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

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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

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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, Kenworthy & Laube 2003; Hickman & Banister 2014). Figure 1 shows the differing pace of motorisation: Australian cities are mature automobile cities with steady car ownership growth over time. Other 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 & Seo 2010).
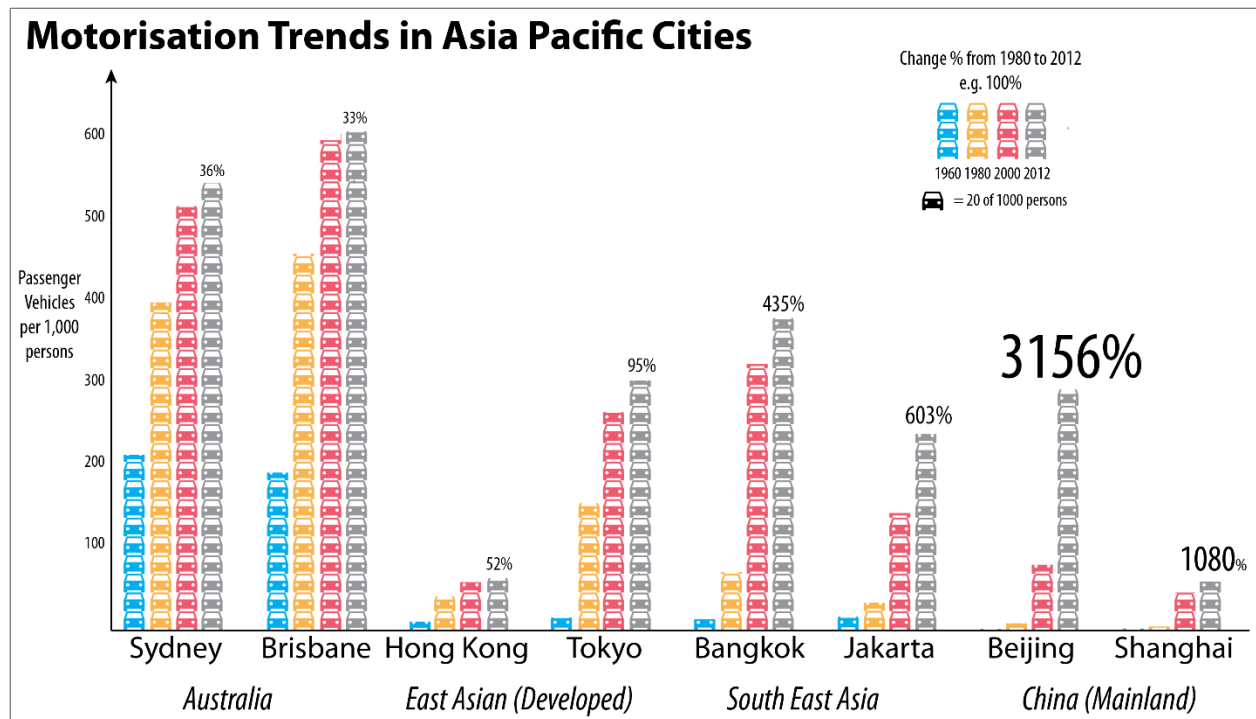
Figure 1: Trends in motorisation in various selected Asia Pacific cities

(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 Central Asia 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 against, 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, Beatley & Boyer 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 & 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, Sipe & Dodson 2017; 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 & Coutard 2014; Warren, Christoff & Green 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, Jewell & Goldthau 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, Failing & Berry 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, Brown & Scharv 1976; Chao, Huang & Jou 2015; Jung & Yoo 2014; Keyes 1982; Wang & 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 & Sipe 2007). Oil vulnerability mapping is a particularly powerful tool in identifying areas that require urgent attention and intervention (Preston, Yuen & Westaway 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 research 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, Anable & Vrotsou 2016; 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 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 comprehensive spatial analysis of oil vulnerability at intra-urban scale.

Table 1: Selected spatial-geographical oil vulnerability studies operating at intra-urban scale

Source	Location (Country)	Main Approach	Exposure	Adaptive Capacity	Sensitivity
Dodson and Sipe (2007) (VIPER Index)	Brisbane. Sydney, Melbourne (Australia)	Composite index with mapping	1. Proportion of households with two or more motor vehicles; 2. Journey to work (JTW) car modal share	Not specified	1. Socio-economic status (SEIFA index)
Dodson and Sipe (2008) (VAMPIRE Index)	Brisbane. Sydney, Melbourne in (Australia)	Composite index with mapping	1. Proportion of households with two or more motor vehicles; 2. Journey to work car modal share	Not specified	1. Mortgage 2. Median Household Income
Fishman and Brennan (2010)	Melbourne (Australia)	Composite index with mapping	1. Average weekly fuel use 2. Percentage of non-automobile weekday travel (all trips)	1. Mode share including public and active transport.	1. Average personal income
Runting et al. (2011)	South East Queensland, (Australia)	Composite index with mapping and dimension table	1. Weighted average JTW distance on road network 2. Car ownership (≥ 2) 3. JTW by car 4. Weighted average JTW distance	1. Proportion of non-motorised access to public transport	1. Socio-economic status (by SEIFA index)
Büttner et al. (2013)	Munich (Germany) and Lyon (France)	Composite index with mapping	1. Munich: Vehicle-km per capita 2. Lyon: Per capita commuting distance by private car	1. Total number of accessible jobs 2. Within one hour by public transport at 3. Peak time	1. Munich: Average monthly income 2. Lyon: Unemploy-ment rate
Akbari and Habib (2014)	Toronto (Canada)	Composite index with mapping	1. Proportion of households with two or more motor vehicles; 2. Car modal share of all trips	Not specified	1. Median household income 2. Prevalence of low income after tax
Lovelace and Philips (2014) ('Hybrid vulnerability index')	Yorkshire and Humber (United Kingdom)	Spatial microsimulation and mapping	1. Average proportion of individual's energy budget spent on commuting	1. Distance to employment centre; 2. Proportion of work trips made by car	Not specified
Rendall et al. (2014) (VOILA Index)	Christchurch (New Zealand)	Activity modelling and mapping	1. Average household car ownership 2. Energy consumption costs (by odometer)	1. Estimation of average 'minimum' required transport energy consumption	1. Median income
Marshall and Henao (2015)	Denver, Colorado	Multimodal fuel cost modelling and scenario analysis of higher fuel price scenarios	1. Estimated household income spent on commuting 2. Drive-alone Mode Share 3. Driving (tour) distance	1. Mode share including public and active transport.	1. Median income
(Leung et al. 2015)	South-East Queensland (Australia)	Composite index with mapping and dimension table	1. Average number of motor vehicles owned per dwelling; 2. Oil-based fuel use of low occupancy vehicles per commuting trip 3. Average commuting distance	1. Proportion of active and public transport mode share 2. Proportion of area within 400m of public transport stop ranked by level of service on weekdays 3. Walkability indices 4. Employment density 5. Proportion of area within 400m buffer of electric transport corridors	1. Median weekly 2. household income 3. Socio-economic status (by SEIFA index)

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, Page & Krumdieck 2014) and spatial microsimulation (Lovelace & Philips 2014). However, it is more data intensive and requires a great deal of specialist knowledge to perform analysis. Vehicle fleet efficiency (Li, Sipe & Dodson 2017, 2013), multimodal transport costs and transport affordability (Li, Dodson & Sipe 2015; Marshall & Henao 2015; Mattioli, Lucas & Marsden 2016) 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, Siegel & Jorgensen 2001; Chambers 1989; Watts & 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:
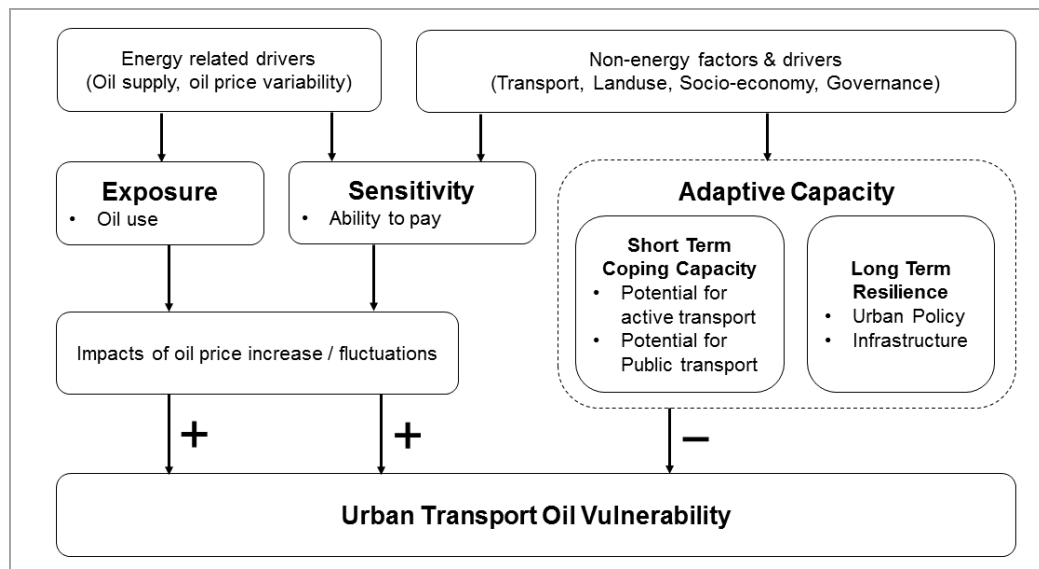

