider range of data is included to reveal potential oil vulnerability over an urban region. The conceptual framework outlined in Chapter 2 and 3 organises the 10 metrics included in this study. These include commuting distance for exposure, and more importantly, adaptive capacity metrics such as public and active mode share, coverage of public transport and its quality of service, walkability, employment density and availability of electricity-based public transport. The normalisation technique is also improved by first employing the use of the standard deviation scores (z-scores).
This resultant new approach is compared with the previous VIPER method. The new method can provide a better estimation of oil vulnerability with a greater emphasis on adaptive capacity, which shows a better spatial representation of the poly-centric urban form in SEQ. Furthermore, a dual dimension classification is also provided, acknowledging the potential impacts of oil price increase (the combination of exposure and sensitivity) which can be countered by adaptive capacity variables.

Composite indicators should include sensitivity testing. However, this paper is a pilot study using South East Queensland as an example. In the subsequent study covering Brisbane and Hong Kong in Chapter 8, sensitivity testing is applied.

The key conceptual underpinnings and the methodology of the paper presented in this Chapter have recently been adopted by Mattioli et al. (2017) to map transport fuel price vulnerability for the whole England.

**Research questions addressed in this paper and contributions**

**Primary question**
How do oil price change impacts vary spatially within an urban area?

**Summary of contributions**
Developed an improved methodology to study intra-urban oil vulnerability in a major urban region (SEQ) in Australia.
7.1 Statement of contribution to co-authored published paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:

Leung, A., Burke, M., Cui, J., Perl, A., 2015. New approaches to oil vulnerability mapping for Australian cities: The case of South-East Queensland, the 200km City. Presented at the State of Australian Cities National Conference (SOAC) 2015, Gold Coast, Australia.

The authors listed below have certified that:

1. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. they agree to the use of the publication in the student's thesis and its publication on the Griffith University database consistent with any limitations set by publisher requirements.

<table>
<thead>
<tr>
<th>Contributors</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abraham Leung</td>
<td>Conceiving, planning and the writing of the manuscript, GIS mapping, data analysis and the preparation of tables and figures. The candidate was also responsible for the revision made at the suggestion of the conference reviewers and the presentation of the paper during the conference.</td>
</tr>
<tr>
<td>Matthew Burke</td>
<td>Provided assistance in the theoretical framing of the research and provided editing revisions in the initial and the reviewed manuscript.</td>
</tr>
<tr>
<td>Jianqiang Cui</td>
<td>Provided editorial suggestions in the initial and the reviewed manuscript.</td>
</tr>
<tr>
<td>Anthony Perl</td>
<td>Provided editorial and conceptual suggestions in the initial and the reviewed manuscript.</td>
</tr>
</tbody>
</table>

Supervisor Confirmation: I have sighted email or other correspondence from all co-authors confirming their certifying authorship.

(Signed) ___________________________ (Date) 24, June, 2017

Co-principal Supervisor: A/Prof Matthew Burke
New Approaches to Oil Vulnerability Mapping for Australian Cities: The Case of South-East Queensland, the 200km City

Abraham Leung¹, Matthew Burke¹, Jianqiang Cui¹ and Anthony Perl²
¹Urban Research Program, Griffith University
²Department of Political Science, Simon Fraser University

Abstract: Australian cities are extremely dependent on oil for transportation, with relatively high automobile mode shares. ‘Forced car ownership’ is prevalent, especially in the outer suburbs of capital cities due to poor public transport services and connectivity. The potential harm caused by oil dependence and uncertain supply can be seen as a form of vulnerability. This paper develops and applies new approaches to better understand oil vulnerability and its spatial patterning. A new oil vulnerability framework that builds on previous approaches is provided, drawing on climate change vulnerability concepts of exposure, sensitivity and adaptive capacity. GIS-based oil vulnerability mapping is used to reveal the different dimensions across the urbanised coast of South-East Queensland (SEQ). This study is compared with previous approaches, notably Dodson and Sipe’s (2007) VIPER Index, and current regional transport and urban patterns. Consistent with previous studies, outer suburbs away from well-serviced public transport corridors are least prepared for sudden oil shock events, though subtle nuances are revealed using the new methods. This study revealed the multiple dimensions of oil vulnerability with a new visual classification technique. The resultant index could help planners and policy makers to holistically identify areas at high risk and provide more targeted responses. The new indicators and vulnerability mapping methods have a potential to be expanded to other urban jurisdictions within and beyond Australia.

1. Introduction

Australian cities are among some of the most car-dependent in the world. However, oil prices have been increasingly volatile since the 2000s. They reached extremely high levels in 2008 and 2011-2014, as shown in Figure 1. Despite the recent price falls, oil prices are still much higher than the levels between the 1980s and 1990s when suburban growth was expanding rapidly.

![Figure 1: Oil price fluctuations since 1987](Source: US Energy Information Administration, 2015)
Cities with high reliance on oil-based transport remain susceptible to the impacts of higher or fluctuating oil prices. However, progress on transport energy transition is slow, despite various governmental efforts to promote public transport and alternative fuel (Rotmans et al., 2001; Solomon and Krishna, 2011). This can be seen as a form of path dependency caused by vested interests in oil-related businesses and massive built-in oil consumption infrastructure and equipment (Cherp et al., 2011; Dodson, 2013; Geels, 2011). Car dependent urban forms also create 'lock-in' effect that makes transition to non-oil using modes a difficult task at individual and societal levels (Briggs et al., 2015; Unruh, 2000). Meanwhile despite fuel efficiency gains from newer vehicles, outer suburbs remain more affected by oil price increases due to longer average driving distance, lower socio-economic status and driving vehicles with less fuel efficiency (Li et al., 2013). If oil supply diminishes, and prices spike beyond 2008 peak levels, widespread disruption is likely in car-dependent societies and transportation systems. Calls for further research have been made to investigate the effects of increasing oil price on cities in order to better understand the dynamics of energy and financial stresses on urban structures and patterns (Dodson and Sipe, 2012; Renne and Fields, 2013). In response, new methods are tested to provide better ways to understand urban transport oil vulnerability in coastal SEQ, a fast growing 200km long conurbation strip comprising Brisbane, the Gold Coast, and the Sunshine Coast. The potential of adaptive measures that reduce urban transport oil vulnerability are investigated and the resultant conceptual framework is proposed to help guide future research.

2. Conceptualising Oil Vulnerability

The concept of oil vulnerability emerged as a future-looking concept to deal with the dual challenge of Peak Oil and climate change. Dodson and Sipe (2005) appeared to be the first to use this term in their ‘Vulnerability Index for Petroleum Energy Risks’ (VIPER) to describe socioeconomic impacts of increasing oil price on households in relation to transport. Their studies involved area indexing of a number of oil vulnerable indicators, shown visually on maps. They found that outer suburban areas are significantly more oil vulnerable than inner city areas, given they tend to be car dependent and poorly serviced by public transport but with lower socio-economic conditions and higher relative mortgage debt (Dodson and Sipe, 2008). Public and academic attention to oil vulnerability in Australia prompted government response at federal, state and local levels in the form of inquiries, reports and new planning instruments (Australian Senate, 2007; Queensland Government, 2009; Sunshine Coast Regional Council, 2010; Tasmanian Government, 2012). Yet the effectiveness and longevity of these responses is uncertain. Meanwhile, with readily available census data sources, Dodson and Sipe’s approach has been adopted by a number of researchers with localised versions used in Canada (Arico, 2007; Akbari and Nurul Habib, 2014), Melbourne (Fishman and Brennan, 2009), SEQ region (Runting et al., 2011) and six cities in the US (Sipe and Dodson, 2013). Paralleling advances in computation complexity in urban land-use and transportation modelling, advanced microsimulation and activity modelling techniques has been employed in more recent studies (Lovelace and Philips, 2014; Rendall et al., 2014). There remain research gaps on the relationship of oil vulnerability factors and transport infrastructure. This includes a lack of a clear conceptual framework for oil vulnerability studies, unlike more mature vulnerability fields such as climate change (Janssen et al., 2006; Choy et al., 2010; Measham et al., 2011), disaster management (Birkmann, 2007; Cardona, 2007) and development aid (Chambers, 1989; Watts and Bohle, 1993; Alwang et al., 2001).

The concepts from prevailing accepted frameworks of vulnerability provide a useful guideline in categorising oil vulnerability variables. Pioneering research on oil vulnerability conducted by Dodson and Sipe implicitly defines the term as ‘the potential exposure of households to adverse socioeconomic outcomes arising from increased fuel costs.’ In recent studies, Lovelace & Philips (2014) interpret oil vulnerability as the combination of local-level variables that would make coping with high oil prices harder and hence define oil vulnerability as ‘a combined probability and magnitude of negative effects resulting from high oil price or shortage scenarios’. In view that oil vulnerability research at the urban level has not been fully defined before, and without any preceding guidance, a commonly used framework by the Intergovernmental Panel on Climate Change (2001) is adapted as a framework for further oil vulnerability research. Oil vulnerability is therefore defined in this research as ‘the degree to which a system is susceptible to, or unable to cope with, adverse effects of oil price variability and extremes’. Three major components are adapted for oil vulnerability (Figure 2):

- Exposure (E) represents to what extent energy-related events are able to affect the system. It is usually measured by oil consumption variables, such as car ownership or distance of travel.
- Sensitivity (S) represents the degree to which a system is affected by both energy and non-energy drivers. It is often measured by social variables, such as income or socio-economic wellbeing.

- Adaptive capacity (AC) represents the ability of a system to change in a way that makes it better equipped to manage its future exposure and/or sensitivity to oil price influences. Adaptive capacity can be short term or long term and can include capacity for substituting mobility for other means of communication.

Adaptive capacity can involve complex social, economic and cultural adjustments, but there are difficulties in conceiving and measuring these. While there is potential in utilising information commutation technology (ICT) for trip substitution, the effect is contested: some suggest face-to-face meetings remain important and ICT may actually create more personal or business contact opportunities that could induce more travel demand (Aguiléra et al., 2012; Litman, 2005). Previously, public transport has been assessed by simple buffer analysis of public transport stops with room for further improvement (Runting et al., 2011). For long-term resilience, urban factors that can reduce oil use, such as widespread adaptation of alternative fuels or public transport remain largely untouched in existing oil vulnerability assessments.

**Study Area – the 200km city of South-East Queensland**

Figure 3 shows the urban extent of SEQ. This expansive urban region is facing a transport energy challenge given its overall low-density development with most travel by automobile (Spearritt, 2009). Extensive programs of motorway infrastructure (e.g.: tunnels, bridges) building remain the usual response to address traffic growth (Mees and Groenhart, 2012). Despite some positive signs of public transport revival, marked by the commencement of light rail on the Gold Coast in 2014, the car is still the dominant travel mode. From the most recent travel surveys, private vehicle mode share in SEQ for all trips remained over 80% with public transport accounting merely 8% in 2009 (Queensland Transport and Main Roads Department, 2009). This presents a significant oil vulnerability risk.
Figure 3: Urban areas and transport infrastructure of South-East Queensland
3. Methodology

Dodson and Sipe’s (2007, 2008) approach used census statistics to create a rough measure of vulnerability by ranking the proportion of households deemed to be vulnerable (owning more than 2 cars, driving to work, socio-economic disadvantage and having a home under mortgage). New metrics not included in Dodson and Sipe’s approach, such as public transport coverage, frequency and active transport, are included for the first time. Table 1 outlines the expanded set of variables used in this study with their respective vulnerability component groupings.

<table>
<thead>
<tr>
<th>Vulnerability Component</th>
<th>Variable</th>
<th>Transformed Value</th>
<th>Data Source</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td><em>E1</em>) Estimated average number of motor vehicle owned per dwelling</td>
<td>Converted into z-scores (standard deviation) of equal weighting</td>
<td>• 2011 Australian Census</td>
<td>Oil consumption for both work and non-work trips</td>
</tr>
<tr>
<td></td>
<td><em>E2</em>) Estimated oil-based fuel use of low occupancy vehicles (LOVs) per commuting trip (see Table 2)</td>
<td></td>
<td>• 2011 Australian Census</td>
<td>Oil consumption for work trips</td>
</tr>
<tr>
<td></td>
<td><em>E3</em>) Weighted average commuting distance</td>
<td></td>
<td>• 2006 Australian Census</td>
<td>Oil consumption for work trips</td>
</tr>
<tr>
<td>Sensitivity</td>
<td><em>S1</em>) Median weekly household income</td>
<td>Converted into z-scores (standard deviation) of equal weighting</td>
<td>• 2011 Australian Census</td>
<td>Short-term ability to pay for increasing oil prices</td>
</tr>
<tr>
<td></td>
<td><em>S2</em>) Socio-Economic Indexes for Areas (SEIFA): Index of Relative Socio-economic Advantage and Disadvantage (IRSAD)</td>
<td></td>
<td>• 2011 Australian Census</td>
<td>Long-term ability to pay for increasing oil prices</td>
</tr>
<tr>
<td>Adaptive Capacity</td>
<td><em>AC1</em>) Proportion of mode share that does not consume oil (railways, trams, walk and cycle)</td>
<td></td>
<td>• 2011 Australian Census</td>
<td>Ability to use non-oil based transport</td>
</tr>
<tr>
<td></td>
<td><em>AC2</em>) Proportion of area within 400m of public transport stop ranked by level of service in weekdays (see Table 3)</td>
<td>Converted into z-scores (standard deviation) of equal weighting</td>
<td>• 2015 Translink General Transit Feed Specification (GTFS) data</td>
<td>Ability to use public transport instead of driving</td>
</tr>
<tr>
<td></td>
<td><em>AC3</em>) Walkability indices (Walk Score, 2015, see Table 4)</td>
<td></td>
<td>• 2015 Walk Score (Suburb level)</td>
<td>Ability to walk or cycle instead of driving</td>
</tr>
<tr>
<td></td>
<td><em>AC4</em>) Employment density (jobs / sq.km)</td>
<td></td>
<td>• 2011 Australian Census</td>
<td>Ability to walk or cycle to work</td>
</tr>
<tr>
<td></td>
<td><em>AC5</em>) Percentage of area within 400m buffer of electric public transport corridors (Railways and tramways)</td>
<td></td>
<td>• 2015 Translink data</td>
<td>Ability to provide non-oil based transport in the long run</td>
</tr>
</tbody>
</table>

**Exposure (E)**

This component measures the risk exposure of households to increasing oil price. Variables selected for this component made reference from those used in the VIPER index. However the selection of ‘more than 2 cars’ is changed to computing the ‘average car ownership per dwelling’ of motor vehicle responses in the census. The census questionnaire only provides response categories reporting up to ‘four or more’ motor vehicles owned. It is assumed the respondent households owning more than 5 cars are not common, given the very low numbers involved. The 2006 values of journey to work distance are used in this study as it is readily available to this author and travel distance in SEQ overall remained largely the same between 2006 and 2011. For variable *E2* regarding the average fuel...
use of low-occupancy vehicles, this is computed by the average fuel use value from the Motor Vehicle Survey of Australian Bureau of Statistics (2013) as shown in Table 2. This reflects the fuel use differences of cars, trucks and motorcycles as surveyed in the census. It is difficult to estimate the exact fuel use of taxi because part of the journey is unoccupied by the passenger. Previous literature has suggested taxis have higher VKT and fuel use (ranging from 33% to 190%) than car trips depending on the length of the unoccupied journey after serving passengers (Hillman and Whalley, 1983; Stead, 1999). There is, however, no reliable data for Australia on the fuel use intensity of taxi trips. For this study, it is assumed the fuel intensity of a taxi trip would be the same as a car trip.

To reflect a more accurate fuel use of areas, a weighted average commuting distance is estimated from the network distance (road distance) between origin–destination (O-D) zones and the reported commuting figures.

Table 2: Fuel use loadings used for variable E2

<table>
<thead>
<tr>
<th>LOV types for journey to work in ABS Census</th>
<th>Average per capita fuel consumption (L/100km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Car (as driver) and Taxi</td>
<td>11.1</td>
</tr>
<tr>
<td>Car (as passenger)</td>
<td><strong>Included in driver count</strong></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>5.9</td>
</tr>
<tr>
<td>Truck</td>
<td>22.6</td>
</tr>
</tbody>
</table>

(Source: ABS, 2013)

Sensitivity (S)

This component measures the ability to withstand future oil price increases. In the VIPER study, SEIFA is employed as it is a robust measure to denote relative advantage or disadvantage in socio-economic status (Australian Bureau of Statistics, 2006). The SEIFA values represent a longer-term ability to withstand risks as the level of income, education level and ownership of economic assets are also accounted for in this index. To reflect a more short-term ability to respond, median household income is included as a direct measure despite SEIFA having included income level within its weighting.

Adaptive Capacity (AC)

This component has been the least surveyed area in previous oil vulnerability assessments. Runtting et al’s (2011) study included a simple buffer of public transport stops with 400m (or 5 min walking distance buffer). However, this is a crude measure of public transport service and accessibility. With increasing proliferation of public transport data in the form of General Transit Feed Specification (GTFS) and GIS analytical capacities, it is possible to estimate public transport service level by its frequency (Antrim and Barbeau, 2013; Keller, 2012). A pedestrian walk-shed distance of 400m is calculated with road network data. The level of service is measured by a stop frequency scoring scheme similar to the one used in the Land Use & Public Transport Accessibility (LUPTAI) Index (Pitot et al., 2006). While it is acknowledged that frequency does not represent actual accessibility, it remains an important indicator of public transport usability (Walker, 2012). In addition, the potential to use active transport is considered by an objectively measured walkability index - Walk Score™. Walk Score™ utilises suburb level accessibility data and has been validated in American research for revealing walking patterns and better health outcomes (Duncan et al., 2011). In Australia, such validation is lacking for the time being and this is noted as a potential limitation.

Table 3: Public transport level of service scores for variable AC2

<table>
<thead>
<tr>
<th>Frequency (minutes)</th>
<th>Trips per hour calculated from GTFS data</th>
<th>Public Transport Level of Service Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>30</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>60</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>more than 60</td>
<td>less than 1</td>
<td>1</td>
</tr>
</tbody>
</table>
Table 4: Description of Walk Score™ (2015) values for variable AC3

<table>
<thead>
<tr>
<th>Description</th>
<th>Walk Score (1 - 100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walker’s Paradise</td>
<td></td>
</tr>
<tr>
<td>Daily errands do not require a car</td>
<td>90-100</td>
</tr>
<tr>
<td>Very Walkable</td>
<td></td>
</tr>
<tr>
<td>Most errands can be accomplished on foot</td>
<td>70-89</td>
</tr>
<tr>
<td>Somewhat Walkable</td>
<td></td>
</tr>
<tr>
<td>Some errands can be accomplished on foot</td>
<td>50-69</td>
</tr>
<tr>
<td>Car-Dependent</td>
<td></td>
</tr>
<tr>
<td>Most errands require a car</td>
<td>25-49</td>
</tr>
<tr>
<td>Car-Dependent</td>
<td></td>
</tr>
<tr>
<td>Almost all errands require a car</td>
<td>0-24</td>
</tr>
</tbody>
</table>

(Adapted from Pitot et al. (2006))

The differences in vulnerability components for selected local government areas in SEQ are shown in Table 5. The exposure, sensitivity and adaptive capacity variables are mean adjusted by converting into z-scores (standard deviation values) for which 0 is the mean value.

Table 5: Descriptive statistics, mean values by Local Government Areas (LGAs)

<table>
<thead>
<tr>
<th>Indicator Variables</th>
<th>Brisbane</th>
<th>Gold Coast</th>
<th>Ipswich</th>
<th>Logan</th>
<th>Redland</th>
<th>Moreton Bay</th>
<th>Sunshine Coast</th>
<th>Noosa</th>
<th>All LGAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 (cars per dwellings)</td>
<td>1.60</td>
<td>1.72</td>
<td>1.71</td>
<td>1.81</td>
<td>1.84</td>
<td>1.78</td>
<td>1.67</td>
<td>1.56</td>
<td>1.69</td>
</tr>
<tr>
<td>E3 (average JTW distance, km)</td>
<td>10.93</td>
<td>15.70</td>
<td>17.10</td>
<td>18.11</td>
<td>16.97</td>
<td>19.66</td>
<td>18.67</td>
<td>14.73</td>
<td>14.95</td>
</tr>
<tr>
<td>S1 (income, $/week)</td>
<td>1644.55</td>
<td>1270.66</td>
<td>1282.20</td>
<td>1337.89</td>
<td>1462.05</td>
<td>1368.47</td>
<td>1124.95</td>
<td>1032.01</td>
<td>1433.41</td>
</tr>
<tr>
<td>S2 (SEIFA)</td>
<td>1055.14</td>
<td>1013.26</td>
<td>952.60</td>
<td>962.56</td>
<td>1025.83</td>
<td>994.38</td>
<td>1002.37</td>
<td>1002.63</td>
<td>1018.26</td>
</tr>
<tr>
<td>A1 (oil-free mode share, %)</td>
<td>12.87</td>
<td>5.75</td>
<td>8.45</td>
<td>4.43</td>
<td>5.89</td>
<td>9.02</td>
<td>5.37</td>
<td>6.54</td>
<td>9.00</td>
</tr>
<tr>
<td>A2 (public transport level of service, 1-5 scores)</td>
<td>2.40</td>
<td>1.78</td>
<td>1.54</td>
<td>1.57</td>
<td>1.56</td>
<td>1.48</td>
<td>1.09</td>
<td>1.46</td>
<td>1.88</td>
</tr>
<tr>
<td>A3 (walkability, 1-100 scores)</td>
<td>59.87</td>
<td>47.69</td>
<td>35.16</td>
<td>41.42</td>
<td>36.11</td>
<td>38.41</td>
<td>39.94</td>
<td>41.86</td>
<td>48.61</td>
</tr>
<tr>
<td>A4 (employment density, jobs/km²)</td>
<td>1340.41</td>
<td>551.79</td>
<td>214.81</td>
<td>312.95</td>
<td>252.89</td>
<td>209.03</td>
<td>332.44</td>
<td>152.46</td>
<td>734.83</td>
</tr>
<tr>
<td>A5 (area within electric public transport corridor, %)</td>
<td>16.91</td>
<td>9.94</td>
<td>12.88</td>
<td>7.83</td>
<td>7.75</td>
<td>8.29</td>
<td>3.21</td>
<td>0</td>
<td>11.68</td>
</tr>
</tbody>
</table>
GIS methods were used to conduct spatial analysis and to visualise data and to identify patterns of oil vulnerability. Standard deviation z-scores and composite aggregation of vulnerability components are used in this study, which is a common normalisation procedure in other vulnerability assessments, such as climate change (Cutter et al., 2003). The advantage of this is the spatial variance of each component can be better preserved. It can also be directly computed into a component oil vulnerability (OV) score using the equation:

\[ OV = E + S - AC \]

4. Results and Discussion

The previous VIPER method looked at the Brisbane metropolitan area only for Queensland and other capital cities in Australia. This study attempts to examine oil vulnerability at a regional scale. Advancing from VIPER or VAMPIRE oil vulnerability assessment methods that use a simple percentile group ranking (i.e.: 1-5 scores assigned by percentile breaks of 10, 25, 50, 75 and 90), the methodology used in this oil vulnerability assessment preserves the variation of oil vulnerability components. Figure 4 presents a VIPER index constructed using the same data of this study at Statistical Area 1 (SA1) level, as compared to the new method. The values of the individual oil vulnerability components are shown in Figure 5. The exposure map reflects oil use patterns. The sensitivity map shows income and socio-economic status levels, which approximates the ability to withstand higher oil prices. This adaptive capacity map reflects the relative ability of each area in adapting to higher oil prices. Finally, the data was classified into nine oil vulnerability classes, based on their respective potential impact and adaptive capacity values (see Table 6). Figure 6 provides the outputs of this classification, mapped across SEQ. It reveals the detailed extent of potential oil vulnerability and adaptive capacity that has not been shown in prior studies. The red areas denote high potential impact with low adaptive capacity. These areas are mostly located in outer suburban areas. Table 7 shows the percentage of population within each oil vulnerability class by local government area (LGA).

As displayed in Figure 4, the composite measure reveals a more nuanced spatial variation of oil vulnerability than the VIPER method, which a less concentric pattern radiating out of Brisbane can be seen. This is made possible by the new variables and visualisation method employed in this research. The inclusion of public transport accessibility and walkability variables can help identify highly vulnerable areas not detected in the VIPER approach. These areas tend to be at the urban fringes and peri-urban areas, in particular within the Moreton Bay and Logan LGAs. The new approach reflects the poly-centric urban pattern of South East Queensland as outer urban centres such as Ipswich are also assessed to be less vulnerable via this new approach. Another advantage of our approach is a more systematic analysis of what constitutes overall oil vulnerability. Confirming previous studies (Dodson and Sipe, 2007; Runting et al., 2011), the central areas of Brisbane with better public transport services and higher income levels are assessed to be least vulnerable (green areas). The outer suburbs of Brisbane and the growth areas in the LGAs of Ipswich, Logan, Redland and Moreton Bay all have higher E+S value and low AC. The more distinct urban centres of Gold Coast and Sunshine Coast are also found to have higher ES and low AC despite their ability to contain employment and commuting trips. However, the Gold Coast still has areas with low E+S and high AC. This could be due to its recent introduction of light rail services which helped to boost the AC score significantly as oil-free electric public transport is considered in this assessment. Whereas for the Sunshine Coast, the low E+S and High AC areas are sparse. For a SEQ region-wide perspective, high E+S with low or mid AC population outnumbers low E+S with high or mid AC population.

This assessment highlights the importance of sustainable transport. The ‘Avoid-Shift-Improve’ approach has been recognised as an effective way to reduce oil use and congestion simultaneously (Dalkmann and Brannigan, 2007; Schipper and Marie-Lilliu, 1999). Yet, better planning of urban development is imperative in reducing oil vulnerability. Outer suburban areas are seen to be highly oil vulnerable, characterised with high car use, lower socio-economic status but with low adaptive capacity. There is a strong case to make public transport more competitive and attractive given active transport has only a short range. Gilbert and Perl’s (2009) argument for electricity grid-connected vehicles to address oil vulnerability is also supported by this new assessment. Echoing Dodson and Sipe (2007; 2011) and Mees (2009), a network approach for improved public transport is urgently needed to reduce oil vulnerability in SEQ, which requires substantial infrastructure investment. Whilst the SEQ 2031 Transport Plan indicated expansion in railway infrastructure (Queensland Government, 2011) only the Moreton Bay Railway Link is confirmed to be completed. This research calls for greater attention on oil vulnerability and prompt investigation of providing energy-efficient transport...
infrastructure to help alleviate transport cost pressures of the most affected areas, in particular the red areas shown in our Figure 4’s Composite Index and Figure 6.

Figure 4: Comparing the composite scores of the new method (left) and previous methods (right, VIPER Scores by Dodson & Sipe, 2007) using the same data
Figure 5: The oil vulnerability components of South-East Queensland’s more urbanised local government areas
Table 6: Oil vulnerability classification

<table>
<thead>
<tr>
<th>Adaptive Capacity (AC)</th>
<th>33% percentile below mean values</th>
<th>33% ± mean</th>
<th>33% percentile above mean values</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;33%</td>
<td>Low E + S High AC</td>
<td>Mid E + S High AC</td>
<td>High E + S High AC</td>
</tr>
<tr>
<td>33% ± mean</td>
<td>Low E + S Mid AC</td>
<td>Mid E + S Mid AC</td>
<td>High E + S Mid AC</td>
</tr>
<tr>
<td>&lt;33%</td>
<td>Low E + S Low AC</td>
<td>Mid E + S Low AC</td>
<td>High E + S Low AC</td>
</tr>
</tbody>
</table>

Table 7: Comparison of the percentage of population of each oil vulnerability class across Local Government Areas

<table>
<thead>
<tr>
<th>Oil Vulnerability Classes</th>
<th>Brisbane</th>
<th>Gold Coast</th>
<th>Ipswich</th>
<th>Logan</th>
<th>Redland</th>
<th>Moreton Bay</th>
<th>Sunshine Coast</th>
<th>Noosa</th>
<th>ALL LGAs avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>High E+S Low AC</td>
<td>9.8%</td>
<td>29.0%</td>
<td>21.3%</td>
<td>27.0%</td>
<td>34.4%</td>
<td>32.3%</td>
<td>33.7%</td>
<td>11.0%</td>
<td>21.7%</td>
</tr>
<tr>
<td>High E+S Mid AC</td>
<td>10.9%</td>
<td>7.4%</td>
<td>7.2%</td>
<td>9.6%</td>
<td>18.5%</td>
<td>9.2%</td>
<td>2.9%</td>
<td>0.6%</td>
<td>9.4%</td>
</tr>
<tr>
<td>High E+S High AC</td>
<td>5.8%</td>
<td>2.4%</td>
<td>2.9%</td>
<td>1.5%</td>
<td>3.5%</td>
<td>1.3%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>3.3%</td>
</tr>
<tr>
<td>Mid E+S Low AC</td>
<td>4.3%</td>
<td>9.4%</td>
<td>19.0%</td>
<td>11.3%</td>
<td>4.2%</td>
<td>11.8%</td>
<td>21.5%</td>
<td>26.2%</td>
<td>9.4%</td>
</tr>
<tr>
<td>Mid E+S Mid AC</td>
<td>15.2%</td>
<td>13.4%</td>
<td>7.0%</td>
<td>15.6%</td>
<td>15.4%</td>
<td>12.5%</td>
<td>14.1%</td>
<td>15.3%</td>
<td>14.0%</td>
</tr>
<tr>
<td>Mid ES High AC</td>
<td>15.6%</td>
<td>8.1%</td>
<td>3.0%</td>
<td>4.3%</td>
<td>6.0%</td>
<td>7.3%</td>
<td>2.3%</td>
<td>0.0%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Low E+S Low AC</td>
<td>1.0%</td>
<td>3.3%</td>
<td>9.7%</td>
<td>4.7%</td>
<td>7.9%</td>
<td>3.4%</td>
<td>6.7%</td>
<td>13.9%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Low E+S Mid AC</td>
<td>6.2%</td>
<td>8.8%</td>
<td>16.9%</td>
<td>12.6%</td>
<td>6.6%</td>
<td>10.4%</td>
<td>12.5%</td>
<td>25.4%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Low E+S High AC</td>
<td>31.2%</td>
<td>18.2%</td>
<td>13.0%</td>
<td>13.4%</td>
<td>3.5%</td>
<td>12.0%</td>
<td>6.3%</td>
<td>7.6%</td>
<td>19.9%</td>
</tr>
</tbody>
</table>

(Underline denotes the figure is significantly higher than overall area average)
Figure 6: Urban transport oil vulnerability classification map of potential oil price impact (exposure plus sensitivity) and adaptive capacity
5. Conclusion

This paper advances previous oil vulnerability research by establishing clear conceptualisations of exposure, sensitivity and adaptive capacity in the context of the role and impacts of oil supply and price fluctuations in transport and land use systems. The new methods use data that are readily available from the census, supplemented with other publicly available datasets. This method, therefore, can be expanded to other Australian cities with ease. Given the conceptual framework, it should also be possible to ‘plug-and-play’ urban data for cities beyond Australia for such analysis as well. Caution, however, needs to be exercised when drawing direct comparisons with other urban jurisdictions.

