

# Exploring the Sustainability of Public Transport in Australasia

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## Abstract

Public transport (PT) sustainability is important because all world cities need solutions to economic, congestion, environmental and social transport challenges and PT is widely seen as a sustainable way to address these. This paper empirically measures PT sustainability in five Australasian cities – Melbourne, Sydney, Brisbane, Perth and Wellington – and compares their performance to PT in international cities. Despite a widespread view that public transport is good for sustainability compared to other modes, results show that public transport in the Australasian cities studied performs poorly relative to public transport in other world cities. Overall Australasia rates last with the Middle East out of eight world regions in terms of the sustainability performance of urban PT. Results suggest that PT in Australasia has better relative performance for Environmental and Social sustainability but poorer performance on Service Effectiveness and Economic indicators. Eastern Europe is the only world region with a relatively high level of performance for all categories.

Of the Australasian cities studied, each have relatively good but also poor aspects of PT sustainability performance. Perth has the best average score but this is caused by a high rating for a single indicator (mass of pollutants emitted per hectare). For individual raw indicator scores, Perth has more 'last placed' values compared to other Australasian cities studied. Wellington, Melbourne, Brisbane and Sydney have average standardised scores which are almost the same. But this hides a very wide range of performance variation between these cities. Melbourne though placed 3<sup>rd</sup>, actually has more 'good' individual raw indicator ratings than any other Australasian city. It is let down by long public transport trip distances, long trip times and a relatively small public transport fleet size. Sydney rates last in Australasia for overall PT sustainability but has many mid-range to good individual indicator scores. However, it can improve on its pollution performance. Wellington placed 2<sup>nd</sup> in Australasia but has many mid-range scores by individual indicators. It could do more to improve public transport affordability and mode split. Brisbane was another mid-range score city and ranked 4<sup>th</sup> out of the 5 cities. It can improve performance in energy use, affordability, operating costs and system effectiveness. Implications for policy and future areas for research are discussed.

## 1. Introduction

It is a widely accepted view that public transport is a naturally 'sustainable' form of transport compared to other modes (Vuchic 1999, Litman 2009) mainly because it competes with the private car and it is the private car that generates significant economic, environmental and social problems in growing cities. Traffic congestion is considered a major problem in world cities (Cervero 1991); in Australia the economic costs of congestion were estimated at AU\$ 9.4 billion p.a. (2005) and were expected to rise to AU\$ 20.4 billion by 2020 (Bureau of Transport and Regional Economics 2007). Public transport is a far more space efficient means of carrying large volumes of travellers in cities than the car and provides considerable traffic congestion relief in growing cities (Nguyen et al. 2015). Significant social issues such as lack of affordability of car based travel in disadvantaged groups (Currie and Senbergs 2007) and segregation of communities around major traffic routes impose social costs for the

disadvantaged (Rosenbloom 2007). Although there is contemporary improvement in the environmental emission rates of automotive travel, public transport remains a far more emission effective mode per passenger (Dora and Phillips 2000) and it was transport, mainly the private car, which was the only sector of the UK economy for which environmental emissions in 2007 are higher than in 1990 (Woodcock et al. 2007).

Although public transport is strongly associated with solutions to each of these concerns it is not without its own problems. A considerable burden of growing public subsidies has been major concern of urban public transport systems for at least the last 50 years (Larwin 1999) spurring a trend towards commercialisation, contestability and outsourcing as a means to reduce costs (Currie 2016). So the sustainability of public transport in economic terms is not without its problems suggesting a need to explore all aspects of sustainability of public transport systems in greater depth.

While public transport may well be relatively more sustainable than the car, how does sustainability of one public transport system compare with others? In 2015, the United Nations created sustainable development goals for the future of humanity and transport was a major feature of these goals (United Nations 2015). Shouldn't public transport be part of these laudable objectives? If so how sustainable is public transport and which systems are more sustainable than others?

This paper is an empirical study of public transport sustainability indicators in world cities (and regions of cities) with a particular focus on the relative performance of public transport in the cities of Australia and New Zealand. The focus is the relative sustainability of public transport in one city compared to public transport in others rather than looking at how public transport compares to other modes of travel. The paper aims to understand how sustainable public transport systems are from a range of perspectives including environmental, economic, social, and a service effectiveness perspective.

The paper is structured as follows. The next section presents a review of selected literature associated with sustainability and its relevance to public transport. The methodology used to compile the sustainability indicators is then described. The results then explore the public transport sustainability performance of cities in Australasia including a disaggregate analysis of specific Australian and New Zealand cities where data was available. The paper concludes with a summary and discussion of key findings. Areas for future research are also explored.

## **2. Research Context**

This section reviews research literature regarding sustainability with particular reference to sustainability in public transport. Sustainable development has been defined as:

'Development that meets the needs of the present while safeguarding Earth's life-support system, on which the welfare of current and future generations depends.'

(Griggs et al. 2013)

This definition highlights the intergenerational dimension of sustainability although the environmental concerns associated with this are clearly significant. However, Earth's life systems also provide the basis of all economic and social systems valued by humanity. Hence, sustainability is increasingly recognised as having social, economic and environmental dimensions.

Despite this, a focus has typically been placed on economic sustainability in the transport context, with less consideration often given to social and environmental dimensions in practice. In assessing the sustainability of public transport systems, attention needs to be suitably given to all relevant dimensions of sustainability to provide a holistic understanding of social, environmental and economic performance.

Very little research has focused on the sustainability of individual public transport systems compared to other public transport systems. Miller (2014) created a framework using a

composite sustainability index technique to assess 33 public transport systems in the United States from a sustainability viewpoint. The framework is structured around 4 categories of indicators including environmental, economic, social and system effectiveness indicators. This compared relative sustainability performance of heavy and light rail systems throughout the United States. In 2016, Miller also applied these indicators to a more disaggregate case: the Broadway corridor in Vancouver, Canada, Miller et al. (2016). Miller's research includes 20 indicators and a normalisation method to ensure variables were comparable between applications. However none of these applications considered locations outside the United States; hence it is difficult to compare public transport in US cities relative to world city practice.