Figure 2: A proposed framework for oil vulnerability research
(Adapted from Marshall et al. (2010))

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).
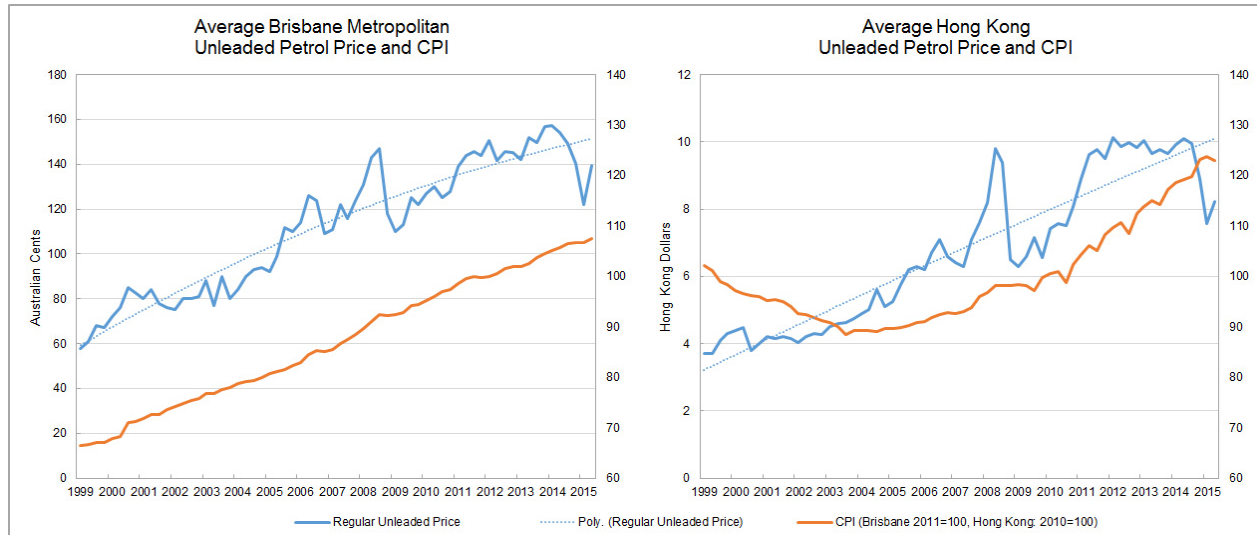
Figure 3: Average fuel price of Brisbane and Hong Kong, 1999 to 2015
(Hong Kong Consumer Council 2015; Queensland Government Statistician's Office 2015)

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. To allow a fair comparison between cities, only census tracts that are of urbanised nature are considered. 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. Immigraton controls are in place at 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

Key Differences	Greater Brisbane	Hong Kong
Total population (2011)	2,003,499	7,070,388
Urbanised population (%) (2011)	1,930,767 (96.4%)	7,053,701 (99.8%)
Total area	5,904 km²	1,104 km²
Private vehicle per 1000 persons	613.40	50.08
Mode share of low occupancy vehicles (private cars)	93.09%	28.07%
Annual transport energy use per person	31.6 gigajoules	6.5 gigajoules
Urban form and density	Dispersed and low	Compact and high
Society and culture	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.	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.
Development expansion space	With room for further expansion but controlled by regional planning	Constrained by natural geography with limited room to expand. Future large-scale development most likely by sea reclamation or redevelopment of existing urban areas.
Planning governance	4 local councils (Brisbane, Logan, Redlands and Moreton Bay) with strong Queensland State Government involvement under the South East Queensland Regional plan	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.
Borders	No border controls to neighbouring areas	Border and immigration controls along Hong Kong-China border.
Natural geography	Coastal city separated by Brisbane River, some outlying islands but largely undeveloped	Coastal city separated by a wider Victoria Harbour, numerous outlying islands, some highly populated and connected by bridges or tunnels.
Built-up area (%)	840 km² (14.2%)	264 km² (14.9%)
Average per-capita income:	US$47,124	US$55,167
Year founded by British settlement	1825 (Australia - federated in 1901)	1842 (ended in 1997 due to sovereignty change)
Human development index	0.933 (very high)	0.891 (very high)
Motorised transport modes	Bus, rail, ferry, car	Bus, rail, ferry, tram/light-rail, car

(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)
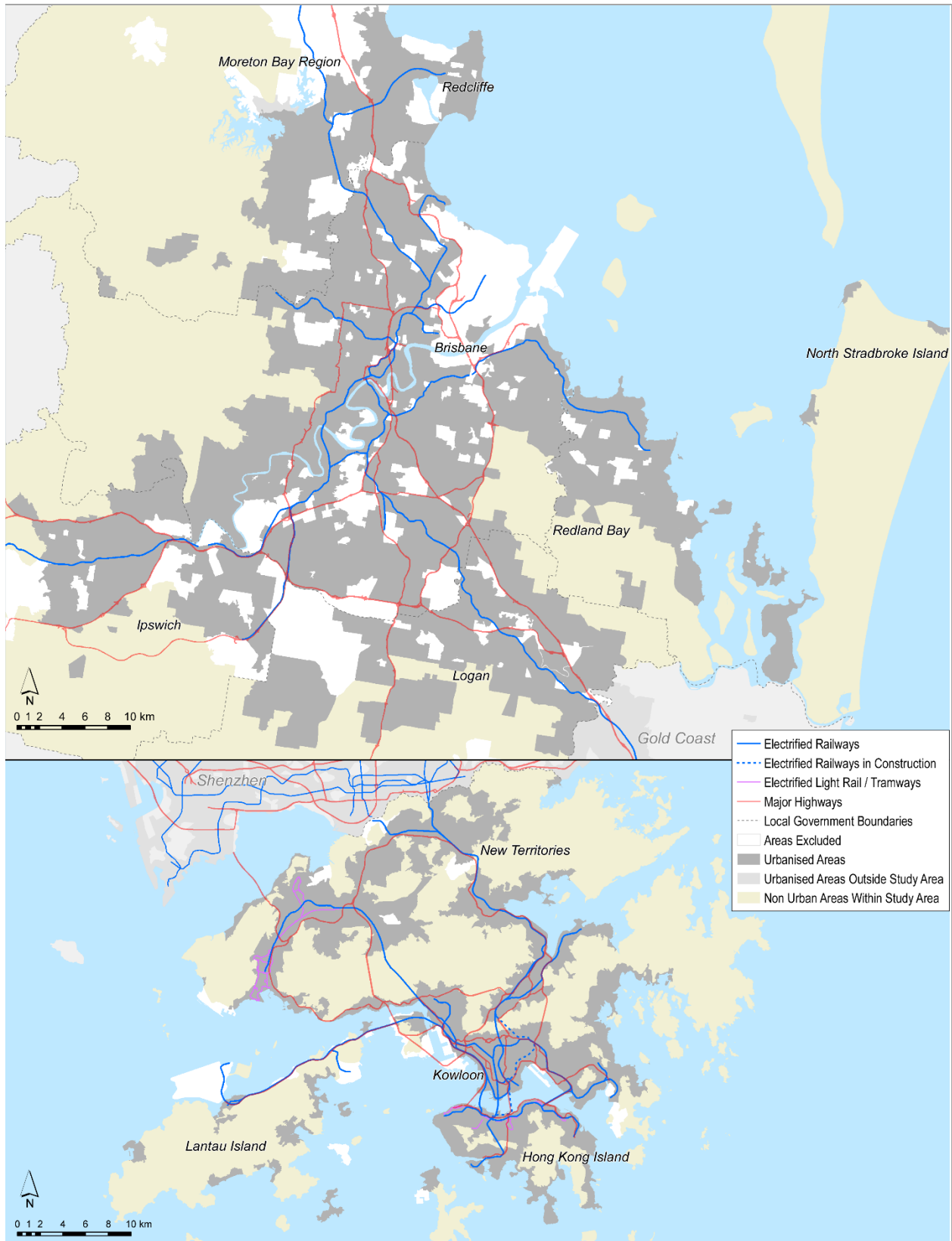
Figure 4: Urban extent and transport features of Brisbane (top) and Hong Kong (bottom)

