Transport Energy Use and Greenhouse Gases in Urban Passenger Transport Systems: A Study of 84 Global Cities

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The transport sector will be very hard hit by the "big rollover" in world oil production due to occur within the next 10 years. Urban transport in particular is almost entirely dependent upon oil, and will take many years to shift to other energy sources. Most cities will be particularly vulnerable during the transition to a post-petroleum world. Likewise, the growing focus on global warming and greenhouse issues places additional pressure on urban transport to reduce its CO_2 output. This paper provides a review of transport, urban form, energy use and CO_2 emissions patterns in an international sample of 84 cities in the USA, Australia, Canada, Western Europe, high income Asia, Eastern Europe, the Middle East, Africa, low income Asia, Latin America and China. This overview concentrates on factors such as urban density, transport infrastructure and car, public transport and non-motorised mode use, which help us to better understand the different levels of per capita passenger transport energy use and CO_2 emissions in different cities. Patterns of energy consumption, modal energy efficiency and CO_2 emissions in private and public transport in the different groups of cities are examined. Automobile cities such as those in the USA use extraordinary quantities of energy in urban transport. An average US urban dweller uses about 24 times more energy annually in private transport as a Chinese urban resident. Public transport energy use per capita represents a fraction of that used in private transport in all cities, with rail being the most energy-efficient mode. CO_2 emissions from passenger transport follow a similar pattern. For example, Atlanta produces105 times more CO_2 per capita than Ho Chi Minh City. Some policy recommendations are outlined to reduce urban passenger transport energy use and greenhouse gases and provide other positive outcomes in terms of sustainability and livability in cities.

Key Words: transport energy and greenhouse, urban/transport planning, policy

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1. INTRODUCTION

Cities everywhere are concerned about growing automobile dependence. Two of the factors that are increasingly important to consider are the energy and greenhouse implications of automobile dependence in cities. This paper provides a global view of these issues. It examines not only the patterns of automobile dependence, transport energy use and CO_2 emissions across a global sample of some 84 cities in nearly all regions of the world, but also some underlying reasons for these patterns. The discussion points to a series of policy implications, which are briefly discussed. The paper commences with a brief description of the methodology, data sources and cities covered by the study. Results are then presented for a wide range of transport and urban form characteristics of cities, summarised by different regions in the world and divided according to high and low income areas. Data covered include urban form and wealth, vehicle ownership, private and public transport infrastructure and usage, public transport service and modal split. A comprehensive set of transport energy use and efficiency data are presented for private and public transport along with the resulting CO_2 emissions. All relevant data are set out in tables on the basis of averages for eleven world regions. Some overall conclusions and perspectives are drawn.

2. METHODOLOGY AND DATA SOURCES

This paper brings together a number of factors, which help us to characterise the transport, urban form, energy use and transport greenhouse gas emissions of cities. The data are drawn from the **Millennium Cities Database for Sustainable Transport** compiled over 3 years by Kenworthy and Laube (2001) for the International Union (Association) of Public Transport (UITP) in Brussels. The database provides data on 100 cities on all continents. Data summarised here represent regional averages from 84 of these fully completed cities in the USA, Australia and New Zealand, Canada, Western Europe, Asia (high and low income areas), Eastern Europe, the Middle East, Latin America, Africa and China. Table 1 contains a list of the cities in the database.

The database contains data on 69 primary variables, which depending on the city and the administrative complexity and multi-modality of its public transport system, can mean up to 175 primary data entries. The methodology of data collection for all the factors was strictly controlled by agreed upon definitions contained in a technical booklet of over 100 pages and data were carefully checked and verified by three parties before being accepted into the database. A detailed discussion of methodology is not possible in this paper.

From this complex range of primary factors, some 230 standardised variables have been calculated. Cities can thus be compared across the areas of urban form, private and public transport performance, overall mobility and modal split, private and public transport infrastructure, the economics of urban transport (operating and investment costs, revenues), passenger transport energy use and environmental factors, including CO_2 emissions. For this overview, which is focussed on energy and greenhouse in cities, only a selection of salient features is chosen for comment. Tables 2 to 7 provide these data summarised according to the 11 regions shown in Table 1, divided into higher and lower income parts of the world.[1] The data are

[1] The key to regional abbreviations used in Tables 2 to 7 is as follows. The specific cities comprising the regional averages are found in Table 1.

HIGHER INCOME

USA US cities
ANZ Australia/New Zealand cities
CAN Canadian cities
WEU Western European cities
HIA High income Asian

for the year 1995. Data collection on these cities commenced in 1998 and was only completed at the end of 2000. At this point, data for 1995 provides the latest perspective one can reasonably expect for a study of this magnitude.