The authors of this paper have developed a new set of public transport sustainability indicators and applied them to global cities data recently released by the International Association for Public Transport (UITP 2001, UITP 2015). The original application of the sustainability methodology was to explore patterns of sustainability performance between cities in world regions with a focus on Asia (De Gruyter et al. 2017). The approach has also been adopted to explore empirical links between land use patterns and their influence on the sustainability of public transport in world cities (Currie and De Gruyter 2017). More recently the approach was used to explore the sustainability performance of public transport in cities with entirely 'public sector' based operations compared to cities which had introduced some degree of private sector commercialisation into public transport operations (Currie et al. 2017).

In this paper the methodology developed in the above papers is applied to public transport systems in cities in Australia and New Zealand where data was available. In doing so, this paper aims to contribute to the literature through providing an understanding of the relative sustainability performance of public transport in Australasian cities compared to global cities in other world regions.

### 3. Methodology

The methodology adopts 'Miller's framework' (Miller 2014) to assess and compare the sustainability performance of urban public transport systems. The application is on a total city basis and assesses the sustainability performance of the public transport system as a whole in those cities. This framework includes measures of economic, social, environmental and system effectiveness sustainability. The adaptation is shown in Table 1 and contains a total of 15 indicators, grouped into the same four headings used by Miller (2014) to reflect key dimensions of public transport sustainability. Indicators for each city use data collated by the International Association for Public Transport (UITP 2001, UITP 2015). The indicators related to the years 1995 and 2012; but were not available for each year for all cities. The research adopted the most recent year data (2012) if it was available or 1995 if not. In practice, high quality data measuring a wide range of aspects of sustainability performance is not available. A pragmatic approach fitting sustainability measures around available data is therefore adopted.

All indicators are 'normalised' resulting in values between 0 and 1 to allow comparison between cities on a comparable basis. Indicators have equal weight since little evidence suggests some aspects of sustainability are more important than others (Haghshenas and Vaziri 2012, Miller et al. 2016).

Table 1 shows some indicators have 'better' results if their outcome values are lower while others have better values that are higher. To aid clarity in understanding the final indicators, all indicators are adjusted such that all normalised sustainability values are better if they are higher; this requires reversing the direction of some indicators.

Data was collated using this approach for over 100 cities. In addition, average performance indicators were computed for world regions of cities including Western Europe, Eastern Europe, North America, South America, Asia, Africa, the Middle East and Australasia; the focus of the research.

Five cities are included in the analysis from Australasia: Brisbane, Melbourne, Sydney, Perth and Wellington (the selection is entirely based on available data in the UITP databases). The analysis of city results sought to firstly explore indicator results for the Australasian region as a whole with other world regions of cities. A disaggregate analysis of the sustainability data in each of the five Australasian cities was then undertaken.

**Table 1: Indicators for assessing urban public transport sustainability**

<b>ID</b>	<b>Indicator</b>	<b>Units</b>	<b>Desirability</b>
<b>A</b>	<b>ENVIRONMENTAL</b>		
A1	Quantity of energy consumed	MJ/pkm	Less is desirable
A2	Mass of total pollutants emitted (e.g. NO <sub>x</sub> , VOC, CO <sub>2</sub> )	kg/ha	Less is desirable
A3	Land area consumed by public transport facilities	% of urban area	Less is desirable
<b>B</b>	<b>SOCIAL</b>		
B1	System accessibility	pkm/capita	More is desirable
B2	Average user trip distance	km	Less is desirable
B3	Affordability	10 <sup>-4</sup> per capita GDP/trip	Less is desirable
B4	Public transport related deaths	fatalities/billion-pkm	Less is desirable
<b>C</b>	<b>ECONOMIC</b>		
C1	Annual operating cost	\$US/pkm	Less is desirable
C2	Cost recovery (proportion of costs recovered)	% of total costs	More is desirable
C3	Passenger km travelled per unit GDP	pkm/\$US	More is desirable
C4	Average time per trip	mins	Less is desirable
<b>D</b>	<b>SYSTEM EFFECTIVENESS</b>		
D1	Average occupancy rate of passenger vehicles	% of seated capacity	More is desirable
D2	Annual public transport trips per capita	trips/capita	More is desirable
D3	Public transport mode split	% of all trips	More is desirable
D4	Public transport fleet size	vehicles/million people	More is desirable

Source: De Gruyter et al. (2017)

## 4. Results

### 4.1. Aggregate Regional Analysis

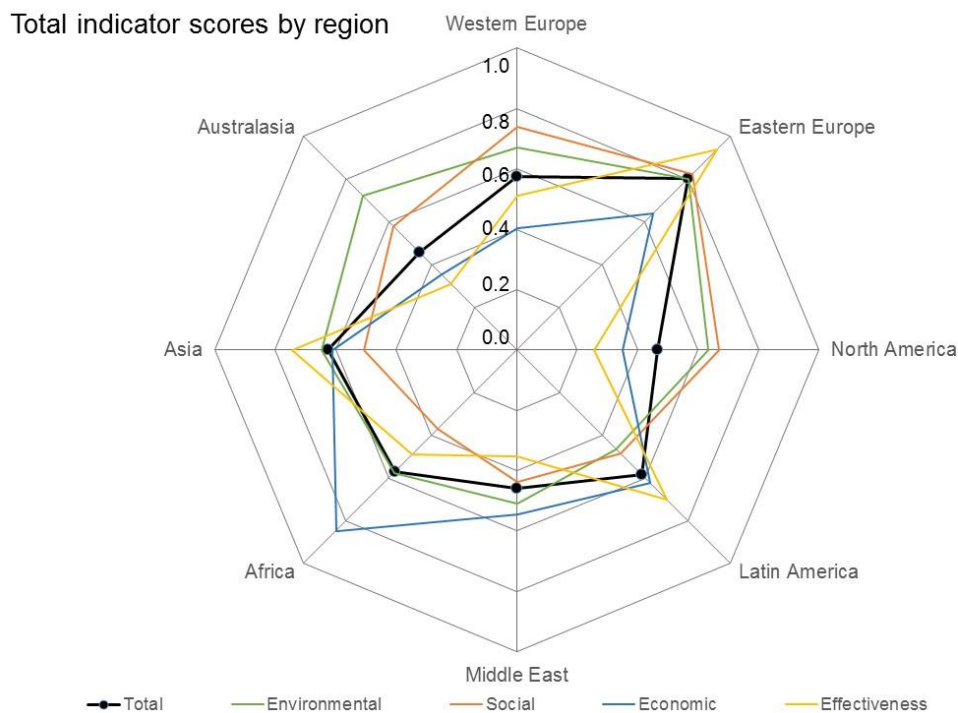
Attachment A presents a full set of the world region data for each indicator including the results of normalisation adjustments, based on the original study undertaken by the authors (De Gruyter et al. 2017). Figure 1 and Table 2 illustrates the regional normalised results using spiral plot analysis including total results and separate results for the environmental, social, economic, and effectiveness analysis.