There is growing evidence of oil vulnerability and transport disadvantage in particular at the outer fringes of Australian metropolitan areas. Despite increased governmental awareness of oil vulnerability in Australia as reflected in recent plans and policy, the effectiveness of these measures on addressing this issue by integrated transport and land use planning remains untested. Further research on the verification of actual transport energy use and cost statistics with oil price could provide empirical evidence of oil vulnerability. Statistical tools such as regression modelling can be used to correlate other census statistics with observed travel behaviour. Recent comments of a ‘peak car travel’ phenomenon and its relation to demographic changes emerged in transport fields, which is marked by delayed licence acquisition of young people (Delbosc and Currie, in press) and the ageing of baby-boom (and car-boom) generation (Newman and Kenworthy, 2011; Zeitler and Buys, 2014). Future studies on oil vulnerability could also include age demographics and statistics of driving licence data to allow cross-comparison of driving behaviour and oil price trends. For a more fine-grained approach, household travel surveys may be used in conjunction with other census statistics to develop models to further interrogate the socio-economic determinants of oil vulnerability. Apart from data-based approaches, qualitative understanding of the perception of urban actors and decision makers can help to shed light on what policy and societal barriers are in place against the measures to better oil-proof our cities.

As a final remark, this research hopes to reignite awareness on oil vulnerability even though oil price pressure has eased due to recent global surplus in oil production. There is still ample room to improve understanding of oil vulnerability and energy transition of cities. The nexus of energy, transport and land use planning remain under researched and warrants further research. Scholarly attention in this nexus is still scant due to data limitations. Future research in this area would help to improve theoretical, conceptual and practical understanding of oil vulnerability. This can help to inform policy of transport in an energy-constrained future while responding to the global climate change challenge at the same time.

References


doi:10.1007/s13762-014-0641-9


Queensland Transport and Main Roads Department, 2009. Travel in south-east Queensland.


8. The tale of two (very different) cities - Mapping the urban transport oil vulnerability in Brisbane and Hong Kong

The work presenting here in Chapter 8 was previously published as Leung, A., Burke, M., Cui, J., 2016. The tale of two (very different) cities - Mapping urban transport oil vulnerability of Brisbane and Hong Kong. Presented at the 14th World Conference on Transport Research 2016, Shanghai, China.

It is later submitted as Leung, A., Burke, M., Cui, J., (Accepted). The tale of two (very different) cities - Mapping the urban transport oil vulnerability of Brisbane and Hong Kong. Transportation Research Part D: Transport and Environment. Accepted for inclusion in the Transportation Research Part D: Transport and Environment on 23/10/2017.

The earlier Chapter 7 offers a methodological basis for intra-urban analysis of oil vulnerability. In this chapter, the author presents a paper that expands the intra-urban oil vulnerability mapping analysis to the international stage. The oil vulnerability conceptual framework and the normalisation approach based on a z-score are tested in two very different cities – Hong Kong and Brisbane. This paper first outlines the key differences of the two study areas, then the selection of data is explained, which proves to be more challenging than one study area alone. The metrics need to be available in both cities, and care must be taken to harmonise data differences, and to ensure the comparison is appropriate. Fortunately, Hong Kong has datasets available with fine-grain resolution census tract that are comparable to Australia’s. The result shows a very contrasting
pattern – Hong Kong, with excellent public transport, allows its commuters, on average, to travel on public transport for slightly longer distances than commuters in Brisbane. This proves that Hong Kong’s land use and transport policy of rail connected “New Towns” at the outer areas and its “Rail as backbone” policy are working to reduce oil vulnerability. Active transport is also considered in this paper, which shows that the authorities Brisbane are more willing to invest in active transport that of Hong Kong. For policy implications, it is acknowledged that the model that works in Hong Kong may not apply in Brisbane, or in other Australian cities. It is proposed that an investigation of the policy-making and response to fuel price increase challenges to be carried out in a qualitative manner, which is detailed in Chapter 9.

Research questions addressed in this paper and contributions

Primary question
How do oil price change impacts vary spatially within cities?

Summary of contributions
First study to compare intra-urban oil vulnerability across cities
8.1 Statement of contribution to co-authored published paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:

**Leung, A., Burke, M., Cui, J.,** (Accepted subject to revisions). The tale of two (very different) cities - Mapping the urban transport oil vulnerability of Brisbane and Hong Kong. *Transportation Research Part D: Transport and Environment.*

The authors listed below have certified that:

1. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. they agree to the use of the publication in the student's thesis and its publication on the Griffith University database consistent with any limitations set by publisher requirements.

<table>
<thead>
<tr>
<th>Contributors</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abraham Leung</td>
<td>Conceiving, planning and the writing of the manuscript, GIS mapping, data analysis and the preparation of tables and figures. The candidate was also responsible for the revision made at the suggestion of the conference reviewers and the presentation of the paper during the conference.</td>
</tr>
<tr>
<td>Matthew Burke</td>
<td>Provided assistance in the theoretical framing of the research and provided editing revisions in the initial and the reviewed manuscript.</td>
</tr>
<tr>
<td>Jianqiang Cui</td>
<td>Provided editorial suggestions in the initial and the reviewed manuscript.</td>
</tr>
</tbody>
</table>

Supervisor Confirmation: I have sighted email or other correspondence from all co-authors confirming their certifying authorship.

(Signed)  ___________________________  (Date) 24, June, 2017

Co-principal Supervisor: A/Prof Matthew Burke
The tale of two (very different) cities - Mapping the oil vulnerability of Brisbane and Hong Kong

Abstract: The volatility in oil prices has been a major concern to car dependent cities, in particular the period of higher oil prices circa 2005-2015. Higher transport costs could exacerbate transport disadvantage and cause social exclusion, yet the fine scale comparison of the spatial variation of oil vulnerability within cities has not been fully explored to date. This paper studies the comparative experience of spatial urban oil vulnerability within two very different Asia Pacific cities – Brisbane and Hong Kong. Census and journey-to-work data are used to evaluate and map oil vulnerability based on prevailing vulnerability concepts of exposure and sensitivity, with a specific focus on adaptive capacity. A cross-city composite indicator is created to visualise car dependence and oil vulnerability based on various socio-demographic, public and active transport indicators. This study allows direct comparison of the stark contrasts between one Asian and one western city in terms of urban form (dispersed vs. compact) and mode share (transit vs. car based). Both of these cities’ urban transport policies are also examined to explain their resulting oil vulnerability. The results show transit-led transport policies and land-use matching with rail and active infrastructure investments which reduce transport oil consumption, and could offer longer term resilience.

Keywords: Peak oil; oil vulnerability; vulnerability mapping; car dependence; composite indicator

1. Introduction
1.1 Background
Oil prices have been increasingly volatile in the 2000s. They reached extremely high levels in 2008 and 2011-2014 and have caused concern in many car-dominant cities, in particular in oil importing nations such as Australia and cities like Hong Kong. Unconventional fossil fuels made possible by fracking might have caused a global collapse in the oil price (Khan, 2017), yet prices do not defy the physics of a reduction in energy return on (energy) invested (EROI) on oil extraction. ‘Peak conventional oil’ remains a problem as transport contributes up to 93% of global oil use and is a main contributor of carbon emissions (International Energy Agency, 2009). The transport sector remains highly reliant on an affordable and constant oil supply. Many cities have embraced widespread car ownership and usage, in particular, the New World cities of North America and Australia. At the same time, the Asia Pacific region is experiencing rapid industrialisation and urbanisation with drastic changes being observed in the past few decades (Marcotullio, 2003). Increased wealth and economic development also bring exponential growth in transport needs. While municipal policy makers acknowledge the need for sustainable transport, policies to create viable public transport systems are in conflict with the popular aspiration for western style private transport by means of car ownership (Barter et al., 2003; Hickman and Banister, 2014). Figure 1 shows the differing pace of motorisation: Australian cities are mature automobile cities with steady car ownership growth over time.
Asia Pacific cities are generally undergoing rapid motorisation, Japanese cities started earlier in terms of private motoring, and South East Asia and especially China are now ‘catching up’, due to increasing wealth and strong aspirations for car ownership. Exceptions are found in certain dense cities such as Hong Kong, Shanghai and Singapore which have more stringent car control measures and which have developed efficient mass public transport networks (Cullinane, 2003; Han and Seo, 2010).

![Motorisation Trends in Asia Pacific Cities](image)

**Figure 1: Trends in motorisation in various selected Asia Pacific cities**
(Data source: Brahmanand Mohanty et al., 2012; Kenworthy and Laube, 2001; Kenworthy et al., 1999)

Gilbert and Perl (2012) suggest that the radical changes in transport mode and energy choice concerning the continual use of oil may spark a ‘transport revolution’ due to the following reasons:

1. Energy security and reducing the risk of international conflict over energy resources (66% of the world’s oil reserves are located in the Middle East).
2. Climate change and carbon emissions.
3. Sustainability (oil supplies are finite and are not renewable).
4. Pollution (airborne emissions from tailpipes, water pollution from oil runoff and solid waste of disused cars).

Energy security risks remain real as shipping lines for oil transport are vulnerable to disruptions that may cause a sudden oil supply shortfall (Blackburn, 2013). Both Hong Kong and Australia are heavily reliant on foreign oil supply. It is not for no reason that China is building a land route via Pakistan and a sea route with stronger military support to maintain oil supply from the Gulf (aka. the One Belt, One Road initiative). This is also evidenced by Australia’s embarking on a US$38 billion submarine building program, in part to...
protect its own off-shore oil and gas infrastructure, and to ensure that shipping lanes can continue to supply oil to Australia. It remains possible that oil prices rise again, with wide-ranging implications for car-dependent societies. There is also growing concern among the scientific community about global warming and sea level rise (Clark et al., 2016), and there is increasing consensus that continued reliance on oil is not sustainable (Chauvet et al., 2012; Glynn et al., 2014; Newman et al., 2009; Sovacool, 2007). To phase out oil, a transition in transport energy by promoting alternative fuel has been proposed (Brandt et al., 2013). While electric vehicles (EVs) are seen as a likely solution for reducing oil dependence (Stein 2013), a corresponding socio-technical system transition, such as changes in social mobility practices and infrastructure provision are necessary (Cohen, 2012; Dodson, 2013; Geels, 2012). Even in an aggressive promotion scenario (China as a case study), with rapid deployment of clean energy and EVs, fuel use and emission will peak at the soonest in 2030 (Zhao and Heywood, 2017). In addition, there are concerns on battery material (commonly lithium or rare earths) resource supply (Grosjean et al., 2012) and the likely inequity of EV ownership patterns due to high initial ownership costs (Li et al., 2017b; Wells, 2012).

The progress of large-scale replacement of internal combustion engines remains slow, despite various national efforts over recent decades to promote alternative energy source for vehicles (Rutherford and Coutard, 2014; Warren et al., 2016). Path dependence of the continued oil use remains due to vested interests, century-long investments in oil-related infrastructure and technology, from oil production (oil wells), oil transport (pipelines, tankers) to oil consumption (automobiles) (Cherp et al., 2011, p. 2011; Geels, 2011; Klitkou et al., 2015). Depending on the global oil supply, the cost of retrofitting the world’s transport system is gigantic. It might take many decades, given the sheer numbers of oil-based infrastructure and equipment. With the exception of grid-connected modes (e.g., electric rail), oil is likely to retain its dominance in most motorised transportation, in particular for automobiles. Apart from energy supply concerns, policy makers tend to focus on equipment and fleet (for instance, alternative fuel vehicles) but are not addressing the root of the problem - oil consumptive urban form and infrastructure (Jaccard et al., 1997). Analyses of the extent to which the urban and transportation systems could cope with such shocks are often based on fuel price elasticity analysis (Becker et al., 1976; Chao et al., 2015; Jung and Yoo, 2014; Keyes, 1982; Wang and Skinner, 1984), which measures the responsiveness of fuel use to price changes. This approach does not adequately consider the issue of social equity and spatial disadvantage caused by different levels of transport services provision within a city (Lucas et al., 2016).

1.2 Emergence of ‘oil vulnerability’

In the recent years during which oil prices rose, the concept of ‘oil vulnerability’ emerged as a forward-looking concept in dealing with the dual challenges of peak oil and climate change in Australia (Dodson and Sipe, 2007). Oil vulnerability mapping is a particularly powerful tool in identifying areas that require urgent attention and intervention (Preston et al., 2011; Reid et al., 2009). The impact of Dodson’s and Sipe’s (2007, 2008; 2013) research, which spurred public attention on oil vulnerability, demonstrates the value of mapping
based research (Australian Senate, 2007; Brisbane City Council, 2007; New Zealand Transport Agency, 2008; Queensland Government, 2007; Sunshine Coast Regional Council, 2010; Tasmanian Government, 2012). Most of the researches before were largely limited to Europe, North America and Australasia. There is scant research into broader international experiences of oil vulnerability at a local level. To this end, this study aims to create a methodology to extend the analysis of oil vulnerability to Asian cities, with the use of commonly available indicators across jurisdictions. This should make a contribution to international understandings about car dependence and the quality of urban transport systems. This helps fill the gaps of Newman’s and Kenworthy’s (1989; 1999) research on car dependence and oil, which used a comparative study of aggregated urban data alone.

This paper is organised as follows. A literature review is presented in Section 2 to further explain the concept of oil vulnerability and to develop a conceptual framework for this research. The scope of the paper and the justification for the choice of Brisbane and Hong Kong is then provided in Section 3. The methods are outlined in Section 4, including the choice of variables for analysis. The results are then provided in Section 5, with a discussion of the patterns of oil vulnerability identified in the two cities, by sub-region statistics and in city-wide mapping outputs. The paper concludes in Section 6, with a brief reflection on contributions, limitations and on future research directions.

2. Literature Review of oil vulnerability and car dependence studies

Research into oil vulnerability, or fuel price related impacts on urban transport, is mostly undertaken at three major levels. The first is using the entire city or urban area as the unit of analysis. Key examples are Newman and Kenworthy’s (1989) work in establishing the relationship between population density and estimated fuel consumption per capita. Studies at this level are adept at making international comparisons, but are less able to show the internal spatial differences within an urban area. On a microscopic scale, a number of studies looked at disaggregated data, usually treating households or persons as the unit of analysis (Berry et al., 2016; Mattioli et al., 2016a; Mayer et al., 2014). This level of analysis can establish the level of fuel stress (fuel expenditure minus disposable income) or the response to fuel price changes (elasticity). The drawback is cost and lack of spatial information - large sample surveys are expensive to conduct, and the microdata of household expenditure surveys offered by government statistical agencies usually does not provide the location of the respondent due to confidentiality. In the period of heightened oil prices since 2005, urban scholarship has seen renewed urban interest in oil prices. A new form of study has looked at an intra-urban scale, which treats a census tract area as a unit of analysis. This was first pioneered by Dodson and Sipe (2005), and in this study they created the recent notion of ‘oil vulnerability’. Their study is likely the first to use fine grained census tracts to construct composite indicators as a measure of the potential impacts of rising fuel prices on households. The method has also been adapted by various authors and in a number of locations, as outlined in Table 1. The advantage of using composite indicators for oil vulnerability is that it allows spatial analysis of oil vulnerability at intra-urban scale.
### Table 1: Selected spatial-geographical oil vulnerability studies operating at intra-urban scale

<table>
<thead>
<tr>
<th>Source</th>
<th>Location (Country)</th>
<th>Main Approach</th>
<th>Exposure</th>
<th>Adaptive Capacity</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dodson and Sipe (2007) (VIPER Index)</td>
<td>Brisbane, Sydney, Melbourne (Australia)</td>
<td>Composite index with mapping</td>
<td>1. Proportion of households with two or more motor vehicles; 2. Journey to work (JTW) car modal share</td>
<td>Not specified</td>
<td>1. Socio-economic status (SEIFA index)</td>
</tr>
<tr>
<td>Dodson and Sipe (Dodson and Sipe, 2008) (VAMPIRE Index)</td>
<td>Brisbane, Sydney, Melbourne in (Australia)</td>
<td>Composite index with mapping</td>
<td>1. Proportion of households with two or more motor vehicles; 2. Journey to work car modal share</td>
<td>Not specified</td>
<td>1. Mortgage 2. Median Household Income</td>
</tr>
<tr>
<td>Fishman and Brennan (2010)</td>
<td>Melbourne (Australia)</td>
<td>Composite index with mapping</td>
<td>1. Average weekly fuel use 2. Percentage of non-automobile weekday travel (all trips)</td>
<td>1. Mode share including public and active transport.</td>
<td>1. Average personal income</td>
</tr>
<tr>
<td>Runting et al. (2011)</td>
<td>South East Queensland, (Australia)</td>
<td>Composite index with mapping and dimension table</td>
<td>1. Weighted average JTW distance on road network 2. Car ownership (≥ 2) 3. JTW by car 4. Weighted average JTW distance</td>
<td>1. Proportion of non-motorised access to public transport</td>
<td>1. Socio-economic status (by SEIFA index)</td>
</tr>
<tr>
<td>Büttner et al. (2013)</td>
<td>Munich (Germany) and Lyon (France)</td>
<td>Composite index with mapping</td>
<td>1. Munich: Vehicle-km per capita 2. Lyon: Per capita commuting distance by private car</td>
<td>1. Total number of accessible jobs 2. Within one hour by public transport at 3. Peak time</td>
<td>1. Munich: Average monthly income 2. Lyon: Unemployment rate</td>
</tr>
<tr>
<td>Akbari and Habib (2014)</td>
<td>Toronto (Canada)</td>
<td>Composite index with mapping</td>
<td>1. Proportion of households with two or more motor vehicles; 2. Car modal share of all trips</td>
<td>Not specified</td>
<td>1. Median household income 2. Prevalence of low income after tax</td>
</tr>
<tr>
<td>Lovelace and Philips (2014) (‘Hybrid vulnerability index’)</td>
<td>Yorkshire and Humber (United Kingdom)</td>
<td>Spatial microsimulation and mapping</td>
<td>1. Average proportion of individual’s energy budget spent on commuting</td>
<td>1. Distance to employment centre; 2. Proportion of work trips made by car</td>
<td>Not specified</td>
</tr>
<tr>
<td>Rendall et al. (2014) (VOILA Index)</td>
<td>Christchurch (New Zealand)</td>
<td>Activity modelling and mapping</td>
<td>1. Average household car ownership 2. Energy consumption costs (by odometer)</td>
<td>1. Estimation of average ‘minimum’ required transport energy consumption</td>
<td>1. Median income</td>
</tr>
</tbody>
</table>
Research into ‘oil vulnerability’ has improved since Dodson and Sipe’s 2005 study. Recent research uses more sophisticated methods, such as minimum energy accessibility modelling (Rendall et al., 2014) and spatial microsimulation (Lovelace and Philips, 2014). However, it is more data intensive and requires a great deal of specialist knowledge to perform analysis. Vehicle fleet efficiency (Li et al., 2013, 2017b), multimodal transport costs and transport affordability (Li et al., 2015; Marshall and Henao, 2015; Mattioli et al., 2016b) dimensions have also been recently added to this domain of research. These studies largely show similar socio-spatial vulnerability patterns, with outer suburban areas owning less efficient motor vehicles and were most affected. Apart from methodological and scoping refinements, there have been conceptual developments in drawing mature vulnerability fields, including climate change (Measham et al., 2011), disaster management (Birkmann, 2007; Cardona, 2007) and development aid (Alwang et al., 2001; Chambers, 1989; Watts and Bohle, 1993). The concepts from these prevailing accepted frameworks of vulnerability could provide useful guidance in conceptualising oil vulnerability variables, considering that oil vulnerability research at the urban level has not been fully defined previously. A commonly used framework established by the Intergovernmental Panel on Climate Change (2001, p. 388) has been adapted as a framework in recent oil vulnerability research. In this study, oil vulnerability is defined as ‘the degree to which an urban system is susceptible to, or unable to cope with, adverse effects of oil price variability and extremes’. Three major components are proposed for oil vulnerability as represented graphically in Figure 2:

![Figure 2: A proposed framework for future oil vulnerability research (Adapted from Marshall et al. (2010))](image)

These include:

- **Exposure (E)** represents to what extent energy related events are able to affect the urban system. It is usually measured by oil consumption variables, such as car ownership or distance of travel.
• **Sensitivity (S)** represents the degree to which an urban system is affected by both energy and non-energy drivers. It is often measured by social variables, such as income or socio-economic wellbeing.

• **Adaptive capacity (AC)** represents the ability of an urban system to change in a way that makes it better equipped to manage its future exposure and/or sensitivity to oil price influences. Adaptive capacity can be short term or long term and can include capacity for substituting mobility for other means of communication.

These components have been used in previous oil vulnerability studies but have not been stated explicitly. Exposure (usage of oil consumptive modes) and sensitivity (income levels, disadvantage or house ownership pressures) have been widely included in previous research efforts. However, adaptive capacity has not been adequately included in most previous studies. Public transport access was considered by Runting et al.’s (2011) research, using a short Euclidian buffer to public transport stops, but with no consideration of service quality. Active transport was considered by Rendall et al.’s (2014) method to estimate the ability to use active travel to reach activity destinations (e.g., shops and services) but this requires intensive computing methods and good quality activity location datasets. The effect of long term resilience on a city’s oil vulnerability, such as the effects of urban policy and infrastructure, are difficult to measure quantitatively.

### 3. Scope of Study

This study aims to expand oil vulnerability mapping to international comparisons, using variables that are closely related to oil-related transport costs in urban areas. The chief rationale is that non-urban areas should not be considered within the scope of research due to lack of critical mass for public transport provision, and hence should be treated differently. Definitions of ‘urban area’ differ, ranging from population size, density, administrative or political boundaries or economic function (Cohen, 2006). In a transport study context, Newman and Kenworthy’s (1989; 1999) international city comparison study defined an urban area as a “large, fairly contiguous built-up area”. In more recent studies, with better improvements in geographic datasets, Mees (2009) was able to ‘reconstruct’ urban areas based on smaller census tracts to allow more accurate inter-urban comparisons. This study adopts the same approach by selecting Asian Pacific cities that have available ‘block level’ datasets comparable across jurisdictions. The urban areas of Hong Kong and Brisbane are chosen as two cases for international comparison because of comparable data availability at fine grained census level. The two cities provide a contrasting example of how a city with low oil vulnerability might look using previously tested mapping methods, as compared to a more car-dependent city. Both cities have experienced similar fluctuations in petrol price (Figure 3), despite the level of fuel tax in Hong Kong being much higher than in Brisbane. In 2014, Hong Kong’s average unleaded petrol price was at a US average for unleaded petrol, at US$2.06 compared to Australia’s US$1.23 (German Society for International Cooperation, 2015).
The other similarities and differences of the two selected study cities are outlined in Table 2. Both Hong Kong and Brisbane are heavily influenced by British rule, are relatively young cities (only nearly 200 years since founding). The institutions and governance exhibit certain similarities and there is no language barrier in obtaining and analysing the datasets. To allow intercity comparison, this study will compare the urban census blocks of the two cities together, which differs from previous oil vulnerability intra-city studies, as no inter-city comparison attempts have been made. Considerable emphasis is put on ensuring that measurements are comparable. These measurements were not made in previous oil vulnerability studies, only urban nature census tracts to allow a fair comparison between cities. In order to define ‘urban-ness’, Australia uses minimum threshold population as an urban definition, which is known as the Linge criteria (Australian Bureau of Statistics, 2011a; Linge, 1965). The advantage of this criteria is its relative objectivity and consistency. There is no urban definition found in Hong Kong. We apply the following urban definition in the smallest census blocks of both cities for delimiting urban extent, which is based on the Linge criteria:

- Those which have a population density greater or equal to 100 persons per sq. km. and a dwelling density greater or equal to 50 dwellings per sq. km.; or
- Those which have a population density greater or equal to 200 persons per sq. km.

Figure 4 shows the urban extent of the study areas based on this criteria. Large urban area blocks with no significant resident population, such as airports, heavy industrial facilities and seaports are excluded. Another delimiting issue is the scope of the outer border. Like many major cities, both Brisbane and Hong Kong have neighbouring urban settlements bordering them. In the case of Brisbane, the urban area extends to the entire South East Queensland (SEQ) region from the Gold Coast in the south to Noosa in the north. Pleasant weather and interstate ‘sea-change’ migration have helped SEQ’s population growth. Commonly,
the Greater Brisbane area includes large swathes of peri-urban area to the north of Redcliffe, which falls within ABS’s urban definition. Hong Kong borders the Special Economic Zone of Shenzhen and forms part of the Pearl River Delta in the Guangdong province – an industrial powerhouse and a fast-growing megacity region. However, due to a history of British rule, Hong Kong is unique in that it has borders with the adjacent mainland of China. Visas are required to enter/exit the respective borders and the cross-border flow of labour is not entirely free. However commuting for jobs or education across borders is rising due to increased economic activity across the Hong Kong-Shenzhen border.

### Table 2: Key urban characteristics of Greater Brisbane and Hong Kong

<table>
<thead>
<tr>
<th>Key Differences</th>
<th>Greater Brisbane</th>
<th>Hong Kong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total population (2011)</td>
<td>2,003,499</td>
<td>7,070,388</td>
</tr>
<tr>
<td>Urbanised population (%) (2011)</td>
<td>1,930,767 (96.4%)</td>
<td>7,053,701 (99.8%)</td>
</tr>
<tr>
<td>Total area</td>
<td>5,904 km²</td>
<td>1,104 km²</td>
</tr>
<tr>
<td>Private vehicle per 1000 persons</td>
<td>613.40</td>
<td>50.08</td>
</tr>
<tr>
<td>Mode share of low occupancy vehicles (private cars)</td>
<td>93.09%</td>
<td>28.07%</td>
</tr>
<tr>
<td>Annual transport energy use per person</td>
<td>31.6 gigajoules</td>
<td>6.5 gigajoules</td>
</tr>
<tr>
<td>Urban form and density</td>
<td>Dispersed and low</td>
<td>Compact and high</td>
</tr>
<tr>
<td>Society and culture</td>
<td>A new world European society with dominant Western culture but also increasingly multicultural due to sustained global immigration. Indigenous rights and awareness also growing in recent decades.</td>
<td>Dominant Chinese population and society but with significant British and Western cultural influences due to prolonged British administration. English widely used as business and official language.</td>
</tr>
<tr>
<td>Development expansion space</td>
<td>With room for further expansion but controlled by regional planning</td>
<td>Constrained by natural geography with limited room to expand. Future large-scale development most likely by sea reclamation or redevelopment of existing urban areas.</td>
</tr>
<tr>
<td>Planning governance</td>
<td>4 local councils (Brisbane, Logan, Redlands and Moreton Bay) with strong Queensland State Government involvement under the South East Queensland Regional plan</td>
<td>Hong Kong Special Administrative Region Government as a 'quasi-city state' (Kirby, 1997) with British-based planning legislation. Increasing cooperation with the mainland Chinese government on cross-border coordination.</td>
</tr>
<tr>
<td>Borders</td>
<td>No border controls to neighbouring areas</td>
<td>Border and immigration controls along Hong Kong-China border.</td>
</tr>
<tr>
<td>Natural geography</td>
<td>Coastal city separated by Brisbane River, some outlying islands but largely undeveloped</td>
<td>Coastal city separated by a wider Victoria Harbour, numerous outlying islands, some highly populated and connected by bridges or tunnels.</td>
</tr>
<tr>
<td>Built-up area (%)</td>
<td>840 km² (14.2%)</td>
<td>264 km² (14.9%)</td>
</tr>
<tr>
<td>Average per-capita income:</td>
<td>US$47,124</td>
<td>US$55,167</td>
</tr>
<tr>
<td>Year founded by British settlement</td>
<td>1825 (Australia - federated in 1901)</td>
<td>1842 (ended in 1997 due to sovereignty change)</td>
</tr>
<tr>
<td>Human development index</td>
<td>0.933 (very high)</td>
<td>0.891 (very high)</td>
</tr>
<tr>
<td>Motorised transport modes</td>
<td>Bus, rail, ferry, car</td>
<td>Bus, rail, ferry, tram/light-rail, car</td>
</tr>
</tbody>
</table>

(Source: Australian Bureau of Statistics, Hong Kong Census and Statistics Department, Brisbane City Council, Hong Kong Transport Department, UITP Millennium Cities Database for Sustainable Transport, United Nations)
Figure 4: Urban extent and transport features of Brisbane (top) and Hong Kong (bottom)
To delimit the size of urban extent and in order for it to be comparable with the more ‘compact’ Hong Kong, the outer parts of Brisbane’s metropolitan area are excluded in this study. Another scoping issue is that this paper examines passenger transport only. The main rationale is that the potential reduction of passenger transport is easier to achieve than freight transport – by organising trips collectively in public transport. Another consideration is a practical one, as urban freight is still not as adequately understood as passenger transport and there is limited data available (Cui et al., 2015). The oil vulnerability of freight transport will be useful for future research, but is beyond the scope of this analysis.

4. Methodology

This paper is an advancement in previous studies as the vulnerability conceptualisation is better defined and the indicators are sensitivity tested. A number of commonly available urban and transport variables are chosen to reveal and visualise oil vulnerability. The ideal measure of oil vulnerability in urban transport is using the proportion of fuel expenditure of disposable income. This data at fine spatial scale is not available in either Australia or Hong Kong, which necessitates the use of proxy variables. We have collected a number of variables and tested their suitability in order to measure oil vulnerability in both cities. Table 3 lists the data oil vulnerable variables and the rationale for their inclusion. Each component is explained further in the following sub-section regarding the justifications of inclusion based on previous literature and considerations during the course of this research.

### Table 3: Oil vulnerability components and the variables used

<table>
<thead>
<tr>
<th>Vulnerability Component</th>
<th>Variable</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Exposure</strong></td>
<td>E1) Proportion of the use of low occupancy vehicles as the usual mode to work</td>
<td>To estimate oil consumption and a proxy of low occupancy vehicle ownership</td>
</tr>
<tr>
<td></td>
<td>E2) Estimated average commuting distance</td>
<td>To estimate oil consumption of a necessary trip and a proxy to vehicle distance travelled</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>S1) Proportion of households with low income</td>
<td>To estimate the inability to pay for increased transport costs due to higher oil prices</td>
</tr>
<tr>
<td><strong>Adaptive Capacity</strong></td>
<td>AC1) Proportion of area within 400m of public transport stop ranked by level of service in weekdays</td>
<td>To estimate the ability to use public transport instead of driving low occupancy vehicles</td>
</tr>
<tr>
<td></td>
<td>AC2) Percentage of area within 400m buffer of electric public transport stops (For this case, railways and tramways, includes stops under construction)</td>
<td>To estimate the ability to use non-oil based public transport</td>
</tr>
<tr>
<td></td>
<td>AC3) Proportion of mode to work by active transport (walk or cycle)</td>
<td>To estimate the ability to use active modes</td>
</tr>
</tbody>
</table>

4.1 Exposure (E)

This component measures the risk of exposure to increasing oil prices. Variables selected for this component are largely similar to those used by Dodson and Sipe (2007). The mode share of low occupancy vehicles (LOV) to work is the main variable used in determining car use and hence oil consumption. Car ownership has been previously considered in most prior oil vulnerability studies. However, this variable is not available in Hong Kong’s census. While estimated car ownership data is available in the Hong Kong Government’s Household Travel Survey, it is not detailed enough to compare with Australian census data. Instead, the journey to work (JTW) flow weighted average commuting distance based on JTW matrices of
the 2011 Censuses of Hong Kong and Australia is used, a similar approach of Runting et al.’s. (2011). Both sets of data are from 2011, and EVs were not popular in either city at that time, therefore the use of commuting distance as a proxy for fuel use is still feasible. An area’s average distance is the summation of each JTW flows from origin to destination then multiplied with the respective network distance to destinations. The JTW data is only available at a district level census block (Statistical Area Level Two (SA2) in Australia and District Council Constituency Areas in Hong Kong). The shape of this census geography level is directly overlayed onto other smaller blocks for an approximation of commuting distance value. While this may cause problems in the issue of modifiable areal unit, this is the only comparative data available for this study. To reflect commuting to areas adjacent to the study cities, especially at the periphery, the commuting flows to the surrounding areas are included. For Brisbane, this includes the whole of SEQ, and for Hong Kong, this includes trips to neighbouring urban areas, i.e., Shenzhen and Macau.