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 metroplitan 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, Dodson & Hall 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

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

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.
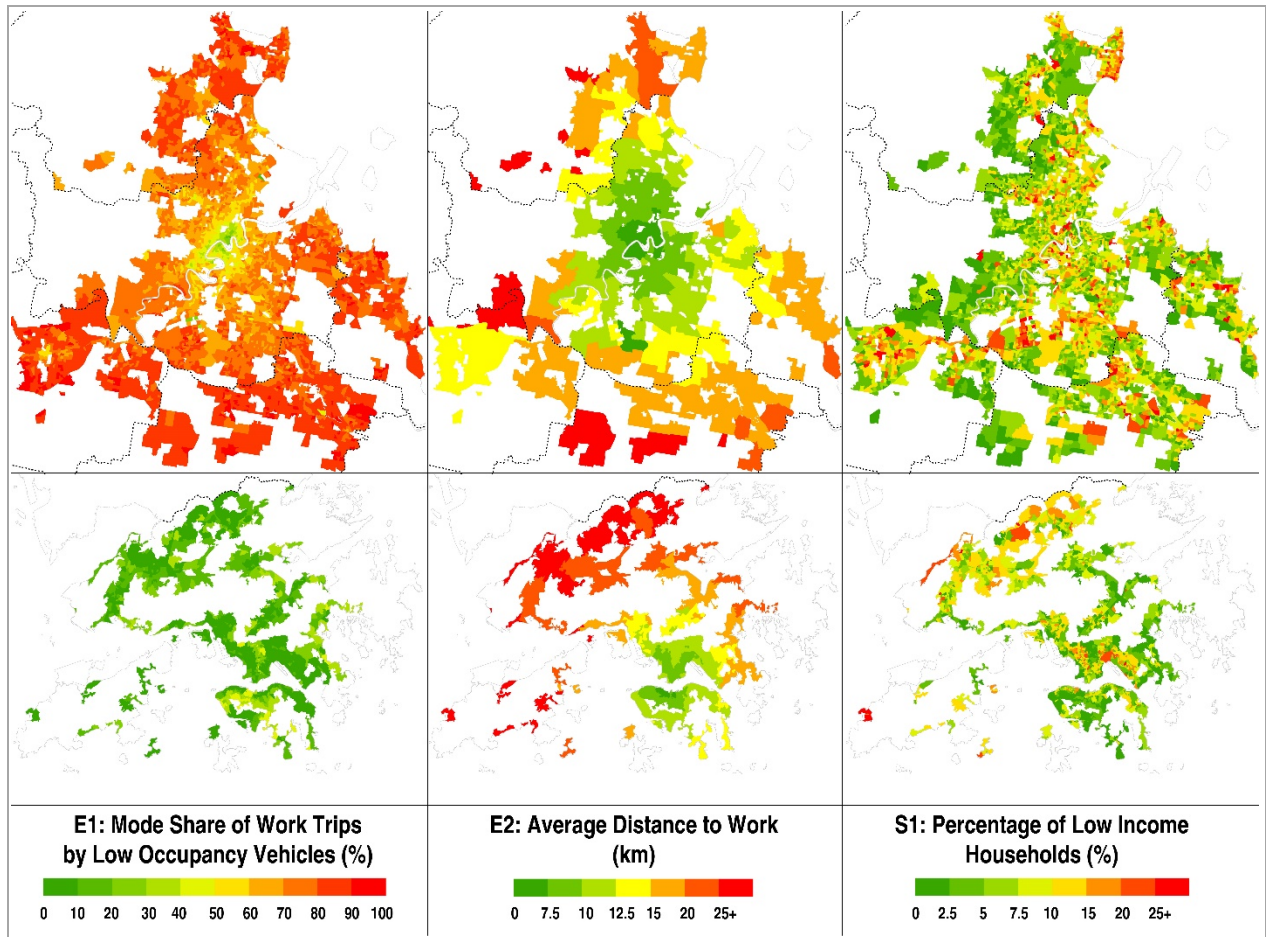
Figure 5: Potential impact of oil prices: Exposure and Sensitivity variables in Brisbane (top) and Hong Kong (bottom)

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 & Barbeau 2013; Keller 2012). In this study, we developed a public transport level of service (PTLOS) method, pilot tested in South East Queensland by (Leung et al. 2015). The following equations are used for this index:

$$PTLOS = Average\ Frequency\ Score \times Effective\ Span\ of\ Service \times Serviced\ Days\ in\ a\ week$$

Whereas:

$$Average\ Frequency = \frac{Peak\ Frequency\ Score \times Off\ Peak\ Frequency\ Score}{2}$$

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

(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)**)**

Frequency (minutes)	PTLOS Score
less than 5	6
10	5
15	4
30	3
60	2
more than 60	1

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 400m is used, which is a widely adapted standard used in various jurisdictions as a reasonable distance for accessing public transport by foot (Daniels & 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 is used to form 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.
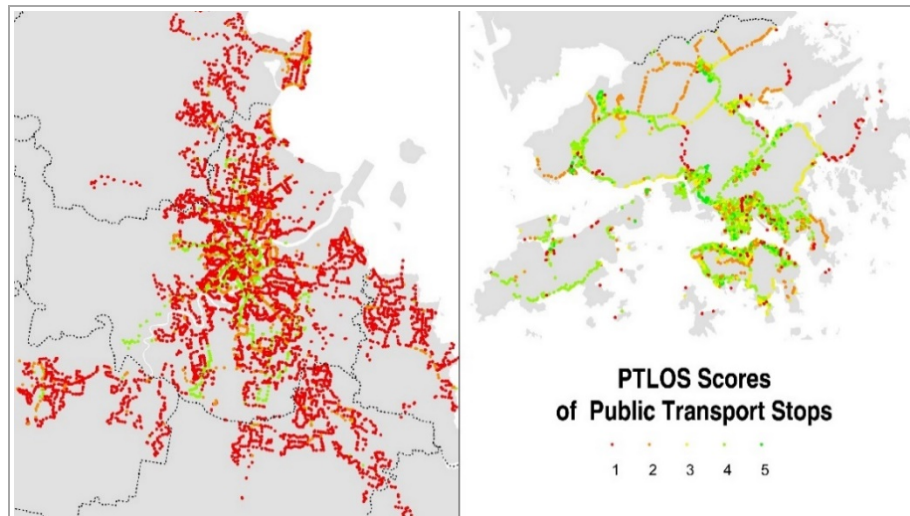
Figure 6: The estimated PTLOS score for each transport stop within the urban extent of Brisbane (left) and Hong Kong (right)
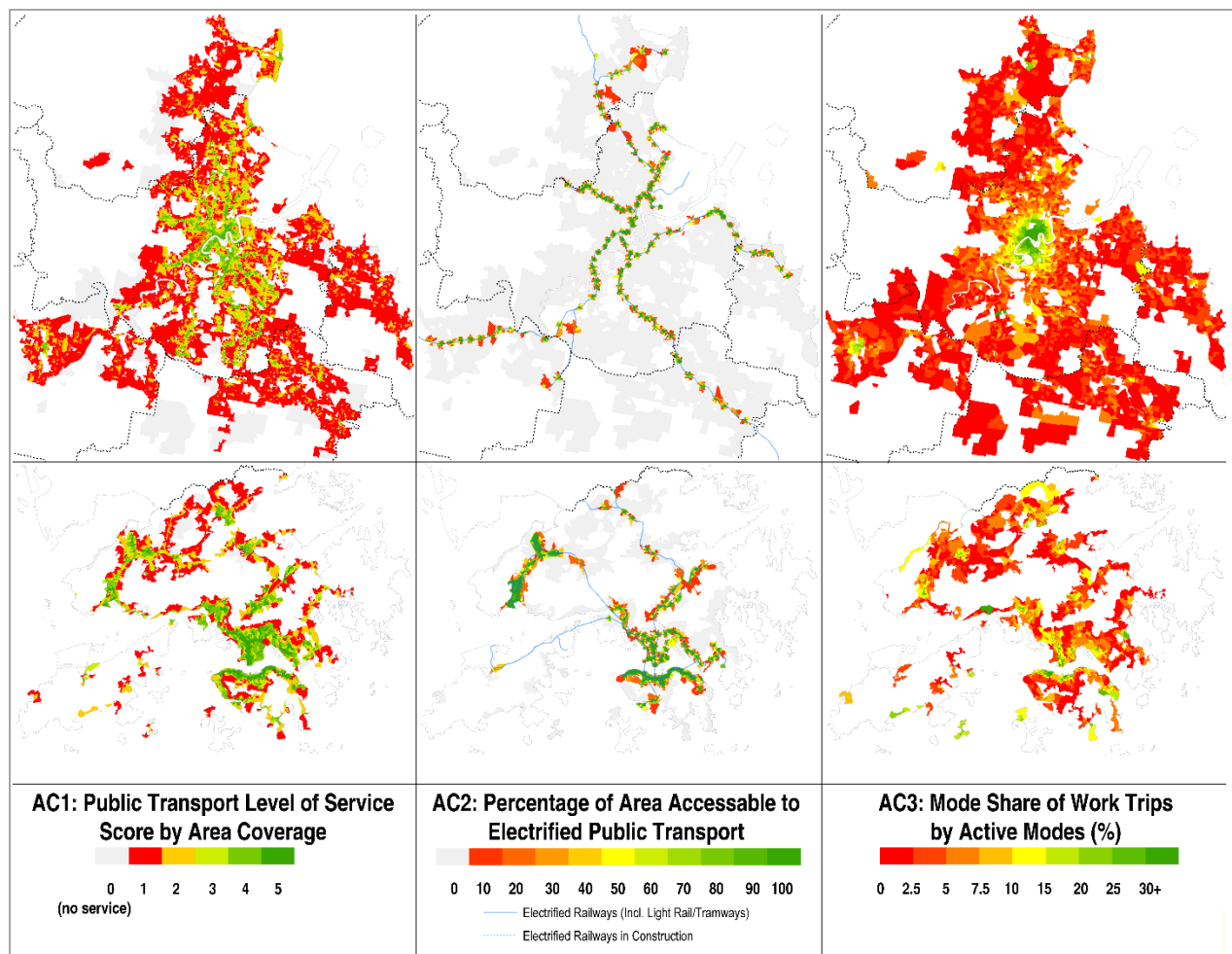