**Table 2: Aggregate Normalised Public Transport Sustainability Indicators by World Region**

ID	Indicator category	Western Europe	Eastern Europe	North America	Latin America	Middle East	Africa	Asia	Australasia
A	Environmental	0.670	0.803	0.633	0.465	0.508	0.576	0.647	<b>0.721</b>
B	Social	0.738	0.825	0.669	0.484	0.438	0.371	0.505	<b>0.579</b>
C	Economic	0.405	0.639	0.350	0.624	0.545	0.847	0.609	<b>0.355</b>
D	System effectiveness	0.510	0.940	0.255	0.703	0.354	0.489	0.744	<b>0.309</b>
<b>Total</b>		0.575	0.801	0.466	0.584	0.458	0.570	0.625	<b>0.458</b>

Source: De Gruyter et al. (2017)<sup>1</sup>

**Figure 1: Aggregate Normalised Total and Category Public Transport Sustainability Indicators by World Region**



Note: all indicator scores are normalised to give a value of between 0 and 1; a higher score is more desirable across all indicator types

Figure 1 and Table 2 illustrate that:

- Overall Australasia has a very low score for total public transport sustainability compared to other world regions; its score is 0.458 out of 1.0; it is placed equal last with the Middle East out of eight world regions.
- Eastern Europe (0.801), Asia (0.625) and Latin America (0.584) achieve the highest aggregate normalised scores in that order.
- Australasia achieves the second highest score of all world regions on the Environmental category of PT sustainability (0.721). It achieved a mid-range rating (4<sup>th</sup>, 0.579) for the Social category of PT sustainability and the second lowest rating for the System

<sup>1</sup> Note: some of these regional average values differ from those published in De Gruyter et al (2017) since this source adopted UITP computed average regional values; we have adopted our own computed from the data directly for this analysis; values differ between the two sources but not by much.

Effectiveness (0.309) category of PT sustainability. It also has the second lowest score (0.355) of all world regions for Economic sustainability (above North America at 0.350).

- Eastern Europe has the highest rating results of all regions which is a result of high scores on all scales but particularly a first place rating for Social PT sustainability, a second place for Environmental and third place for the other categories.
- Asia is second ranked because it has a second place rating for Service Effectiveness and a fourth for Economic indicators. It is however rated only 5<sup>th</sup> out of the 8 regions for Social and Environmental indicators respectively.
- Latin America is rated third place because it has a third place rank for Service Effectiveness and Economic indicators but 6<sup>th</sup> and last place for social and environmental indicators respectively.

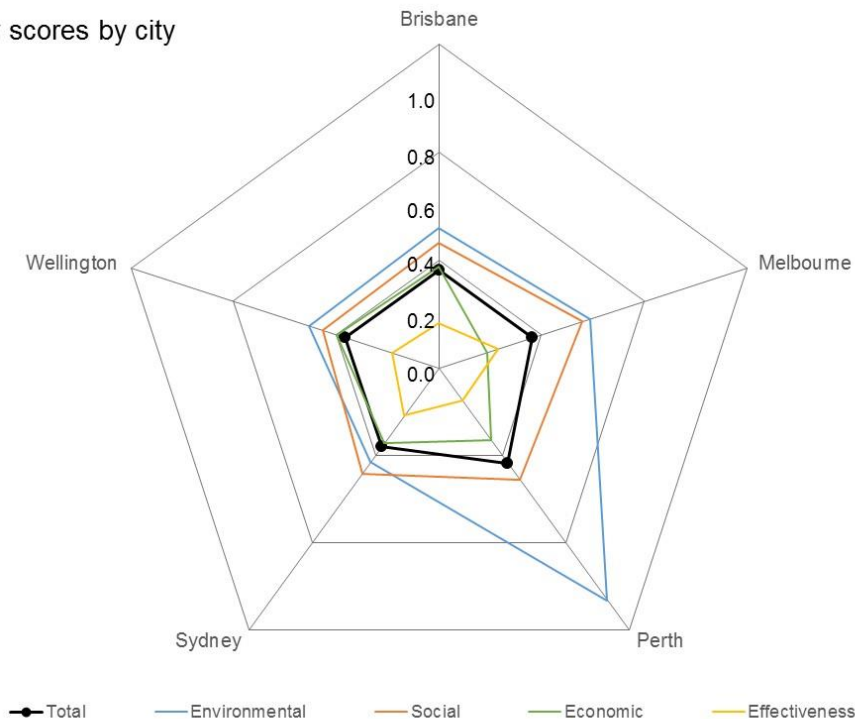
In general, the results suggest that western developed countries (Australasia, Western Europe and North America) have better performance on Environmental and Social PT sustainability but poorer performance on Service Effectiveness and Economic indicators. Asia and Latin America perform the other way round; better on Economic and Service Effectiveness and worse on Social and Economic. Eastern Europe is the only world region with a relatively high level of performance for all categories.

## 4.2. Disaggregate Results by Australasian City

Attachment B presents a full set of the data for each Australasian city studied for each indicator including the results of normalisation adjustments. Figure 2 and Table 3 illustrate the city results using spiral plot analysis including total results and separate results for the standardised environmental, social, economic, and effectiveness analysis.