The following discussion summarises the results of how the eleven regions of the world compare to each other on factors related to closely passenger transport energy use and consequently, CO_2 emissions from passenger transport in cities.

3. CHARACTERISTICS OF URBAN TRANSPORT SYSTEMS

3.1 Urban Transport and The Wealth of Cities

Rising wealth is a factor that is nearly always associated with increasing energy use and motorisation, so a brief examination of wealth patterns in cities is provided here, especially in relation to transport energy use. The relative income or wealth of metropolitan regions in this paper is measured by the Gross Domestic (or Regional) Product (GDP) per capita in US dollars of the actual functional urban region, not the state, province or country in which the city resides (Tables 2 and 5). This factor is the basis for the split in the sample of cities between higher and lower income regions. The higher income cities have average GDPs between $US 20,000 and $US 32,000, while the lower income metro regions range from $US 2,400 to $US 6,000. As will be seen later from the patterns of private and public transport, wealth alone does not provide a consistent or satisfactory explanation of transport patterns in cities. This is despite claims by a number of commentators that increasing wealth automatically tends towards higher auto dependence (Lave, 1992; Kirwan, 1992; Gomez-Ibañez, 1991). Rather, the data point towards deeper underlying policy and physical differences between cities in the different regions.

Likewise, in the case of transport energy use, within the higher income cities there is no significant statistical correlation between per capita private transport energy use and metropolitan GDP per capita. This is because within these cities there is no significant relationship between the level of wealth and the use of private transport, which is the driver of energy use. Reasons for this perhaps counter-intuitive result will become clearer in later discussions.

LOWER INCOME

EEU Eastern European cities
MEA Middle Eastern cities
LAM Latin American cities
AFR African cities
LIA Low income Asian cities
CHN Chinese cities

3.2 Private Transport

3.2.1 Car ownership

Globally there is an enormous variation in the magnitude of urban vehicle ownership and use. Clearly, North American and Australian/New Zealand (ANZ) cities lead the world in car ownership with over 500 cars per 1000 people (US cities nearly 600). Western European cities are, however, closing on 'new world' cities with 414 cars per 1000, while Eastern European car ownership is more moderate at 332, though it is rising rapidly. All other groups of cities average between only 100 and 200 cars per 1000 people, except for the Chinese cities which in 1995 had a mere 26 cars per 1000 people, though this is growing at an enormous rate (Tables 2 and 5).

Car ownership is always associated with wealth in the literature, so that a useful way of looking at these data is to express car ownership as a factor of wealth (ie cars owned per $1000 of GDP). Here we see that that the ANZ and Canadian cities are clearly the leaders in the higher income cities (25 to 30 cars per $1000GDP), while US cities are less at 19. Western European and prosperous Asian cities have only a fraction of the cars relative to their wealth (13 and 6 respectively). What is of major concern in lower income regions is the much higher level of car ownership compared to their low-income status. Eastern European cities lead the race with 56 cars per $1000GDP, but African and Latin American cities are not so far behind with 48 and 41 respectively. Less prosperous Asian cities already have a rate of car ownership relative to wealth that is virtually equal to cities in Australia/New Zealand. Chinese cities, despite an average GDP of only $2,400, have almost the same rate of car ownership per dollar of GDP as Western European cities (11 compared to 13), despite the latter cities having an average GDP per capita of $32,000.

3.2.2 Motor cycle ownership

Motor cycle ownership is relatively insignificant in all regions (between 5 and 30 motor cycles per 1000 people), except in the Asian cities (Tables 2 and 5). In the high and low-income Asian cities, including China, motor cycles average between 55 and 127 per 1000 people, and they form a significant part of the transport system. The extraordinary take up of motor cycles in low income Asian cities and in urban China is seen in the fact that they have between 23 and 34 motor cycles per $1000GDP, compared to an average across all other regions of just 2. Motor cycles are the most manoeuvrable motorised mode for avoiding traffic queues and the most energy-efficient and affordable form of motorised private transport for moderate-income people. As well, however, they are a major cause of air pollution, noise, traffic danger and transport deaths in these cities.

3.2.3 Car usage

Car usage in world cities follows a more extreme pattern than mere ownership, indicating that whilst cars may be owned to a similar degree in different regions, the need to use them varies dramatically (Tables 2 and 5). This in turn relates to urban form factors and the viability of other modes for various trip purposes. US cities require over 18,000 car passenger kms per capita to meet the essential access needs and discretionary travel of their inhabitants. By contrast, their high-income counterparts in Europe and Asia require only between 20% and 63% of that level of use. In the lower income regions, car passenger kms per capita range from a mere 814 (4% of the US figure) in Chinese cities, up to 3,300 in Middle Eastern cities (18% of the US figure).