4.2 Sensitivity (S)

In other prevailing oil vulnerability studies, income levels were often chosen as a sensitivity measure. For an international city, care is taken to allow comparison in spite of constant fluctuations of currency exchange and varying purchasing power. To make a better comparison, we focus on low income households as a ‘sensitivity’ variable. The cut-off of low income level was set at HK$10,000 monthly and AU$400 weekly, which is approximately US$321 and US$427 weekly at 2011 exchange rates. This difference averages out the higher wage levels in Australia compared to Hong Kong. Using this cut-off, the mean value of low income household percentage is around 8% for both cities, with a similar frequency distribution. The main aim of this approach was to allow identification of spatial variation of those less able to pay for future impacts. Testing with other income cut-offs exhibited similar spatial patterns. Figure 5 shows the spatial patterns of the Exposure and Sensitivity variables in both cities.

4.3 Adaptive Capacity (AC)

We focus mainly on short term adaptive capacity in this study. Faced with longer term stress, residents in cities may have long term adaptations, such as relocating, selling/changing vehicles, or reducing car travel. It would be more difficult to estimate the propensity of these long term responses. For relocation to closer to work or activity destinations, this is not easy as both Brisbane (61%) and Hong Kong (53%) have fairly high rates of home ownership (Australian Bureau of Statistics, 2011b; Hong Kong Census and Statistics Department, 2011). Our focus therefore falls on alternatives to car use. Runting et al.’s (2011) study included a simple buffer of public transport stops with a 1km distance buffer, which is a crude measure of public transport service and accessibility.
With increasing proliferation of public transport data and GIS analytical capacities, it is possible to estimate public transport service level by its frequency and span (Antrim and Barbeau, 2013; Keller, 2012). In this study, we developed a public transport level of service (PTLOS) method, pilot tested in South East Queensland by Anonymous (2015). The following equations are used for this index:

\[
\text{PTLOS} = \text{Average Frequency Score} \times \text{Effective Span of Service} \times \text{Serviced Days in a week}
\]

Whereas:

\[
\text{Average Frequency} = \frac{\text{Peak Frequency Score} \times \text{Off Peak Frequency Score}}{2}
\]

Effective Span of Service = Hours with regular service available of each day

(Note: services with frequency less than 2 hours are not regarded as a regular service)

The estimation of public transport frequency scores is based on a scoring system in Table 4.
Table 4: Public transport level of service (PTLOS) scores for variable AC1
(Adapted from Pitot et al. (2006))

<table>
<thead>
<tr>
<th>Frequency (minutes)</th>
<th>PTLOS Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 5</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>30</td>
<td>3</td>
</tr>
<tr>
<td>60</td>
<td>2</td>
</tr>
<tr>
<td>more than 60</td>
<td>1</td>
</tr>
</tbody>
</table>

The PLOTS requires detailed route and stop data which is available for both study areas. The PTLOS score measures public transport usability in two ways: 1) summation for an estimated total routes passing a stop in a day (both the weekdays and the weekend are estimated) regardless of needing a transfer to reach final destination and 2) the best level of service for the stops along a route without a transfer, and more attractive to users. A composite index of the two values is used which reflects the level of service of public transport by span and frequency and provides a city-wide measure of public transport availability. The routes are assigned with a PTLOS value, which is spatially linked to the stops, as shown in Figure 6. The Network Analysis in ArcGIS software, creates a walkability estimation by pedestrian shed analysis. The threshold of 400 metres is used, which is a widely adapted standard used in various jurisdictions as a reasonable distance for accessing public transport by foot (Daniels and Mulley, 2013). While a score of 6 is the maximum attainable score for less than 5 minute frequency services for 24 hours and 7 days, it is not actually attainable even in Hong Kong. The best stops in Hong Kong attained a score of 5 while Brisbane only has a maximum score of 4. The percentage of the areas covered by the PTLOS score of each census block is variable AC1. While this method does not measure the monetary and time cost of actual origin and destination, it is an adequate measure for this research for a general estimation of whether an area is covered by a usable public transport service which provides alternative mobility to a car (Walker, 2012). In addition, to reflect electric rail-based transport as oil free modes, a measure of a 400 metres buffer from electrified railway stops is included as variable AC2 (Figure 7). Variable AC2 also includes rail stops that are under construction. Previous Australian research (Lenzen, 1999) estimated the direct and indirect energy use of various modes at a broad level (i.e., national or city-wide). This paper aims to estimate the energy use and household burden of oil fuel at a smaller census block level.

This paper also uses based on census data to represent the propensity of use active travel by including mode share of walking or cycling trips to work as AC3. Most of the areas with high AC3 score are located in denser urban centres, or outlying islands in some cases, where employment is closer to residence.
Figure 6: The estimated PTLOS score for each transport stop within the urban extent of Brisbane (left) and Hong Kong (right).

Figure 7: Adaptive capacity variables of Brisbane (top) and Hong Kong (bottom).
4.4 Summary statistics of the variables and composite oil vulnerability (OV) measure

The summary statistics of city-wide and local area variation within each city are shown in Tables 5 and 6 respectively. Hong Kong stands out with very low levels of LOV mode share to work, significantly better public transport service and rail transport infrastructure, when compared to Brisbane. The overall commuting distance and prevalence of low income are similar for both cities. Yet for both cities, mode share to work by active transport is low, at only 5.22% and 9.01 respectively. The patterns are concentrated for Brisbane’s city centre, and are more dispersed for Hong Kong.

Table 5: Summary statistics of oil vulnerability variables

<table>
<thead>
<tr>
<th>City Area</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater Brisbane</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E1 – To work by LOV (%)</td>
<td>71.95</td>
<td>13.31</td>
<td>12.05</td>
<td>100.00</td>
</tr>
<tr>
<td>E2 – Average commute distance (km)</td>
<td>13.42</td>
<td>45.43</td>
<td>4.87</td>
<td>34.50</td>
</tr>
<tr>
<td>S1 – Low income (%)</td>
<td>9.70</td>
<td>7.04</td>
<td>0.00</td>
<td>55.78</td>
</tr>
<tr>
<td>AC1 – Area coverage of PTLOS score</td>
<td>1.23</td>
<td>1.14</td>
<td>0.00</td>
<td>4.00</td>
</tr>
<tr>
<td>AC2 – Area with electrified public transport (%)</td>
<td>61.60</td>
<td>37.46</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>AC3 – To work by active modes</td>
<td>5.22</td>
<td>6.97</td>
<td>0.00</td>
<td>63.44</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hong Kong</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 – To work by LOV (%)</td>
<td>10.23</td>
<td>10.79</td>
<td>0.00</td>
<td>47.01</td>
</tr>
<tr>
<td>E2 – Average commute distance (km)</td>
<td>14.36</td>
<td>6.32</td>
<td>6.57</td>
<td>34.18</td>
</tr>
<tr>
<td>S1 – Low income (%)</td>
<td>7.66</td>
<td>5.45</td>
<td>0.00</td>
<td>50.16</td>
</tr>
<tr>
<td>AC1 – Area coverage of PTLOS score</td>
<td>3.17</td>
<td>1.63</td>
<td>0.00</td>
<td>5.00</td>
</tr>
<tr>
<td>AC2 – Area with electrified public transport (%)</td>
<td>76.92</td>
<td>34.03</td>
<td>0.00</td>
<td>100.00</td>
</tr>
<tr>
<td>AC3 – To work by active modes</td>
<td>9.01</td>
<td>8.24</td>
<td>0.00</td>
<td>41.71</td>
</tr>
</tbody>
</table>

Table 6: Mean values of oil vulnerability variables (before standardisation)
by the broad internal divisions of Hong Kong and Brisbane

<table>
<thead>
<tr>
<th>Area</th>
<th>E1 – To work by LOV (%)</th>
<th>E2 – Avg. Commute Distance (km)</th>
<th>S1 – Low-Income (%)</th>
<th>AC1 – Area Coverage of PTLOS Score (1-5)</th>
<th>AC2 – Area with Electrified Public Transport (%)</th>
<th>AC3 – To work by Active Modes (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater Brisbane</td>
<td>71.95</td>
<td>13.42</td>
<td>9.70</td>
<td>1.23</td>
<td>61.60</td>
<td>5.22</td>
</tr>
<tr>
<td>Brisbane</td>
<td>66.35</td>
<td>10.69</td>
<td>9.44</td>
<td>1.62</td>
<td>64.19</td>
<td>6.90</td>
</tr>
<tr>
<td>Ipswich</td>
<td>82.65</td>
<td>16.56</td>
<td>9.99</td>
<td>0.68</td>
<td>51.01</td>
<td>3.13</td>
</tr>
<tr>
<td>Logan</td>
<td>83.54</td>
<td>17.74</td>
<td>10.96</td>
<td>0.64</td>
<td>53.89</td>
<td>2.19</td>
</tr>
<tr>
<td>Moreton Bay</td>
<td>78.99</td>
<td>17.09</td>
<td>9.02</td>
<td>0.83</td>
<td>49.45</td>
<td>3.06</td>
</tr>
<tr>
<td>Redland Bay</td>
<td>72.44</td>
<td>17.20</td>
<td>13.05</td>
<td>0.52</td>
<td>54.83</td>
<td>3.41</td>
</tr>
<tr>
<td>Hong Kong SAR</td>
<td>10.23</td>
<td>14.36</td>
<td>7.66</td>
<td>3.17</td>
<td>76.92</td>
<td>9.01</td>
</tr>
<tr>
<td>Hong Kong Island</td>
<td>13.12</td>
<td>9.71</td>
<td>5.95</td>
<td>3.83</td>
<td>89.27</td>
<td>10.94</td>
</tr>
<tr>
<td>Kowloon</td>
<td>6.58</td>
<td>9.81</td>
<td>9.03</td>
<td>4.00</td>
<td>73.01</td>
<td>11.14</td>
</tr>
<tr>
<td>New Territories</td>
<td>11.56</td>
<td>20.43</td>
<td>8.33</td>
<td>2.23</td>
<td>66.63</td>
<td>5.94</td>
</tr>
<tr>
<td>Lantau</td>
<td>3.61</td>
<td>24.51</td>
<td>14.17</td>
<td>0.88</td>
<td>22.18</td>
<td>10.90</td>
</tr>
</tbody>
</table>
Table 7: Correlation of the variables used for the oil vulnerability composite indicator

<table>
<thead>
<tr>
<th>Brisbane</th>
<th>E1</th>
<th>E2</th>
<th>S1</th>
<th>AC1</th>
<th>AC2</th>
<th>AC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>1</td>
<td>.593**</td>
<td>-.298*</td>
<td>-.475**</td>
<td>-.207*</td>
<td>-.719**</td>
</tr>
<tr>
<td>E2</td>
<td>.593**</td>
<td>1</td>
<td>-.083*</td>
<td>-.505**</td>
<td>-.166*</td>
<td>-.479**</td>
</tr>
<tr>
<td>S1</td>
<td>-.298*</td>
<td>-.083*</td>
<td>1</td>
<td>.184**</td>
<td>.073**</td>
<td>.218**</td>
</tr>
<tr>
<td>AC1</td>
<td>-.475**</td>
<td>-.505**</td>
<td>.184**</td>
<td>1</td>
<td>.409**</td>
<td>.447**</td>
</tr>
<tr>
<td>AC2</td>
<td>-.207*</td>
<td>-.166*</td>
<td>.073**</td>
<td>.409**</td>
<td>1</td>
<td>.104**</td>
</tr>
<tr>
<td>AC3</td>
<td>-.719**</td>
<td>-.479**</td>
<td>.218**</td>
<td>.447**</td>
<td>.104**</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hong Kong</th>
<th>E1</th>
<th>E2</th>
<th>S1</th>
<th>AC1</th>
<th>AC2</th>
<th>AC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>1</td>
<td>.090**</td>
<td>-.486**</td>
<td>-.343**</td>
<td>-.127**</td>
<td>-.450**</td>
</tr>
<tr>
<td>E2</td>
<td>.090**</td>
<td>1</td>
<td>.077**</td>
<td>-.571**</td>
<td>-.150**</td>
<td>-.333**</td>
</tr>
<tr>
<td>S1</td>
<td>-.486**</td>
<td>.077**</td>
<td>1</td>
<td>.069**</td>
<td>.087**</td>
<td>.360**</td>
</tr>
<tr>
<td>AC1</td>
<td>-.343**</td>
<td>-.571**</td>
<td>.069**</td>
<td>1</td>
<td>.508**</td>
<td>.412**</td>
</tr>
<tr>
<td>AC2</td>
<td>-.127**</td>
<td>-.150**</td>
<td>.087**</td>
<td>.508**</td>
<td>1</td>
<td>.230**</td>
</tr>
<tr>
<td>AC3</td>
<td>-.450**</td>
<td>-.333**</td>
<td>.360**</td>
<td>.412**</td>
<td>.230**</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: (**) Correlation is significant at the 0.01 level (2-tailed)

The inter-relationship of the variables is significant, as shown in Table 7’s correlation analysis. E1’s variables are more correlated in Brisbane than in Hong Kong, which reflects Brisbane’s car dependence. Other variables are more similar across cities, albeit with local variations.

4.5 Composite indicator construction and sensitivity analysis

The composite vulnerability score is based on the conceptual framework shown earlier, which is:

\[
\text{Vulnerability} = E + S - AC
\]

Equal weighting is adopted. This approach is acceptable when there is insufficient understanding of underlying processes to assign meaningful weights (Cutter et al., 2003; Tate, 2012). There is no fuel expenditure data at census tract level available for both cities. Composite metrics such as this are useful in bringing together ‘incommensurable’ variables. However, a limitation of a composite indicator is the apparent ‘subjectiveness’ of the indicator development process (OECD, 2008), as the results would be largely determined by the choice of variables. The normalisation, or weighting of variables has been tested for sensitivity in previous composite indicators (Cherchye et al., 2006; Freudenberg, 2003; Hudrlíková, 2013; Sharpe and Andrews, 2012). For this study, the normalisation and variable weights are relatively simple and are not tested. We have undertaken sensitivity tests on the effect of the inclusion of variables. Table 8 shows five sets of composite indicators, in which number 5 has the most variables and is considered to be final. The minimum and maximum values of the change in percentile ranking of the set (1-100) caused by the progressive inclusion of each set are used to generate the sensitivity value. Table 9 presents the sensitivity level of variable inclusion, sorted by the internal broad area divisions in both cities, and the spatial detail of variable sensitivity is mapped in Figure 8.
Table 8: Composite indicator sets for progressive sensitivity testing

<table>
<thead>
<tr>
<th>Set No.</th>
<th>Variables included</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Baseline)</td>
<td>$zscore_{E1} + zscore_{S1}$</td>
</tr>
<tr>
<td>2</td>
<td>$zscore_{E1} + zscore_{S1} - zscore_{AC1}$</td>
</tr>
<tr>
<td>3</td>
<td>$\frac{zscore_{E1} + zscore_{E2}}{2} + zscore_{S1} - zscore_{AC1}$</td>
</tr>
<tr>
<td>4</td>
<td>$\frac{zscore_{E1} + zscore_{E2}}{2} + zscore_{S1} - \frac{zscore_{AC1} + zscore_{AC2}}{2}$</td>
</tr>
<tr>
<td>5 (Final)</td>
<td>$\frac{zscore_{E1} + zscore_{E2}}{2} + zscore_{S1} - \frac{zscore_{AC1} + zscore_{AC2} + zscore_{AC3}}{3}$</td>
</tr>
</tbody>
</table>

Table 9: Internal division sensitivity level of variable inclusion effects of Brisbane and Hong Kong

<table>
<thead>
<tr>
<th>Area</th>
<th>Sensitivity of the variable inclusion effects of the five sets</th>
<th>Average Shift of percentile rank of all areas</th>
<th>Minimum Shift</th>
<th>Maximum Shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater Brisbane</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brisbane</td>
<td>17.80</td>
<td>0.00</td>
<td>69.85</td>
<td></td>
</tr>
<tr>
<td>Ipswich</td>
<td>20.11</td>
<td>0.00</td>
<td>69.85</td>
<td></td>
</tr>
<tr>
<td>Logan</td>
<td>15.56</td>
<td>0.04</td>
<td>58.18</td>
<td></td>
</tr>
<tr>
<td>Logan</td>
<td>13.55</td>
<td>0.02</td>
<td>63.86</td>
<td></td>
</tr>
<tr>
<td>Moreton Bay</td>
<td>16.61</td>
<td>0.29</td>
<td>65.07</td>
<td></td>
</tr>
<tr>
<td>Redland Bay</td>
<td>12.40</td>
<td>0.22</td>
<td>49.18</td>
<td></td>
</tr>
<tr>
<td>Hong Kong SAR</td>
<td>16.34</td>
<td>0.53</td>
<td>75.34</td>
<td></td>
</tr>
<tr>
<td>Hong Kong Island</td>
<td>6.88</td>
<td>0.84</td>
<td>39.87</td>
<td></td>
</tr>
<tr>
<td>Kowloon</td>
<td>7.55</td>
<td>0.73</td>
<td>48.04</td>
<td></td>
</tr>
<tr>
<td>New Territories (Excluding Lantau)</td>
<td>27.62</td>
<td>0.53</td>
<td>75.34</td>
<td></td>
</tr>
<tr>
<td>Lantau</td>
<td>48.58</td>
<td>11.51</td>
<td>72.62</td>
<td></td>
</tr>
</tbody>
</table>

To our best knowledge, indicator choice sensitivity analysis has not been conducted in previous oil vulnerability studies. As this study only uses equal weighting and a limited number of variables, we believe that this sensitivity analysis is sufficient. More complex methods (e.g. Monte Carlo), are not necessarily warranted.
Figure 8: Sensitivity level of variable inclusion, based on the minimum and maximum difference of variable inclusion effects. Brisbane (top) and Hong Kong (bottom)
The average shift in ranking due to variable inclusion is about 16 to 17 ranks out of 100 in both cities. Also, most inhabited areas are not subject to significant change after variable inclusion from the baseline (E1+S1). Brisbane is more sensitive to variable inclusion in inner areas and to public and active transport variables (AC1-3). Brisbane’s indicators are more affected in areas with better public transport and in dense urban locations. Whereas in Hong Kong, outer urban areas differ more, especially when variables such as E1 (car mode share to work) and E2 (average distance of work) are included. The next section presents the final results based on the final Set 5 Composite Indicator.

5. Results and Discussion
5.1 Patterns of oil vulnerability in the two cities

Figure 9 maps the spatial distribution of the composite oil vulnerability based on Set 5, with values visualised by standard deviation breaks of -2.5 to 2.5 with intervals of 1. Advancing from previous studies (Dodson and Sipe, 2007; Runting et al., 2011) the figures provide more detailed analysis and allow direct comparison across the two cities. The population share of the same values of each level for the broad areas of both cities is shown in Figure 10. The mapping and population analysis of composite oil vulnerability are able to reflect the spatial variation of higher car dependence, commuting distance, low-income areas and public transport services. The produced maps show nuanced patterns largely based on the central peripheral arrangement of both cities, yet Hong Kong’s outer new towns in the New Territories (e.g., Tuen Mun, Yuen Long, North District and Tai Po) are adequately served by heavy rail or light rail. Hong Kong’s oil vulnerability is much less than Brisbane’s across all its regions, with the exception of the outlying areas.

Despite longer average commuting distances, Hong Kong’s transport passenger tasks are mostly carried by energy efficient rail transport, with the exception of the outlying islands. These islands rely on ferry transport which is also oil vulnerable. This study did not examine ferry transport thoroughly but it has attracted some local concerns in Hong Kong due to high oil prices and ferry fares increased (Hong Kong Legislative Council, 2015). In Brisbane, outer urban development is mainly facilitated by highways, with railways playing a more limited role. The frequency of train services is often only every 30 minutes, while Hong Kong is able to provide metro-style services to much of the population, with a frequency less than 10 minutes, and even less than 3 minutes at peak hours on some lines. Geographically, it should be noted that Hong Kong and Brisbane are both separated by water features. However, Hong Kong already has three cross-harbour rail links between Hong Kong Island and Kowloon. An additional crossing, the Shatin to Central link is expected to begin operations in 2020. The Tung Chung Line also connects the urban core via Lantau Island to the airport. Brisbane’s rail network is shaped radially but with only one railway crossing across the Brisbane River. This creates a bottleneck, severely restricting the ability to run trains with higher frequency. To address this, a new Cross River Rail project is expected to commence works in late 2017, and to be completed by 2024. Other than railways, in Brisbane, a 23-km long network of bus rapid transit (known as the Busway) is an important piece of public transport infrastructure (Tanko and Burke, 2013).
Figure 9: Composite oil vulnerability index of Brisbane (top) and Hong Kong (bottom)
5.2 Housing costs and spatial mismatch

The cost of housing should also be considered alongside transport, and fuel costs, as evident in some oil vulnerability studies (Cao and Hickman, 2017; Dodson and Sipe, 2008; Li et al., 2017a). The issue of housing cost is complicated, as the level of burden varies for renters and mortgage buyers. Despite the absence of fine-grained spatial data on housing cost or land value, household expenditure surveys can shed some light in this respect. Table 10 shows the respective transport and housing cost share to total expenditure of 18 major districts in Hong Kong. Similar district (SA3) level data for Brisbane is not available, but the overall metropolitan area expenditure data is available for comparison with Hong Kong’s. The residents living at “green” coloured oil vulnerability zones in Hong Kong (in particular Hong Kong Island and Kowloon) are spending a much higher proportion in housing. Even so, Hong Kong has imposed territory-wide standards requiring major housing (including public ones) and population intensive activity centres to be located within 500m of major public transport stations or interchanges with properly planned walkway systems. Up to 70-80% of the city’s population is covered by this 500m service area (Hong Kong Planning Department, 2014). Hence, Hong Kong’s outer urban areas still have lower oil vulnerability when compared to Brisbane, despite the latter’s recent policies to promote higher density with ‘integrated transport with land use’ as outlined in the South-East Queensland Regional Plan (Queensland Government, 2009). As evident from this study’s mapping results in Figure 9 and expenditure share in Table 1, Brisbane’s higher share of...
Transport and housing cost data obtained from Household Expenditure Surveys (2009-10) of Hong Kong Census and Statistics Department and Australian Bureau of Statistics

5.3 Urban transport solutions to oil vulnerability

The exposure and sensitivity to oil vulnerability data used in this study are based on 2011 Census data. Recently, developments in alternative fuels (e.g. electrification or biofuels) offer a promising solution for reducing oil consumption in transport. Despite the call for rapid transition of EVs in private vehicles, it is compounded by significant infrastructural costs and equity concerns. EVs should be part, but not the entire solution to reduce oil use (Riesz et al., 2016). While not analysed in our oil vulnerability mapping due to lack of EV ownership data, it should be noted that Hong Kong has implemented tax waivers for EV purchase and has permitted buildable area bonus for incorporating EV charging carparks (Hong Kong Environment Bureau, 2011). Future oil vulnerability studies should consider these latest developments. Meanwhile, the avoid-shift-improve approach has been recognised as an effective way to reduce oil use simultaneously (Dalkmann and Brannigan, 2007; Schipper and Marie-Lilliu, 1999). For the avoid-approach, reducing oil use by controlling car dependence not only helps in addressing oil vulnerability, the benefits also include improving air quality, saving valuable urban land from car parking provisions, and creating the opportunity for physical activity. This is achieved in part by high fuel taxes and parking restrictions in Hong Kong (Barter, 2014; German Society for International Cooperation, 2015). Transport and land use planning based on non-oil public transport is also imperative in reducing oil vulnerability. Overall, both Hong Kong’s and Brisbane’s peripheral areas are seen to be more vulnerable due to higher car use, and lower socio-economic status.
Increasing the proportion of new dwellings that are built in the central areas of the city, especially in Brisbane, would be helpful. But low adaptive capacity could be improved by widespread provision of public transport into suburban areas. Public transport need not be expensive and costly and could be improved, given the current inefficiencies in existing systems. Improved transit networks that maximise the existing fleet can reduce oil vulnerability further, particularly in Brisbane (Mees and Dodson, 2011).

Gilbert and Perl’s (2007) argument for the use of electricity grid-connected rail to address oil vulnerability is also supported by the oil vulnerability mapping results. Figure 11 shows indicative rail development plans for the two cities. Hong Kong’s plans to further pursue rail-based investment, as indicated in the latest Railway Development Strategy 2014 (Hong Kong Transport and Housing Bureau, 2014). Whilst the SEQ 2031 Transport Plan indicates further expansion of railway infrastructure across SEQ, funding is more limited and uncertain (Queensland Government, 2011). Unless these planned railway expansions are commenced, Brisbane is likely to remain oil vulnerable for some time to come. Hong Kong uses value capture of station air-rights or adjacent land to help fund railway network expansion, known as the ‘rail plus property’ (R+P) model (Cervero and Murakami, 2009; Mass Transit Railways, 2014). Only recently, Australian cities are beginning to explore value capture as a way to finance public transport (Mulley et al., 2016).

Beyond public transport, perhaps active transport should also be considered to replace motorised work-related trips. This would require matching locations of jobs and residential areas closely, as mode share of active travel for commuting is low in both cities. We believe active transport should be considered more in future research. More sophisticated GIS-based planning tools have been developed in order to gain an understanding of the propensity to cycle in the UK (Lovelace et al., 2011) and crowdsourced information from mobile phone ‘apps’ has been proven to show ‘hotspots’ of active transport (Heesch et al., 2016).

To give a brief outline of current active transport policies of the two cities - Brisbane appears to be more ‘pro-active’ than Hong Kong. This is evidenced by on-going public investments in cycling infrastructure such as the CityCycle bike sharing scheme (Fishman et al., 2015) and an expanding network of Veloways (Heesch et al., 2016). Yet cycling mode use remains highly concentrated near the CBD, and the usage rate of CityCycle is comparably low compared to European schemes (Fishman et al., 2013), perhaps due to helmet laws. Hong Kong’s transport policy generally discourages cycling in core urban areas and sees cycling more of a recreation or local commuting mode in the New Territories (Hong Kong Legislative Council, 2012). This is finally changing with a plan for the expansion of cycling tracks (but largely in the New Territories) and the introduction of a new, dockless bicycle scheme GoBee (2017) in the new town of Shatin. This scheme is modelled on similar schemes in Mainland China, which are run by mobile phone activation and payment (Phillips and Yao, 2016). It should be noted that the topography of Hong Kong is more difficult than that of Brisbane. This therefore poses greater challenges for a city-wide cycle network.
Figure 12 shows a map of the location of existing and planned cycling track networks in Hong Kong and Brisbane. Other innovative solutions in addressing energy use in cities are work travel substitution by information technology (Alizadeh, 2012), or even reducing work hours, as suggested by King and van den Bergh (King and van den Bergh, 2017). To make an account of these possible ways to reduce oil use, perhaps the broadband internet penetration into households, or reported telework behaviour, should also be considered in future endeavours in oil vulnerability mapping.

Figure 11: Indicative rail development plans for Hong Kong and Brisbane for 2031
(Hong Kong Transport and Housing Bureau, 2014; Queensland Government, 2011)
5.4 The ‘ultimate’ future of cities under threat by oil use

Another issue to take into consideration in research into oil vulnerability should be beyond the use of oil for movement, but also the impacts of climate change caused by it. Even a relatively ‘oil-proof’ coastal city like Hong Kong could be significantly affected by possible future sea level rise, according to Clarke et al. (2016). Overlaying our proposed oil vulnerability maps for urban transport with potential areas which will be affected by mean sea level increase could depict another very ‘real’ consequence of oil dependence. This is not just a risk to residential property, but also potentially disruptive or damaging to transport infrastructure. Ironically, in both cities, waterfront living is highly sought after by the wealthy, and who are more likely to drive their own cars.

6. Concluding Remarks

The key contributions of this paper are theoretical (contribution to the energy debate), methodological (international comparison, the new approach to estimating oil vulnerability and reproducibility in other cities) and practical (identifying oil vulnerability and therefore, possible solutions). The novel methods of this research highlight the need to provide affordable and energy efficient transport modes, especially in outer urban areas. The oil vulnerability composite indicator is tested with sensitivity analysis with clear visualisation of the variable inclusion effects. This research also considers oil vulnerability analysis in a major Asian city for the first time. By developing common metrics, delimiting urban extent and the use of small census blocks, the paper shows that comparative oil vulnerability mapping across quite different urban contexts is achievable. Our approach, using the concepts of exposure, sensitivity and adaptive capacity to oil vulnerability could be further expanded to other cities, or could even be used to map global
warming impacts. Maybe, a global oil vulnerability index can one day be created if there is enough data, or further refinements of the methodology to harmonise data differences from various statistical agencies. It is a limitation that older 2011 data is used rather than the 2016 census that had not been released fully at the time of writing. It is likely non-car mode share of core urban areas in Brisbane has increased due to recent trends, but the suburbs are likely to remain the same. For Hong Kong, the mode share patterns are likely to remain similar except in areas that experienced rail expansion. A 2011-16 comparison could be useful in future studies.

As shown in the analysis in this paper, Hong Kong’s urban development style is far less oil vulnerable than Brisbane’s. Land use and transport policies, such as public transport oriented development should be considered with higher priority than mass private vehicle fleet electrification. The hurdles of high capital cost and land acquisition for high capacity metro-style railways are well justified by the benefits of long term energy savings, at both household and city-wide levels. Despite higher housing costs, it can also be a way to finance rail transport by value capture. As seen in previous and current studies, oil vulnerability indices are useful - as an approach in warning policy makers to expedite action. Further research into the verification of actual transport energy uses and costs can offer more empirical evidence of fuel price impacts. To address this, statistical tools (e.g., principal component analysis or regression modelling) can be used to develop empirically driven weights for composite indices, with observed travel or energy use data. As a conclusion, despite today’s lower prices, research into oil vulnerability should be continued by looking at these limitations and research opportunities.

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9. The peak oil and oil vulnerability discourse in urban transport policy: A comparative discourse analysis of Hong Kong and Brisbane


Upon investigation of spatial intra-urban oil vulnerability patterns in both Hong Kong and Brisbane in Chapter 8, this chapter presents a qualitative approach to a comparison of these two cities. This is likely the first published policy analysis paper looking at peak oil and oil vulnerability responses. The period of higher fuel price in 2000-10s offers a good opportunity to understand what policy has been made, and why it has been made (or not made). Using existing policy analysis frameworks of Multiple Streams Framework (MSF, policy, problems and politics) (Kingdon 1984) and Discourse Analysis (key storylines of whether peak oil is an issue in the discourse of policy actors) (Hajer 1993), this paper provides a discourse analysis in detail based on interview and literature data sources. The interview texts were transcribed, entered and classified in NVivo. Relevant passages were coded as key themes based on the MSF and Hajer’s discourse analysis. While both cities are found to have emerging ‘affordability’ storylines due to increased fuel prices, only Brisbane from 2007 to 2012, assisted by the leadership of ‘policy entrepreneurs, has seriously attempted to tackle oil vulnerability. In contrast, Hong Kong largely adapts a ‘wait-and-see’ approach,
possibly due to the complacency of policy makers and a lack of awareness about energy risks.

The template of the interview questions is provided in Appendix A.