**Figure 2: Disaggregate Normalised Total and Category Public Transport Sustainability Indicators by Australasian City**

Total indicator scores by city



Note: all indicator scores are normalised to give a value of between 0 and 1; a higher score is more desirable across all indicator types; some values are not shown where there are not enough component indicators to provide a reliable result

Figure 2 suggests that, in general, indicators in total and by category are quite similar between cities; the exception is the Environmental category which shows a distinct higher performance for Perth.

**Table 2: Disaggregate Normalised Total and Category Public Transport Sustainability Indicators by Australasian City**

ID	Indicator category	Brisbane	Melbourne	Perth	Sydney	Wellington
A	Environmental	0.259	0.295	0.532	0.216	0.252
B	Social	0.232	0.279	0.255	0.242	0.227
C	Economic	0.187	0.093	0.166	0.172	0.199
D	System effectiveness	0.083	0.116	0.075	0.109	0.091
	<b>Total</b>	<b>0.181</b>	<b>0.182</b>	<b>0.218</b>	<b>0.180</b>	<b>0.184</b>

The individual normalised scores in Table 2 suggest that:

- Perth has the highest standardised score (0.218) of the five Australasian cities. Sydney has the lowest (0.180) but Brisbane (0.181), Melbourne (0.182) and Wellington (0.184) have very similar standardised scores.
- Perth has the highest score as a result of a top (and very high) Environmental sustainability score (0.532) and a second top Social sustainability score (0.255). Perth is second last for Economic sustainability (0.166) and is last for System Effectiveness (0.075).
- Perth's high relative rating for Environmental sustainability score (0.532) is about twice as high as the other cities (ratings between 0.216 to 0.295). This is driven by indicator A2; mass of pollutants emitted per hectare which has a value of 1,244 kg/ha for Perth. Melbourne, the second best performance for this indicator has a value substantially higher: 2,595 kg/ha (more than double that of Perth). It is unclear exactly why this indicator should be so favourable for Perth; one possible theory is that the indicator relates to a 'per hectare' value and Perth is one of the lowest density cities in the cities studied and hence has lots of hectares to dilute environmental pollution. The value of indicator A2 has a critical outcome on Perth's standardised score. This is because Perth's performance on indicator A2 is the best for all world cities studied i.e. it has an individualised indicator value of 1.0.
- Melbourne achieves the highest standardised Social sustainability score (0.279) followed by Perth (0.255). Wellington trails the group with a score of 0.227. Melbourne achieves the highest rating as a result of best performance on public transport related deaths (B4, 5.88 fatalities/billion-pkm) second best affordability (B3, 29.14x10<sup>-4</sup> per capita GDP/trip) and second highest public transport accessibility (B1, 994 pkm/capita). Interestingly Melbourne is last placed for the Social indicator trip distance with an average travel distance which is even longer than Sydney (B2, 16.00km compared to 14.98km). Wellington's last place Social sustainability rating comes about because it has the second last rating for PT accessibility (B1, 726 pkm/capita), the worst fatalities per passenger km (B4, 6.84), and the second worst affordability (B3, 71.61x10<sup>-4</sup> per capita GDP/trip). Brisbane had the worse affordability (B3, 71.84x10<sup>-4</sup> per capita GDP/trip).
- In terms of Economic sustainability, Wellington achieves the highest standardised score (0.199) and Melbourne a substantially low last place (0.093). Wellington achieves top spot due to its best value of operating costs per pkm (C1, \$US 0.14), its second highest rating for operating cost recovery (C2, 69.5%; Sydney had top cost recovery at 80.5%), it also has mid-range values for the other economic indicators. Melbourne's last place for Economic sustainability is due to a last place in trip travel time (C4, 57 mins, substantially higher than the other cities; range 22-34mins), its second last place rating for public transport cost recovery (C2, 34.7%; Perth had last place at 30.1%) and its 3<sup>rd</sup> last place

ranking for costs per pkm (C1, \$US 0.21). Interestingly Melbourne had the second best performance for Economic indicator pkm/GDP (C3, 0.0247 behind Sydney at 0.0249).

- In terms of System Effectiveness, Melbourne has the top place (standardised score of 0.116) well ahead of the other cities (scores range from 0.075-0.109). This is because Melbourne has the top score for vehicle occupancy (D1, 20.12% just ahead of Sydney at 20.01%), highest score for trips per capita (D2, 125, well ahead of second placed Sydney at 95.0) and top score for PT mode split (D3, 7.5%; interestingly the data suggests Brisbane is second placed at 6.4% and Sydney third at 5.9%). Interestingly Melbourne is last placed of these cities for the System Effectiveness measure; fleet size (D4, 822.3 vehicles/million people). Perth is last placed in terms of System effectiveness (standardised score of 0.075) since it has the lowest trips per capita (D2, 51.1), lowest PT mode split (D3, 3.71%) and second lowest rating of fleet size (D4, 825.35 vehicles/million people) and occupancy (D1, 16.52%).

Figure 3 shows the raw sustainability indicator scores and also the standardised scores by city including shading to indicate good scores within each indicator set (green) and poor relative scores (red).

Figure 3 suggests a slightly different picture of raw indicator performance by city:

- All cities have elements of good and poor performance.
- While **Perth** might have the best standardised average score, this is highly influenced by a single outlier raw data point related to Environmental sustainability (A2). When all other raw data indicators are considered, within Australasia, Perth has more red (poor) performance by indicator than almost any other city, notably in Economic and System Effectiveness Sustainability.
- **Melbourne** though placed on a standardised score basis as third of five cities, actually has more green (good) indicator ratings than any other city. It is let down by trip distance (B2), trip time (C4) and fleet size (D4) indicators where it rates worst in Australasia.
- **Sydney** although rating last out of five in standardised score terms has a large number of indicators with neutral to green shading suggesting relatively good performance. It is let down by Environmental sustainability indicator A2 (pollutants) with an enormous 3,901.25 kg/ha value; 50% higher than that in Melbourne (the second largest city explored and probably the one which is the most comparable in the region).
- **Wellington** although placed 2<sup>nd</sup> in Australasia in standardised score terms, has a wide range of neutral, mid-range scores but not much green (good scores) and not much red (poor scores). It can do much better in affordability (B3) and mode split (D3) measures where it rates last in Australasia.
- **Brisbane** results have not figured much in the above discussion because its performance is mid-range. It rates 4<sup>th</sup> out of 5 in standardised score terms out of the five cities but has generally yellow (mid-range) scores in the individual indicator values shown in Figure 3. Nevertheless it can improve performance in all categories of indicators with red (poor) scores for energy use (A1), affordability (B3), operating costs (C1) and system effectiveness (D).