Figure 7: Adaptive capacity variables of Brisbane (top) and Hong Kong (bottom)

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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, average small area 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

City Area	Mean	S.D.	Min	Max
Greater Brisbane				
E1 - To work by LOV (%)	71.95	13.31	12.05	100.00
E2 - Average commute distance (km)	13.42	45.43	4.87	34.50
S1 - Low income (%)	9.70	7.04	0.00	55.78
AC1 - Area coverage of PTLOS score	1.23	1.14	0.00	4.00
AC2 - Area with electrified public transport (%)	61.60	37.46	0.00	100.00
AC3 - To work by active modes	5.22	6.97	0.00	63.44
Hong Kong				
E1 - To work by LOV (%)	10.23	10.79	0.00	47.01
E2 - Average commute distance (km)	14.36	6.32	6.57	34.18
S1 - Low income (%)	7.66	5.45	0.00	50.16
AC1 - Area coverage of PTLOS score	3.17	1.63	0.00	5.00
AC2 - Area with electrified public transport (%)	76.92	34.03	0.00	100.00
AC3 - To work by active modes	9.01	8.24	0.00	41.71

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

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

Table 7: Correlation of the variables used for the oil vulnerability composite indicator

Brisbane	E1	E2	S1	AC1	AC2	AC3
E1	1	.593**	-.298**	-.475**	-.207**	-.719**
E2	.593**	1	-.083**	-.505**	-.166**	-.479**
S1	-.298**	-.083**	1	.184**	.073**	.218**
AC1	-.475**	-.505**	.184**	1	.409**	.447**
AC2	-.207**	-.166**	.073**	.409**	1	.104**
AC3	-.719**	-.479**	.218**	.447**	.104**	1

Hong Kong	E1	E2	S1	AC1	AC2	AC3
E1	1	.090**	-.486**	-.343**	-.127**	-.450**
E2	.090**	1	.077**	-.571**	-.150**	-.333**
S1	-.486**	.077**	1	.069**	.087**	.360**
AC1	-.343**	-.571**	.069**	1	.508**	.412**
AC2	-.127**	-.150**	.087**	.508**	1	.230**
AC3	-.450**	-.333**	.360**	.412**	.230**	1

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:

$$Vulnerability = E + S - AC$$

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; Hudrliková 2013; Sharpe & 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 Set 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

Set No.	Variables included
1 (Baseline)	$zscoreE1 + zscoreS1$
2	$zscoreE1 + zscoreS1 - zscoreAC1$
3	$\dfrac{zscoreE1 + zscoreE2}{2} + zscoreS1 - zscoreAC1$
4	$\dfrac{zscoreE1 + zscoreE2}{2} + zscoreS1 - \dfrac{zscoreAC1 + zscoreAC2}{2}$
5 (Final)	$\dfrac{zscoreE1 + zscoreE2}{2} + zscoreS1 - \dfrac{zscoreAC1 + zscoreAC2 + zscoreAC3}{3}$

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

Area	Average Shift of percentile rank of all areas	Minimum Shift	Maximum Shift
Greater Brisbane	**17.80**	**0.00**	**69.85**
Brisbane	20.11	0.00	69.85
Ipswich	15.56	0.04	58.18
Logan	13.55	0.02	63.86
Moreton Bay	16.61	0.29	65.07
Redland Bay	12.40	0.22	49.18
Hong Kong SAR	**16.34**	**0.53**	**75.34**
Hong Kong Island	6.88	0.84	39.87
Kowloon	7.55	0.73	48.04
New Territories (Excluding Lantau)	27.62	0.53	75.34
Lantau	48.58	11.51	72.62

(Column header note: "Sensitivity of the variable inclusion effects of the five sets" spans the Average Shift, Minimum Shift, and Maximum Shift columns.)

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.
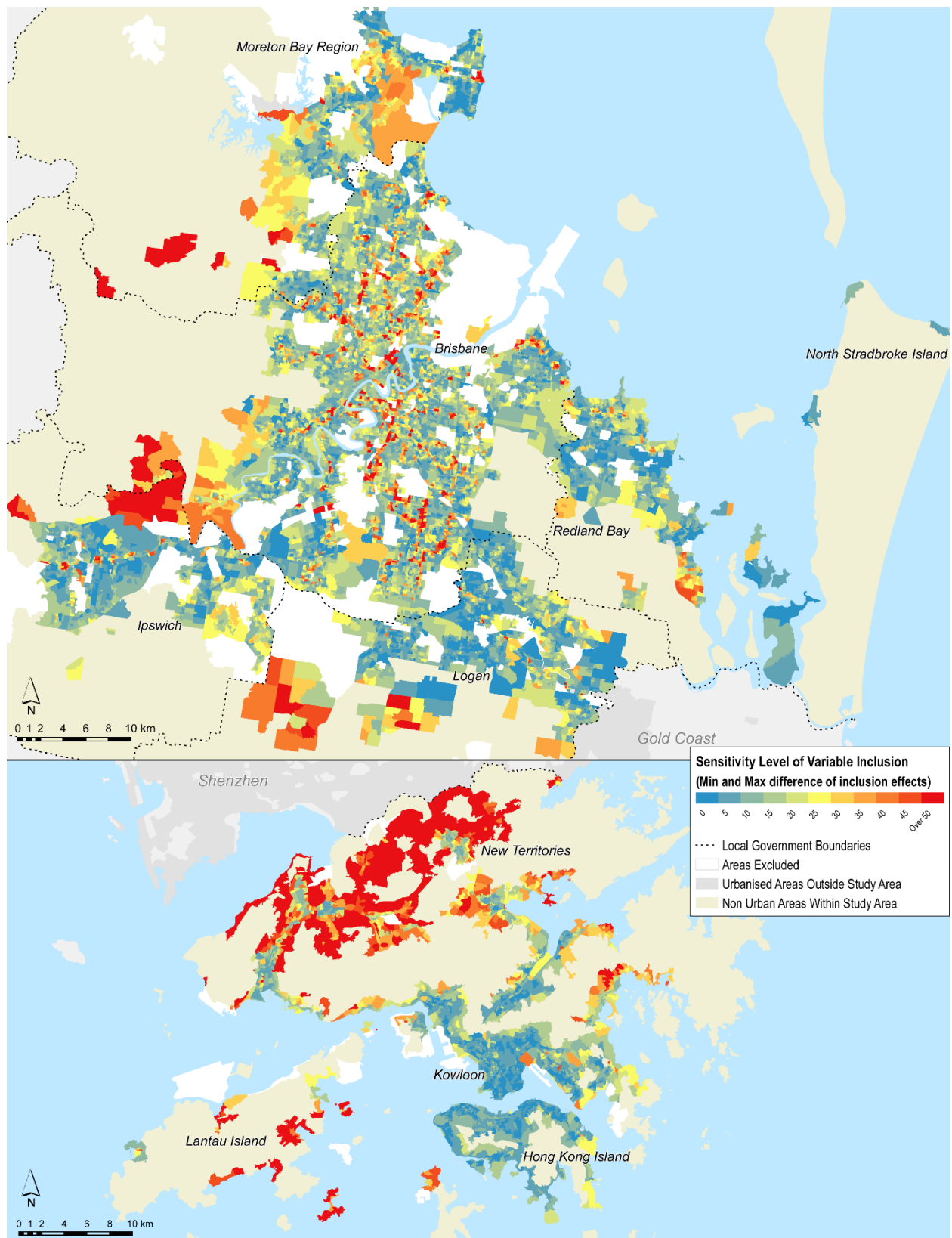
Figure 8: Sensitivity level of variable inclusion, based on the minimum and maximum difference of variable inclusion effects. Brisbane (top) and Hong Kong (bottom)