**Research questions addressed in this paper and contributions**

**Primary question**
How are policies developed to respond to increasing oil prices?

**Summary of contributions**
First study that analysed the policy responses to peak oil and oil vulnerability in Hong Kong and Brisbane

*This chapter is an exact copy of the published paper referred to above.*
9.1 Statement of contribution to co-authored published paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:


The authors listed below have certified that:

1. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. they agree to the use of the publication in the student’s thesis and its publication on the Griffith University database consistent with any limitations set by publisher requirements.

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<th>Contributors</th>
<th>Statement of contribution</th>
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<tr>
<td>Abraham Leung (Signed)</td>
<td>Conceiving, planning and the writing of the manuscript, travelled to Hong Kong and Brisbane to conduct the interview, and the preparation of tables and figures. The candidate was also responsible for the revision made at the suggestion of the conference reviewers and the presentation of the paper during the conference.</td>
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The peak oil and oil vulnerability discourse in urban transport policy: A comparative discourse analysis of Hong Kong and Brisbane

Abraham Leung, Matthew Burke, Anthony Perl, Jianqiang Cui

1. Introduction

As evidenced by the volatility in energy prices during the past decade, there is growing concern about finite energy sources from fossil fuels. By the turn of the 21st century, awareness had grown regarding the risks inherent in society's dependence on oil, especially to fuel private automobiles. The recent period of extremely high oil prices between 2000 and 2010 attracted widespread attention. The notion of peak oil re-emerged, focusing on the uncertainty of reserves and limits to future oil supplies (McGlade, 2012; Simmons, 2005). This period is of interest because high oil prices brought forth a number of trends, including, 1) a re-evaluation of car dependence and its related urban form (Aftabuzzaman and Mazloumi, 2011; Shove et al., 2015); 2) a push to produce previously uneconomic unconventional sources of oil, such as shale, and tar sands; 3) alternative energy sources for transport which also became economically competitive, creating calls for a transport energy transition (Li and Loo, 2014). In many jurisdictions, there is a mismatch of aims between policy makers who attempt to restrict car use by the implementation of sustainable transport policies for the car-owning public, or for those aspiring to car use who are averse to changing their expectations (Hickman and Banister, 2014). While there is increasing policy focus on reducing car dependence and oil use in the transport sector, progress was constrained by the enormous lock-in of socio-technical systems of car related infrastructure in the society (Newman and Kenworthy, 2015) and the strong aspiration to drive by the car-owning masses (Sperling and Gordon, 2009). During the oil crisis of the 1970s, oil supply shortages prompted various governments to ration fuel, limit speed on highways and establish strategic petroleum reserves. Yet, with the risk of energy shocks receding during the 1980s and 1990s during an oil glut, there was less research interest in this topic. Oil prices increased tremendously in the 2000s, and this has led to heightened research and public
debate about the issue of oil vulnerability, in particular in the transport sector, as internal combustion engine (ICE) powered vehicles are dominant and there are high levels of car dependence in many countries. The discourse regarding ‘peak oil’ regained attention, created a global following and organisations were established to raise awareness of the idea and its implications. With increased public debate around the problem, governments in many cities also used the term to justify transport policy adjustment (Lee and Scott, 2007; Maribyrnong City Council, 2009; Smith, 2010; Sunshine Coast Regional Council, 2010). However, what is less understood is how the term entered the agenda of transport policy and planning, and what the results of that entry have been.

This paper aims to investigate how the discourse about peak oil entered policy making and problem framing in two cities – Brisbane and Hong Kong – during this critical period. The study assembles and analyses qualitative data to compare the experiences in addressing oil vulnerability in two contrasting cities in the Asia-Pacific region: Hong Kong and Brisbane (the state capital of Queensland, Australia). Because of the high levels of car dependence, Brisbane has been a pioneering city in researching and developing policy measures targeting oil vulnerability (Dodson and Sipe, 2015). Hong Kong is known for its extreme compactness and high public transport mode share, offering ‘natural defences’ against oil vulnerability. While geographic and cultural differences can partly explain such disparity, deliberate action and policy are imperative in creating more sustainable and less oil vulnerable means of transport. Yet the 21st century’s higher oil prices have generated political, public and academic attention on policies that attempt to reduce oil vulnerability in Brisbane. This is one of the reasons why authorities and researchers in Brisbane focus more on reducing oil vulnerability, thus recognising it as an issue, compared with those in Hong Kong.

The contributions of this paper can be summarised as: 1) providing in-depth cross-cultural understanding of how oil vulnerability and energy-related economic stress in transport are understood, in both car dependent and non-dependent cities; 2) to apply multiple, but theoretically consistent policy analysis frameworks to analyse how the peak oil discourse has resonated in Hong Kong and Brisbane; and 3), to reveal ways in which political and societal contexts shape transport policy outcomes and the implications for policy actors in advancing their agenda priorities. This requires acumen of policy actors to connect the ‘streams of problems, policy solutions and politics’ (as per Kingdon’s (1984) multiple streams approach), and to engage in ‘winning discourse arguments’ (as per Hajer’s (1995) argumentative discourse). These approaches will be explained in greater detail in Section 3.

This paper consists of seven sections. Following the introduction, Section 2 outlines the existing literature about the emerging study of ‘energy-related transport stress’ research in urban transport. Section 3 summarised the urban transport context of Hong Kong and Brisbane’s oil vulnerability. The theoretical framework and the discursive methodology of this study are presented in Section 4. The results are elaborated in Section 5, followed by a discussion in Section 6 and lastly, Section 7 concludes the paper.

2. Existing scholarship of oil vulnerability and ‘energy-related transport stress’

From the early 2000s until 2015, a period of higher and unstable oil prices sparked public and scholarly debates about the need to address vulnerabilities caused by volatile oil prices. Increased attention on oil and energy in transport research has sought to develop better understanding and identify possible solutions (Anable et al., 2012; Banister et al., 1997; Gilbert and Perl, 2007). In Australia, a notion of ‘oil vulnerability’ has emerged as Dodson and Sipe (2005, 2007, 2008) used visual mapping analysis to reveal the spatial extent of car dependence, social disadvantage and household affordability (based on mortgage debt levels) in Australian cities. They referred to these combined variables of oil vulnerability as the “potential exposure of households to adverse socioeconomic outcomes arising from increased fuel costs” (Dodson and Sipe, 2007, p. 46). It was found that a disproportionately higher impact of higher oil prices is more likely to be borne by those living in outer suburbs, due to high car ownership, lower income levels and higher mortgage indebtedness, with inner urban cores being less impacted. Other studies also used oil vulnerability as an umbrella term for the wider vulnerabilities caused by the use of oil (Kerschner et al., 2013; Roupas et al., 2009). This issue is exacerbated by concerns of peak oil, the geo-politics of a continued supply of oil (e.g., the use of plastics, carbon emissions, food production, etc.) (Brecha, 2013; Coventry, 2013; Neff et al., 2011). In the context of transport, oil vulnerability refers especially to car dependence, in particular to the extensive use of vehicles fuelled by oil.

With readily available data sources and ease of use, this census-based spatial indexing approach was soon adopted by a number of researchers looking at cities in Canada (Arico, 2007), Australia (Fishman and Brennan, 2009), and the United States (Sipe and Dodson, 2013), demonstrating the transferability of this method. In later studies, advances in methodology were seen to take account of commuting distance and trip volumes derived from journey to work data (Li et al., 2015; Runting et al., 2011). Sophisticated simulation and modelling techniques, such as spatial agent-based microsimulation (Lovelace and Philips, 2014) and minimum energy activity modelling (Rendall et al., 2014), have recently been experimented with in this area. The notion of vulnerability has also been expanded to look at the adaptive capacity (the level of resilience), exposure (oil use patterns) and sensitivity (the ability to absorb higher prices) to oil price increases (Leung et al., 2015). Oil vulnerability, however, is not the only concept used to denote energy-related economic stress in transport. A plethora of terms and frameworks have been developed to understand social disadvantage related to transport, urban form and energy price increases, volatility, and uncertainty. As noted by Mattioli (2014, 2015), terms such as ‘transport poverty’ (Lucas, 2012) from the UK, précaritéénergétique (energy precariousness) from France and energiearmut (energy poverty) from Germany, have also been used to study the impacts of higher oil prices on cities.

Whilst such diversity of terms has fostered academic debate and has appeared in many government policy initiatives globally, most scholarly studies used these concepts as a way to study urban issues such as the spatial patterning of urban form, transport and energy use (Mattioli, 2014; Mattioli et al., 2016; Mayer et al., 2014; Motte-Baumvol et al., 2009). However, there have been few studies about policy responses to oil vulnerability. Notably, these studies tend to focus on jurisdictions that have a higher level of car ownership and dependence, particularly Western industrialised countries (Australasia, Europe and North America). An understanding about whether oil vulnerability poses risks to other regions, such as in Asia, is relatively scant. Meanwhile, a number of qualitative studies have been produced on the perceptions of private car use versus public transport (Beirão and Cabral, 2007; Steg, 2003), and there have been local studies on car dependence in Hong Kong (Cullinane, 2002) and in Australian cities (Hensher, 1998). However, the wider issue of energy and oil use has not been addressed, in particular, how is the problem of oil vulnerability framed? What are the social and political context of the development of energy-related transport policies? Discussions about these issues are yet to be seen in the literature. In this paper, we attempt to use a discursive framework to examine the different responses of the case study cities during the period of higher oil prices.

3. Problem framing and discourse analysis in transport policy

Traditionally, policy making and its studies and analysis are derived from a positivist epistemology which follows a positivist view of
science. This is also known as the rationalist view, in which policy can be understood as ordered, linear stages starting from problem identification, and going through policy formation, and implementation (Jann and Wegrich, 2007). This approach assumes an objective, value-free stance to reality and knowledge which are increasingly challenged by the emerging worldviews of critical theory and constructivism, which view the world and knowledge production as subjective, contingent, and mediated by values (Guba and Lincoln, 1984). The rationalist view also tends to overlook the complexities and uncertainties of policy processes that are in reality chaotic and random in nature. It is increasingly evident that policy makers do not view a problem in a purely objective way but through a lens which is coloured by their own ‘history, traditions, attitudes and beliefs’ (Howlett et al., 2009). A post-positivist ‘linguistic’ turn of public policy research has put great emphasis on the role of discourse in policy making (Bacchi, 2000; Dryzek, 2005; White, 1994). In this view, language is not natural. The way in which a problem is framed is particularly important as it forms public opinion, and also the agenda of various actors in policy making (Fischer, 2003; Gasper and Apthorpe, 1996). Problem framing is an important aspect of more recent policy analysis models, for instance, the prominent example of Kingdon’s (1984) multiple streams framework (MSF) which aims to reveal the complex dynamics of agenda setting and policy adaptation.

The MSF sees policy making as resulting from independent streams of inputs, namely ‘problems, policies and politics’. When these streams converge, there is a window of opportunity that opens in which political support for a solution can initiate its application to solve a problem (Parsons, 1995; Zahariadis, 2007). ‘Policy entrepreneurs’ are key agents in this process because of their capability in joining these streams to policy initiation. Policy entrepreneurs invest considerable time and resources to promote ideas or draw attention to problems in the hope of precipitating change. While the MSF is quite versatile in a large range of settings and promotes consensus building, it has been criticised for downplaying the argumentative nature of policy making (Brunner, 2008; Peters and Zitoun, 2016; Sabatier, 1999), and not being able to explain policy implementation (Jann and Wegrich, 2007). Nevertheless, Kingdon’s view of how policy issues can gain attention is relevant for how energy issues, such as peak oil and higher fuel prices, could be framed and used to initiate change in policy making. Previously, Kingdon’s work showed how the public transport lobby failed to gain support for its preferred goals in the United States during the 1970s, when reducing automobile dependence was framed as a solution for congestion alleviation (instead of building more highways) and environmental protection (to reduce air pollution). Instead, public transport lobby was able to gain some support as the issue was reframed as contributing to energy security (after the oil crisis in 1973), but later lost attention and resources as oil prices dropped in the 1980s to the 1990s. Another way to understand framing in policy making is the ‘argumentative’ turn of public policy analysis pioneered by Hajer (1993), who systematically defined the role of discourse and proposed a method of analysis in his research on the politics and policy of acid rain in the UK and the Netherlands. To him, discourse analysis is the examination of argumentative structure in either written or spoken statements, in which these utterances can provide an important tool to understand the meaning of policy actions (Hajer, 2006, p. 66). Hajer views discourse as a “specific ensemble of ideas, concepts and categories that are produced and reproduced and transformed in a particular set of practices and through which meaning is given to physical and social realities” (Hajer, 1995, p. 44). Policy debate can be seen as attempts to maintain or challenge the discursive order, as various actors see a problem in their own way, and attempt to influence others to believe the same. To understand discourse, Hajer put forwards the concepts of ‘metaphor’, ‘storyline’ and ‘discourse coalition’. ‘Metaphor’ is a notion that stands for something else. A key example used by Hajer is ‘acid rain’, which is simpler two-word term that encompasses the complex chemical process of industrial air pollution causing elevated acid levels in precipitation, and the associated environmental impacts (e.g.: dying trees and killing fishes). Some other examples of the use of metaphors in the environmental field are the ‘spaceship’ analogy of Earth or the ‘greenhouse’ effect of the atmosphere (Myerson and Rydin, 1996, p. 26). Metaphors are important in helping the wider public to conceptualise an issue (for the case of acid rain, the indirect effects of air pollution) and empowering those does not possess a complete technical knowledge to engage in policy discussions with a simpler metaphoric term (Huijtema, 2003, pp. 40–43; Macnaghten, 2003).

This problem identification through metaphor justifies the subsequent stage of discursive deliberation, the creation of a ‘storyline’. It is defined as: “A condensed statement summarising complex narratives” (Hajer, 1995, p. 61). Hajer sees the storyline as being central to understanding discourse, as elaborated by Kurki et al. (2015, p. 3) it “creates, maintains, and transforms the discursive order by positioning subjects and structures”. Focusing on the storyline then enables the highlighting of the influence of a discourse coalition, which refers to “a group of actors that, in the context of an identifiable set of practices, share the usage of a particular set of storylines over a particular period of time” (Hajer, 2006, p. 70). Through storylines, knowledge is clustered and actors are positioned so that coalitions can be formed amongst the actors within a policy domain. The storyline acts not only as a ‘discursive cement’ that keeps a discourse coalition together, it also helps to reduce the complexity of a certain phenomenon which makes the problem more manageable. Moreover, it helps to gain attention and acceptance of more actors and puts the issue into the centre of public debate. It also affects the production of knowledge, as now those who claim to have knowledge (i.e., scientists, environmentalists or politicians) can illustrate how they can resolve the problem. Actors are united through this shared discourse, and through these storylines and their socio-political resonance, the discursive construction of reality becomes an important source of power when discourse hegemony is achieved, and institutionalisation is in place to attain substantial authority (Hajer, 1995). Discourse coalition analysis provides the opportunity to understand the social dynamics of problem formulation, and thus how policy can be initiated or changed. While Hajer’s discursive analysis focuses more on the argumentative tactics behind policy adjustment, these forces feed the flow of ideas and issues into Kingdon’s multiple streams framework, making it possible to connect both frameworks. The coupling of these analytical concepts has been theoretically advanced by Winkel and Leipold (2016).

Transport policy can also be viewed as the outcome of competing discourses and storyline as in prior research (Vigar, 2002). Parallel to Hajer’s (1993) discourse analysis of acid rain, peak oil and high oil price are seen to signify the structural problem of oil dependence. Similarly, ‘peak oil’, ‘car dependence’ and ‘reliance on fossil fuels’ might be constructed as an element of a metaphor of an unsustainable industrial society and globalisation (Bliss, 2005). In this study, we examine whether ‘peak oil’ is employed as a storyline during the period of higher oil prices from 2003 to 2015, by stakeholders in Hong Kong and Brisbane to promote policy change that could address oil dependence in urban transport. In this study, we analyse peak oil and oil vulnerability policy development in both Hong Kong and Brisbane. The key concepts of MSF and Hajer’s approach are used in tandem.

4. The context of case study cities and data collection

Both cities chosen in this paper are oil importing cities, but with different urban form and transport infrastructure designs. Previous assessments of transport energy use have been focused on large sample quantitative studies (Newman and Kenworthy, 1989; Kenworthy et al., 1999). In this paper, we chose a small city sample (n=2) but a more qualitative approach in order to better understand the framing of transport policy in relation to transport energy use. Currently, oil vulnerability research primarily focuses on car dependent cities in the
Western world. Adding non-western cities would help to enrich the understanding of transport policy with a different cultural and geographic context. Hong Kong is often seen as a classic example of public transport success due to its compact urban form, yet there are other compact ‘city-state’-like urban jurisdictions, such as Macao or Malta, that retain considerable levels of dependence on private motorised transport. A policy of public transport infrastructure and car restraint, undertaken deliberately in the 1970s, is seen as the key to Hong Kong’s current success (Tang and Lo, 2008). Conversely, Brisbane was once a public transport city with a very large street-car tramway network, but this was abandoned and cars now dominate. Brisbane also fits within the type of large ‘provincial cities’ with similar geography and urban form, such as Vancouver in Canada and Portland in the USA. Table 1 outlines the mode share of these cities, showing that Brisbane is on the public transport side of the spectrum while Brisbane is on the private automobile side. In contrast to ‘large-N’ urban studies, ‘small-N’ research focuses on the local uniqueness of each city with in-depth qualitative research (Seawright and Gerring, 2008). Such uniqueness can also be highlighted with a deliberate selection of disparate cases. Another consideration in choosing these two cities is a practical one: the authors also be highlighted with a deliberate selection of disparate cases. Another consideration in choosing these two cities is a practical one: the authors also be highlighted with a deliberate selection of disparate cases. Another consideration in choosing these two cities is a practical one: the authors also be highlighted with a deliberate selection of disparate cases.

As with most major urban regions and cities in the world, both Brisbane and Hong Kong border adjacent urban areas. In the case of Brisbane, it is within an urban conurbation known as the South East Queensland (SEQ) region which stretches from the Gold Coast in the south to Noosa in the north. This area has experienced sustained high rates of inward migration thanks to a warm climate and relatively affordable living costs (Spearritt, 2009). Hong Kong is a former British colony and, since the handover of 1997, has become a Special Administrative Region (SAR) of China. It has maintained high levels of

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### Table 1

<table>
<thead>
<tr>
<th>Mode Share</th>
<th>‘City-state’-like jurisdictions</th>
<th>Large ‘provincial cities’</th>
</tr>
</thead>
<tbody>
<tr>
<td>High occupancy vehicles</td>
<td>76.2%</td>
<td>31.2%</td>
</tr>
<tr>
<td>Active modes</td>
<td>14.9%</td>
<td>27.9%</td>
</tr>
<tr>
<td>Low occupancy vehicles</td>
<td>5.7%</td>
<td>35.3%</td>
</tr>
<tr>
<td>Others</td>
<td>3.2%</td>
<td>5.6%</td>
</tr>
</tbody>
</table>

### Table 2

Key characteristics of Greater Brisbane and Hong Kong.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Hong Kong</th>
<th>Greater Brisbane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total population (2011)</td>
<td>7,070,388</td>
<td>2,003,499</td>
</tr>
<tr>
<td>Urbanised population (%) (2011)</td>
<td>7,053,701 (99.8%)</td>
<td>1,930,767 (96.4%)</td>
</tr>
<tr>
<td>Total area</td>
<td>1104 km²</td>
<td>5904 km²</td>
</tr>
<tr>
<td>Private vehicles per 1000 persons</td>
<td>50.08</td>
<td>613.40</td>
</tr>
<tr>
<td>Estimated transport energy use per person</td>
<td>6.5 GJ</td>
<td>31.6 GJ</td>
</tr>
<tr>
<td>Urban form and density</td>
<td>Compact and high</td>
<td>Dispersed and low</td>
</tr>
<tr>
<td>Society and culture</td>
<td>Dominant Chinese population and society but with significant British and Western cultural influences due to prolonged British administration. English widely used as business and official language.</td>
<td>A new world European society with dominant Western culture but also increasingly multicultural due to sustained global immigration. Indigenous rights and awareness also growing in recent decades.</td>
</tr>
<tr>
<td>Development expansion space</td>
<td>Constrained by natural geography with limited room to expand. Future large scale development most likely by sea reclamation or redevelopment of existing urban areas.</td>
<td>Room for further expansion but controlled by regional planning.</td>
</tr>
<tr>
<td>Planning governance</td>
<td>Hong Kong Special Administrative Region Government as a ‘quasi-city state’ (Kirby, 1997) with British-based planning legislation. Increasing cooperation with the mainland Chinese government on cross-border coordination.</td>
<td>4 local councils (Brisbane, Logan, Redlands and Moreton Bay) with strong Queensland State Government involvement under the Southeast Queensland Regional Plan</td>
</tr>
<tr>
<td>Borders</td>
<td>Immigration controls along the Hong Kong-China border.</td>
<td>No border to neighbouring areas.</td>
</tr>
<tr>
<td>Natural geography</td>
<td>Coastal city separated by a wider Victoria Harbour, numerous outlying islands, some highly populated and connected by bridges or tunnels.</td>
<td>Coastal city separated by Brisbane River, some outlying islands but largely undeveloped.</td>
</tr>
<tr>
<td>Built-up area percentage</td>
<td>14.9% (264 km² of 1104 km²)</td>
<td>14.2% (840 km² of 5904 km²)</td>
</tr>
<tr>
<td>Average per-capita income</td>
<td>US$55,167</td>
<td>US$47,124</td>
</tr>
<tr>
<td>British colonial settlement since</td>
<td>1842 (ended in 1997 due to sovereignty change)</td>
<td>1825 (Australia - federated in 1901)</td>
</tr>
<tr>
<td>Human Development Index</td>
<td>0.891 (very high)</td>
<td>0.933 (very high)</td>
</tr>
</tbody>
</table>
autonomy, with separate customs and immigration arrangements with China (Kirby, 1997). It borders Shenzhen and forms part of the Pearl River delta in Guangdong province. The delta is a global industrial powerhouse and is also rapidly growing, on a much greater scale and with a higher population than Brisbane. While it is possible to study both cities according to administrative boundaries, this approach is not ideal as there are considerable free moving flows of passenger travel beyond administrative boundaries, particularly for Brisbane. To allow meaningful comparison of these two cities, the scope of Brisbane includes the urbanised parts of the surrounding local government areas of Ipswich, Logan, Redland and Moreton Bay. We refer to Brisbane as the ‘Greater Brisbane Metropolitan Area’ instead of only Brisbane City Council’s administrative area. In the case of Hong Kong with its defined borders, studying the entire SAR as a discrete study unit is preferred. The key similarities and differences in these cities are outlined in Table 2 to provide a brief background regarding urban land use, transport and energy use which is important in understanding oil vulnerability.

To facilitate understanding of the two case study cities, purposive sampling in the form of semi-structured interviews with key actors in the urban transport domain were conducted (n=15, see Appendix A for the details of interviewees, names and organisation of the interviewees, all of which are anonymised). Brisbane’s interviewees included those who are working at the local government area in the Greater Brisbane Area. The range of interviewees, including government officials, academics, non-government organisations (NGOs) and transport operators, encompassed Hajer’s (2006, p. 73) notion of ‘helicopter interviews’ with participants from different fields across the policy domain. The questions asked were aimed at obtaining the interviewee’s perceptions and experiences of transport policy related to the period of higher oil prices, with a focus on peak oil and oil vulnerability.

We focus our study mainly on domestic urban passenger transport due to constraints of time and resources. However, other aspects of oil use, including freight transport, global trade, and even agriculture, were mentioned by the stakeholders during the interviews, demonstrating the wide range of the impact caused by higher oil prices. This paper follows a part of Hajer’s (2006) discourse analysis method. The full version includes ten steps, which are:

1. Desk research.
2. ‘Helicopter interviews’.
3. Document analysis.
4. Interviews with key players.
5. Sites of argumentation.
6. Analyse for ‘positioning effects’.
7. Identification of key incidents.
8. Analysis of practices in particular cases of argumentation.
9. Interpretation.
10. Second visit to key actors.

Due to resource constraints, a second interview with the participants were not able to be conducted. Additional inputs included transport and land use policy, hansards, parliamentary reports and meetings of the legislative bodies of Hong Kong and Brisbane. Media reports also were used to examine how the debate about higher oil prices was conducted, as these are regarded as ‘sites of argumentation’ (Hajer, 1995). NVivo 11 software was used to transcribe and analyse the data. This qualitative approach enabled direct engagement with stakeholders and provided an opportunity to explore this topic in greater detail and access previously unseen views or perceptions that are not observable through mere third-party data and quantitative methods such as vulnerability mapping.

5. Peak oil as a global discourse coalition

The concept of peak oil was first coined by geologist Hubbert (1956), who studied oil production patterns and found that oil wells and reserves follow a pattern of a bell-shaped curve. The study of peak oil became stagnant until the period of higher oil prices in the 2000s. The appearance of the term ‘peak oil’ became more frequent among mainstream English language media and academic publications (Bailey et al., 2010; Bardi, 2009; Becken, 2014). This is largely associated with the emergence of a globally connected discourse coalition that produces and spreads knowledge about this issue. The Association for the Study of Peak Oil (ASPO) was begun in order to unite a number of similar minded experts in the oil industry, and the message rapidly disseminated on websites such as theoildrum.com, peakoil.com and energy-bulletin.net in the early 2000s. With increased interest, locally affiliated groups of ASPO appeared across the globe. For instance, ASPO-Australia was founded in 2005 and Peak Oil Hong Kong was established in 2007 (Chen et al., 2007). Peak oil advocates frame the issue of higher oil prices in relation to increased oil demand from rapidly industrialising giants such as China and India, and the lack of transparency of oil reserve data to justify urgent action to reduce oil use (Brecha, 2013; Hirsch et al., 2007; Li, 2007). In the case of transport, solutions included the provision of public and active transport, better urban planning to reduce travel distance or demand, car restraint policies and seeking alternative fuel to replace oil. Sustainable transport policies could be promoted without the peak oil storyline, as there are other benefits such as fewer carbon emissions to address climate change, alleviation of air pollution and a reduction in the impact caused by mass car usage, for instance, road trauma, lack of exercise and obesity, and reduced visual amenity of car-based infrastructure, such as highways and parking spaces (Banister, 2003; Barter et al., 2003; Chapman, 2007; Eliasson and Proost, 2015; Hensher, 2008; Hickman and Banister, 2014; Litman, 2011). However, the use of peak oil storylines was more apparent in car dependent cities between the periods of the 2000s and 2010s. The following subsections explore how differently the peak oil storyline is employed in Hong Kong and Brisbane, respectively.

5.1. The peak oil storyline in Hong Kong

From the data collected, we were able to analyse the discourse of peak oil largely utilised by academic and NGO groups in Hong Kong. The explicit mention of the term ‘peak oil’ is absent in the official transport policy. For public responses to the issue of higher oil prices, the official response of the Hong Kong government is mainly to monitor the situation and to provide information for users (for instance, price watch initiatives on fuel prices) (Hong Kong Government Information Services, 2014). In view of the realities of rising oil prices, the Hong Kong government sees oil prices hikes as merely market fluctuations, not a structural oil dependence risk. Also, the issue is viewed as being beyond the government’s control, as seen from a comment from a politician:

Of course, there are things that we cannot change, including the international oil price. This is a relatively important issue and is related to international politics, geopolitics and the impact on the economy, which are beyond our control.

(Hon. Kwok Ka-Kei, Independent, Legislative Council (LegCo) member, 2008)

The political reality is that this ‘let the market decide’ and a ‘wait-and-see’ approach is largely pragmatic and sees the issue of oil price as beyond the control of local level governments and at the mercy of international markets. Peak oil has not been used widely in Hong Kong as a discourse in explaining the period of higher oil prices. One respondent who expressed stronger interest in peak oil in Hong Kong commented:

I do not think there is any research in peak oil and the knowledge and sense of a looming energy crisis is not prevalent in Hong Kong.
This does not mean there is a complete lack of knowledge about peak oil among Hong Kong’s policy makers, as revealed from an interview response by a government official regarding peak oil:

I have heard a bit about peak oil. But in Hong Kong people rarely mention it. They tend to assume oil will keep flowing to Hong Kong from the Middle East and it is not a concern at all. (Hong Kong government official interviewee, 2015)

Beyond urban transport, the term ‘peak oil’ appeared in a number of NGO’s submissions to government policy consultations regarding ecological footprint and biodiversity (Cheung and To, 2014) and to oppose the construction of a third runway (Hong Kong Airport Authority, 2014). These submissions suggested that energy needs to be considered in policy making. Apart from this, it appears that the peak oil discourse is only present outside government policy making, and its advocates present as a fringe group. Those who represent persons affected by higher oil prices, such as the motorists’ lobby, mostly do not connect the issue to a wider resource depletion issue. They tend to link the issue of higher oil prices to affordability and financial strains of people who are required to pay for fuel, such as professional drivers and people living in areas that depend on oil-based fuel for transport, for example, those living on outlying islands (Hong Kong Legislative Council Secretariat, 2005). The responses of the participants and documentary data collected in this study suggested that people were mostly interested in asking the government to reduce fuel taxes or to provide subsidies. In Hong Kong, no official policy document was found publicly which dealt with higher oil prices specifically in the period between 2003 and 2015.

5.2. The peak oil storyline in Brisbane

Conversely, in the case of Brisbane and Queensland, oil prices became a serious issue in the early 2000s. Peak oil gained widespread media attention and government response at the same time. A number of stakeholders were involved in Brisbane’s local and state government bureaucracy around that time, and advocacy groups concerned with peak oil existed within their organisations.

There was a background paper on peak oil and energy for Brisbane City Council in 2005. We worked with senior bureaucrats who were working on a vision for the council. Looking at long-term strategic challenges globally and for Brisbane, it included climate change, peak oil, nanotechnology, ageing population, globalisation and so on. Then they did the classical risk assessment of all of those. Peak oil came out as the most urgent and impactful in the short to medium term, way back in 2005. (Brisbane government planning officer interviewee, 2015) Peak oil interest groups were also evident inside transport agencies, as demonstrated by a comment from a transport planner:

In there (the transport agency), it was a big thing. People were wearing badges saying ‘peak oil’, some people were having a very strong interest in it. ( Former Queensland state government transport planner interviewee, 2015)

This reveals that the peak oil discourse has a certain acceptance in Brisbane and its advocates are forming a discourse coalition that is able to influence policy making. Further, the Labor Government which was in power in Queensland from 1998 to 2012 was more attuned to the storyline of peak oil. At a state level, a public committee named the ‘Impact of Petrol Pricing Select Committee’ was instigated to investigate the issue of fuel price increases in Queensland in 2005. While the official purpose of the committee was to investigate the economic competitiveness of ethanol, peak oil was used as a storyline in a majority of the submissions to explain the issue of increasing oil prices. About the same time, the ‘Oil Vulnerability Taskforce’ was set up. The term was included in subsequent regional planning and transport policies (Queensland Government, 2009). Interviewees suggested that discussions about peak oil were spearheaded by Andrew McNamara, a Queensland member of parliament with a strong interest in peak oil, who can be seen as a ‘political entrepreneur’ in Kingdon’s multiple streams framework. The following statement was made by him in a parliamentary question time.