**Figure 3: PT Sustainability Indicators by Australasian City – Raw and Standardised Values**  
 (Shading highlights good performance (green) and poor performance (red) for each separate indicator)

**Raw Values by City**

ID	Indicator	Units	Basis for normalisation	Country Indicator	Year	Australia Brisbane	Australia Melbourne	Australia Perth	Australia Sydney	New Zealand Wellington
<b>A Environmental</b>										
A1	Public transport energy use per passenger km	MJ/pkm	A lower value (less) is better	A1	1995	1.27	0.72	1.25	0.71	0.65
A2	Mass of transport pollutants emitted (e.g. NO <sub>x</sub> , VOC, CO <sub>2</sub> ) per hectare	kg/ha	A lower value (less) is better	A2	1995	2,742.04	2,595.41	1,244.95	3,901.25	3,262.09
A3	Urban land area consumed by public transport facilities	%	A lower value (less) is better	A3	2012					
<b>B Social</b>										
B1	Public transport system accessibility	pkm/capita	A higher value (more) is better	B1	1995/2012	721	994	642	1,155	726
B2	Average public transport trip distance	km	A lower value (less) is better	B2	1995/2012	13.77	16.00	12.14	14.98	13.27
B3	Affordability of public transport	10 <sup>-4</sup> per capita GDP/trip	A lower value (less) is better	B3	1995	71.84	29.14	26.08	48.90	71.61
B4	Public transport related deaths per passenger km	fatalities/billion-pkm	A lower value (less) is better	B4	1995	6.37	5.88	7.74	7.24	6.84
<b>C Economic</b>										
C1	Annual public transport operating cost per passenger km	\$US/pkm	A lower value (less) is better	C1	1995	0.22	0.21	0.22	0.16	0.14
C2	Public transport cost recovery (proportion of costs recovered)	%	A higher value (more) is better	C2	1995	48.60	34.70	30.10	80.50	69.50
C3	Passenger km travelled per unit GDP	pkm/\$US	A higher value (more) is better	C3	1995/2012	0.0171	0.0247	0.0098	0.0249	0.0192
C4	Average public transport trip time	mins	A lower value (less) is better	C4	1995/2012	22	57	23	33	24
<b>D System effectiveness</b>										
D1	Average occupancy rate of public transport vehicles	%	A higher value (more) is better	D1	1995	10.94	20.12	16.52	20.01	17.14
D2	Annual public transport trips per capita	trips/capita	A higher value (more) is better	D2	1995/2012	62.00	125.00	51.10	95.00	54.75
D3	Public transport mode split	%	A higher value (more) is better	D3	1995/2012	6.40	7.50	3.71	5.90	3.76
D4	Public transport fleet size	vehicles/million people	A higher value (more) is better	D4	1995/2012	1,081.40	822.30	825.35	1,203.30	1,520.15

**Standardised Values by City**

ID	Indicator	Units	Country Indicator	Australasia	Australia Brisbane	Australia Melbourne	Australia Perth	Australia Sydney	New Zealand Wellington
<b>A Environmental</b>									
A1	Public transport energy use per passenger km	MJ/pkm	A1		0.063	0.111	0.064	0.113	0.123
A2	Mass of transport pollutants emitted (e.g. NO <sub>x</sub> , VOC, CO <sub>2</sub> ) per hectare	kg/ha	A2		0.454	0.480	1.000	0.319	0.382
A3	Urban land area consumed by public transport facilities	%	A3						
<b>B Social</b>									
B1	Public transport system accessibility	pkm/capita	B1		0.120	0.165	0.107	0.192	0.121
B2	Average public transport trip distance	km	B2		0.234	0.201	0.265	0.215	0.243
B3	Affordability of public transport	10 <sup>-4</sup> per capita GDP/trip	B3		0.091	0.224	0.251	0.134	0.091
B4	Public transport related deaths per passenger km	fatalities/billion-pkm	B4		0.485	0.526	0.399	0.427	0.452
<b>C Economic</b>									
C1	Annual public transport operating cost per passenger km	\$US/pkm	C1		0.045	0.048	0.045	0.063	0.071
C2	Public transport cost recovery (proportion of costs recovered)	%	C2		0.153	0.109	0.095	0.254	0.219
C3	Passenger km travelled per unit GDP	pkm/\$US	C3		0.004	0.006	0.003	0.006	0.005
C4	Average public transport trip time	mins	C4		0.545	0.211	0.522	0.364	0.500
<b>D System effectiveness</b>									
D1	Average occupancy rate of public transport vehicles	%	D1		0.085	0.156	0.128	0.155	0.133
D2	Annual public transport trips per capita	trips/capita	D2		0.060	0.120	0.049	0.091	0.053
D3	Public transport mode split	%	D3		0.108	0.127	0.063	0.100	0.064
D4	Public transport fleet size	vehicles/million people	D4		0.081	0.061	0.062	0.090	0.114
<b>Average Indicator Category Scores</b>									
A	Environmental		A		0.259	0.295	0.532	0.216	0.252
B	Social		B		0.232	0.279	0.255	0.242	0.227
C	Economic		C		0.187	0.093	0.166	0.172	0.199
D	System Effectiveness		D		0.083	0.116	0.075	0.109	0.091
	Total		Total		0.181	0.182	0.218	0.180	0.184

## 5. Discussion and Conclusions

Sustainability is a critical issue for public transport because all world cities need transport solutions to economic, congestion, environmental and social challenges and public transport is widely seen as a sustainable way to address these challenges relative to other modes of travel. The aim of this paper has been to empirically measure the sustainability of public transport in Australasian cities compared to other public transport systems such that Australasian cities may be compared to other world cities and regions of cities. Despite a widespread view that public transport sustainability is good compared to other modes of travel, the results show public transport in Australasian cities is not very good when compared to public transport in other cities. Overall Australasia rates last with the Middle East out of eight world regions. Results suggest that Australasia (like other western developed regions) has better performance on Environmental and Social PT sustainability but poorer performance on Service Effectiveness and Economic indicators. Eastern Europe is the only world region with a relatively high level of performance for all categories.