The average shift in ranking due to variable inclusion is about 16 to17 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 & 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 & Burke 2013).
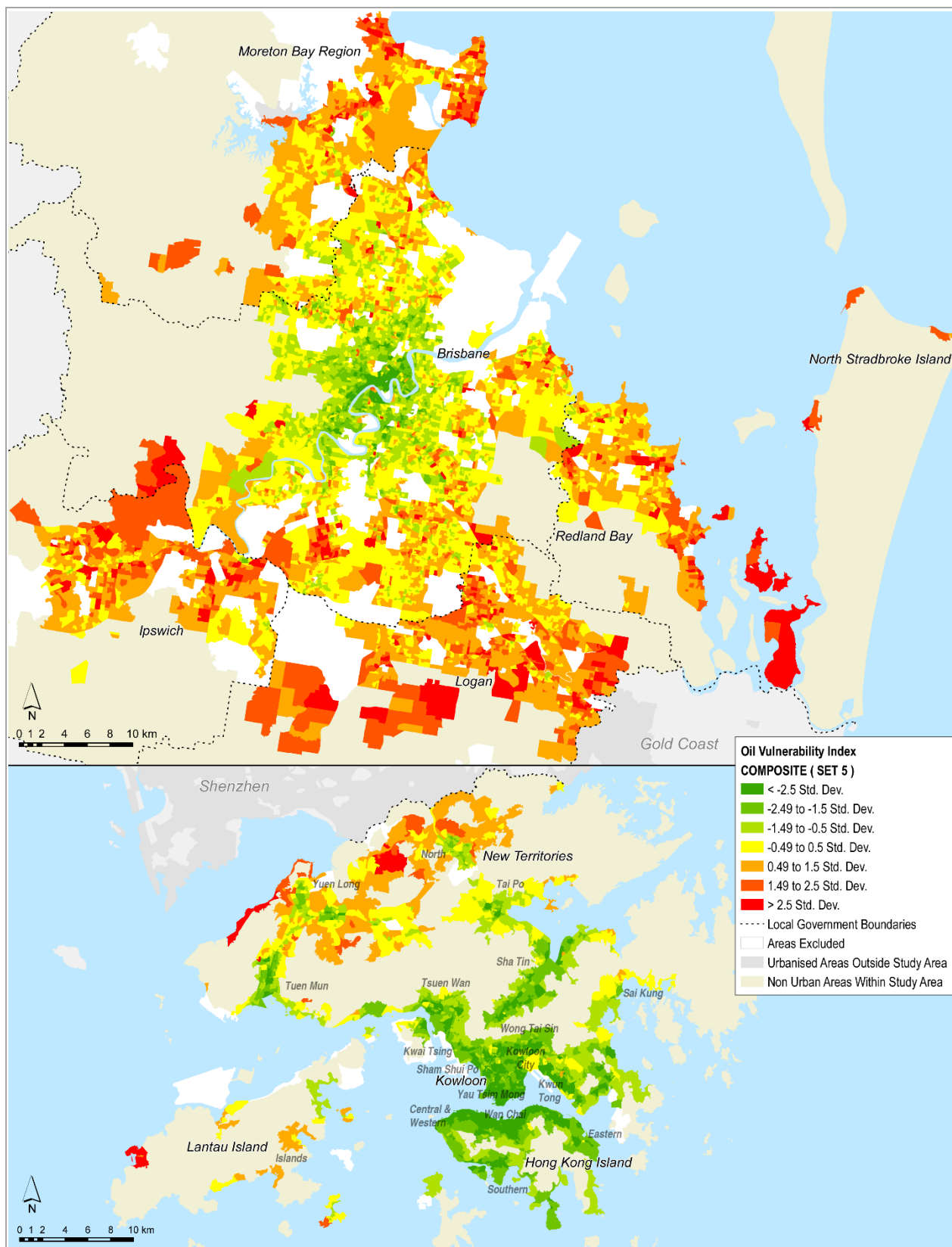
Figure 9: Composite oil vulnerability index of Brisbane (top) and Hong Kong (bottom)
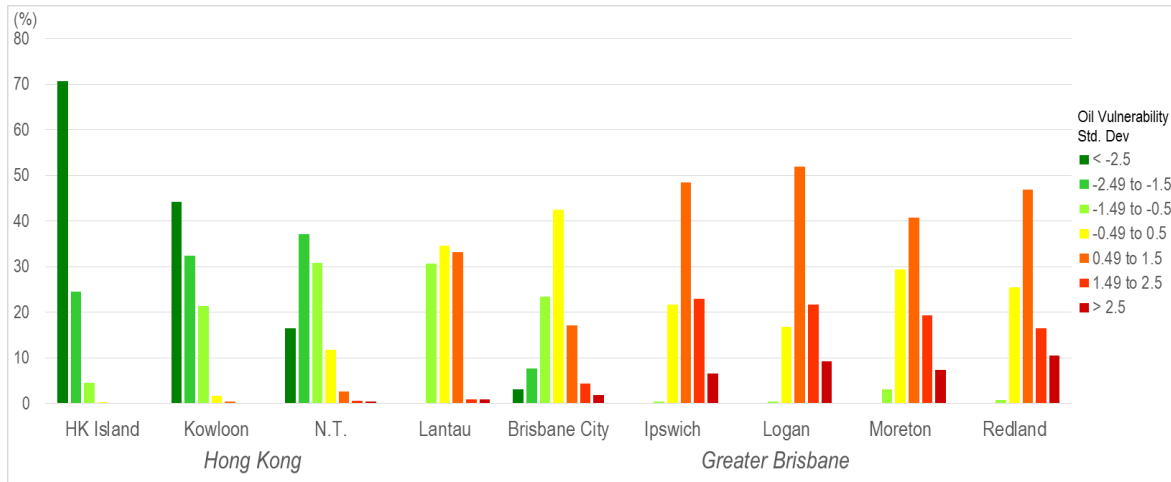
Figure 10: Comparison of the percentage of population of oil vulnerability levels across the internal divisions of Hong Kong and Greater Brisbane

Hong Kong does not have such dedicated busways, but has a streetcar double-deck tramways in Hong Kong Island and a light rail network in the northwest New Towns. In terms of fuel for buses, the Brisbane City Council has adopted a policy of purchasing only compressed natural gas (CNG) buses. Hong Kong's minibuses and taxies are mostly powered by liquefied petroleum gas (LPG, an oil refinery by-product). While the use of gas-based fuel offers some oil resilience, their prices are still subject to oil price fluctuations, and both finite fossil fuels are interacting each other in the commodity market.

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 & Hickman 2017; Dodson & Sipe 2008; Li, Dodson & Sipe 2017). The issue of housing cost is complicated, as the level of burden varies for renters and mortgage buyers. Despite the absence 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 less oil vulnerable 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 costs might be compensated by the lower housing costs, but this represents high oil vulnerability risks in an event of oil supply shortfall and also unsustainable transport.