The future availability of fossil fuel and alternative energy supplies is one of the main sustainability issues facing society today. The significance of this issue means that Queenslanders and people all around the world will need to address the increasing price and diminishing availability of oil in coming years. (Hon. Andrew McNamara, Queensland Minister for Sustainability, Climate Change and Innovation, 2008)

The notion of peak oil and the solutions for it were also becoming institutionised. Funding was allocated to devise whole-of-government coordination to implement the policies and recommendations identified by the Oil Vulnerability Task Force in the Queensland Budget in 2008. The Office of Sustainable Transport was established to devise policies to promote sustainable transport. However, within the opposing discourse coalition, the issue of peak oil and car dependence were not seen as being so urgent. Key actors on the opposing side are those on the conservative spectrum of politics, in particular the Liberal National Party (LNP) in Brisbane and Queensland’s political scene, led by Brisbane’s then mayor, Campbell Newman, who was later elected as Premier of the State of Queensland. When asked about oil vulnerability at a local meeting, Newman replied:

Whether they run cars on wood-shavings, tea leaves or canola oil, people will continue to drive. (Campbell Newman, Former Lord Mayor of Brisbane, 2006, as cited in The Courier Mail, (Clarke, 2006))

During Campbell Newman’s reign at the Brisbane City Council, especially after his re-election in 2008 securing majority control in Council, greater powers were gained by his government. This allowed his government to promote pro-road and pro-car policies as evidenced by the construction of the ‘TransApex’ bypass tunnels under Brisbane’s city centre along with a diminished focus on public and active transport. Some interviewees in Brisbane even suggested that discussions about peak oil and oil vulnerability were being discouraged in Council. This resulted in the resignations of many public servants who held strong views on energy and sustainability issues. This later had an effect on state-wide politics, as Campbell Newman ran for the position of Premier of Queensland and was elected in 2012. Officially, in Queensland the storylines of peak oil and oil vulnerability in state transport receded in transport and land use planning policies after 2012. Instead, massive road building projects were embarked upon under the storylines of ‘flood-reconstruction’, ‘dangerous roads due to the neglect of previous government’, ‘economic growth’ and ‘state building’. These policies lasted until 2015, when the Labor Party returned to power. Yet as oil prices reduce, in Brisbane the issue of peak oil no longer appears to be a pressing matter. From a retrospective view, the effectiveness of the peak oil storyline in transport policy appeared limited with a legacy of only “to adding a little paragraph of oil vulnerability in the regional plan” (Brisbane academic interviewee, 2015) and public servants feel “we are not actually doing anything and I feel we were incapable of doing anything.” (Brisbane local government officer interviewee, 2015). While little is being done to modify the transportation system in Brisbane city, statewide biofuel policy gained traction in 2014 as it is supported by the LNP State Government. Even after Labor regained power in 2015, this policy continued with the support of rural interests and bipartisan support. A biofuel mandate was approved in December.
2015, and is expected to be in force in 2017. Analysis of the submissions has shown that the biofuel industry used arguments about energy security.

6. Using MSF and Hajar's discursive framework to understand problem framing, and links with policy and politics

The results show that the use of storylines varies based on local conditions arising from the social and political context. Public concerns about a particular issue are important in promoting transport change (Butler et al., 2015). This relates to Kingdon’s (1984) idea of the coupling of various streams and which could be analysed alongside with the Hajar's discursive framework in the following analysis.

First, the MSF lens are viewed from the problem stream, as attention lurched to the problem of car and oil dependence in Hong Kong and Brisbane during the period of higher oil prices circa 2003–2015. This is followed by the policy stream, possible solutions to the problem were looked for. While there are ample ideas floating about in the ‘policy primeval soup’, the timing to connect those ideas with policies is most important. For Brisbane, a more receptive uptake of the peak oil storyline is largely due to the greater impact of higher oil prices and widespread car ownership/usage. This is relatively less in Hong Kong, but still attracts debate in Hong Kong, with calls for reducing fuel tax and increased scrutiny on the perceived monopoly of oil companies.

By analysing the material from published sources in conjunction with the interview data, the combined issues of fuel affordability and car dependence were used to explain why the issue of peak oil received attention at particular moments. These are analysed by looking at the key events of the case study cities, in particular, the release of the policy documents during the higher oil price period as shown in Appendix B. With lower car dependence in Hong Kong, the narratives of peak oil were not used as storylines in Hong Kong’s official transport planning practices from 1999 to now. By contrast, the peak oil storyline has been officially employed by the Queensland Labor Party government since 2005 to promote sustainable transport policies. Academic researchers and NGOs in Brisbane worked together to promote the idea of ‘oil vulnerability’ during the same time period (ASPO Australia, 2008; Burke and Bonham, 2010; Dodson and Sipe, 2005). It is apparent these actors in Brisbane are functioning as a discourse coalition, using the storylines of peak oil and oil vulnerability to promote a similar goal – the reduction of car and oil dependence. The differences in how peak oil was used to frame the problem of higher oil prices, the proposed policies and the level of success of policy change in the two case cities are shown in Table 3. For simplicity, the discourse groups are categorised as those who believe that peak oil is likely to happen soon, and those who do not or those who have no strong view. An illustrative network of discourse coalitions is summarised from the data collected, as shown in Fig. 1.

Using the MSF’s politics stream, the political entrepreneurs in Brisbane had a greater success than Hong Kong in using the Peak Oil discourse to push forward policies attempting to reducing car and oil dependence. The discourse coalitions on peak oil and sustainable transport in Brisbane were about to be institutionalised by a ‘whole-government response’ to oil vulnerability and the setting up of the Office of Sustainable Transport. This ended with Labor’s election loss in 2012, which saw the end of policies using peak oil as a key storyline. Documentary analysis indicated a cessation of the use of the terms ‘oil vulnerability’ and ‘peak oil’ for urban passenger transport in the Newman Government. Interview material also reviewed the ways in which civil servants were discouraged from raising peak oil issues under the Newman government. Only after the return of a Labor government in 2015, oil vulnerability re-appeared in the most recent State Infrastructure Plan in 2016.

Interviewees in both Hong Kong and Brisbane have identified that there are political barriers to addressing energy issues in transport. The political systems in Hong Kong and Brisbane are similar in some ways. They both have a unicameral parliament (the State of Queensland is an exceptional case in Australia as it does not have an upper house). However, Hong Kong has greater fiscal powers than Brisbane at the municipal local level, as taxation is independent under the existing arrangements as an SAR. However, Brisbane is unique in a way as the capital city of the most decentralised state in Australia but with a unified local government with a population much higher than the State of Tasmania (Caulfield and Wanna, 1995). Brisbane can be seen as being governed jointly by the Federal Government (which controls funding for infrastructure of national importance such as railways, highways and airports), the State Government (which controls the regional planning system and transport infrastructure) and several local governments which control local planning and transport operations. However, the Brisbane City Council has the greatest population share and greatest influence in local policy setting and fiscal revenue. For both cities, Hong Kong and Brisbane, policies promoted by the government are scrutinised by the legislative body which is democratically elected, as budgets and legislation require in-house voting. Unlike Brisbane or Queensland, no change in the governing party occurs in Hong Kong, as the ‘pro-establishment’ coalition have a constant edge in numbers over the ‘pro-democratic’ parties in controlling the LegCo, or in electing the Chief Executive under an electoral system design in a ‘hybrid regime’ (Lau and Kuan, 2002; Wong, 2015).

With a tradition of ‘executive-led’ government, Hong Kong had a tendency (or ability) to develop and implement technocratic-based transport policies even before the handover in 1997. Hong Kong's government and transport policy-makers generally sees Hong Kong as not car dependent nor oil dependent. Hence there was little political attention to the oil vulnerability problem. Nevertheless, a policy to promote electric vehicles (EVs) started in the 2009–10 policy address. The stated aim of EVs is to address air pollution rather than oil vulnerability (Hong Kong Department of Environment, 2016). It should be noted political pressure from the Hong Kong public can still affect policy proposals even with limited political enfranchisement (Chow, 2014). An example was the failure of electric road pricing in the late 1980s due to fierce opposition from car owners and taxi/minibus drivers (Borins, 1988; Luk and Chang, 1997).

Competing priorities in transport policy organisations are observed in both cities, just as time is seen as an important consideration of policy priority in the MSF. An example of this is seen in Hong Kong, where oil-related affordability pressures were not perceived as being a pressing issue when compared with mega-infrastructure construction and affordable housing. One Hong Kong interviewee commented:

> But there are so many pressing issues. The high speed rail project is already a big mess now (construction delays and over-budget). There are also calls for more public housing and etc. I am very sympathetic to the government officials. I know that they want to work on energy policies and peak oil, but there are more pressing issues to be dealt with.

(Hong Kong peak oil advocate interviewee, 2015)

Another issue raised by a Hong Kong transport advocacy stakeholder is the apparent lack of transport knowledge among the political class. Reflecting the comments of pro-car politicians who objected the recent renewed attempt to implement electric road pricing in Hong Kong, an NGO interviewee stated:

> “Also you can observe that the elected LegCo members only voice their concerns to the government when their voters are complaining ... or based on how the media is portraying a policy issue. But what I feel is some politicians in Hong Kong do not even have a basic grasp of the connection of transport policies and its social and environmental effects. As you asked about the policy barriers for addressing sustainable transport and oil vulnerability, I think the ignorance of some stakeholders is a major issue.”

(Hong Kong NGO interviewee, 2015)
Table 3
Different peak oil discourses with different problem framing and policies proposed.

<table>
<thead>
<tr>
<th>Main discourse coalition groups</th>
<th>City</th>
<th>Key actors who tend to uphold such view.</th>
<th>The problem being framed? (problem stream)</th>
<th>Proposed policies to deal with the ‘problem’. (policy stream)</th>
<th>Level of success in policy change (politics stream)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak oil is likely to happen soon.</td>
<td>HKG</td>
<td>• Environmental groups</td>
<td>Transport is mainly rail and public transport based. Impact of peak oil on Hong Kong’s local transport scene is rather limited. However, higher oil prices could cause immense affordability impact on outlying island ferries and outgoing air travel.</td>
<td>Public transport is ‘doing fine’ in Hong Kong, but active transport, mobility substitution measures are currently underutilised and should also be promoted to further reduce oil use.</td>
<td>Limited success as Hong Kong is already having low car ownership and mode share, there is a lack of political support. Additional policies implemented were the development of the Energy Saving Plan and the promotion of electric vehicles. Periodic success when Labor Party was in power. Whole-in-Government measures are briefly promoted from 2009 to 2012. In 2015, the biofuel mandate policy was successfully enacted with support from the two major parties and rural interest parties.</td>
</tr>
<tr>
<td></td>
<td>BNE</td>
<td>• Some government officials</td>
<td>Brisbane is highly car dependent and increase in oil prices will cause widespread affordability issues.</td>
<td>Drastic measures to reduce car use by public transport and active transport and also better urban planning.</td>
<td></td>
</tr>
<tr>
<td>Peak oil is not likely to happen soon or no strong view on peak oil.</td>
<td>HKG</td>
<td>• Government</td>
<td>Oil is important to transport and increased oil price is an issue for affordability.</td>
<td>Public transport is necessary for Hong Kong and should be continued to expand to meet travel needs. Favours energy transition of private transport and the promotion of electric vehicles, but it is more aimed at tackling air pollution and carbon emissions, but there is little a city level government can do. Favours continued monitoring of the situation and decision makers need more information to support their decisions.</td>
<td>This has been the dominant view in Hong Kong’s transport policy makers and has been the on-going policy response to oil price changes.</td>
</tr>
<tr>
<td></td>
<td>BNE</td>
<td>• Conservative-leaning political parties (LNP)</td>
<td>Oil is important to transport and increased oil price is an issue for affordability.</td>
<td>Driving is still necessary and favoured by the public. Excessive government intervention will constrain individual choice. Favours control of oil price increase. Public transport is provided only when congestion is an issue.</td>
<td>Driving remain an important mode in Australia. Stringent policies to curb car use are unlikely as this may cause voter backlash. However policies that aimed for replacing oil use by biofuels were still acceptable and were successfully enacted.</td>
</tr>
</tbody>
</table>

Note: HKG=Hong Kong, BNE=Brisbane.
The disconnect between technical expertise and politics is also noted from a Brisbane advocate stakeholder:

“The connection between the science and politics is very tenuous. The politician is more attuned to what they hear in their electorate because (it) can reflect the votes on polling day.”

(Brisbane peak oil advocate interviewee, 2015)

In Australian society, it is more common to see driving ‘as a right’ which is built into voting preferences. This makes it very difficult for decision-makers to implement policies that can effectively address the problem of car dependence and energy use. Another academic stakeholder commented:

If too many people are in cars and on the roads is the issue, then you would reduce it by reducing the cars on the roads and build better public transport. But they are facing the political backlash of people wanting to drive their cars. So it is paradoxical but you can’t do anything about it without changing attitudes.

(Brisbane peak oil advocate interviewee, 2015)

In contrast, another issue of resource depletion affecting South East Queensland between 2001 and 2011 was the ‘Millennium Drought’ which resulted in a concerted community response to the conservation of water. Rainwater tanks became popular and households voluntarily adjusted their behaviour, contributing to a rapid reduction in water use from 330 L per day prior to the drought to 124 L per day. Comparing such a difference in community response to a water and oil crisis, a government stakeholder commented that the water problem is more manageable and it is also more visible to the public:

“The problem of oil vulnerability is too big. Australia imports about, I am guessing, 90% of its oil at the moment. What can we do about that? But for water? You can do more about it. Also, the people could see the dams drying up in the west of Brisbane. They could see it! It is tangible!”

(Brisbane former local government urban planner interviewee, 2015)

As oil prices fell after 2014, the previously opened policy window in Brisbane has now shut, despite the efforts made to influence policy during the increase in oil prices. The change in government just after the height in oil prices foreclosed on enacting policy changes that had made it onto the state government’s agenda under the Labor government. Another opportunity to revisit preparations for oil vulnerability may come if oil prices rebound and electrification of the automobile fleet remains slow, or maybe it will simply fade from view. However, the policy window to enable the use of biofuels as a response in Queensland opened with the arrival in government of a more rural based party, the LNP from 2012 to 2015. Together with the support of a third minority party - the Katter’s Australian Party, that represents rural and sugar cane agriculture interests, the successful passage of the biofuel mandate policy was achieved. It is beyond the scope of this paper to look in detail at how pro-biofuel discourse coalitions acted as policy entrepreneurs to achieve their objectives. However, it is evident...
from the data collected that oil depletion and energy security are used as justifications to promote their aims, coupled with arguments to support ‘local sugar cane agriculture’. This had bipartisan support in Queensland’s state parliament and was seen as a policy solution with less political resistance.

In Hong Kong, policy actors are focusing on other issues for which the public demand government attention. A higher level of intervention in transport policy does not correlate with the appropriateness of such choice as it implies greater political obstacles to be met in its promotion or implementation (Chatterton et al., 2015). Such difficulty varies in jurisdictions, for instance, car restraint policies are more acceptable in Hong Kong but are less successful in Brisbane due to political barriers. In Hong Kong, the car lobby remained relatively small due to low car ownership. Nevertheless, it appears that Hong Kong does not rely on a peak oil storyline to promote rail-based development, electric road pricing and the development of electric vehicles. Other storylines such as easing congestion to address air pollution and carbon emissions are used to promote these policies, with specific studies to be conducted to justify investment in rail and public transport.

From a wider perspective, an implication of this paper for policy makers is the issue of policy acceptance and transferability. It is common to see policy makers or discourse coalitions citing ‘best-practices’ of transport policy or solutions around the world. However, the consideration of how policy options fit in a local context is also paramount. The qualitative approach, with critical theory and a constructivist worldview used in this paper, is able to unpack the local political and policy context. This section has explored the influence of peak oil discourse in recent transport policy development using Kingdom’s and Hajer’s frameworks. Like many other issues dealing with uncertainty and complex interests, policy makers will have to move beyond simply ‘selling their policy’ by putting forward their own beliefs and arguments. A further step to build discourse coalitions and to win support from the public is needed. Moreover it is sometimes necessary to make compromise between various discourse coalitions, in addition to fortunate timing of the political mood and electoral cycles, in order to attain actual policy change.

7. Concluding remarks

This study’s contribution to understanding responses to peak oil discourse comes from examining in detail the experiences of two very different cities. It is hoped that this paper’s in-depth analysis can help to reveal the dynamics leading to differing problem framing and policy outcomes in distinct geographic settings. There are some limitations to this study which could hopefully be addressed in future research. While a large amount of data has been collected for this research, it is also possible that certain key stakeholders have been omitted, in particular in Hong Kong, as there the issue of peak oil attracts less attention than it does in Brisbane. A more holistic analysis could be done if Hajer’s (2006, p. 73) full ten steps of analysis were carried out. Implementation and evaluation of policies related to energy in transport should also be looked into in greater detail, which has been proposed in the ‘Five-Stream’ adaptation of the MSF (Howlett et al., 2016). This may, however, be challenging for the discourse about peak oil, as globally, as systematic implementation of ‘oil-proofing’ policies are yet to be seen.

Broadening the research to a greater range of transport policy issues where discourse coalitions emerge may be beneficial. A useful focus of inquiry may be those groups promoting shifts in the ways governments fund and finance transportation, given the important technological, privacy and equity concerns that distance-based road pricing and similar options bring. Contextualising the experience of higher oil price during the 2000s to the 2010s is important in order to devise measures to reduce oil vulnerability, prevent future energy shocks and to hasten energy transition, which can also address climate change and achieve sustainable transport. Peak oil may not pose as much risk if an alternative power source for transport (e.g., electrification of private vehicles) arrives quickly enough. But there will inevitably be new transport problems and crises which emerge and that coalesce around new discourse coalitions. As this paper shows, transport policy is highly political in nature. It is evident that any policy has to deal with social and political pressure. This underscores the importance of producing a winning ‘discourse’ to gain hegemony and to facilitate policy change. In particular, policy actors who have an interest in promoting sustainable transport to highlight the issue of unsustainable energy use in transport and affordability issues caused by oil prices, need to be aware of how vested interests form and respond to discourse coalitions. While policy attention on a certain storyline may wax and wane, continued efforts to generate public debate and reliable knowledge are essential ingredients in developing sensible transport policy.

Research into urban transport’s oil vulnerability and efforts to manage its associated risks in non-oil producing nations, in particular for the Asia Pacific region, remains worthwhile, as long as short term shocks such as conflict in the oil shipping lanes (e.g., the South China Sea) or major oil producing regions like the Middle East remain possible. Though engine and battery technology may ‘solve’ the oil problem, policy makers should not be complacent, as oil prices are volatile and difficult to predict (Baumeister and Kilian, 2015) and most industrialised nations are likely to remain oil importers for years to come.

Acknowledgements

The authors would like to thank the interview participants in this research. We are grateful to Dr. Edward Morgan for his helpful suggestions for an earlier draft. The interview protocol was followed as outlined by ethics approval no. ENV0615HREC by Griffith University. This work was supported by the Australian Government Research Training Program Scholarship which provides the Ph.D. research expenses of the first author. The first author was also the recipient of an Australian Government Endeavour Research Fellowship. The second author is a recipient of an Australian Research Council – Discovery Future Fellowship (FT120100976). Transport research at the Cities Research Institute at Griffith University is supported by the Queensland Department of Transport and Main Roads and the Motor Accident and Insurance Commission.

Appendix A. Details of the interviewees

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Organisation Type</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government official</td>
<td>Government department</td>
<td>17/4/2015</td>
</tr>
<tr>
<td>Government official</td>
<td>Government department</td>
<td>17/4/2015</td>
</tr>
</tbody>
</table>
Appendix B. Key events/policies concerning Brisbane and Hong Kong regarding fuel price, usage and transport policy

Brisbane

<table>
<thead>
<tr>
<th>Date</th>
<th>Event/Document</th>
<th>Author/Actor</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>1997 Integrated Regional Transport Plan</td>
<td>Queensland</td>
<td>Reducing fuel use was one of the targets of the plan. However, the main focus was on relieving congestion and reducing air pollution.</td>
</tr>
<tr>
<td>2000</td>
<td>Regional Framework for Growth Management, 2000</td>
<td>Queensland</td>
<td>Aimed to “Champion energy conservation, the adoption of green energy, and alternative eco-efficient fuel sources, consistent with improving air quality in the region.”</td>
</tr>
<tr>
<td>2002</td>
<td>Transport Plan for Brisbane 2002–2016</td>
<td>Brisbane City Council,</td>
<td>Proposed multi-modal transport improvements with a focus to boost public transport ridership. The key goals of the plan were improving air quality and reducing greenhouse gas emissions.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local Government</td>
<td></td>
</tr>
<tr>
<td>September</td>
<td>Integrated Transport Planning Framework for</td>
<td>Queensland</td>
<td>Problem framing included a statement: “The community is also concerned about the impact of emissions from transport. Noise and air pollution are key issues for Queenslanders while rising greenhouse gas emissions are a global concern.”</td>
</tr>
<tr>
<td>2003</td>
<td>Queensland</td>
<td>State</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oil Vulnerability Taskforce was set up</td>
<td>Government</td>
<td></td>
</tr>
<tr>
<td>May 2005</td>
<td>Queensland Oil Vulnerability Taskforce was set up</td>
<td>Queensland</td>
<td>The aim of the taskforce was to “address concerns that future world supplies of oil for energy may diminish, to the detriment of Queensland’s sustainable future, and that ‘peak oil’ may be a world-wide phenomenon.”</td>
</tr>
<tr>
<td>June 2005</td>
<td>South-East Queensland Regional Plan 2005 – 2026</td>
<td>State</td>
<td>Proposed to create a more compact urban form that would reduce travel demands, thereby reducing energy usage and emission of pollutants. ASPO’s claimed to be “a nationwide network of professionals working (as volunteers) to reduce our oil vulnerability.” and aimed to bring the probabilities, risks and opportunities that peak oil presents to the attention of decision-makers.”</td>
</tr>
<tr>
<td>2005</td>
<td>ASPO Australia founded</td>
<td>ASPO</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>Future Energy and Peak Oil – discussion paper</td>
<td>Brisbane City Council,</td>
<td>A discussion paper that gathered the facts about peak oil and potential impacts on Brisbane city and the council. Urged the development of measures to address the issue.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local Government</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>Transport Plan for Brisbane 2006–2026 (Draft)</td>
<td>Brisbane City Council,</td>
<td>Included a section outlining the background of peak oil and proposed to increase the use of ‘environmentally friendly fuels’. The council proposed strategies to “preparing for increased oil prices including purchasing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local Government</td>
<td></td>
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</tbody>
</table>
CNG buses, investing in CNG refuelling facilities and trialling alternative fuels including bio-diesel which can be sourced from plant crops." It viewed increasing public transport services as "an important way for the City Council to reduce the exposure of the community to price increases."

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>State</th>
<th>Government</th>
</tr>
</thead>
<tbody>
<tr>
<td>April 2006</td>
<td>Inquiry into petrol pricing in Queensland</td>
<td>Queensland State</td>
<td>Government</td>
</tr>
<tr>
<td>August 2006</td>
<td>Climate Change and Energy Taskforce was set up</td>
<td>Brisbane City Council, local government</td>
<td></td>
</tr>
<tr>
<td>March 2007</td>
<td>Climate Change and Energy Taskforce Report Completed</td>
<td>Brisbane City Council, local government</td>
<td></td>
</tr>
<tr>
<td>April 2007</td>
<td>Brisbane’s Plan for Action on Climate Change and Energy</td>
<td>Brisbane City Council, local government</td>
<td></td>
</tr>
<tr>
<td>April 2007</td>
<td>Oil Vulnerability Taskforce Report Completed</td>
<td>Queensland State</td>
<td>Government</td>
</tr>
<tr>
<td>November 2007</td>
<td>South East Queensland Principal Cycle Network Plan</td>
<td>Queensland State</td>
<td>Government</td>
</tr>
<tr>
<td>2008</td>
<td>Queensland Budget</td>
<td>Queensland State</td>
<td>Government</td>
</tr>
<tr>
<td>July 2009</td>
<td>South-East Queensland Regional Plan 2009–2031</td>
<td>Queensland State</td>
<td>Government</td>
</tr>
<tr>
<td>July 2009</td>
<td>Office of Sustainable Transport Established</td>
<td>Queensland State</td>
<td>Government</td>
</tr>
</tbody>
</table>
Government future carbon/emissions trading and peak oil.

Queensland State Government acknowledged the “current taxi fleet is entirely dependent upon fossil fuels as an energy source. This meant that the taxi system is extremely vulnerable to rising oil prices.” Proposed to take-up more fuel efficient vehicle and engine technologies (for example, lighter vehicles and hybrids) and to adopt more fuel-efficient practices (e.g., eco-driving).

Queensland State Government stated that “cycling makes transport more resilient to oil shortages” and “by establishing cycling as an attractive travel choice, the vulnerability to reduced oil supply and rising oil prices can be minimised.”

Queensland State Government acknowledged that “action is necessary to avoid the negative consequences of unsustainable transport patterns, like air pollution, congestion, excessive reliance on oil-based fuels, increasing greenhouse gas emissions and reduced access to essential goods and services.” And “any sustained increase in oil prices or chronic shortages of oil would increase the cost of living. This increase could also impact disproportionately on urban fringe communities and low income earners.” Proposed to “urgently improving the viability, capacity and priority of modes which are not reliant on oil-based fuels, especially electric passenger rail and non-motorised active transport.”

Queensland State Government fuel costs were seen as a challenge to the tourism industry.

Queensland State Government it “recognises the strategic importance of oil shale to contribute to energy security” and removed a memorandum to freeze oil shale development in Queensland in 2008.

Queensland State Government the Act was made to “help develop an ethanol mandate to ensure a certain percentage of fuel sold in Queensland must be biofuel.” Biofuel industry submissions indicated support the Act as it would “reduce Queensland dependence on this foreign oil.” and “help transform the Queensland oil industry and prepare the economy to better weather the next oil price shock.”

Queensland State Government the Act requires the fuel industry in Queensland to meet targets for the sale of bio-based petrol (3%), and bio-based diesel (0.5%).

Queensland State Government stated “a switch to more energy-efficient infrastructure models may have a positive economic impact by reducing reliance on imported fuels and reducing potential fuel supply chain interruptions or spikes in global fuel prices.” The plan proposed facilitating more freight on rail, and greater public transport patronage.

Hong Kong

<table>
<thead>
<tr>
<th>Date</th>
<th>Event/Document</th>
<th>Author/Actor</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td><em>The Third Comprehensive Transport Study</em></td>
<td>Transport Department</td>
<td>Strategic transport policy with a focus on cleaner fuels, controlling congestion, air pollution and emissions. He stated that “The (Hong Kong) Government is closely monitoring international oil prices as the surge will affect the local economy, particularly the transport trade. The Government is monitoring retail prices and liaising with oil companies.”</td>
</tr>
<tr>
<td>September 2004</td>
<td>Statement from the Financial Secretary on rising oil price</td>
<td>Financial Secretary, Henry Tang</td>
<td></td>
</tr>
</tbody>
</table>
References


Hong Kong Airport Authority, 2014. Environmental impact assessment report no. ESBD-22/2014 on the expansion of Hong Kong International Airport into a three-runway system – Questions submitted by Dr. Gary W J Aades, EIABC, ACE. Hong Kong Airport Authority, Hong Kong.


Leung, A., Burke, M., Cui, J., Perl, A., 2015. New Approaches to Oil Vulnerability: Mapping for Australian Cities: The Case of South-East Queensland, the 200 km City. Presented at the State of the Australian Cities National Conference, Gold Coast, Australia.


10. Effects of contemporary light rail on vehicle use: An exploratory analysis of Gold Coast, Australia

The work presented here in Chapter 10 has been submitted as Leung, A., Burke, M., Eccarius, T., Yen, B.T.H., and Chiou, Y.-C., 2017. Effects of contemporary light rail on vehicle use: An exploratory analysis of Gold Coast, Australia. Presented at the World Symposium on Transport and Land Use Research (WSTLUR) 2017, Brisbane, Australia.

The analysis in this paper returns to Australia, with a more microscopic look at oil vulnerability on the City of Gold Coast, a mid-sized, rapidly growing but car dependent city that has recently completed a modern light rail system in 2014. Using household travel survey (HTS) data of 2009 and 2015, the effects of the opening of the light rail, along with other land use and transport factors, are measured by a multi-level regression model (MLM). Vehicle kilometres travelled is treated as a measure of oil vulnerability, which is used in Chapter 5 and 6 at city-wide level. Disaggregate (e.g., household) level oil vulnerability has not been researched in Australia before. The results show that VKT of households in Gold Coast is moderated by public transport, in particular light rail. The key findings are

- From 2012 to 2015, for every kilometre a resident is located further from a light rail station, VKT per capita increases by 1.2%. The introduction of light rail may have some effect in reducing car use.
- Non-car mode share may also contribute to VKT per capita reduction, with varying effects ranging from for each 10% increase of these modes,
the VKT reduction is at bus (20%), cycling (28%), train (19.5%) and tram (18.8%) in 2015.

The results justify the uptake of more sustainable non-car modes in reducing oil vulnerability. Future research can improve the model with more sampling adjustments or specialised regression methods. The modelling results can be used to develop empirically driven weights, in order to address a key limitation of current oil vulnerability composite indices (lack of empirical support on weights used). Future works derived from this study, with the inclusion of journal experience variable, or international comparisons of light rail corridors could also be worthwhile. In addition, a more sustainable transport framing might be, more inclusive than merely VKT or oil vulnerability.

**Research questions addressed in this paper and contributions**

**Primary question**
Do new public transport improvements help reduce oil vulnerability (measured by VKT per capita)?

**Summary of contributions**

VKT changes on the Gold Coast, before and after the opening of the G:link light rail were assessed. The regression models presented in this chapter offer an estimate of VKT for small areas (SA2). The estimate of VKT using household travel survey is more advantageous than census based commute variables, as the latter is limited in mode share and car ownership values.
10.1 Statement of contribution to co-authored published paper

This chapter includes a co-authored paper. The bibliographic details of the co-authored paper, including all authors, are:


The authors listed below have certified that:

1. They meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
2. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
3. there are no other authors of the publication according to these criteria;
4. they agree to the use of the publication in the student’s thesis and its publication on the Griffith University database consistent with any limitations set by publisher requirements.

<table>
<thead>
<tr>
<th>Contributors</th>
<th>Statement of contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abraham Leung</td>
<td>Conceiving, planning and the writing of the manuscript, data collection, and the preparation of tables and figures. The candidate was also responsible for the revision made at the suggestion of the conference reviewers.</td>
</tr>
<tr>
<td>Matthew Burke</td>
<td>Provided assistance in the theoretical framing of the research and edited in the initial and the reviewed manuscript.</td>
</tr>
<tr>
<td>Timo Eccarius</td>
<td>Provided assistance in the data analysis, modelling, preparation of tables and figures, and the writing of the methodology/data analysis section.</td>
</tr>
<tr>
<td>Barbara T.H. Yen</td>
<td>Provided assistance in framing, data analysis and modelling.</td>
</tr>
<tr>
<td>Yu-Chiun Chiou</td>
<td>Provided editorial suggestions in the initial manuscript.</td>
</tr>
</tbody>
</table>

Supervisor Confirmation: I have sighted email or other correspondence from all co-authors confirming their certifying authorship.