Of the Australasian cities studied each have relatively good but also poor aspects of performance in terms of public transport sustainability. Perth has the highest standardised average score but this is caused by a high rating for a single indicator (A2; mass of pollutants emitted per hectare) which is the highest rated performance of all world cities for this indicator. Perth has more last placed ratings for raw individual indicators than any other Australasian city. Wellington, Melbourne, Brisbane and Sydney have aggregate average standardised scores which are almost the same. But this hides a very wide range of performance variation between these cities. Melbourne though placed third of 5 cities, actually has more 'good' individual raw indicator ratings than any other Australasian city. It is let down by long trip distance (B2), long trip time (C4) and low fleet size (D4) indicators which rate worst in Australasia. Sydney, despite rating last in Australasia, has much mid-range to good individual raw indicator scores. It needs to improve in terms of pollutants (A2). Wellington placed 2nd in Australasia but has many mid-range scores by individual indicator. It should improve in terms of affordability (B3) and mode split (D3). Brisbane was another mid-range score city and ranked 4th out of the 5 cities. It can improve performance in energy use (A1), affordability (B3), operating costs (C1) and system effectiveness (D).

The results imply that there is much room to improve the sustainability performance of urban public transport in Australasian cities and that Economic sustainability and System Effectiveness sustainability are the major areas to target. However there is a complex patchwork of issues to address in each city and each differs in performance for individual indicators. Annual reporting of sustainability indicators by public transport agencies across Australasia, along with continued efforts to monitor the public transport sustainability performance of other world regions, would help in moving towards a stronger consideration of sustainability objectives in the planning and operation of public transport systems.

There is also much room for improvement in the methodologies applied in this research and data availability and quality are an important area to target. The high performance of Perth relative to indicator A2 (mass of pollutants emitted per hectare), might be a data quality problem. Certainly we can see no logical reason to suggest why Perth's pollutant performance should be significantly better than any other city. We are also surprised by Melbourne's high ratings for travel time (C4) and distance (B2); do transit users in Melbourne really travel further on average than those in Sydney?

The total average standardised values (Table 2) seem to tell a different story of city performance relative to each individual raw indicator (Figure 3). Table 2 suggests Perth has the best performance but Figure 3 shows that Melbourne has more well performing raw indicators than Perth. On reflection, we consider that the average standardised values (Table 2) tell a more balanced story since they are weighted relative to **all** the world cities studied (indeed this is the point of standardisation). The analysis of individual indicator scores in

Figure 3 has only been undertaken on a localised Australasian basis. Hence while Melbourne may well have individual raw values which are a little better than Perth it is the relative size of the differences in scores between the two cities that determines if it is an important relative to scores in all the other world cities studied. Standardisation acts to consider these differences and it is on this basis that Perth gets its best performance rating within the Australasian context. Having said this we note a word of caution since the role of indicator A2 considerably influences Perth's relative position. Perth has the lowest mass of pollutants emitted per hectare of all world cities. This gives it a normalised value of 1.000, compared with other Australasian cities which have normalised values for this indicator ranging from 0.319 to 0.480. Is this value correct? Certainly it is the value published in the UITP source.

There is much room to add new indicators since categories such as environmental performance have many more facets than just energy use (A1) and pollutants (A2) yet this is all the data that was available to this study in this region.

Overall the findings suggest much effort is needed in all areas to address the sustainability performance of public transport in Australasian cities into the future.

## 6. References

- Bureau of Transport and Regional Economics (2007). Estimating urban traffic and congestion cost trends for Australian cities - working paper 71. Canberra, Department of Transport and Regional Services.
- Cervero, R. (1991). Congestion, growth and public choices. Berkeley, California., University of California Transportation Center. **Reprint No. 51.**
- Currie, G. (2016). Deregulation, Franchising, Outsourcing and Corporatisation in Local Public Transport – International Experience. OECD Discussion Paper 2016-10. I. T. Forum. Paris, France, Prepared for the Working Group on Public Transport Market Organisation and Innovation.
- Currie, G. and C. De Gruyter (2017). Exploring links between the sustainability performance of urban public transport and land use in international cities. World Society of Transport and Land Use Research Conference. Brisbane Australia, WSTLUR.
- Currie, G. and Z. Senbergs (2007). Exploring forced car ownership in metropolitan Melbourne. 30th Australasian Transport Research Forum. Melbourne, Australia.
- Currie, G., L. Truong and C. De Gruyter (2017). Regulatory Structures and their Impact on the Sustainability Performance of Public Transport in World Cities. 15th International Conference on Competition and Ownership in Land Passenger Transport (Thredbo 15). Stockholm, Sweden.
- De Gruyter, C., G. Currie and G. Rose (2017). "Sustainability Measures of Public Transport in Cities: A World Review and Focus on the Asia/Middle East Region." Sustainability 2017, 9, 43.
- Dora, C. and M. Phillips, Eds. (2000). Transport, environment and health. WHO Regional Publications. European Series, World Health Organization (Regional Office for Europe).
- Griggs, D., M. Stafford-Smith, O. Gaffney, J. Rockström, M. Öhman, P. Shyamsundar, W. Steffen, G. Glaser, N. Kanie and I. Noble (2013). "Sustainable development goals for people and planet." Nature(495): 305-307.
- Haghshenas, H. and M. Vaziri (2012). "Urban sustainable transportation indicators for global comparison." Ecological Indicators 15: 115-121.
- Larwin, T. F. (1999). Urban Transit. Transport planning Handbook. I. o. T. Engineers, Prentice Hall. **Second Edition**: pp 427-498.
- Litman, T. (2009). Sustainable Transportation Indicators: A Recommended Research Program for Developing Sustainable Transportation Indicators and Data. 88th