Table 10: Comparison of Transport and Housing Costs with Oil Vulnerability Indicators

Area	District	Transport Cost Share	Housing Cost Share	Cross-city Composite Oil Vulnerability
		(% of total household expenditure)		*(S.D.)* *(lower is better)*
HK Island	Central & Western	7.60	44.50	-3.64
	Wan Chai	8.90	45.60	-3.36
	Eastern	5.80	39.50	-2.25
	Southern	7.40	31.80	-2.24
Kowloon	Sham Shui Po	11.50	30.90	-2.69
	Kowloon City	7.10	35.00	-2.40
	Wong Tai Sin	6.70	28.80	-2.29
	Kwun Tong	7.20	28.80	-3.26
	Yau Tsim Mong	6.60	38.80	-3.12
New Territories	Kwai Tsing	7.80	26.20	-1.77
	Tsuen Wan	7.50	33.10	-1.13
	Tuen Mun	9.10	25.40	-0.16
	Yuen Long	10.50	23.70	-1.18
	North	13.30	24.90	-1.99
	Tai Po	13.20	28.00	-0.78
	Sha Tin	7.70	32.90	-1.93
	Sai Kung	8.80	34.70	0.10
	Islands	8.00	28.70	0.81
	Hong Kong Overall	8.30	32.80	-2.01
	Greater Brisbane Overall	12.00	27.60	0.38

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 & Brannigan 2007; Schipper & 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 & 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 & 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 Brisbane CBD, and the usage rate of *CityCycle* is comparably low compared to European schemes (Fishman, Washington & Haworth 2013), perhaps due to mandatory helmet laws in Australia. 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 new, dockless bike-sharing schemes in various new towns in the New Territories (Sun 2017). These scheme are modelled on similar schemes in Mainland China, which are run by mobile phone activation and payment (Phillips & 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 & 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)

Figure 12: Indicative strategic cycle network plans for Hong Kong and Brisbane (Bauhinia Foundation 2013; Queensland Department of Transport and Main Roads 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 properties are 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.

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 first before mass private 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.

Acknowledgements

References

Akbari, S & Nurul Habib, K 2014, 'Oil vulnerability in the greater Toronto area: impacts of high fuel prices on urban form and environment', *International Journal of Environmental Science and Technology*, vol. 11, no. 8, pp. 2347–2358.

Alizadeh, T 2012, 'Teleworkers' Characteristics in Live/Work Communities: Lessons from the United States and Australia', *Journal of Urban Technology*, vol. 19, no. 3, pp. 63–84.

Alwang, J, Siegel, P & Jorgensen, S 2001, 'Vulnerability: a view from different disciplines',.

Antrim, A & Barbeau, SJ 2013, 'The Many Uses of GTFS Data - Opening the door to transit and multimodal applications', in *Conference proceedings for 2013 TransITech Conference*, Phoenix Arizona.

Australian Bureau of Statistics 2011a, *Australian Statistical Geography Standard (ASGS): Volume 4 - Significant Urban Areas, Urban Centres and Localities, Section of State*,.

Australian Bureau of Statistics 2011b, '2011 Census', accessed from <http://abs.gov.au/websitedbs/censushome.nsf/home/Census>.

Australian Senate 2007, *Australia's future oil supply and alternative transport fuels: Final report*, Senate Printing Unit, Canberra.

Barter, P, Kenworthy, J & Laube, F 2003, 'Lessons from Asia on Sustainable Urban Transport', in NP Low & BJ Gleeson (eds), *Making Urban Transport Sustainable*.

Barter, PA 2014, 'A parking policy typology for clearer thinking on parking reform', *International Journal of Urban Sciences*, pp. 1–21.

Bauhinia Foundation 2013, 'How far is Hong Kong from a cycling city?', accessed June 8, 2017, from <http://www.bauhinia.org/index.php/english/analyses/73>.

Becker, BW, Brown, DJ & Scharv, PB 1976, 'Behavior of car owners during gasoline shortage', *Traffic Quarterly*, vol. 30, no. 3, pp. 469–483.

Berry, A, Jouffe, Y, Coulombel, N & Guivarch, C 2016, 'Investigating fuel poverty in the transport sector: Toward a composite indicator of vulnerability', *Energy Research & Social Science*, accessed July 4, 2016, from <http://linkinghub.elsevier.com/retrieve/pii/S2214629616300123>.

Birkmann, J 2007, 'Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications', *Environmental Hazards*, vol. 7, no. 1, pp. 20–31.

Blackburn, J 2013, *Australia's Liquid Fuel Security - A Report for NRMA Motoring and Services*,.

Brahmanand Mohanty, Bernhard Barth, Fernando Cabrera & Roman Rollnick 2012, *Sustainable Urban Energy - A sourcebook for Asia*, United Nations Human Settlements Programme (UN-HABITAT), Kenya.

Brandt, AR, Millard-Ball, A, Ganser, M & Gorelick, SM 2013, 'Peak oil demand: the role of fuel efficiency and alternative fuels in a global oil production decline.', *Environmental science & technology*, vol. 47, no. 14, pp. 8031–41.

Brisbane City Council 2007, *Climate Change and Energy Taskforce Final Report (prepared by Maunsell Australia)*, Brisbane.

Büttner, B, Wulfhorst, G, Ji, C, Crozet, Y, Mercier, A & Ovtracht, N 2013, 'The impact of sharp increases in mobility costs analysed by means of the Vulnerability Assessment', in Rio de Janeiro, Brazil.

Cao, M & Hickman, R 2017, 'Car dependence and housing affordability: An emerging social deprivation issue in London?', *Urban Studies*.

Cardona, OD 2007, *Indicators of disaster risk and risk management : program for Latin America and the Caribbean: summary report*, Inter-American Development Bank, Sustainable Development Department, Washington DC, USA.

Cervero, R & Murakami, J 2009, 'Rail and Property Development in Hong Kong: Experiences and Extensions', *Urban Studies*, vol. 46, no. 10, pp. 2019–2043.

Chambers, R 1989, 'Vulnerability, coping and policy', *IDS Bulletin*, vol. 20, no. 2, pp. 33–40.

Chao, M-C, Huang, W-H & Jou, R-C 2015, 'The asymmetric effects of gasoline prices on public transportation use in Taiwan', *Transportation Research Part D: Transport and Environment*, vol. 41, pp. 75–87.

Chauvet, M, Selody, JG, Laxton, D, Kumhof, M, Benes, J, Kamenik, O & Mursula, S 2012, *The Future of Oil: Geology Versus Technology*,.

Cherchye, L, Moesen, W, Rogge, N & Puyenbroeck, TV 2006, *Creating Composite Indicators with DEA and Robustness Analysis: the case of the Technology Achievement Index*, Joint Research Centre, European Commission, Italy.

Cherp, A, Jewell, J & Goldthau, A 2011, 'Governing global energy: Systems, transitions, complexity', *Global Policy*, vol. 2, no. 1, pp. 75–88.

Clark, PU, Shakun, JD, Marcott, SA, Mix, AC, Eby, M, Kulp, S, Levermann, A, Milne, GA, Pfister, PL, Santer, BD, Schrag, DP, Solomon, S, Stocker, TF, Strauss, BH, Weaver, AJ, Winkelmann, R, Archer, D, Bard, E, Goldner, A, Lambeck, K, Pierrehumbert, RT & Plattner, G-K 2016, 'Consequences of twenty-first-century policy for multi-millennial climate and sea-level change', *Nature Climate Change*, vol. 6, no. 4, pp. 360–369.

Cohen, B 2006, 'Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability', *Technology in Society*, vol. 28, no. 1–2, pp. 63–80.

Cohen, MJ 2012, 'The future of automobile society: a socio-technical transitions perspective', *Technology Analysis & Strategic Management*, vol. 24, no. 4, pp. 377–390.

Cui, J, Dodson, J & Hall, PV 2015, 'Planning for Urban Freight Transport: An Overview', *Transport Reviews*, vol. 35, no. 5, pp. 583–598.

Cullinane, S 2003, 'Hong Kong's low car dependence: lessons and prospects', *Journal of Transport Geography*, vol. 11, no. 1, pp. 25–35.

Cutter, SL, Carolina, S, Boruff, BJ & Shirley, WL 2003, 'Social Vulnerability to Environmental Hazards', , vol. 84, no. 2.

Dalkmann, H & Brannigan, C 2007, 'Module 5e Transport and Climate Change', in *GIZ Sourcebook for Decision-Makers in Developing Cities*.

Daniels, R & Mulley, C 2013, 'Explaining walking distance to public transport: The dominance of public transport supply', *Journal of Transport and Land Use*, vol. 6, no. 2, p. 5.

Dodson, J 2013, 'Suburbia under an Energy Transition: A Socio-technical Perspective', *Urban Studies*.

Dodson, J & Sipe, N 2005, *Oil Vulnerability in the Australian City*, Urban Research Program, Griffith University, Brisbane.

Dodson, J & Sipe, N 2007, 'Oil Vulnerability in the Australian City: Assessing Socioeconomic Risks from Higher Urban Fuel Prices', *Urban Studies*, vol. 44, no. 1, pp. 37–62.

Dodson, J & Sipe, N 2008, 'Shocking the suburbs: urban location, homeownership and oil vulnerability in the Australian city', *Housing Studies*, vol. 23, no. 3, pp. 377–401.

Fishman, E & Brennan, T 2010, 'Oil vulnerability in Melbourne', in ARRB Group Limited, Canberra, Australia.