(Signed) ___________________________ (Date) 24, June, 2017

Co-principal Supervisor: A/Prof Matthew Burke
Effects of contemporary light rail on vehicle use: An exploratory analysis of Gold Coast, Australia

**Abstract:** In Australia, the Gold Coast’s introduction of light rail is proving to be a promising start and this beachside tourist city is heading towards a more sustainable direction. However, the effects of this new improvement in its public transport system have not been validated so far. We present the exploratory analyses of patterns of private vehicle use after the commencement of the G:link light rail on the Gold Coast. This paper primarily studies the effects of the Gold Coast’s new light rail system on private vehicle kilometres travelled (VKT). Using a repeated cross-section multi-level regression model based on the 2009 and 2015 Household Travel Surveys, the results show that the aggregated reduction effects of VKT before and after the introduction of the light rail. Furthermore, the distance of households from the nearest public transport plays a varying role in VKT reduction. This model can be a first step to develop empirically driven weights using statistical regression or spatial microsimulation for future oil vulnerability composite indices. The overall finding supports the further expansion of light rail, and the upcoming second stage of the G:Link which will connect the urban core of the Gold Coast to heavy rail connections in Brisbane, which should further reduce private VKT and oil vulnerability.

**Keywords:** oil vulnerability; light rail; repeated cross-sectional analysis; household travel surveys
1 Introduction

Increased fuel price has been a concern in Australia in particular during 2004 to 2014, as the oil price skyrocketed to US$147 per barrel at the highest point in 2008. Various levels of governments in Australia have produced dedicated policy statements in response (Australian Senate, 2007; Queensland Government, 2007; Sunshine Coast Regional Council, 2010). Similar responses have been seen around the world (Lee and Scott, 2007; New Zealand Transport Agency, 2008; Sweden Commission on Oil Independence, 2006).

The potential impacts of a rising oil price are also related to the spatial distribution of transport disadvantage (Denmark, 1998), forced car ownership (Currie and Senbergs, 2007) and transport-related poverty (Lucas, 2009). This has led to the emergence of “oil vulnerability research” to assess the spatial impacts of higher oil prices on urban households based on vulnerability components, namely Exposure (i.e., factors inducing oil use in transport, such as car ownership rates, mode share and vehicle kilometre travelled (VKT)), Sensitivity (i.e., factors affecting the ability to afford fuel, such as income) and Adaptive Capacity (e.g., factors affecting the ability to travel in modes other than oil-using vehicles, such as public transport availability and walking/cyclability) (Akbari and Nurul Habib, 2014; Dodson and Sipe, 2007; Fishman and Brennan, 2010; Leung et al., 2015; Rendall et al., 2014; Renting et al., 2011). However, these oil vulnerability studies are mostly focused on the ‘potential’ impact of higher oil prices on households (Lucas et al., 2016). Limited research has been carried out into the actual impacts of higher fuel prices, and how these vulnerability components are interacting with each other. Further complicating oil vulnerability studies is the fact that since 2014, oil prices have receded to around US$40 due to recent geo-political developments, and because unconventional oil
has been extracted more extensively (Khan, 2017). The threat of oil price rises remains as Australia depends on oil imports and fragile shipping lines (Blackburn, 2013). Unconventional oil production is controversial, in particular for its environmentally damaging effects (Metze and Dodge, 2016). In Australia, the pace of energy transition away from fossil fuels (mainly oil) has remained slow (Warren et al., 2016). Nevertheless, providing better public transport is a key solution to the problems associated with private vehicle dependence and oil vulnerability. Highly energy efficient heavy rail is more costly per capita for medium-sized cities when compared to large ones. Hence, light rail is increasingly adopted as an ‘affordable’ sustainable transport solution for mid-sized cities, as seen in a number of New World cities such as Portland, Los Angeles and St Louis in the USA (Culver, 2017), Edmonton and Calgary in Canada (Newman and Kenworthy, 2015) and recently on the Gold Coast, Australia, where the G:link Light Rail started operations in mid-2014. Using household travel surveys (HTS) conducted for the city in 2009 and in 2015, this paper aims to explore the use of HTS for oil vulnerability research, while in earlier studies, census data were used predominately. HTS data reveals VKT figures, which are not available in census data directly (only contains aggregated distance to work at small area level). VKT could serve as an important indicator of exposure in oil vulnerability analysis. For Australia, this is an issue, as odometer data is generally not available at micro-scale. The aggregated and city-wide effects of public transport improvement, in particular the provision of light rail using a case study of the Gold Coast, are also examined.

This paper consists of five sections. Following the introduction, Section 2 outlines the existing literature about the emerging study of oil vulnerability, the effects of public
transport improvements on cities and the methodological considerations of time series research into urban public transport. Section 3 outlines the background information of the study area, the data used in this paper and the proposed methodology. The results are presented in Section 4, followed by concluding remarks in Section 5.

2 Literature review

It is imperative that a well patronised public transport system be more efficient in terms of energy use, in particular in its use of oil due to its much higher vehicle capacity. Also, railways are often powered by a fixed electricity supply which can tap into renewable energy (Gilbert and Perl, 2012; Renne and Fields, 2013). During the period of higher oil prices, these notions are linked specifically with oil price increases, giving rise to ‘oil vulnerability’ urban transport studies which incorporate energy and social dimensions in traditional transport and land use studies (Berry et al., 2016; Dodson and Sipe, 2007; Li et al., 2015; Lovelace and Philips, 2014; Rendall et al., 2014). A widely used way to measure oil vulnerability is based on census-based proxy measures such as private vehicle ownership or mode share (Dodson and Sipe, 2007, 2008). However, most oil vulnerability studies of this kind have only assessed the potential impact of oil vulnerability due to lack of actual fuel usage data. Only a handful of studies were able to provide analysis of more accurate energy usage by using vehicle odometer data (Rendall et al., 2014) which is not available in Australia, or computationally intensive spatial microsimulation with synthetic data (Lovelace and Philips, 2014). A remaining issue of these oil vulnerability studies is that the exposure, sensitivity and adaptive capacity variables used to generate the composite indices are often not empirically tested.
For medium sized cities such as the Gold Coast, heavy rail can be costly to construct and operate, and there may not be sufficient demand to justify its implementation. This brings us to the argument for cheaper ‘hardware upgrade’ alternatives such as modern light rail systems or bus rapid transport. Light rail possesses a special appeal to the public, as it is perceived to be more reliable, have network legibility and a higher level of comfort (during the ride and while waiting) when compared to conventional buses (Currie, 2005). This probably explains the recent proliferation of light rail systems globally, especially in Western New World jurisdictions (Cervero, 1984; Lane, 2008). A change in transport thinking is also happening in many middle-sized cities in Australia, such as Canberra, Newcastle and the Sunshine Coast, and proposals for light rail are being suggested in a number of inner-city sites in Sydney and Perth (Currie and Burke, 2013). There is also considerable interest in these light rail projects in urban transport research, particular for their effects. For a pre-construction evaluation of the potential effects of light rail infrastructure, modal-choice model frameworks have been developed to evaluate the potential to reduce the daily commuting costs incurred in using light rail systems (Marshall et al., 2015). A majority of post-construction studies have compared the effects of new light rail services. In the studies looking at public transport effects, private VKT is often used as a performance indicator of the effect in reducing trips done by private vehicle (Familar et al., 2011; Nasri and Zhang, 2014; Zhang et al., 2012). Studies examining travel behaviour changes arising from new services often require longitudinal sampling from the same subjects, with treatment and control measures being considered to be methodologically superior (Arentze et al., 2001; Boarnet et al., 2013, 2013; Houston et al., 2015). The travel behaviour of new residents attracted to areas with new light rail provision (Cao and
Ermagun, 2016) and congestion alleviation effects (Bhattacharjee and Goetz, 2012) have also been considered. It should be acknowledged that public transport improvements often accompany land use changes, such as the creation of transit-oriented development (Arrington and Cervero, 2008). Apart from transport specific effects, the effects of changes in urban form were also considered. Early studies with more limited data looked at city-wide changes of density and land use on mode use (Frank and Pivo, 1994), whilst more recent studies were able to assess changes in travel behaviour based on household survey data (Baum-Snow and Kahn, 2000). It is also noteworthy that a wide range of studies have focused on the effect of public transport projects on property values (Forrest et al., 1996; Mulley and Tsai, 2016; Murray, 2016; Rosiers et al., 2010; Weinberger, 2001; Yan et al., 2012), yet VKT studies are rather limited due to a lack of accurate travel data and the expenses of ‘before and after’ surveys. As the Gold Coast, is one of the latest Australian cities to actually complete a light rail project. A study of this city might offer useful insights into how a contemporary light rail system has improved transport sustainability and reduced oil vulnerability.

3 Methodology

3.1 Context of the study area – the City of Gold Coast

The study focuses on the City of Gold Coast in South-East Queensland (SEQ), a relatively new urban settlement based on sub-tropical beach tourism, which is the largest non-state capital city in Australia (Bosman et al., 2016). Since the 1960s when the city first became an urban centre, the Gold Coast has had no line-haul rail system where most of its residents live, and is extremely private vehicle dependent. In general, the contemporary urban
settlement has followed the coastline and the Pacific Highway. A dense urban strip now runs north-south along the coast from Labrador to Broadbeach. Low-density suburbs run inland, some of which are serviced by an inter-city commuter rail line that connects to Brisbane, the larger city to the north and the capital of Queensland. However, this intercity rail line does not connect to the Gold Coast’s densest part, resulting in limited patronage. The City of Gold Coast’s (2012) Transport Strategy 2031 acknowledged that the city-region had reached a point that a car and bus-based transport system would not be capable of coping with the ever-growing transportation task. It shows a significant paradigm shift away from freeway programs to embracing alternative modes: a mix of newly proposed railway lines (both light and heavy) and active transport connections. The first major project completed is Stage 1 of the Gold Coast’s light rail scheme – the G:link (pictured in Figure 1), which opened in July 2014.

Figure 1: G:link operations in 2014, Griffith University Station (Source: Author)
Somewhat unusually for Australia, this project was funded by all three tiers of government – local, State (Queensland) and the Commonwealth. At the local level, the City of Gold Coast placed a levy to help fund transport improvements across the city (as of now, the rate is A$117 per ratepayer annually). The 13km route of Stage 1 is almost entirely segregated in its own right-of-way with less than 1% of the route in mixed traffic. There are sixteen stations spaced on average 812m apart. The line connects a major teaching hospital and the city’s largest university campus at Parkwood, through the commercial centre of Southport, to the dense tourist centres of Main Beach, Surfers Paradise and Broadbeach. This southern section consists of some of the densest land uses in any Australian city, but was built up along a highway corridor that has never been serviced by high-capacity and rail-based electric public transport. The fleet consists of 14 Bombardier *Flexity 2* trams with a top speed of 70km/h. These run frequently, with a headway of around ten minutes throughout most of the day, with services late on Friday and Saturday nights servicing the city’s large night-time economy.

As shown in Figure 2, the patronage of the G:link increased rapidly soon after its commencement in late 2014, despite the shortness of its route which does not connect to the city’s heavy rail line, and which has inconvenient interchanges for passengers who must switch from bus services north or south of the route. For comparison, the bus and rail patronage from 2004 to 2013 is shown in Figure 3. Data after 2013 is not available to the authors at this stage. The extension to the heavy rail line at Helensvale station is now under construction and is due to be opened in time for the Commonwealth Games sporting event.
in 2018. Planning has commenced on a third stage to take to the line a further 30km south to the Gold Coast Airport at Coolangatta via Burleigh Heads.

**Figure 2: Patronage of light rail services on the City of Gold Coast**
(Source: Queensland Department of Transport and Main Roads)

**Figure 3: Patronage of rail and bus services on the City of Gold Coast**
(Source: Queensland Department of Transport and Main Roads)
The urban and land use context of the City of Gold Coast, in particular energy use, are visually depicted in Figure 4. The left portion shows a composite oil vulnerability assessment of SEQ by Leung et al. (2015), encompassing the Brisbane region in the centre, the Sunshine Coast to the north and the Gold Coast. This oil vulnerability mapping assessment is based on 2015 data, after G:link began operations. A composite indicator based on census and transportation data is created, which includes three main components, namely Exposure (private vehicle ownership, mode share and commuting distance),
Sensitivity (income and socio-economic disadvantage levels) and Adaptive Capacity (public transport frequency and its coverage, coverage of electric-powered public transport, walkability and mode share of non-motorised modes). Overall, Brisbane is the least oil vulnerable city in the regional context of SEQ. The Gold Coast is found to be least oil vulnerable only along the G:link corridor. Oil vulnerability level then intensifies when radiating out, and the outer suburbs are assessed to be highly oil vulnerable. The right portion of Figure 4 shows new urban growth (black areas) on the outskirts of the Gold Coast, which is based on mapping residential expansion from aerial images and cadastral data. Public transport re-organisation is also observed during the commencement of the G:link, mainly to avoid duplication of bus and light rail services. However, large swaths of the low-density south-western suburbs have had their bus services rerouted to serve the newly developed northernmost fridges around Coomera and Ormeau. These transport and land use changes on the Gold Coast have not been thoroughly studied to date.

3.2 Description of the data

To assess the impacts of light rail and other urban changes, we used two intervals of the Household Travel Surveys (HTS) in 2009 and 2015 covering the Gold Coast, which were conducted by a private company under contract to the Department of Transport and Main Roads (DTMR) of the Queensland State Government. Both HTS were both conducted in July, August and September and the seasonal variations are minimised. These surveys were conducted in the form of a travel diary of a day with a stratified random sampling of households covering the entire City of Gold Coast’s jurisdiction. The HTS trip data provides a wealth of information such as purpose, mode used and locations of trips taken.
and the demographic attributes of the household surveyed (e.g., income, household and dwelling characteristics and the vehicles owned). These variables would be of interest in endeavours to understand the relationship between trip patterns, household demographics, urban form and transport effects. The data includes a network distance of trips, providing the basis of private VKT data for this study, which is an indicator of oil vulnerability that was usually estimated from journal-to-work data from the census, with no consideration of other trips, such as those made for educational and personal/social reasons. While electric vehicles (EVs) may help reduce vehicle oil use (Zhang et al., 2017) and may suppress oil prices (Rabah Arezki et al., 2017), the uptake of EVs on the Gold Coast is slow, due to the lack of official promotion and charging infrastructure – no EVs were found in 2009 HTS and there were only 3 EVs found in the 2015 HTS.

For the location of households, the geographical components were confidentialised into a fine-grained census tract unit of Statistical Area level 1 (SA1) in accordance with the Australian Statistical Geography Standard (ASGS) as specified by the Australian Bureau of Statistics (2010). This is due to privacy considerations, as stipulated in data release conditions. Each SA1 generally contains on average 400 persons (ranging from 200–800). This small unit allows a fairly accurate estimation of the distance from the residential location to other locational features of interest. Road network data from the DTMR is used to provide a basis for calculation of network distances from the centroids of SA1s to the nearest locational features. The major urban activity centre classification (namely Brisbane CBD, principal and major centres) is defined by the SEQ Regional Plan of the Queensland State Government (2009). This is put into consideration, as a number of respondents might
be regular commuters travelling outside the Gold Coast. Most of these trips are made to destinations such as Brisbane, which is approximately 60-90 kilometres away from the SA1s of the Gold Coast. In addition to the HTS data, other relevant demographic variables from the Australian Bureau of Statistics are used, such as the 2011 Census. Projected figures of population in 2015 are obtained from the Queensland Government Statistician’s Office (QGSO). Public transport stops as applicable in 2015 are generated from the General Transit Feed Specification (GTFS) data released by DTMR’s public transport authority - Translink (2016), whereas the 2009 stops data are directly obtained from Translink, as GTFS had not been introduced at that time. These two sets of transport stops data are able to account for changes in the public transport network before and after the light rail was introduced and before the bus route reorganisation occurred in 2014. Further analysis on frequency is possible, but this study aims to focus on the locational changes of the stops. Only week-day trips (Monday to Friday) were considered, as week-end (Saturday and Sunday) trips are usually less regular compared to week-day trips. Data cleaning procedures, such as removal of trips by uncommon modes such as planes and boats, were performed to improve the data quality for the urban transport study. The background information and key demographics detail of the surveys in 2009 and 2015 and fuel prices are shown in Table 1 for reference. The sampled area coverage has expanded in the 2015 HTS, with 213 more SA1s containing household samples. This reflects the rapid urban expansion on the Gold Coast. For sampling rate estimations at SA1 level, 2011 Census data of the usual resident population (URP) is used to approximate both years, as 2015 URP estimates are not accurate at SA1 level. The overall sample rate of populations across the Gold Coast is around 2% to 3%, yet this measure is not accurate as it includes outer areas
that are rural in nature and are sparsely populated, and are actually excluded as HTS study areas. If only considering the sampled SA1s, the sampling rate of households is about 5% in both years. Hence, the household is the most suitable unit of analysis for HTS data on the Gold Coast. This also takes into consideration vehicles in households which are usually operated and shared by other household members. For further analysis, the trips are then aggregated into units of households. Variables in the census considered in the study include usual resident population density (2011 Census data and 2015 estimated figures, at SA2 level) and employment (job) density (Only 2011 Census data is available, at SA2 level).

We also considered fuel price differences of the two HTS. The sample data did not capture the years with the highest fuel prices (2008 and 2014), with A$1.26 per litre in 2009 and A$1.35 in 2015. However, the inclusion of fuel price in the analysis was inconclusive.

<table>
<thead>
<tr>
<th>Table 1: Background Information</th>
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</thead>
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<tr>
<td><strong>Background Information</strong></td>
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<td>Number of SA1s containing HTS samples</td>
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<td>Population covered (based on 2011 usual resident population at SA1)</td>
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<td>Households</td>
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<tr>
<td>Trips</td>
</tr>
<tr>
<td>Trips per household</td>
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<tr>
<td>Residents sampled</td>
</tr>
<tr>
<td>Vehicles sampled</td>
</tr>
<tr>
<td>Average vehicles per household</td>
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**Sampling rates**

**Estimated HTS population sample rate of entire Gold Coast** (HTS sample size ÷ 2011 population, %)

<table>
<thead>
<tr>
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<th>2009</th>
<th>2015</th>
</tr>
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<tr>
<td>Estimated HTS population sample rate of sampled SA1s only</td>
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<td>2.45</td>
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<tr>
<td>Estimated HTS household sample rate of entire Gold Coast (HTS sample size ÷ 2011 households, %)</td>
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<td>1.34</td>
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<tr>
<td>Estimated HTS household sample rate of sampled SA1s only</td>
<td>5.57</td>
<td>4.46</td>
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**Additional information**

Fuel price (mean value of sampled months, A$ per litre)

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Source: HTS and Census data)</td>
<td>1.26</td>
<td>1.35</td>
</tr>
</tbody>
</table>
3.3 Multi-level modelling

This study uses private vehicle kilometre travelled (VKT) as the major indicator of negative transport impacts, in particular oil vulnerability. One of the benefits used to support the case for the construction of the G:Link is the reduction of VKT, which leads to less air pollution (GoldLinQ Consortium, 2008). While there was a four-step multimodal travel model conducted for the SEQ region, it was made from data at SA3 level and is aimed at long-term and regional scale travel forecasts. This study uses a more fine-grained resolution at household level, which is geographically coded as SA1s. The key research question of this study is to explore the use of HTS data for oil vulnerability analyses; in particular to investigate whether the major changes in transport (G:link commencement, public transport restructure) and land use (urban expansion and intensification) between 2009 and 2015 have helped to reduce private VKT, which is an important exposure determinant of oil vulnerability.

There are two main research designs for measuring time effects for urban transport intervention, namely; 1) repeated cross-sectional surveys at the same area using different subjects for before and after; and 2) a longitudinal study on the same sample before and after the intervention (Ho and Mulley, 2013). The consideration of research design is usually constrained by data availability. In urban transport fields, longitudinal panel data are often considered to be methodologically superior (Graham-Rowe et al., 2011; Stopher et al., 2009) but they require dedicated before and after surveys which could be costly and difficult to conduct. As longitudinal panel data is not available for analysis in the study area, this paper uses repeated cross-sectional sample surveys in the form of HTS. A
limitation of this approach is that it requires that an assumption of households sampled before and after are equally representative (Stopher et al., 2009). This is acceptable for the HTS of SEQ, as it was conducted by random stratified sampling with a fairly large sample size (over 20,000 trips covering at least 2.5% of the urban population and close to 5% of urban households). Socio-demographic and sampling differences are potentially an issue. This is an exploratory study, and the use of sampling adjustments or weights to reduce these error effects is considered in the further studies. Control and treatment comparisons could be considered in future studies to measure the specific effects of the changes in transport and land use, chiefly the effects of light rail.

Based on the stated research aims in the earlier sections, we model log-transformed vehicle-kilometres travelled per capita (dependent variable) by using information from 2009 and 2015 HTS. We take into consideration attributes specifying the household structure, trip purposes and mode choices. Additionally, neighbourhood level accessibility attributes are taken into account. A time dummy, as well as, interactions with time for all included variables are considered. The resultant linear regression model can be represented by an Ordinary Least Square (OLS) regression in the following equation (1):

$$Y_i = \text{constant} + \sum_j \alpha_j S_{ij} + \sum_j \beta_j P_{ij} + \sum_j \gamma_j M_{ij} + \sum_j \zeta_j A_{ij} + \sum_j \delta_j D_{ij} + \theta \cdot \text{year} + \varepsilon_i \ldots (1)$$

Where:

- $i$ is the household indicator (1, … , 4606)
- $Y_i$ is the aggregated-log transformed VKT per capita of household $i$
- $S_{ij}$ is the household attribute $j$ of household $i$ (household level predictor)
- $P_{ij}$ is the trip purpose $j$ of household $i$ (household level predictor)
$M_{ij}$ is the trip mode $j$ of household $i$ (household level predictor)

$A_{ij}$ is the access attribute $j$ of household $i$ (neighborhood level predictor)

$D_{ij}$ is the density attribute $j$ of household $i$ (neighborhood level predictor), and

$year$ is the time dummy to capture base effect changes between 2009 and 2015

However, VKT could be influenced by unobserved attributes of the neighbourhood which is omitted by OLS due to model and data structure. Instead, multi-level modelling (MLM) approach is adopted. The suitability of multi-level modelling has been tested on a null-model (i.e. a varying-intercept model without any other predictors), resulting an intra-class correlation (ICC) of 0.12, which means 12% of the variance within the neighbourhood level is not captured by equation (1), the OLS model. Generally, ICC values between 0.05 and 0.25 justify the use of MLM (Gelman, 2006). Previous studies have demonstrated the use of MLM in time-series cross-section data (Shor et al., 2007). Another advantage of multi-level modelling is its ability to reveal the random effect, as seen in a property price effect study of West Sydney’s bus rapid transit (Mulley and Tsai, 2016). An earlier study in Sydney also employed mixed modelling at Travel Zone (TZ) level (Familar et al., 2011), which suggested that it is preferable to treat the household as the level 1 entity with the spatial (land use and transport) effects operating at level 2. No similar VKT effect studies have been conducted on the Gold Coast for reference. This methodology is particularly appropriate for hierarchical or clustered data structures, for the case of the data in this paper, there are household (individual) and neighbour (SA1) levels. This can be done by transforming equation (1) into an MLM equation (2):

$$Y_{i[k]} = \beta_{0[k]} + \beta_1 X_{i} + u_k + \epsilon_{i[k]} \ldots \ldots (2)$$
Where:
household $i$ is located in neighbourhood $k$
$X_i'$ the vector of independent variables
$u_k$ is the neighbourhood level error term, and
$\epsilon_{i[k]}$ is the individual household level error term

The variation of household VKT is the sum individual household level variation and the respective neighbourhood level variation, which includes a time dummy and the interaction terms. In order to investigate changes in the impact of individual explanatory variables, equation (1) and (2) are combined as equation 3:

$$Y_{i[k]} = \text{constant}_{[k]} + \theta \cdot \text{year} + \sum_j \alpha_j X_{ij} + \sum_j \beta_j X_{ij} \cdot \text{year} + u_k + \epsilon_{i[k]} \ldots \ldots (3)$$

where:
$\text{constant}_{[k]}$ is the intercept for neighbourhood $k$ (*random effect*)
$\text{year}$ is the time indicator representing the years 2009 (=0) and 2015 (=1)
$X_{ij}$ is the household and neighbourhood specific attribute $j$ of household $i$ for base year 2009
$X_{ij} \cdot \text{year}$ is the household and neighbourhood specific attribute $j$ of household $i$ for the year difference between 2009 and 2015
$k$ is the neighbourhood indicator (1, … , 759)
$i$ is household indicator (1, … , 4606)

This model is then applied to this study. The summary and coding of variables considered in this study are shown in Table 2. The descriptive statistics of the variables for modelling are provided in Table 3 and Table 4:
Table 2: Data source of the variables used in modelling

<table>
<thead>
<tr>
<th>Variable Description</th>
<th>Variable Code</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dependent Variable (DV)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VKT of household</td>
<td>VKT</td>
<td>HTS*</td>
</tr>
<tr>
<td>Log-transformed VKT (km)</td>
<td>Log_VKT</td>
<td>HTS</td>
</tr>
<tr>
<td><strong>Household Attributes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income (weekly, in AU$)</td>
<td>INC</td>
<td>HTS</td>
</tr>
<tr>
<td>Standardised income by year (0 = mean level in respective year)</td>
<td>ZHHINC</td>
<td>HTS</td>
</tr>
<tr>
<td>Total no. of motor vehicles</td>
<td>TOTALVEHS</td>
<td>HTS</td>
</tr>
<tr>
<td>Bicycle ownership (=1 if household owns at least 1 bicycle)</td>
<td>BIKE_Dummy</td>
<td>HTS</td>
</tr>
<tr>
<td>Household size</td>
<td>HHSIZE</td>
<td>HTS</td>
</tr>
<tr>
<td>Centered Household size</td>
<td>C_HHSIZE</td>
<td>HTS</td>
</tr>
<tr>
<td><strong>Household Structure</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sole persons</td>
<td>HHST_SolePer</td>
<td>HTS</td>
</tr>
<tr>
<td>Couple with children</td>
<td>HHST_CoupWKid</td>
<td>HTS</td>
</tr>
<tr>
<td>One parent</td>
<td>HHST_OneParent</td>
<td>HTS</td>
</tr>
<tr>
<td>Couple without children</td>
<td>HHST_CoupNoKid</td>
<td>HTS</td>
</tr>
<tr>
<td><strong>Access Attributes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to nearest bus stop (km)</td>
<td>DIST_BusStop</td>
<td>GIS**</td>
</tr>
<tr>
<td>Distance to nearest Queensland Rail stop (km)</td>
<td>DIST_QRStop</td>
<td>GIS</td>
</tr>
<tr>
<td>Distance to nearest G:link station (km)</td>
<td>DIST_GlinkStop</td>
<td>GIS</td>
</tr>
<tr>
<td>Distance to nearest highway ramp (km)</td>
<td>DIST_HwyRamp</td>
<td>GIS</td>
</tr>
<tr>
<td>Distance to GC major centre (km)</td>
<td>DIST_GC_MajorCentre</td>
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</tr>
<tr>
<td>Distance to Brisbane CBD (km)</td>
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</tr>
<tr>
<td>Distance to nearest Principal Urban Activity Centres (km)</td>
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<tr>
<td><strong>Trip Attributes</strong></td>
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<tr>
<td>Total trips made by the household</td>
<td>TRIP_COUNT</td>
<td>HTS</td>
</tr>
<tr>
<td>Share of personal/social trips (%)</td>
<td>TRIP_PerSoc_P</td>
<td>HTS</td>
</tr>
<tr>
<td>Share of work trips (%)</td>
<td>TRIP_Work_P</td>
<td>HTS</td>
</tr>
<tr>
<td>Share of education trips (%)</td>
<td>TRIP_Edu_P</td>
<td>HTS</td>
</tr>
<tr>
<td>Share of goods related trips (%)</td>
<td>TRIP_Goods_P</td>
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</tr>
<tr>
<td><strong>Mode share of household</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>by car (%)</td>
<td>MODE_Car_P</td>
<td>HTS</td>
</tr>
<tr>
<td>by bus (%)</td>
<td>MODE_Bus_P</td>
<td>HTS</td>
</tr>
<tr>
<td>by QR train (%)</td>
<td>MODE_Train_P</td>
<td>HTS</td>
</tr>
<tr>
<td>by G:link light rail (%)</td>
<td>MODE_Glink_P</td>
<td>HTS</td>
</tr>
<tr>
<td>by walking (%)</td>
<td>MODE_Walk_P</td>
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</tr>
<tr>
<td>by bicycle (%)</td>
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<tr>
<td><strong>Time Change</strong></td>
<td></td>
<td></td>
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<tr>
<td>Year of samples (YEAR = 0 if 2009, YEAR = 1 if 2015)</td>
<td>YEAR</td>
<td>HTS</td>
</tr>
<tr>
<td><strong>Urban attributes</strong></td>
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<tr>
<td>Population Density (SA2 level)</td>
<td>POPDEN_SA2</td>
<td>Census</td>
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<tr>
<td>Job Density (SA2 level)</td>
<td>JOBDEN_SA2</td>
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<tr>
<td>Log-transformed Population Density (SA2 level)</td>
<td>log.POPDEN_SA2</td>
<td>Census</td>
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<tr>
<td>Log-transformed Job Density (SA2 level)</td>
<td>log.JOBDEN_SA2</td>
<td>Census</td>
</tr>
</tbody>
</table>

*HTS = Household Travel Survey data
**GIS = Geographic Information System derived data
### Table 3: Descriptive statistics of the variables used in modelling

<table>
<thead>
<tr>
<th>Variables</th>
<th>Before Light Rail (2009)</th>
<th></th>
<th></th>
<th></th>
<th></th>
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<td>Obs.</td>
<td>Mean</td>
<td>S.D.</td>
<td>Min.</td>
<td>Max.</td>
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<td>0.56</td>
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<td>YEAR</td>
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<tr>
<td>INC</td>
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<tr>
<td>BIKE Dummy</td>
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Table 4: Descriptive statistics of the variables used in modelling

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<th>Variables</th>
<th>Obs.</th>
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<th>S.D.</th>
<th>Min.</th>
<th>Max.</th>
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<td>493.20</td>
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<td>2.44</td>
<td>0.51</td>
<td>0.79</td>
<td>3.37</td>
</tr>
</tbody>
</table>

The detailed description of the variables is as follows:

**Dependent variable:** The household aggregated vehicle-kilometres travelled per capita are transformed to natural logarithm. This mitigates heteroscedasticity issues, which may occur resulting from reduced value scale. Furthermore, it allows for the interpretation of independent variable effects percentage changes from coefficients $\alpha_j$, $\beta_j$, $\gamma_j$ and $\delta_j$.

**Household structure:** Each household contains a weekly income data. To deal with inflation changes, this income variable is standardised as z-score (mean = 0) within the
year so as to allow inter-year comparison by the variance of means values of the samples within the year of survey. Additionally, standardised household income is interacted with a time change dummy (2009 = 0, 2015 = 1), due to the presence of structural effects between 2009 and 2015. Doing such allows the time effect of income on VKT to be revealed from modelling. Other factors describing household structure are the number of household members, total motor vehicles and dummy indicators for bicycles, and household family structures (couple with or without children, single parent or single person household).

**Household trip purposes:** Trip purposes included as work (includes commuting and work-related trips), personal/social, education and shopping. Shopping trips to a minor extent also include trips which in the survey were labelled as “picking up things”. All four variables are calculated as ratios in relation to household trip count, and consequently, add up to exactly 1 (=100%). In the regression model, one of the four is hence dropped, due to collinearity. This forms the baseline, in our case personal/social trips.