- Transportation Research Board (TRB) Annual Meeting. Washington D.C., United States.
- Miller, P. (2014). Sustainability and Public Transportation: Theory and Analysis. PhD, University of Calgary.
- Miller, P., A. G. de Barros, L. Kattan and S. C. Wirasinghe (2016). "Analyzing the sustainability performance of public transit." Transportation Research Part D **44**: 177-198.
- Nguyen, P. Q. D., G. Currie and B. Young (2015). **Public Transport Congestion Relief Measurement – A New Framework and Its Impacts**. Australasian Transport Research Forum, Sydney, Australia,
- Rosenbloom, S. (2007). Lessons for Australia from the US: An American looks at transportation and social exclusion. No Way to Go - Transport and Social Disadvantage in Australian Communities. Currie Graham, Stanley Janet and S. John. Melbourne, Australia, Monash University epress. **3**.
- UITP (2001). Millenium Cities Database for Sustainable Mobility. Brussels, Belgium, International Association of Public Transport.
- UITP (2015). Mobility in Cities Database 2015. Brussels, Belgium, International Association of Public Transport.
- United Nations (2015). Transforming our World: The 2030 Agenda for Sustainable Development.
- Vuchic, V. (1999). Transportation for Livable Cities. Rutgers, The State University of New Jersey, New Brunswick, NJ, Center for Urban Policy Research.

### Attachment A: Data Results for the World Region Analysis of Public Transport Sustainability

#### Raw Indicators by Region

ID	Indicator	Units	Western Europe	Eastern Europe	North America	Latin America	Middle East	Africa	Asia	Australasia
<b>A Environmental</b>										
A1	Quantity of energy consumed	MJ/pkm	14.67	11.77	24.86	15.41	12.20	14.48	12.59	<b>14.88</b>
A2	Mass of total pollutants emitted (e.g. NO <sub>x</sub> , VOC, CO <sub>2</sub> )	kg/ha	5,298	4,543	3,905	7,368	15,044	6,591	10,115	<b>2,749</b>
A3	Land area consumed by transit facilities	m <sup>2</sup>	-	-	-	-	-	-	-	-
<b>B Social</b>										
B1	System accessibility	pkm/capita	1,524	4,218	634	2,556	815	1,924	2,615	<b>918</b>
B2	Average user trip distance	km	7.81	8.84	10.52	11.80	10.12	13.83	10.96	<b>12.90</b>
B3	Affordability	10 <sup>-4</sup> per capita GDP/trip	30.31	23.92	33.16	77.04	89.90	161.89	74.34	<b>49.51</b>
B4	Transit related deaths	fatalities/billion-pkm	9.61	18.07	7.01	38.93	18.03	34.35	26.66	<b>6.81</b>
<b>C Economic</b>										
C1	Annual operating cost	\$US/pkm	0.28	0.04	0.29	0.05	0.10	0.04	0.05	<b>0.19</b>
C2	Cost recovery (proportion of costs recovered)	%	59.2	58.2	41.9	115.6	108.2	95.6	122.6	<b>52.7</b>
C3	Passenger km travelled per unit GDP	pkm/\$US	0.03	0.11	0.01	0.13	0.06	0.16	0.13	<b>0.02</b>
C4	Average time cost per trip	mins	22	31	27	42	30	36	39	<b>28</b>
<b>D System effectiveness</b>										
D1	Average occupancy rate of passenger vehicles	%	19.77	30.35	15.62	24.10	19.58	26.53	39.97	<b>16.95</b>
D2	Annual transit trips per capita	trips/capita	193	467	58	256	106	146	255	<b>73</b>
D3	Transit mode split	%	18.72	45.82	5.31	41.82	12.11	24.95	29.31	<b>5.09</b>
D4	Transit fleet	vehicles/million people	1,230.2	1,708.2	704.7	1,850.7	1,030.2	1,604.2	1,758.4	<b>1,065.9</b>

#### Normalised indicators by Region

ID	Indicator	Basis for normalisation	Western Europe	Eastern Europe	North America	Latin America	Middle East	Africa	Asia	Australasia
<b>A Environmental</b>										
A1	Quantity of energy consumed	A lower value (less) is good	0.802	1.000	0.473	0.764	0.964	0.813	0.935	<b>0.791</b>
A2	Mass of total pollutants emitted (e.g. NO <sub>x</sub> , VOC, CO <sub>2</sub> )	A lower value (less) is good	0.519	0.605	0.704	0.373	0.183	0.417	0.272	<b>1.000</b>
A3	Land area consumed by transit facilities	A lower value (less) is good								
<b>B Social</b>										
B1	System accessibility	A higher value (more) is good	0.361	1.000	0.150	0.606	0.193	0.456	0.620	<b>0.218</b>
B2	Average user trip distance	A lower value (less) is good	1.000	0.883	0.742	0.662	0.772	0.565	0.713	<b>0.605</b>
B3	Affordability	A lower value (less) is good	0.789	1.000	0.721	0.310	0.266	0.148	0.322	<b>0.483</b>
B4	Transit related deaths	A lower value (less) is good	0.709	0.377	0.971	0.175	0.378	0.198	0.255	<b>1.000</b>
<b>C Economic</b>										
C1	Annual operating cost	A lower value (less) is good	0.143	1.000	0.138	0.800	0.387	1.000	0.817	<b>0.211</b>
C2	Cost recovery (proportion of costs recovered)	A higher value (more) is good	0.483	0.475	0.342	0.943	0.883	0.780	1.000	<b>0.430</b>
C3	Passenger km travelled per unit GDP	A higher value (more) is good	0.216	0.685	0.067	0.799	0.353	1.000	0.775	<b>0.117</b>
C4	Average time cost per trip	A lower value (less) is good	1.000	0.708	0.802	0.514	0.728	0.605	0.558	<b>0.782</b>
<b>D System effectiveness</b>										
D1	Average occupancy rate of passenger vehicles	A higher value (more) is good	0.495	0.759	0.391	0.603	0.490	0.664	1.000	<b>0.424</b>
D2	Annual transit trips per capita	A higher value (more) is good	0.413	1.000	0.124	0.548	0.227	0.313	0.545	<b>0.156</b>
D3	Transit mode split	A higher value (more) is good	0.409	1.000	0.116	0.913	0.264	0.545	0.640	<b>0.111</b>
D4	Transit fleet	A higher value (more) is good	0.665	0.923	0.381	1.000	0.557	0.867	0.950	<b>0.576</b>