Fishman, E, Washington, S & Haworth, N 2013, 'Bike Share: A Synthesis of the Literature', *Transport Reviews*, vol. 33, no. 2, pp. 148–165.

Fishman, E, Washington, S, Haworth, N & Watson, A 2015, 'Factors influencing bike share membership: An analysis of Melbourne and Brisbane', *Transportation Research Part A: Policy and Practice*, vol. 71, pp. 17–30.

Freudenberg, M 2003, *Composite Indicators of Country Performance*, accessed June 9, 2017, from <http://www.oecd-ilibrary.org/science-and-technology/composite-indicators-of-country-performance_405566708255>.

Geels, FW 2011, 'The multi-level perspective on sustainability transitions: Responses to seven criticisms', *Environmental Innovation and Societal Transitions*, vol. 1, no. 1, pp. 24–40.

Geels, FW 2012, 'A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies', *Journal of Transport Geography*, vol. 24, pp. 471–482.

German Society for International Cooperation 2015, *International Fuel Prices 2014*, Eschborn, Germany.

Gilbert, R & Perl, A 2007, 'Grid-connected vehicles as the core of future land-based transport systems', *Energy Policy*, vol. 35, no. 5, pp. 3053–3060.

Gilbert, R & Perl, A 2012, *Transport Revolutions: Moving People and Freight Without Oil* 2nd edn, Earthscan, London.

Glynn, J, Chiodi, A, Gargiulo, M, Deane, JP, Bazilian, M & Gallachóir, BÓ 2014, 'Energy Security Analysis: The case of constrained oil supply for Ireland', *Energy Policy*, vol. 66, pp. 312–325.

Grosjean, C, Herrera, P, Perrin, M & Poggi, P 2012, 'Assessment of world lithium resources and consequences of their geographic distribution on the expected development of the electric vehicle industry', *Renewable and Sustainable Energy Reviews*, vol. 16, no. 3, pp. 1735–1744.

Han, S-Y & Seo, Y-W 2010, 'International Comparative Analysis for Energy Efficiency of Transport Sectors in OECD Countries - Using Energy Intensity Method and Malmquist Approach',.

Heesch, KC, James, B, Washington, TL, Zuniga, K & Burke, M 2016, 'Evaluation of the Veloway 1: A natural experiment of new bicycle infrastructure in Brisbane, Australia', *Journal of Transport & Health*, vol. 3, no. 3, pp. 366–376.

Hickman, R & Banister, D 2014, *Transport, climate change and the city*, Routledge, Taylor & Francis Group, London ; New York.

Hong Kong Census and Statistics Department 2011, 'Hong Kong Population Census', accessed from <www.census2011.gov.hk/>.

Hong Kong Consumer Council 2015, 'Oil Price Data Archive', accessed September 28, 2015, from <http://www.consumer.org.hk/pricewatch/oilwatch/>.

Hong Kong Environment Bureau 2011, *Technical Guidelines for Electric Vehicle (EV) Charging-enabling for Car Parks of New Building Developments*, Hong Kong, accessed from <http://www.pland.gov.hk/pland_en/tech_doc/joint_pn/jpn1_e.pdf>.

Hong Kong Legislative Council 2012, 'LCQ2: "Bicycle friendly" policy', accessed from <http://www.info.gov.hk/gia/general/201211/21/P201211210301.htm>.

Hong Kong Legislative Council 2015, 'LCQ14: Reply by Secretary for the Environment regarding an queston by a LegCo member on oil price', accessed from <http://www.info.gov.hk/gia/general/201501/28/P201501280460.htm>.

Hong Kong Planning Department 2014, 'Chapter 8 : Internal Transport Facilities', in *Hong Kong Planning Standards and Guidelines*, Hong Kong Planning Department, Hong Kong.

Hong Kong Transport and Housing Bureau 2014, *Railway Development Strategy 2014*,.

Hudrliková, L 2013, 'Composite Indicators as a Useful Tool for International Comparison: The Europe 2020 Example', *Prague Economic Papers*, vol. 22, no. 4, pp. 459–473.

Intergovernmental Panel on Climate Change 2001, *Climate Change 2001: Synthesis Report*, Geneva, Switzerland, accessed from <https://www.ipcc.ch/ipccreports/tar/vol4/english/>.

International Energy Agency 2009, *World Energy Outlook 2009*,.

Jaccard, M, Failing, L & Berry, T 1997, 'From equipment to infrastructure : community energy management and greenhouse gas emission reduction', , vol. 25, no. 13, pp. 1065–1074.

Jung, S-Y & Yoo, K-E 2014, 'Passenger airline choice behavior for domestic short-haul travel in South Korea', *Journal of Air Transport Management*, vol. 38, pp. 43–47.

Keller, A 2012, 'Creating a Transit Supply Index'.

Kenworthy, J & Laube, F 2001, *UITP Millennium Cities Database for Sustainable Transport*, s, International Union [Association] of Public Transport [UITP], Brussels.

Kenworthy, JR, Laube, FB, Newman, P & Barter, PA 1999, *An International Sourcebook of Automobile Dependence in Cities 1960–1990*, University Press of Colarado, Boulder.

Keyes, DL 1982, 'Energy for travel: The influence of urban development patterns', *Transportation Research Part A: General*, vol. 16, no. 1, pp. 65–70.

Khan, MI 2017, 'Falling oil prices: Causes, consequences and policy implications', *Journal of Petroleum Science and Engineering*, vol. 149, pp. 409–427.

King, LC & van den Bergh, JCJM 2017, 'Worktime Reduction as a Solution to Climate Change: Five Scenarios Compared for the UK', *Ecological Economics*, vol. 132, pp. 124–134.

Kirby, A 1997, 'Global cities or city states?', *Cities*, vol. 14, no. 5, p. iii.

Klitkou, A, Bolwig, S, Hansen, T & Wessberg, N 2015, 'The role of lock-in mechanisms in transition processes: The case of energy for road transport', *Environmental Innovation and Societal Transitions*, vol. 16, pp. 22–37.

Lenzen, M 1999, 'Total requirements of energy and greenhouse gases for Australian transport', *Transportation Research Part D: Transport and Environment*, vol. 4, no. 4, pp. 265–290.

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', in *State of Australian Cities National Conference (SOAC) 2015*, Gold Coast, Qld, Australia.

Li, T, Dodson, J & Sipe, N 2015, 'Differentiating metropolitan transport disadvantage by mode: Household expenditure on private vehicle fuel and public transport fares in Brisbane, Australia', *Journal of Transport Geography*, vol. 49, pp. 16–25.

Li, T, Dodson, J & Sipe, N 2017, 'Examining household relocation pressures from rising transport and housing costs – An Australian case study', *Transport Policy*, accessed April 8, 2017, from <http://linkinghub.elsevier.com/retrieve/pii/S0967070X17301920>.

Li, T, Sipe, N & Dodson, J 2013, 'Investigating Private Motorised Travel and Vehicle Fleet Efficiency: Using New Data and Methods to Reveal Socio-Spatial Patterns in Brisbane, Australia', *Geographical Research*, vol. 51, no. 3, pp. 269–278.

Li, T, Sipe, N & Dodson, J 2017, 'Social and spatial effects of transforming the private vehicle fleet in Brisbane, Australia', *Transportation Research Part D: Transport and Environment*, vol. 51, pp. 43–52.

Linge, GJR 1965, *The delimitation of urban boundaries for statistical purposes with special reference to Australia : a report to the Commonwealth Statisticia*, Dept. of Geography, Australian National University.

Lovelace, R, Beck, SBM, Watson, M & Wild, A 2011, 'Assessing the energy implications of replacing car trips with bicycle trips in Sheffield, UK', *Energy Policy*, vol. 39, no. 4, pp. 2075–2087.

Lovelace, R & Philips, I 2014, 'The "oil vulnerability" of commuter patterns: A case study from Yorkshire and the Humber, UK', *Geoforum*, vol. 51, pp. 169–182.

Lucas, K, Mattioli, G, Verlinghieri, E & Guzman, A 2016, 'Transport poverty and its adverse social consequences', in *Proceedings of the Institution of Civil Engineers - Transport*, Thomas Telford (ICE Publishing).

Marcotullio, PJ 2003, 'Globalisation , Urban Form and Environmental Conditions in Asia-Pacific Cities', , vol. 40, no. 2, pp. 219–247.

Marshall, NA, Marshall, PA, Tamelander, J, Malleret-King, D & Cinner, JE 2010, *A Framework for Social Adaptation to Climate Change: Sustaining Tropical Coastal Communities and Industries*, IUCN (International Union for Conservation of Nature), Gland, Switzerland.