**Household mode shares:** In order to capture existing household specific mode choice preferences, ratios of numbers of trips with a certain mode were divided by the overall trip count of the household. The trip modes considered were private vehicle, train, light rail (G:link), bus, walking and cycling. Private vehicle mode is the most used mode (80%), which is treated as a baseline and is not included in the model. Also, we are interested in the change of VKT resulting from public and active transport modes changes.
Accessibility attributes: Measures of the accessibility of transportation infrastructure are available at a neighbourhood level (SA1). These include network distances from the centroid of the neighbourhood to the SEQ Regional Plan defined urban activity centres that are with high trip attraction rates for services or employment. These include Brisbane CBD and the principal centres of Surfers Paradise and Robina on the Gold Coast. Public transport variables include the distance to the nearest stops. The G:link system has only been present since 2015, hence the 2009 data are all treated as zero, indicated nil effects.

Urban attributes: Measures of job density in the survey area are only available at a larger geographic unit (SA2) and are only with 2011 data. Population data are available at SA1 and SA2 levels, with 2011 census data and 2015 estimated projections. However, testing with population data at SA1) resulted in low ICC values. Both density variables were log-transformed to deal with heteroscedasticity issues.

4 Results

Estimation results of the regression model are presented in Table 5. It shows the estimated coefficient values for 2009 and the coefficient values for the year interaction terms as ‘Diff.’. The 2015 coefficients are not direct regression results, but rather derived as the sum of “2009 Coefficients” and the “2009 to 2015 Differences” (coefficients of interaction variables containing year).
Table 5: Estimation results of multi-level model

<table>
<thead>
<tr>
<th></th>
<th>2009 Coefficients</th>
<th>2009 to 2015 Differences</th>
<th>2015 Coefficients</th>
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<tr>
<td>constant</td>
<td>1.122</td>
<td>0.928</td>
<td>2.049</td>
</tr>
<tr>
<td>HH Income</td>
<td>0.179 ***</td>
<td>-0.115</td>
<td>0.065</td>
</tr>
<tr>
<td>HH Vehicles</td>
<td>0.181 ***</td>
<td>0.095</td>
<td>0.276</td>
</tr>
<tr>
<td>HH Trips</td>
<td>0.077 ***</td>
<td>0.012</td>
<td>0.088</td>
</tr>
<tr>
<td>HH Size</td>
<td>-0.174 ***</td>
<td>-0.016</td>
<td>-0.190</td>
</tr>
<tr>
<td>HH owns bikes</td>
<td>0.117 **</td>
<td>-0.027</td>
<td>0.091</td>
</tr>
<tr>
<td>HH Couple</td>
<td>0.180 **</td>
<td>-0.120</td>
<td>0.060</td>
</tr>
<tr>
<td>HH Single</td>
<td>-0.357 ***</td>
<td>0.023</td>
<td>-0.335</td>
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<tr>
<td>HH Single parent</td>
<td>-0.038</td>
<td>0.063</td>
<td>0.024</td>
</tr>
<tr>
<td>HH Other</td>
<td>0.042</td>
<td>-0.055</td>
<td>-0.013</td>
</tr>
<tr>
<td>SA1 Dist. to Tram</td>
<td>0.089 ***</td>
<td>-0.063</td>
<td>0.026</td>
</tr>
<tr>
<td>SA1 Dist. to Bus</td>
<td>0.089 ***</td>
<td>-0.063</td>
<td>0.026</td>
</tr>
<tr>
<td>SA1 Dist. to Highway</td>
<td>-0.007</td>
<td>0.015</td>
<td>0.007</td>
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<tr>
<td>SA1 Dist. to Brisbane Centre</td>
<td>-0.001</td>
<td>-0.004</td>
<td>-0.004</td>
</tr>
<tr>
<td>SA1 Dist. to nearest Principal Centre</td>
<td>0.014 **</td>
<td>-0.008</td>
<td>0.006</td>
</tr>
<tr>
<td>SA1 Population density (log)</td>
<td>0.233 **</td>
<td>-0.171</td>
<td>0.062</td>
</tr>
<tr>
<td>SA1 Job density (log)</td>
<td>0.285 *</td>
<td>-0.121</td>
<td>0.164</td>
</tr>
<tr>
<td>SA1 Interaction b/w Pop. &amp; Job density</td>
<td>-0.049 **</td>
<td>0.024</td>
<td>-0.025</td>
</tr>
<tr>
<td>HH Work</td>
<td>0.480 ***</td>
<td>0.103</td>
<td>0.583</td>
</tr>
<tr>
<td>HH Education</td>
<td>0.529 ***</td>
<td>-0.045</td>
<td>0.484</td>
</tr>
<tr>
<td>HH Shopping</td>
<td>-0.347 ***</td>
<td>-0.215 (')</td>
<td>-0.562 (')</td>
</tr>
<tr>
<td>HH MODE_Glink_P</td>
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<td>-1.882 ***</td>
<td>-1.882</td>
</tr>
<tr>
<td>HH MODE_Bus_P</td>
<td>-2.047 ***</td>
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<tr>
<td>HH MODE_Cycle_P</td>
<td>-1.949 ***</td>
<td>-0.835</td>
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</tr>
</tbody>
</table>

Random effects
- Group variance (Intercept): 0.009
- Residual variance: 0.753
- Log-Likelihood: -6008.6
- Observations: 4606
- Groups (SA1): 759

(*** p < 0.001, ** p < 0.01, * p < 0.05; significant or marginally significant values are in bold)
The following baseline scenario is hypothetical, but it serves as a starting point for the interpretation of regression results.

- 2009 couple-without-children household with mean Income (AU$ 1,619.87)
- Average household Size (2.8 persons)
- No vehicle/bicycles
- All trips are for Personal/Social purpose (= 100%)
- All trips are made by Private Vehicle (car = 100%)
- Distances to transport infrastructure and relevant urban centres are zero
- VKT’s constant value is 1.122log, which corresponds to approximately 3 km per person per day

Except for the dummy variables for single parents and other family structures, and distance to highway ramp and Brisbane Centre, all remaining 2009 factors show a significant effect on VKT.

### 4.1 Household attribute effects

As expected, the variables of household income, number of motor vehicles and total trips undertaken are important determinants of VKT. In particular, the impact of income is considerably reduced when comparing the years 2009 and 2015. Income increases of one z-score value in 2009 resulted in an increase VKT of 17.9% in 2009, but this is only 6.5% in 2015. This needs to be compared with other variables. For an additional vehicle owned in a household, there is an increase of 18.1% in VKT in 2009; and 27.6% in 2015. This implies in overall, vehicle owners tend to drive more and the effect is not determined by income in 2015.
The number of trips undertaken by a household is also an important determinant of VKT. Each additional trip made in a household causes an increase of 7.7% in VKT in 2009, and 8.8% in 2015. While the degree of change in 2015 is smaller, it is statistically significant. From the results, VKT increases when household size is lower than the average of 2.8 persons per household, and decreases when above. This is possibly due to larger households are able to share car use with increase car occupancy rates. This might pose a concern as household sizes are decreasing in Australian cities as a national trend (Australian Department of Infrastructure and Regional Development, 2015). The following subsection discusses the mode specific effects of the variables on VKT.

4.2 Accessibility and mode attribute effects

Distance to nearest G:link/bus stops and principle urban activities centres are significant, while highway ramps are not. For every kilometre further from the nearest bus stop, VKT increases by 8.9% in 2009, but this increase is only 2.6% in 2015. This may indicate that buses have a lesser VKT reduction effect and they were less used by the residents. Also, for every 10% mode-switch from car to bus, VKT decreased by 20%, which is comparable to the same effect for G:link light rail, which is a 19% decrease. Each kilometre further from G:link stops resulted in 1.2% increase in VKT. Both figures indicate light rail might have replaced the role of bus along the light rail corridor with good frequency services, but this needs further investigation, such as to include an interaction between bus and G:link variables. The network overhaul in 2014 also had bus coverage reduced in some areas, which might make buses less attractive. For QR Trains, every 10% of mode-switch from car to train, the VKT effect changed from +6% in 2009, to -15% in 2015. This effect is
fairly significant, which could be explained by improved service frequencies and the opening of Varsity Lakes station. Further analysis could be conducted to explore the underlying reasons for these changes, such as by looking at origin and destination of the trips.

For active modes, bicycle ownership has displayed an increasing effect on VKT, those that have at least one bicycle have 12% more VKT. Based on HTS data, the mode share of cycling is extremely low on the Gold Coast which is around 1%. There is no officially run bicycle sharing scheme on the Gold Coast. As this data is income controlled, these bicycle owned might be used during recreational use of bicycles, which involves driving a car. Not using bikes for the whole trip. For mode switch analysis, every 10% mode switch from car to bicycle would reduce VKT by 19% in 2009, and this is improved to 28% decrease of VKT in 2015. The change in the effects of walking and bus modes, however, is not significant between 2009 and 2015. In summary, most non-car modes (train, tram, bus, walk) show a similar VKT reducing effect when switching from car use in 2015. But cycling stands out with a roughly 40% greater VKT reducing effect compared to the other non-car modes.

4.3 Trip type and density effects

For the influence of trip types, it is less obvious as non-car mode share or distance to public transport stops. The baseline for these attributes is personal/social trips. Generally, each trip generates an 8 percent increase in VKT.
When assuming similar trip numbers, households with more work and education trips will generate higher VKT. And households with comparatively more shopping trips will generate less VKT. The only trip type that showed a statistically significant change between 2009 and 2015 are shopping trips. This could imply shopping trips are being undertaken either closer to home than before, mode other than car, or due to online shopping. Work and education trip changes are not significant between 2009 and 2015, their effects are largely similar over the time. The reduced effects over time of both, population and job density, are not statistically significant, but they are considerable in size. Since the log-transformed form of the two density variables was used, elasticity interpretations can be made easily. An increase in **population density** of 10% is associated with 2.3% higher VKT, for job density with 2.8% higher VKT. In areas that have both, high job and population density, their individual effects on VKT would not compound, but rather be moderated (partly reduced). This was confirmed by the reduction effect of an interaction term between the two. This does not seem to concur with other VKT related transport studies carried out within Australia (Corpuz et al., 2006; Mulley and Tanner, 2009) and overseas (Arrington and Cervero, 2008; Næss et al., 1996; Næss, 2010).

### 4.4 Implication from the results

The VKT model demonstrates a good level of explanatory power on the variables tested. The findings can be used to help inform transport and land use planning. From the MLM model based on 2009 and 2015 comparisons, public and active transport is having a statistically significant VKT reduction effect on households. This is proving that Gold Coast’s current plans are on the right track. However, bus use is currently having a reduced
VKT reduction effect which could be the result of network restructure. For policy implications, providing high quality and frequent public transport infrastructure is only the beginning for Gold Coast in relieving car and oil dependence. Regarding the unrealised potential of buses in Gold Coast, we would suggest seamless network integration to reduce the time cost of transferring to different modes. This could be achieved by well-sync timetables or, pulse timetabling - where a mode would wait for another mode to arrive in stops. Also, it will take time for urban development to take place near light rail stations to fully realise the potential of high-quality public transport. Further patronage improvements and VKT reduction could be achieved with the upcoming expansion of the second stage of the G:Link, connecting the existing station at Parkwood to Helensvale, which is the intercity line-haul rail station linking Brisbane CBD. In addition to hardware transport upgrades, ‘soft’ approaches such as targeted personal travel behaviour programmes should also be improved and expanded, such as the TravelSmart scheme in Queensland (James et al., 2017). The inauguration of the second stage of the light rail is planned to take place before the 2018 Commonwealth Games. This rare mega-sporting event presents a prime marketing opportunity for the uptake of sustainable transport modes (Parker et al., 2007).

4.5 Potential for developing empirically driven weights for oil vulnerability composite indicators and spatial mapping analysis

Previous oil vulnerability studies are based on ad hoc assumption (assuming there is a relationship between independent and dependent factors) for estimating the potential socio-spatial impact of fuel price increases (Dodson and Sipe, 2007; Leung et al., 2015; Runting et al., 2011). This study demonstrated the linkages between a number of variables, which
are also used in these previous studies as vulnerability components of exposure (e.g. mode share of vehicles), sensitivities (e.g. income) and adaptive capacity (e.g. public transport accessibility). Further modelling of these variables could help developing empirically driven weights for oil vulnerability composite indicators by statistical methods (e.g. regression) or even spatial microsimulation (Lovelace, 2014). This sets the basis for further research into the interaction of oil vulnerability contributors and validation of previous oil vulnerability with actual household travel data.

This study’s contribution, limitations and policy implications are further elaborated in the conclusion section.

5 Concluding remarks

This analysis has provided an exploratory yet encompassing assessment of the time-related aggregated change of VKT use of average trips across the Gold Coast and interaction with a large number of household characteristics (e.g. income, car ownership), access to nearest public transport, trip type (e.g. work or personal), mode share and land use (population and job density) variables. A key contribution of this study is that it provides new insights on the determinants of private vehicle use in Gold Coast. Yet, this study is constrained by several limitations. This study focused on an assessment of the entire City of Gold Coast. The treatment and control areas of public transport change (e.g., G:link) have not been earmarked and this can be done in future research work. To address random sampling issues, adjustments can be made, for example in school children’s obesity studies in the UK, using observed and expected estimates (Procter et al., 2008; Williams et al., 2014).
Similar methods have also been used in a geo-demographic study looking at the airport trips for Gold Coast (Leung et al., 2016). Spatial-autocorrelation issues can also be examined with geographically weighted regression (GWR), as seen in land-value uplift studies or VKT related urban transport studies (Blainey and Mulley, 2013; Du and Mulley, 2006). Another shortcoming of this study is that a proportion of G:link’s patronage is likely to be non-residents of the Gold Coast, such as tourists, and this is not accounted for in HTS data. The VKT reduction effects from these non-resident trips were not assessed in this study as reliable data pertaining to non-resident trips on the Gold Coast is not yet available.

In the context of the Gold Coast, this study is innovative in its contribution to research in using two instances of HTS to assess VKT changes. The results obtained and the proposed methodology should contribute to the on-going investigation of urban transport, land use and energy use with a greater focus on VKT and the negative impacts of vehicle use. Future study can incorporate this year-adjusted VKT model to other urban sustainability (Yigitcanlar et al., 2014) and oil vulnerability (Leung et al., 2015) assessment frameworks in the SEQ region or beyond. While recent global oil prices have been suppressed due to geo-political stability in the Middle East and because of the improvement in the gap between supply and demand, oil remains a fossil fuel with Peak Oil and climate change implications (Kaufmann, 2010). Although the unexpected oil-price shocks of 2005-2014 created some positive aspects, such as an improved uptake of EVs globally and further improvements in fuel efficiency, as is evident in a still car dominant city such as the Gold Coast, private automobile mode share remains high and the improvements in sustainable mode share are modest at best. Inequity, and transport disadvantage concern of mass car
ownership and usage is also an under researched policy area (Currie and Delbosc, 2011; Lucas et al., 2016), and with only limited studies in the Gold Coast (Buchanan et al., 2005; Martiri, 2013). Urban policy makers should also continue to improve public and active transport as a key measure to reduce oil use. The positive image of light rail is likely to attract higher ridership and public acceptability of public transport. It is hoped that the further expansion of public transport on the Gold Coast will continue and will be emulated, and that other urban areas in Australia and abroad will learn from this city’s success.

Acknowledgements

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11. Conclusion

11.1 Overview

This thesis has sought to address the analysis of oil vulnerability with new conceptualisations and new methods (both quantitative and qualitative). The research activities of this paper operated at multiple units of analysis and covered multiple countries/territories. The papers included in the thesis promote a global understanding of transport and urban planning about oil use. The new conceptualisations were developed and operationalised in various settings, with clear definitions and justified research methods. This research has developed a number of tools for identifying areas of oil vulnerability. It has highlighted gaps in current knowledge and potential areas for future research that will enhance our capabilities to cope with the possible oil price fluctuations and to address the associate issues of socio-spatial inequity.

This chapter is structured as follows: First, the contributions are outlined, followed by discussions serving as a postscript of the result chapters earlier. The limitations are then tabled, then the opportunities for further research.

11.2 Contributions

Table 4 summarises the main contributions made from the thesis. The key contributions are summarised by the type of contribution, namely theoretical-conceptual, methodological and applied, policy and empirical.
<table>
<thead>
<tr>
<th>Research Aim</th>
<th>Research Activity covered in Chapters</th>
<th>Extent of contribution made in this thesis to current knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1. to further develop the concept of oil vulnerability.</td>
<td>Chapters 2 and 3</td>
<td>To a great extent The new oil vulnerability conceptualisation is an advancement in current knowledge and has been cited by leading researchers (Cao and Hickman 2017, Mattioli et al. 2017).</td>
</tr>
<tr>
<td>(theoretical / conceptual contributions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A2. to explore new approaches for understanding, measuring and mapping oil vulnerability.</td>
<td>Chapters 4, 5, 7, 8, 9, 10</td>
<td>To a good extent A number of new approaches have been developed in this thesis, however the application of some approaches are limited by data availability.</td>
</tr>
<tr>
<td>(methodological contributions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A3. to study oil vulnerability in areas, or units of analysis that have not been assessed before.</td>
<td>Chapters 4, 5, 6, 7, 8, 9, 10</td>
<td>To a good extent This study has deepened understanding of oil vulnerability in Australia at multiple levels. Internationally, oil vulnerability research is expanded to Hong Kong in great depth (Chapter 8 and 9), with less depth in Taiwan (Chapter 6) and only at surface depth in 11 Asia-Pacific cities assessed by benchmarking (Chapter 4).</td>
</tr>
<tr>
<td>(applied / empirical contributions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A4. to raise awareness of oil vulnerability by identifying areas of concern.</td>
<td>All Chapters</td>
<td>To some extent Vulnerability measures highlighted which areas are at risk of fuel price increase. However, policy attention on oil vulnerability has waned in transport and land use planning due to lowered oil prices and the potential uptake of electric vehicles. Further studies are needed to look at energy and fuel price issues beyond price, such as socio-spatial inequity.</td>
</tr>
<tr>
<td>(applied / policy contributions)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A5. to inform urban and transport policy making with better information and knowledge of oil vulnerability.</td>
<td>All Chapters</td>
<td>To some extent This research has advanced knowledge with better information and understanding in both quantitative and qualitative dimensions. However, data and resource limitations prevented this research to provide more depth study.</td>
</tr>
<tr>
<td>(policy contributions)</td>
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</table>

### 11.2.1 Theoretical-conceptual contributions

The research findings and contributions have several implications for theory. The comprehensive literature review in Chapter 2 provided the theoretical-conceptual basis of this thesis. It identified the research trends and summarised fuel-related research on urban transport since the 1970s. The research was found to be operating at three main units of analysis, namely ‘inter-city’, ‘intra-urban’ and ‘disaggregate’. The thesis methods were designed in accordance in this view. The research chapters have applied vulnerability-based conceptual framework (exposure, sensitivity and adaptive capacity), as outlined in Chapter 2 and 3.
Additionally, the vulnerability-based framework provides a mechanism for enhancing an understanding of the wider effects of a hazard that is measured (Thomas et al. 2013). This offers a more systematic understanding of the different components of oil vulnerability. The conceptualisation of oil vulnerability is advanced from only looking at exposure and sensitivity (Dodson and Sipe 2007, 2008), to also considering the adaptive capacity. This conceptual framework has since been adopted by other leading researchers (Mattioli et al. 2017).

11.2.2 Methodological and applied contributions

This thesis advanced methodology of oil vulnerability analysis in several ways. Firstly, the conceptual framework outlined in Chapter 2 and 3 led to the development of new definitions and classification of operational metrics. This helped to better explore research methods, and to organise metrics pertaining oil vulnerability, in particular data collection and analysis. This work helped to meet the aim A3 of this study to study oil vulnerability in areas, or at units of analyses that had not been assessed before. Table 5 shows the areas that this research has covered and their respective unit of analysis.

<table>
<thead>
<tr>
<th>Chapters</th>
<th>Geographic Coverage</th>
<th>Unit of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2</td>
<td>Global</td>
<td>N/A (literature)</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>11 Asia Pacific Cities</td>
<td>Inter-city</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>7 Australian Major Cities (Greater Capital Cities Statistical Area (GCCSA))</td>
<td>Urban Region, inter-city</td>
</tr>
<tr>
<td>Chapter 6</td>
<td>Australia (GCCSA and Rest of State) and Taiwan (Municipalities/Counties)</td>
<td>Inter-city / area</td>
</tr>
<tr>
<td>Chapter 7</td>
<td>South-East Queensland (Including 8 Local Government Areas (LGA))</td>
<td>Intra-urban</td>
</tr>
<tr>
<td>Chapter 8</td>
<td>Hong Kong and Brisbane, Australia</td>
<td>Inter-city, intra-urban</td>
</tr>
<tr>
<td>Chapter 9</td>
<td>Hong Kong and Brisbane, Australia</td>
<td>Inter-city, policy analysis</td>
</tr>
<tr>
<td>Chapter 10</td>
<td>Gold Coast, Australia</td>
<td>Households within a city</td>
</tr>
</tbody>
</table>
Chapter 4 used a scorecard benchmarking approach covering 11 Asia Pacific cities, but at a surface depth only. Yet the overall relationship with urban characteristics such as density can be compared with the oil vulnerability benchmark score. This adds a new social vulnerability aspect to previous inter-city studies of urban transport and energy use (Næss et al. 1996, Newman and Kenworthy 1989, 1999). Chapter 5 and 6 experimented with the use of DEA in inter-city oil vulnerability covering Australian and Taiwanese cities and areas. DEA is able to compute values objectively without the need for subjective weightings, a common deficiency of previous methods such as composite indicators. Then, Chapter 6 produced visually clear and conceptually strong oil vulnerability spatial analysis. Chapter 7 is the first inter-city comparison of these composite indicators, comparing Hong Kong with Brisbane. For the first time, sensitivity analysis of variable inclusion is tested in this study. These intra-urban socio-spatial analyses are based on a number of previous oil vulnerability composite indicators (Akbari and Nurul Habib, 2014; Dodson and Sipe, 2007; Fishman and Brennan, 2010; Runting et al., 2011). Chapter 6 and 7 also first used the conceptual framework of exposure, sensitivity and adaptive capacity in oil vulnerability research. A range of adaptive capacity is first included, such as public transport service levels and active transport potential. Composite indices are proven as useful analytical, communication, and collaborative tools that have the potential to support decision making, planning, policy development, and urban management (Baptista 2014).

A qualitative study is presented in Chapter 9, using policy analysis methods to understand the impact of peak oil and oil vulnerability discourse in policy making processes in Hong Kong and Brisbane. This revealed how these concepts
have influenced policy making. Chapter 10 attempted use disaggregated household survey data to analyse the changes of vehicle kilometres travelled (VKT), showing the VKT changes are related to the distance to public transport stops/stations. These findings can be used to develop empirically driven weights for future oil vulnerability composite indices.

### 11.2.3 Practical, empirical and policy contributions

A range of practical and empirical findings is revealed from the research activities. From the geographically broader inter-city study in Chapter 4, the key policies to address oil vulnerability in cities are 1) spatial land use planning 2) public transport and 3) car restraint policies. These need to work in tandem, as seen in the lower car use and high non-car mode usage in the compact and developed Asian cities (Hong Kong, Singapore). The cities with higher oil vulnerability are either having high automobile use (exposure) in the cities of developed countries (e.g., Sydney and Auckland), or cities in developing countries (e.g., Bangkok, Manila and Jakarta) with lower income (sensitivity) but increasing motorisation rates (exposure), and underdeveloped public transport (adaptive capacity). The remainder are cities with moderate levels of oil vulnerability: Shanghai is embracing car-restraint and public transport investment, following the paths of Hong Kong and Singapore, and Taipei is an interesting case as it is covered by decent public transport but with also high motorcycle usage. These findings show insights into what ‘oil-proof’ policies can cities adopt. However, policy applicability depends on local context, which is covered in more detail in the close-up comparative studies of Chapters 8 and 9.
Chapter 5 and 6 are inter-city/area comparisons that used fuel expenditure data to reveal fuel stress. The findings are similar to Chapter 4, but offer an additional dimension of fuel affordability based on actual empirical data, instead of proxy variables such as city GDP and car ownership. These studies show population density and size have a large role to play in lower oil vulnerability by public transport. Smaller cities have great potential to reduce oil vulnerability by active transport due to their smaller size and shorter trip distances. But with a lack of public transport services, motorised trips are mostly done by car. Perhaps electric vehicles might be a solution for these areas, but battery range and charging infrastructure remains an issue. Only certain outlying areas of Taiwan (e.g., Taitung) are having helpful rates of electric mobility usage. This is largely due to a sizeable uptake of electric scooters, which are cheaper than full-sized electric vehicles and support by government policy (e.g., incentives and subsidies).

Chapter 7 used a new set of composite indicator methods to spatially map oil vulnerability in South-East Queensland’s urban areas. This shows a more refined and nuanced pattern of oil vulnerability in that outer areas are not as entirely oil vulnerable as previously thought (Dodson and Sipe 2007). This method is applied to Hong Kong as well in Chapter 8. The key differences in Hong Kong are far lower rates of car mode share and better public transport, both in terms of area coverage and quality of service. This renders most of Hong Kong population much less oil vulnerable compared to Brisbane. Hong Kong’s rail-as-backbone policy is of great reference value to Brisbane, but comes from a more technocratic government, with lower level of enfranchisement and high population density. This allows the government to act against the electorate’s desire for cars, and to implement car-restraint policies. This is further analysed in Chapter 9, with
qualitative interviews and discourse analysis of transport policy. While Peak Oil and oil vulnerability discourses have bolstered “affordability” concerns in both cities, but only Brisbane has seriously attempted to address its car-dependence and oil vulnerability problems with the effort of “political entrepreneurs”. However, changes in government in 2012 and lowered oil prices after 2014 have pushed these out of favour. This discourse-based analysis paper adds a policy research dimension on oil vulnerability research that has not been provided before. Finally, Chapter 10 is a time-series (2009 and 2015) disaggregate analysis that uses household travel survey data and multi-level modelling (MLM) to better understand the relationship of car use (measured by VKT) alongside with land use and socio-economic variables in Gold Coast, which has a new light rail system started running in 2014. The distance of households to this new system is having statistically significant reducing effects to VKT. This justifies high quality public transport improvements as a measure to reduce car use, and oil vulnerability. This section summarised the overall research findings of this thesis. The individual key contributions and findings of each chapter, and how the research questions are addressed, are further summarised in Table 6.

Table 6: Summary of the contributions and findings of chapters

<table>
<thead>
<tr>
<th>Activity</th>
<th>Research Questions</th>
<th>Contribution / Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2 Literature Review and Chapter 3 Methodology Development</td>
<td>Primary Questions: MQs” What is oil vulnerability? What does it mean? Secondary Questions: How is oil vulnerability measured? How was oil vulnerability (or fuel price related urban transport impacts) research been conducted?</td>
<td>Previous fuel price related urban transport studies included the main areas of 1) Urban structure 2) Demand response (elasticity) 3) Policy response 4) Inter-urban comparisons 5) Intra-urban mapping 6) Disaggregate studies (household/personal level) 6) Emerging studies (Conceptual-theoretical) Oil vulnerability can be defined as the function of exposure, sensitivity and adaptive capacity, which can be operationalised</td>
</tr>
</tbody>
</table>

262
<table>
<thead>
<tr>
<th>Activity</th>
<th>Research Questions</th>
<th>Contribution / Findings</th>
</tr>
</thead>
</table>
| Chapter 4 Benchmarking inter-city oil vulnerability – many cities       | **Primary Question:** RQ1 What is the level of oil vulnerability in different Asia Pacific cities?  
**Secondary Questions:**  
• What indicators can be used to assess oil vulnerability in urban transport in a wider region?  
• What is the relationship of key urban characteristics (e.g., density) to oil vulnerability? | (Methodological) Developed method to benchmark oil vulnerability in a number of Asia Pacific cities  
(Applied) Analysed the relationship of key urban characteristics (e.g., density) to oil vulnerability  
(Empirical) Assessed the common characteristics of less oil vulnerable cities, e.g., public transport development and car restraint policies |
| Chapter 5 Benchmarking inter-city oil vulnerability with new data – Local study | **Primary Question:** RQ2 Do fuel use and income levels differ in different cities in relation to adaptive capacity?  
**Secondary Questions:**  
• How to assess oil vulnerability in a way that allows inter-city comparison?  
• What indicators can be used to assess oil vulnerability in urban transport?  
• What is the level of fuel stress in major Australian cities?  
• What is the level of resilience to fuel price changes in major Australian cities? | (Methodological) Use of DEA to allow consideration of oil vulnerability and resilience factors in an objective way without the need for subjective weights.  
(Applied) The use of fuel expenditure data for fuel stress measurement. The slack analysis provides an overall guide to mode share improvement in relation to fuel stress levels  
(Empirical) The actual propensity of the impact caused by higher oil prices also are mixed and complicated as income levels, transport usage patterns differ greatly |
| Chapter 6 Benchmarking inter-city oil vulnerability with new data – International study | **Primary Question:** RQ2 Do fuel use and income levels differ in different areas in relation to adaptive capacity?  
**Secondary Questions:**  
• How can oil vulnerability be assessed in a way that allows inter-city comparison?  
• What indicators can be used to assess oil vulnerability in urban transport?  
• What is the level of fuel stress in Taiwanese and Australian areas?  
• What is the level of resilience to fuel price changes in Taiwanese and Australian areas? | (Methodological) Use of DEA to allow consideration of oil vulnerability and resilience factors in an objective way without the need of subjective weights.  
(Applied) The use of fuel expenditure data for fuel stress measurement. The slack analysis provides an overall guide to mode share improvement in relation to fuel stress levels  
(Empirical) International comparison results are quite mixed as larger cities are not necessary less oil vulnerable and more oil resilient. |
| Chapter 7 Developing new methods to assess of oil vulnerability in intra-urban areas | **Primary Question:** RQ3: How do oil price change impacts vary spatially internally in an urban area?  
**Secondary Questions:**  
• What indicators can be used to assess oil vulnerability in urban transport?  
• How does the spatial distribution of the oil vulnerability components differ in a regional urban setting? | (Methodological) The improvement of previous composite indicators with the consideration of oil vulnerability conceptual framework and new normalisation method (z-score)  
(Applied) Spatial and population share analysis of oil vulnerability levels and their dimension of vulnerability  
(Empirical) Evidence of oil vulnerability and transport disadvantage in at the outer fringes of SEQ |
<table>
<thead>
<tr>
<th>Activity</th>
<th>Research Questions</th>
<th>Contribution / Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 8 Comparing intra-urban oil vulnerability between cities</td>
<td><strong>Primary Question:</strong> RQ3: How do oil price change impacts vary spatially internally in an urban area? <strong>Secondary Questions:</strong> • What indicators can be used to assess oil vulnerability in urban transport? • How does the spatial distribution of the oil vulnerability components differ in internationally?</td>
<td>(Methodological) Application of the composite indicator method developed in Chapter 7 to inter-city analysis with the consideration of intra-urban spatial difference. Likely the first ‘hybrid’ comparison between cities internationally, covering Hong Kong and Brisbane. (Applied) Sensitivity analysis applied on the inclusion of variables. (Empirical) Hong Kong and Brisbane first compared in a study. (Practical) Urban and transport policy analysis of Hong Kong and Brisbane, with a focus on urban planning, and non-car modes (public/active transport)</td>
</tr>
<tr>
<td>Chapter 9 Understanding policy responses to oil vulnerability</td>
<td><strong>Primary Question:</strong> RQ4: How are policies developed to respond to increasing oil prices? <strong>Secondary Questions:</strong> • Is oil vulnerability, or other energy factors, being considered in the current transport and urban planning policy making processes? • Was peak oil an instrumental discourse in promoting policy changes? • What are the obstacles to reducing oil vulnerability?</td>
<td>(Applied) Explored the effects of the peak oil discourse in influencing urban transport policy by qualitative analysis. (Empirical) Examined the policy responses to oil vulnerability of Hong Kong and Brisbane from 2005 to 2015. Political barriers are more evident in Brisbane. (Empirical) Comparative experiences of oil vulnerability. Higher oil prices have bolstered the voice of ‘affordability’ storylines that have emerged in both cities. Yet only Brisbane exhibited official usage of ‘peak oil’ storylines.</td>
</tr>
<tr>
<td>Chapter 10 Using disaggregated data to study oil vulnerability</td>
<td><strong>Primary Question:</strong> RQ5: Do new public transport improvements help reduce oil vulnerability (measured by VKT per capita)? <strong>Secondary Questions:</strong> • Can disaggregated time series data be used to analyse oil vulnerability? • Did Gold Coast’s VKT reduce after the commencement of light rail? • What are the determinants of VKT on the Gold Coast?</td>
<td>(Applied) Use of household travel survey data in Gold Coast to perform regression analysis at household level. (Empirical) Gold Coast’s household VKT is found to be reduced when other variables are considered (e.g., land use and transport). The distance of households to light rail and other public transport station is significant. (Methodological) The findings may help develop empirically driven weights for future oil vulnerability composite indices.</td>
</tr>
</tbody>
</table>

The contributions of this thesis are wide ranging and are significant for oil vulnerability research. The next section discusses the implications of the findings of this thesis to policy in more detail.
11.3 Discussion

11.3.1 Challenges in addressing oil vulnerability and dependence

The issue of oil vulnerability is also interrelated to many aspects, as summarised in the conceptualisation of *urban energy resilience* proposed by Meerow et al. (2016, p. 45), as in Figure 4. The issue of energy (oil supply) affects urban form (transport and residential locations), governance networks (e.g., consumers, governments) and socio-economic dynamics (in particular mobility, equity and justice in the case of oil vulnerability) in different time lags, or speed of change.