#### ID Indicator category

A	Environmental	0.661	0.803	0.589	0.568	0.574	0.615	0.603	<b>0.895</b>
B	Social	0.715	0.815	0.646	0.438	0.402	0.342	0.477	<b>0.577</b>
C	Economic	0.460	0.717	0.337	0.764	0.588	0.846	0.788	<b>0.385</b>
D	System effectiveness	0.495	0.921	0.253	0.766	0.385	0.597	0.784	<b>0.317</b>
<b>Total</b>		<b>0.572</b>	<b>0.815</b>	<b>0.437</b>	<b>0.644</b>	<b>0.475</b>	<b>0.598</b>	<b>0.672</b>	<b>0.493</b>

Source: De Gruyter et al. (2017)

**Attachment B: Data Results for the Australasian City Analysis of Public Transport Sustainability**

**Raw Values by City**

ID	Indicator	Units	Basis for normalisation	Country Indicator	Year	Australia Brisbane	Australia Melbourne	Australia Perth	Australia Sydney	New Zealand Wellington
<b>A Environmental</b>										
A1	Public transport energy use per passenger km	MJ/pkm	A lower value (less) is better	A1	1995	1.27	0.72	1.25	0.71	0.65
A2	Mass of transport pollutants emitted (e.g. NO <sub>x</sub> , VOC, CO <sub>2</sub> ) per hectare	kg/ha	A lower value (less) is better	A2	1995	2,742.04	2,595.41	1,244.95	3,901.25	3,262.09
A3	Urban land area consumed by public transport facilities	%	A lower value (less) is better	A3	2012					
<b>B Social</b>										
B1	Public transport system accessibility	pkm/capita	A higher value (more) is better	B1	1995/2012	721	994	642	1,155	726
B2	Average public transport trip distance	km	A lower value (less) is better	B2	1995/2012	13.77	16.00	12.14	14.98	13.27
B3	Affordability of public transport	10 <sup>-4</sup> per capita GDP/trip	A lower value (less) is better	B3	1995	71.84	29.14	26.08	48.90	71.61
B4	Public transport related deaths per passenger km	fatalities/billion-pkm	A lower value (less) is better	B4	1995	6.37	5.88	7.74	7.24	6.84
<b>C Economic</b>										
C1	Annual public transport operating cost per passenger km	\$/US/pkm	A lower value (less) is better	C1	1995	0.22	0.21	0.22	0.16	0.14
C2	Public transport cost recovery (proportion of costs recovered)	%	A higher value (more) is better	C2	1995	48.60	34.70	30.10	80.50	69.50
C3	Passenger km travelled per unit GDP	pkm/\$US	A higher value (more) is better	C3	1995/2012	0.0171	0.0247	0.0098	0.0249	0.0192
C4	Average public transport trip time	mins	A lower value (less) is better	C4	1995/2012	22	57	23	33	24
<b>D System effectiveness</b>										
D1	Average occupancy rate of public transport vehicles	%	A higher value (more) is better	D1	1995	10.94	20.12	16.52	20.01	17.14
D2	Annual public transport trips per capita	trips/capita	A higher value (more) is better	D2	1995/2012	62.00	125.00	51.10	95.00	54.75
D3	Public transport mode split	%	A higher value (more) is better	D3	1995/2012	6.40	7.50	3.71	5.90	3.76
D4	Public transport fleet size	vehicles/million people	A higher value (more) is better	D4	1995/2012	1,081.40	822.30	825.35	1,203.30	1,520.15

**Standardised Values by City**

ID	Indicator	Units	Country Indicator	Australasia	Australia Brisbane	Australia Melbourne	Australia Perth	Australia Sydney	New Zealand Wellington
<b>A Environmental</b>									
A1	Public transport energy use per passenger km	MJ/pkm	A1		0.063	0.111	0.064	0.113	0.123
A2	Mass of transport pollutants emitted (e.g. NO <sub>x</sub> , VOC, CO <sub>2</sub> ) per hectare	kg/ha	A2		0.454	0.480	1.000	0.319	0.382
A3	Urban land area consumed by public transport facilities	%	A3						
<b>B Social</b>									
B1	Public transport system accessibility	pkm/capita	B1		0.120	0.165	0.107	0.192	0.121
B2	Average public transport trip distance	km	B2		0.234	0.201	0.265	0.215	0.243
B3	Affordability of public transport	10 <sup>-4</sup> per capita GDP/trip	B3		0.091	0.224	0.251	0.134	0.091
B4	Public transport related deaths per passenger km	fatalities/billion-pkm	B4		0.485	0.526	0.399	0.427	0.452
<b>C Economic</b>									
C1	Annual public transport operating cost per passenger km	\$/US/pkm	C1		0.045	0.048	0.045	0.063	0.071
C2	Public transport cost recovery (proportion of costs recovered)	%	C2		0.153	0.109	0.095	0.254	0.219
C3	Passenger km travelled per unit GDP	pkm/\$US	C3		0.004	0.006	0.003	0.006	0.005
C4	Average public transport trip time	mins	C4		0.545	0.211	0.522	0.364	0.500
<b>D System effectiveness</b>									
D1	Average occupancy rate of public transport vehicles	%	D1		0.085	0.156	0.128	0.155	0.133
D2	Annual public transport trips per capita	trips/capita	D2		0.060	0.120	0.049	0.091	0.053
D3	Public transport mode split	%	D3		0.108	0.127	0.063	0.100	0.064
D4	Public transport fleet size	vehicles/million people	D4		0.081	0.061	0.062	0.090	0.114
<b>Average Indicator Category Scores</b>									
A	Environmental		A		0.259	0.295	0.532	0.216	0.252
B	Social		B		0.232	0.279	0.255	0.242	0.227
C	Economic		C		0.187	0.093	0.166	0.172	0.199
D	System Effectiveness		D		0.083	0.116	0.075	0.109	0.091
			Total		0.181	0.182	0.218	0.180	0.184