Marshall, WE & Henao, A 2015, 'The Shock Heard Round the Suburbs: Assessing the Vulnerability, Resilience, and Transportation Affordability of Higher Fuel Price Scenarios', *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2531, pp. 63–75.

Mass Transit Railways 2014, 'Sustainability Report 2014 - Rail plus Property Model', accessed June 23, 2017, from <http://www.mtr.com.hk/en/corporate/sustainability/2014rpt/finan-business.php>.

Mattioli, G, Anable, J & Vrotsou, K 2016, 'Car dependent practices: Findings from a sequence pattern mining study of UK time use data', *Transportation Research Part A: Policy and Practice*, vol. 89, pp. 56–72.

Mattioli, G, Lucas, K & Marsden, G 2016, 'The affordability of household transport costs: quantifying the incidence of car-related economic stress in Great Britain', in *48th Annual Universities' Transport Study Group*, Universities' Transport Study Group, Bristol, UK, accessed from <http://eprints.whiterose.ac.uk/92738/>.

Mayer, I, Nimal, E, Nogue, P & Sevenet, M 2014, 'The two faces of energy poverty: a case study of households' energy burden in the residential and mobility sectors at the city level', in *Transportation Research Procedia*, Munich, Germany, pp. 228–240, accessed February 4, 2016, from <http://linkinghub.elsevier.com/retrieve/pii/S2352146514003019>.

Measham, TG, Preston, BL, Smith, TF, Brooke, C, Gorddard, R, Withycombe, G & Morrison, C 2011, 'Adapting to climate change through local municipal planning: Barriers and challenges', *Mitigation and Adaptation Strategies for Global Change*, vol. 16, pp. 889–909.

Mees, P 2009, 'Density delusion? Urban form and sustainable transport in Australian, Canadian and US cities', *World transport policy and practice*, vol. 15, no. 2, pp. 29–42.

Mees, P & Dodson, J 2011, 'Public Transport Network Planning in Australia: Assessing current practice in Australia's five largest cities', accessed from <http://www.griffith.edu.au/__data/assets/pdf_file/0004/299452/urp_rp34_mees_dodson_2011.pdf>.

Mulley, C, Ma, L, Clifton, G, Yen, B & Burke, M 2016, 'Residential property value impacts of proximity to transport infrastructure: An investigation of bus rapid transit and heavy rail networks in Brisbane, Australia', *Journal of Transport Geography*, vol. 54, pp. 41–52.

New Zealand Transport Agency 2008, *Managing transport challenges when oil prices rise*,.

Newman, P, Beatley, T & Boyer, H 2009, *Resilient cities: responding to peak oil and climate change*, Island Press, Washington, DC, accessed September 1, 2016, from <http://public.eblib.com/choice/publicfullrecord.aspx?p=3317553>.

Newman, PWG & Kenworthy, JR 1989, *Cities and Automobile Dependence: A Sourcebook*, Gower Technical, Aldershot, Hants, UK; Brookfield, VT, US.

OECD 2008, *Handbook on Constructing Composite Indicators*, Organization for Economic Co-operation and Development (OECD).

Phillips, T & Yao, C 2016, 'Bike-sharing revolution aims to put China back on two wheels', *The Guardian*, accessed June 2, 2017, from <https://www.theguardian.com/world/2016/dec/28/bike-sharing-revolution-aims-to-put-china-back-on-two-wheels?CMP=share_btn_tw>.

Pitot, M, Yigitcanlar, T, Sipe, N & Evans, R 2006, 'Land Use & Public Transport Accessibility Index (LUPTAI) Tool - The development and pilot application of LUPTAI for the Gold Coast', in *ATRF06 Forum Papers*.

Preston, BL, Yuen, EJ & Westaway, RM 2011, 'Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks', *Sustainability Science*, vol. 6, no. 2, pp. 177–202.

Queensland Department of Transport and Main Roads 2011, *Queensland Cycle Strategy*, Brisbane, Australia.

Queensland Government 2007, *Queensland's Vulnerability to Rising Oil Prices Taskforce Report*, Oil Vulnerability Taskforce, Brisbane.

Queensland Government 2009, 'South East Queensland Regional Plan 2009', accessed July 10, 2015, from <http://www.dilgp.qld.gov.au/resources/plan/seq/regional-plan-2009/seq-regional-plan-2009.pdf>.

Queensland Government 2011, 'Connecting SEQ 2031 An Integrated Regional Transport Plan for South East Queensland',.

Queensland Government Statistician's Office 2015, 'Petrol: average unleaded retail price per litre, selected Queensland centres', accessed September 28, 2015, from <http://www.qgso.qld.gov.au/products/tables/petrol-avg-ulp-price-qld-centres/index.php>.

Reid, CE, O'Neill, MS, Gronlund, CJ, Brines, SJ, Brown, DG, Diez-Roux, A V & Schwartz, J 2009, 'Mapping community determinants of heat vulnerability.', *Environmental health perspectives*, vol. 117, no. 11, pp. 1730–6.

Rendall, S, Page, S & Krumdieck, S 2014, 'Voila! a new measure of oil vulnerability for cities', in *Conference Proceedings of the 1st International e-Conference on Energies*, pp. 1–22.

Riesz, J, Sotiriadis, C, Ambach, D & Donovan, S 2016, 'Quantifying the costs of a rapid transition to electric vehicles', *Applied Energy*, vol. 180, pp. 287–300.

Runting, R, Corcoran, J, Leung, A & Pullar, D 2011, 'Oil vulnerability: the effect of non-metropolitan areas and master planned estates in South East Queensland 2001–2006', *Australian Planner*, vol. 48, no. 3, pp. 117–130.

Rutherford, J & Coutard, O 2014, 'Urban Energy Transitions: Places, Processes and Politics of Socio-technical Change', *Urban Studies*, vol. 51, no. 7, pp. 1353–1377.

Schipper, L & Marie-Lilliu, C 1999, *Transportation and CO2 emissions : flexing the link - a path for the World Bank*, World Bank.

Sharpe, A & Andrews, B 2012, *An Assessment of Weighting Methodologies for Composite Indicators: The case of the Index of Economic Well-Being (IEWB)*,.

Sipe, N & Dodson, J 2013, 'Oil Vulnerability in the American City', in JL Renne & B Fields (eds), *Transport beyond oil: policy choices for a multimodal future*, Island Press, Washington DC, pp. 31–50.

Sovacool, B 2007, 'Solving the oil independence problem: Is it possible?', *Energy Policy*, vol. 35, no. 11, pp. 5505–5514.

Stein, F 2013, 'Ending America's energy insecurity: Why electric vehicles should drive the United States to energy independence', *Homeland Security Affairs Journal*, vol. 9, p. 4.

Sun, N 2017, 'Singapore operator oBike rides into Hong Kong with 1,000 shared bicycles', *South China Morning Post*, accessed from <http://www.scmp.com/news/hong-kong/health-environment/article/2111463/singapore-operator-obike-rides-hong-kong-1000>.

Sunshine Coast Regional Council 2010, *Sunshine Coast Energy Transition Plan 2010-2020*,.

Tanko, M & Burke, M 2013, 'How Did Brisbane Get it's Busways ? Findings of a study into mode-choice decision-making in Brisbane', in pp. 1–12.

Tasmanian Government 2012, *Tasmanian Oil Price Vulnerability Study*, Hobart.

Tate, E 2012, 'Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis', *Natural Hazards*, vol. 63, no. 2, pp. 325–347.

Walker, J 2012, *Human transit: how clearer thinking about public transit can enrich our communities and our lives*, Island Press, Washington, DC.

Wang, GHK & Skinner, D 1984, 'The impact of fare and gasoline price changes on monthly transit ridership: Empirical evidence from seven U.S. transit authorities', *Transportation Research Part B: Methodological*, vol. 18, no. 1, pp. 29–41.

Warren, B, Christoff, P & Green, D 2016, 'Australia's sustainable energy transition: The disjointed politics of decarbonisation', *Environmental Innovation and Societal Transitions*, accessed September 1, 2016, from <http://linkinghub.elsevier.com/retrieve/pii/S2210422416300016>.

Watts, MJ & Bohle, HG 1993, 'The space of vulnerability: the causal structure of hunger and famine', *Progress in Human Geography*, vol. 17, no. 1, pp. 43–67.

Wells, P 2012, 'Converging transport policy, industrial policy and environmental policy: The implications for localities and social equity', *Local Economy*, vol. 27, no. 7, pp. 749–763.

Zhao, SJ & Heywood, JB 2017, 'Projected pathways and environmental impact of China's electrified passenger vehicles', *Transportation Research Part D: Transport and Environment*, vol. 53, pp. 334–353.