![Figure 4: A conceptual schematic of urban system components by different dimensions](Adapted from Simmonds et al. 2013, Meerow et al. 2016)
The policy responses in the 1970s and 80s were largely on the fuel efficiency side, which might have caused *rebound effects* – higher vehicle usage occurred due to cost savings from efficiency gains (Greening *et al.* 2000). The oil-based system remains firmly in place with a widely established infrastructure (Gilbert and Perl 2012). This generates a *lock-in effect* or *path dependence*. Once a routine of regular automobile use is established, travel decisions become habitual, (Schwanen and Lucas 2011). Automobiles are also seen as time saving devices (Kent 2014), status symbols (Sheller and Urry 2000) and even more, it provides the freedom to travel anywhere and anytime. Restricting this freedom is difficult politically once it is enjoyed by the populace (Jeekel 2014). This feeds into public demand for policies and infrastructure that further facilitate automobile use. Unless car use is restricted in the first place to suppress this aspiration, such as in Hong Kong (see Chapter 9), cities find it difficult to get away from car facilitation policies. Researchers have observed such transport and land use policy lock-in observed in Auckland (Imran and Lee 2010) and Kuala Lumpur (Barter 2004). In addition, industrial policies from higher levels of government tend to support mass automobile use, based on the belief that these such can support economic growth alongside with manufacturing and road infrastructure economic gains (Briggs *et al.* 2015). This is even referred as an *oil-auto-highway complex* (Dunn 1998). Small service-based economies like Hong Kong may have partly avoided this due to the lack of an automobile manufacturing industry (Cullinane and Cullinane 2003). Perhaps Australia’s ceasing automobile manufacturing in the next year may reduce its policy lock-in.

The recent advocacy for alternative fuels on private vehicles might solve the oil problem. Yet, it does not resolve the energy intensity problem, nor the equitable
use of resources and the many other issues caused by mass automobility. On the other hand, it is possible to reverse automobile dependence as evidenced in Curitiba, Brazil by reorganising cities with busways and appropriate land use facilitation (Khayesi and Amekudzi 2011). Brisbane, which is now surrounded by a large swathe of car dependent suburbs would face a major challenge retrofitting to alternative modes.

11.3.2 There is still a silver lining - recent developments
A future with low use of hydrocarbon fuels, of termed as low carbon, is increasingly accepted as a global desire (Stern 2007, Bongardt et al. 2010, Bulkeley 2013). Even oil-producing countries are now preparing to wean off of their current reliance on oil production as an income source (Nurunnabi 2017). Uptake of renewable energy is also evident, as seen in Germany’s Energiewende (energy change) movement, with an ambitious goal to cut emissions by 60% in 2050 (Schmid et al. 2016). On the transport side, there is increased awareness of sustainable transport in policy making (Banister 2008, Böhler-Baedeker et al. 2012, Burns 2013). A new mobility paradigm has also emerged, which refers to transport systems increasingly based on walkability, accessibility and car/ride sharing (Sheller and Urry 2016). Public transport is also back on the agenda in many currently car dependent cities (Currie and Burke 2013, Newman and Kenworthy 2015). There are signs that per person car use has ‘peaked’ in a number of global north cities (Newman and Kenworthy 2011, Buehler et al. 2017). However, motorisation rates remain fast in developing countries and emerging economies (Pojani 2016). Less car use does not necessarily mean cities are less energy consumptive if they are simply replaced by larger cars, in particular SUVs which are dominating new vehicle sales (Lauer 2005). This poses a particular concern
on equity of mobility and energy use. The only realistic pathway to resolve oil vulnerability should be ranked as - avoid, shift and improve, that is: avoiding car use, shift to public or active transport, and at last improving energy efficiency by alternative fuel/vehicle design (e.g., electrification) (German Society for International Cooperation 2011).

11.3.3 Socio-spatial inequity of transport and energy use

Is oil vulnerability a symptom of inequity in urban space? At a city-wide level, our international comparison in Chapter 4 shows the dense and compact cities of Hong Kong and Singapore scoring lowly in Gini co-efficient, while scoring well in low car dependence and public transport use. In Chapter 5 and 6, areas with lower incomes and the less urbanised areas of Australia and Taiwan are also found to be more oil vulnerable due to lower income, but residents are not necessarily driving a lot and with fairly good rates of active transport. The inequity might be operating differently when comparing different areas. At an intra-city level, Chapter 7 and 8 reveal areas with less income but higher car use are more oil vulnerable. This is largely consistent with previous research on transport disadvantage and automobile dependence. Other studies are also comparing oil dependence with vehicle efficiency (Li et al. 2015), mortgage debt (Dodson and Sipe 2008), household debt (Walks 2013) and automobile loans (Walks 2017). While the findings of these studies may support compact urban designs for less energy use, housing prices in these areas could be prohibitive to the socio-economically disadvantaged, as evident in a very recent study in London showing worsening in housing affordability over time, but not car dependence (Cao and Hickman 2017). While the study in Chapter 10 only compared VKT with light rail station distance in Gold Coast, it has been found
property values close to light rail stations are much higher (Yen et al. 2017). The issue of the increasing desirability of public transport accessibility might be in conflict with policy designs to promote public transport and equity concerns.

11.3.4 Transport policies to address oil vulnerability

A key challenge in developing policies to address oil vulnerability, or car dependence is it is often against public aspirations to drive (Sperling and Gordon 2009). Historical wide scale reduction of oil or fuel use was generally achieved during times of peril - a notable example was fuel rationing during World War II (Cohen 2011). The solution is likely needed to be multi-faceted, operating at multiple levels. Based on the research activities, the possible policies are summarised in Figure 5.

Some may argue the ways to reduce oil vulnerability are not just reducing oil consumption (exposure), and car dependence by increasing non-car accessibility (adaptive capacity), but having strong economic growth to bolster the ability to pay (reducing sensitivity). However, relying on addressing sensitivity alone may not be environmentally sustainable and may actually reinforce car dependence. Widespread car ownership also causes other issues such as congestion and unsustainable uses of resources and energy. This relates to the policies at personal level or household level can be social welfare (e.g., subsidies to public transport or fuel), or education (e.g., targeted travel behaviour schemes) (Cairns et al. 2004). Fuel subsidies as a form of welfare were offered in many oil producing countries (such as Malaysia and Indonesia) but are now largely reduced due to increasing fiscal burden and also negative effects on encouraging automobile use (Khoo et al. 2012, Solaymani et al. 2015).
Fuel taxes encourage the uptake of fuel efficient cars, but this in turn reduces tax revenue. There are calls for alternative taxing mechanisms, such as distance-based vehicle tax (Starr McMullen et al. 2010). At a community level, car-sharing (Shaheen and Cohen 2013, Dowling and Kent 2015) can help increase the occupancy-rate of vehicle use and maybe suitable for areas beyond public transport coverage. Targeted local employment policies and training support programmes in socio-economically disadvantaged may also play a role (Lucas 2006). At a wider level, it goes to the domain of integrated transport and land use planning. Transport policy should shift from traffic and car-mobility based to multimodal accessibility (Litman 2005) which links with land use planning. This involves spatially matching transport and land uses to reduce car use and
promote public or active modes, as evident in transit-based Asian cities (e.g., Hong Kong and Singapore) and walking/cycling friendly European cities (e.g., Copenhagen and Amsterdam). Best practice approaches are ‘avoid-shift-improve’ which is advocated by a number of European governments (German Society for International Cooperation 2011, Sustainable Development Commission (UK) 2011). Upper level national level policies are energy (setting energy targets, strategic fuel reserves), foreign affairs (securing foreign energy supply), transport (usually inter-city transport, or taxation on fuel) and land use (regional urban policy). Beyond these are global policies which are under supranational organisations such as the United Nations (United Nations Development Programme 2007) or regional blocs such as the ASEAN (Economic Research Institute for ASEAN and East Asia 2013) or the EU (Cambridge Econometrics 2016). The efforts are usually informative and non-binding. There was once a proposal for a global oil depletion protocol (Heinberg 2006) for an orderly reduction in oil use and transition to alternatives, but it was never taken seriously.

11.3.5 Policy options to address oil vulnerability - using Hong Kong and Brisbane as examples

Policy interventions involve ‘winners and losers’ and often face obstacles from the public. The Ladder of Intervention framework developed by the UK Nuffield Council on Bioethics (2007) could be a useful way to classify polices based on the level of intervention. Another consideration of policies is the effects of current (intra) and future (inter) generations. For instance, a carbon tax aimed at reducing fuel use for the benefit of future generations might negatively affect the socio-economically disadvantaged in the current generation (Mattioli 2013). We apply this view using Hong Kong and Brisbane as examples, following on from the
findings of Chapter 9. The intra- and inter-generational equity levels are estimated by the author with reference to the literature (Throsby 1993, Mattioli 2013). The difficulty to apply the key interventions is estimated by possible public acceptance and whether the policy is in place already, based on the interviews and document discourse collected during the process of Chapter 9’s research. Table 7 shows the result of the summary of policies based on the above-mentioned criteria.

Table 7: Assessment of current and potential oil vulnerability policies of Hong Kong and Brisbane (extension from Chapter 9’s results)

<table>
<thead>
<tr>
<th>Levels of intervention (Based on Nuffield Council on Bioethics, 2007)</th>
<th>Policy options to address oil vulnerability identified in this study</th>
<th>Generational equity effects</th>
<th>Difficulty to apply</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Eliminate or restrict Choice</td>
<td>Car-free neighborhoods (Banning private vehicles) (Some islands in Hong Kong ban private cars, e.g., Ma Wan)</td>
<td>-3</td>
<td>0</td>
</tr>
<tr>
<td>6 Guide Choice through disincentives</td>
<td>Higher car-ownership tax/fees for fuel inefficient cars (There is a luxury car tax in Australia, but not aimed for efficiency)</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Limitation or charging of parking spaces</td>
<td>-2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Electric road pricing (road tax)</td>
<td>-2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Distance based pricing (VKT tax)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5 Guide choices through incentives</td>
<td>Waiver of EV registration and import duty (However, Hong Kong cancelled the EV waiver in mid-2017)</td>
<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Floor area bonuses for provision of facilities that help reduce oil use e.g., EV charging points</td>
<td>-2</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Employment linked transport welfare payment</td>
<td>0</td>
<td>-3</td>
</tr>
<tr>
<td>4 Guide choices through changing the default policy</td>
<td>Land use development control</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Value-capture of public transport station property rights (Cervero and Murakami 2009, Burke 2016)</td>
<td>-2</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Biofuel mandate (petrol stations must sell a certain amount of biofuel or pay a fine)</td>
<td>-2</td>
<td>1</td>
</tr>
<tr>
<td>3 Enable choice</td>
<td>Urban planning approaches (TODs)</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>Public transport Provision</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>City-wide active transport facilities (e.g., cycleways)</td>
<td>1</td>
<td>-2</td>
</tr>
<tr>
<td></td>
<td>Promoting electric vehicles</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Widespread car-sharing schemes</td>
<td>-2</td>
<td>-2</td>
</tr>
<tr>
<td>2 Provide information</td>
<td>Mandatory Vehicle fuel efficiency labelling (Hong Kong’s labelling scheme are voluntary)</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Travel behavior programs (e.g., TravelSmart (James et al. 2017))</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>1 Do nothing or simply monitor the current situation.</td>
<td>Oil and energy use audits</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>Household travel surveys</td>
<td>-1</td>
<td>-1</td>
</tr>
</tbody>
</table>

HKG = Hong Kong, BNE = Brisbane, Hash symbol (#) means already in place

Legend:

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>-3</th>
<th>-2</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generational equity effects</td>
<td>Highly positive</td>
<td>Moderately positive</td>
<td>Marginally positive</td>
<td>Neutral</td>
<td>Marginally negative</td>
<td>Moderately negative</td>
<td>Highly negative</td>
</tr>
<tr>
<td>Difficulty to apply</td>
<td>Very easy</td>
<td>Moderately easy</td>
<td>Marginally easy</td>
<td>Neutral</td>
<td>Marginally difficult</td>
<td>Moderately difficult</td>
<td>Very difficult</td>
</tr>
</tbody>
</table>
The difficulty to apply policies varies in jurisdictions, for instance, car restraint policies have less objection from the public in Hong Kong but faced greater resistance in Brisbane. In Hong Kong, the car lobby remained in check due to low car ownership. An issue for many of the policies aimed at addressing environmental issues is seen as remote to the public and they often do not address current generation equity issues.

11.4 Limitations

The limitations in this thesis could be addressed in future research. These are provided in Table 8.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter 2 Literature Review and Chapter 3 Methodology Development</td>
<td>• Only considered urban related studies, lack of consideration of rural, sparsely populated areas which are highly oil vulnerable • Non-English literature are not considered • Only Web of Science citation database is used</td>
</tr>
<tr>
<td>Chapter 4 Benchmarking inter-city oil vulnerability – many cities</td>
<td>• Subjective weightings and lack of sensitivity analysis • Data limitations, no data on fuel expenditure, tourism and freight aspects are not included, lack of accessibility measures and qualitative measures such as policy</td>
</tr>
<tr>
<td>Chapter 5 Benchmarking inter-city oil vulnerability with new data – Local study</td>
<td>• Micro-level considerations and geographic suitability are not able to be revealed. • Method is rather simplistic and gives limited information on improvement strategies</td>
</tr>
<tr>
<td>Chapter 6 Benchmarking inter-city oil vulnerability with new data – International study</td>
<td>• Micro-level considerations and geographic suitability are not able to be revealed. • Not being able to test its underlying hypothesis. • Did not consider alternative fuel for mobility (e.g., electric).</td>
</tr>
<tr>
<td>Chapter 7 Developing new methods to assess of oil vulnerability in intra-urban areas</td>
<td>• Lack of consideration of fuel expenditure and ‘peak car travel’ phenomenon • Lack of sensitivity analysis of composite indicator</td>
</tr>
<tr>
<td>Chapter 8 Comparing intra-urban oil vulnerability between cities</td>
<td>• Did not consider housing costs • Did not consider climate change ‘consequences’ of oil use • Limited city comparisons due to limited data</td>
</tr>
<tr>
<td>Chapter 9 Understanding policy responses to oil vulnerability</td>
<td>• Possible that certain key stakeholders have been omitted. • Implementation and evaluation of policies related to energy in transport should be also looked into in greater detail, such as the which has been proposed in the ‘Five-Stream’ adaptation of the Multiple Stream Analysis • Limited consideration of transport infrastructure financing, spatial inequity and housing costs</td>
</tr>
<tr>
<td>Chapter 10 Using disaggregated data to study oil vulnerability</td>
<td>• The treatment and control areas of public transport change have not been earmarked. • Sampling adjustments not used • Spatial-autocorrelation can also be examined with Geographic Weighted Regression • Lack of consideration of non-residents</td>
</tr>
</tbody>
</table>
11.5 Opportunities for further research

A list of gaps and future recommendations for research that is by no means exhaustive, which is provided in Table 9.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Future Research Opportunities</th>
</tr>
</thead>
</table>
| Chapter 2 Literature Review and Chapter 3 Methodology Development | • Adapting the ‘oil vulnerability’ conceptual framework  
• Different unit of analysis of oil vulnerability studies and potential hybridisation of unit of analysis  
• New trends that may affect oil vulnerability measures (e.g., energy transition, social inequity, new technologies) |
| Chapter 4 Benchmarking inter-city oil vulnerability – many cities | • Derive weights or normalise the data for benchmarking and sensitivity analysis  
• Qualitative measures (indicators of policy settings for transport, such as pricing controls or car restraint measures) to complement the quantitative measures used.  
• Bottom-up approach |
| Chapter 5 Benchmarking inter-city oil vulnerability with new data – Local study | • To incorporate second stage analysis, using Tobit regression models  
• Add more cities in the proposed DEA approach to examine model applicability |
| Chapter 6 Benchmarking inter-city oil vulnerability with new data – International study | • Possible for stochastic frontier analysis (SFA) when used in efficiency evaluation and it can provide significance testing results  
• To incorporate second stage analysis, using Tobit regression models  
• Start investigating green energy vehicles, such as electric cars/scooters |
| Chapter 7 Developing new methods to assess of oil vulnerability in intra-urban areas | • Further research on the verification of actual transport energy use and cost statistics, for instance, consideration of ‘fuel stress’ variables at intra-urban analysis  
• Expansion of analysis to more study areas |
| Chapter 8 Comparing intra-urban oil vulnerability between cities | • Expansion of analysis to more study areas and better data collection  
• To use statistical tools such as principal component analysis or regression modelling can be used to correlate other census statistics or household travel survey data with observed travel or energy use patterns  
• To consider housing cost in addition to transport costs  
• To include mapping with potential areas affected by mean sea level rise due to climate change |
| Chapter 9 Understanding policy responses to oil vulnerability | • Better interview coverage of stakeholders.  
• Revisiting interviewees.  
• Further research can be broadened by including transport infrastructure financing, inequity and housing costs. |
| Chapter 10 Using disaggregated data to study oil vulnerability | • Improvement of the analysis by better methods and data |

Composite indices should also be able to serve as a measure for tracking and monitoring change. Future research based on time-series analysis could be carried out (Baptista 2014). DEA results, and regression at household level can
possibly be used form the basis or weights for oil vulnerability composite indicators (Ratick and Osleeb 2013). With impending electrification of vehicle fleets, fuel tax revenue may decrease sharply. A regulatory shift to road-pricing appears inevitable, and is currently being considered by Australian policy-makers, but the equity implications of such a shift have not yet been explored. Future work should consider the impacts of different road pricing policy proposals on energy demand and transport equity, both at the household level and geo-spatially across major cities.

This thesis provided a solid foundation for further research on the key concerns of transport equity, climate change, sustainability and energy justice.
Appendix A: Sample interview questions

The interviewer shall keep a few different versions of these questions in mind so that they can encourage the respondent to talk and can thus keep the discussion going. If respondents have difficulty identifying problems, interviewers can give some examples, but should not suggest answers. The questions are classified into several themes which lead to main and additional questions. Clarifying questions are used when the answer received is not clear enough.

<table>
<thead>
<tr>
<th>Themes</th>
<th>Main Questions</th>
<th>Additional Questions</th>
<th>Clarifying Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. About the Participant</td>
<td>What is your current role (or previous role) in urban transport operations / governance / studies?</td>
<td>• How long have you worked in this position?</td>
<td></td>
</tr>
<tr>
<td>2. The Issue and Impacts</td>
<td>Have you heard of peak oil?</td>
<td>• Under what circumstance does the problem arise?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Did the previous oil shocks (1970s Oil Crisis) event lead to reduction in oil use in your city?</td>
<td>• What policies were made?</td>
<td>• Can you expand a little more on this?</td>
</tr>
<tr>
<td></td>
<td>Do you think the oil dependency in transport is a problem in your city?</td>
<td>• Were these policies effective?</td>
<td>• Can you give me some examples?</td>
</tr>
<tr>
<td></td>
<td>Has increasing or fluctuating oil price been an issue during your work or your operations?</td>
<td>• Why?</td>
<td>• Can you tell me anything else about this?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Which place(s) do you think will be the most/or more affected by oil price increases?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Have you received any complaints from the public?</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• Are you aware about this issue from media reports or coverage?</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• Have you noticed any changes in the situation over the past few years?</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• Who are the most affected?</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• Are there socio-groups you would consider as vulnerable groups for oil price increases?</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>• How do you explain the problem?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>o Transport modes?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>o Land use mix?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>o Urban density?</td>
<td></td>
</tr>
<tr>
<td>3. Operations</td>
<td>Is/do you think energy supply and oil price levels are being considered in your city’s transport planning / your operations?</td>
<td>• What is being done to reduce the impact of higher/fluctuating fuel price?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Are these policies effective?</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• What else can you think of that could be more effective but is not carried out now?</td>
<td></td>
</tr>
<tr>
<td>Themes</td>
<td>Main Questions</td>
<td>Additional Questions</td>
<td>Clarifying Questions</td>
</tr>
<tr>
<td>--------</td>
<td>----------------</td>
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</tr>
</tbody>
</table>
| 4. Public Transport | Do you think public transport is a solution to reducing oil vulnerability? | • Is your city’s public transport system well equipped if there is an oil price supply shock?  
  o What are the oil-based modes?  
  o What is the non-oil-based modes?  
  • For areas outside the coverage of the public transport network, what can be done to service this network if the oil price is too expensive? |  |
| 5. Active Transport | Do you think active transport (walking/cycling) is a solution to reducing oil vulnerability? | • Can the inhabitants walk or cycle to satisfy their transport needs?  
  • What are the planned minimum walking distance standards to public transport stations? (for planners only) |  |
| 6. Infrastructure Planning | What are the current major transport planning directions in your city? | • Do you think these plans can reduce oil dependency? |  |
| 7. Lifestyle | Do you think the people in your city prefer alternative urban forms, for instance:  
  HKG: Compact city based on public transport and car-controlling policies, or:  
  BNE: Dispersed city, less dense and based on automobile or:  
  Others (European?) | • Why?  
  • Is car ownership seen as a status symbol? |  |
| 8. Future | Do you think the current continual use of oil is viable? If no, what adaptive measures have been or are planned to be taken in your city to reduce oil use? | • Transport demand measures?  
  • Fuel substitution?  
  • Are electric vehicles a solution?  
  • How about other alternative fuels, such as biofuels, hydrogen?  
  • Combination of these? |  |
| 9. Conclusion | Are there any other energy related urban transport problems that we have not discussed and that you are concerned about?  
  Do you want to add anything about this topic? |  |  |
Appendix B: Griffith University thesis preparation policy

1. Inclusion of papers within the thesis

Higher degree by research is a program of independent supervised study that produces significant and original research outcomes, culminating in a thesis, exegesis or equivalent (refer to Higher Degree by Research Thesis). Inclusion of papers within a thesis is not a suitable thesis format for all research projects, for example: collaborative projects where there may be several co-authors for each paper which may make it difficult for the examiner to establish the independence of the candidates work; where primary data is not collected, or results obtained, until late in the candidature; or where the research will not produce a logical sequence of papers that are able to be presented as an integrated whole. Candidates should also take into account whether this thesis format is an accepted practice within their discipline and likely to be received well by the thesis examiners (refer also to the examination requirements below). Candidates are required to consult with their supervisor(s) early in their candidature to determine if this thesis format is appropriate.

It is expected that candidates will identify as part of the confirmation of candidature milestone if their thesis is to be prepared in this format. Candidates should consult their Group specific guidelines in addition to the requirements detailed below. Candidates are also encouraged to attend the workshop: ‘Inclusion of papers within a thesis’ offered by the Griffith Graduate Research School.

Refer also to the Griffith University Code for the Responsible Conduct of Research, specifically the sections pertaining to publication ethics and the dissemination of research findings, and authorship.
Status of papers
A thesis may include papers that have been submitted, accepted for publication, or published. Some disciplines may specify a variation to the status of papers requirement, refer to your Group specific guidelines.

Type of papers
For the purpose of this requirement, papers are defined as a journal article, conference publication, book or book chapter. Papers which have been rejected by a publisher must not be included unless they have been substantially rewritten to address the reviewers’ comments, or have since been accepted for publication. Some disciplines may specify a variation to the type of papers requirement, refer to your Group specific guidelines.

Number of papers
A thesis may be entirely or partly comprised of papers. A paper maybe included as a single chapter if the paper contributes to the argument of the thesis, or several papers may form the core chapters of the theses where they present a cohesive argument. Where a thesis is entirely comprised of papers, there is no minimum requirement for the number of papers that must be included (except as noted below) and is a matter of professional judgment for the supervisor and the candidate. Overall, the material presented for examination needs to reflect the research thesis standard required for the award of the degree. For example, PhD candidates, on the basis of a program of independent supervised study, must produce a thesis that makes a significant and original contribution to knowledge and understanding in the relevant field of study. This remains a matter of professional judgment for the supervisor and the candidate. Where a thesis is entirely comprised of papers, some disciplines may specify a minimum number of papers to be included, refer to your Group specific guidelines.

Authorship
The candidate should normally be principal author (that is, responsible for the intellectual content and the majority of writing of the text) of any work included in the body of the thesis. Where a paper has been co-authored, the candidate is
required to have made a substantial contribution to the intellectual content and writing of the text. Co-authored work in which the candidate was a minor author can only be used and referenced in the way common to any other research publication cited in the thesis. A signature from the corresponding author is required in order to include co-authored material in the body of the thesis, refer to the declarations section below.

For co-authored papers, the attribution of authorship must be in accordance with the Griffith University Code for the Responsible Conduct of Research, which specifies that ‘authorship must be based on substantial contributions in one or more of:

• conception and design of the research project
• analysis and interpretation of research data
• drafting or making significant parts of the creative or scholarly work or critically revising it so as to contribute significantly to the final output’.

Some disciplines may specify a variation to the authorship requirement, refer to your Group specific guidelines.

Quality of papers
Candidates should endeavour to publish their research in high quality peer reviewed publications. Papers to be included in the body of the thesis should be published (or submitted for publication) in reputable outlets that are held in higher regard in the relevant field of research. Candidates should consult their supervisor(s) for advice on suitable publications specific to their research discipline. Some disciplines may specify quality standards that must be met for papers to be included, refer to your Group specific guidelines.

The library also provides support and advice to candidates on choosing a journal. Candidates are advised to note in particular advice in order to avoid ‘predatory’ publishers.

• Research Guide: Higher degree research candidates - Get Published
• Publishing in Open Access journals
Copyright

As copyright in an article is normally assigned to a publisher, the publisher must give permission to reproduce the work in the thesis and put a digital copy on the institutional repository. Information on how to seek permission is available at: Copyright and Articles in thesis.

If permission cannot be obtained, students may still include the publication in the body of the thesis, however following examination the relevant chapter(s) will be redacted from the digital copy to be held by the Griffith University Library so that the copyright material is not made publicly available in the institutional repository. Students are required to advise the copyright status of each publication included in the thesis via a declaration to be inserted in the thesis, as detailed below.

Students requiring further advice regarding copyright issues can contact the Information Policy Officer on (07) 3735 5695 or copyright@griffith.edu.au.

Group and discipline requirements

Some Groups or Elements may specify additional requirements for including papers within a thesis, refer below:

- Arts, Education and Law
- Griffith Business School (PDF 214k)
- Griffith Health
- Griffith Sciences

2. Format of thesis

General

Consult the thesis preparation and formatting guidelines for general information about the requirements for formatting the thesis. Some disciplines may specify a variation to the thesis format requirements below, refer to your Group specific guidelines.
**Structure of thesis and linking chapters**

The structure of the thesis will vary depending on whether the thesis is partly or entirely comprised of papers. Whatever the format, the thesis must present as a coherent and integrated body of work in which the research objectives, relationship to other scholarly work, methodology and strategies employed, and the results obtained are identified, analysed and evaluated.

In general every thesis should include a general introduction and general discussion to frame the internal chapters. The introduction should outline the scope of the research covered by the thesis and include an explanation of the organisation and structure of the thesis. The general discussion should draw together the main findings of the thesis and establish the significance of the work as a whole, and should not just restate the discussion points of each paper.

It is important that candidates explicitly argue the coherence of the work and establish links between the various papers/chapters throughout the thesis. Linking text should be added to introduce each new paper or chapter, with a foreword which introduces the research and establishes its links to previous papers/chapters.

Depending on the content of the paper(s) and nature of research, a research methods chapter may also be necessary to ensure that any work that is not included in the paper(s), but is integral to the research, is appropriately covered. Any data omitted from a paper may also be included as an addendum to the thesis.

For further information on the thesis structure, refer to the following examples of acceptable ways to format the thesis when including papers.

See Examples of Table of Contents
Format of papers

The papers may be rewritten for the thesis according to the general formatting guidelines; or they can be inserted in their published format, subject to copyright approval as detailed above.

Pagination

Candidates may repaginate the papers to be consistent with the thesis. However, this is at the discretion of the candidate.

Declarations

All theses that include papers must include declarations which specify the publication status of the paper(s), your contribution to the paper(s), and the copyright status of the paper(s). The declarations must be signed by the corresponding author (where applicable). If you are the sole author, this still needs to be specified. The declaration will need to be inserted at the beginning of the thesis, and for any co-authored papers, additional declarations will need to be inserted at the beginning of each relevant chapter. You may wish to consult the declaration requirements for inclusion of papers diagram to ensure that you insert the correct declaration(s) within the thesis. Please note that completion of the declaration(s) does not negate the need to comply with any other University requirement relating to co-authored works as outlined in the Griffith University Code for the Responsible Conduct of Research.

3. Examination requirements

Assessment by examiners

Candidates who wish to include papers within their thesis, and who have determined that this thesis format is appropriate to the research project, should also consider whether this thesis format will be well received by the thesis examiners. The inclusion of papers may negatively impact on the thesis upon assessment by the examiners where: the thesis format is not a common or accepted practice within the candidates discipline area; where the inclusion of co-authored papers makes it difficult for the examiner to establish the
independence and originality of the candidates work; where the thesis does not present to the examiner as an integrated whole; or where there is too much repetition in the thesis which an examiner may view as a weakness. Theses that include papers are subject to the same examination criteria as theses submitted in the traditional format. It should also be noted that the inclusion of published papers within the thesis does not prevent an examiner from requesting amendments to that material.

Candidates should discuss the suitability of this thesis format for examination with their supervisor(s).

**Nomination of examiners**

It is the responsibility of the principal supervisor to nominate thesis examiners, and the process dictates that the principal supervisor must approach all nominees to determine their willingness to examine. Where a candidate’s thesis is formatted to include papers, the principal supervisor must also ensure that the examiners are familiar with and/or accepting of, this thesis format.

Upon dispatch of a candidate’s thesis to an examiner, the examiner will be reminded that the thesis has been formatted to include papers. The examiner will also be provided with the relevant information and regulations regarding this thesis format.


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