In the same way as car ownership, we can normalise these data according to wealth to get a better idea of how the cities compare relative to their incomes. In the case of car usage the US cities and ANZ cities are the leaders with 578 and 576 car passenger kms per $1000GDP, with Canadian cities some way behind at 415. But again, the Western European and the prosperous Asian cities distinguish themselves in their low levels of private car mobility relative to wealth.

The concern again arises with respect to lower income cities where the rates of private car mobility per unit of wealth are comparatively high. African cities have some 940 car passenger kms per $1000GDP, which is close to double the US and ANZ level. This effect seems to come from the South African cities where two clearly distinct transport systems exist side-by-side (the sizeable automobile-based system for high income people and the informal, public transport and walking-based systems for the vast majority of poorer residents). Latin American and Middle Eastern cities are virtually identical to the US and ANZ cities in private mobility relative to wealth (580 and 595 respectively). Already, low-income Asian cities and Chinese cities far exceed their wealthy Asian neighbours and even Western European cities in this factor (494 and 344 car passenger km per $1000GDP compared to 193 and 114).

3.2.4 Motor cycle usage

Usage of motor cycles relative to cars is comparatively small in high-income cities. Motor cycle use, as a percentage of total private passenger kms, ranges from 0.25% in the US cities up to 9% in the high-income Asian cities (Tables 2 and 5). By contrast, in low income Asian cities and Chinese cities, motor cycle mobility represents 26% of passenger kilometres, while in the other lower income regions it again is small, at between 0.7% and 3.8%. Again, if we normalise this by wealth we see the huge commitment to motor cycles in low income Asian cities and Chinese cities compared to anywhere else in the world (they average 152 motor cycle passenger km per $1000GDP, while all the other regions average a meagre 10).

Why motor cycles have burgeoned in such a dramatic way in most Asian cities and in no other parts of the world (nor in Manila where motor cycle ownership is actually about half the US level), is an interesting policy question. The low penetration of motor cycles in Manila is possibly a result of the extensive and effective jeepney system and paratransit-like motorised tricycles (Barter, 1998). The role of motor cycles in urban transport, their potential to facilitate urban sprawl by providing low cost private transport to large numbers of people, and their environmental and human impacts, are important issues to understand. This is especially so in cities like Taipei where ownership is some 200 per 1000 people and usage represents 35% of private mobility. Notwithstanding this, as far as energy-efficiency is concerned, they are the best form of private motorised mobility available.

USA	CANADA	AUST/NZ	WESTERN EUROPE	WESTERN EUROPE	HIGH INCOME ASIA
Atlanta (2.90)	Calgary (0.77)	Brisbane ((1.49)	Graz (0.24)	Athens (3.46)	Osaka (16.83)
Chicago (7.52)	Montreal (3.22)	Melbourne (3.14)	Vienna (1.59)	Milan (2.46)	Sapporo (1.76)
Denver (1.98)	Ottawa (0.97)	Perth (1.24)	Brussels (0.95)	Bologna (0.45)	Tokyo (32.34)
Houston (3.92)	Toronto (4.63)	Sydney (3.74)	Copenhagen (1.74)	Rome (2.65)	Hong Kong (6.31)
Los Angeles (9.08)	Vancouver (1.90)	Wellington (0.37)	Helsinki (0.89)	Amsterdam (0.83)	Singapore (2.99)
New York (19.23)			Lyon (1.15)	Oslo (0.92)	Taipei (5.96)
Phoenix (2.53)			Nantes (0.53)	Barcelona (2.78)	
San Diego (2.63)			Paris (11.00)	Madrid (5.18)	
S. Francisco (3.84)			Marseilles (0.80)	Stockholm (1.73)	
Washington (3.74)			Berlin (3.47)	Bern (0.30)	
			Frankfurt (0.65)	Geneva (0.40)	
			Hamburg (1.70)	Zurich (0.79)	
			Dusseldorf (0.57)	London (7.01)	
			Munich (1.32)	Manchester (2.58)	
			Ruhr (7.36)	Newcastle (1.13)	
			Stuttgart (0.59)	Glasgow (2.18)	
Av. Pop. 5.74	**Av. Pop. 2.30**	**Av. Pop. 2.00**	**continued**	**Av. Pop. 2.17**	**Av. Pop. 11.03**

EASTERN EUROPE	MIDDLE EAST	AFRICA	LATIN AMERICA	LOW INCOME ASIA	CHINA
Prague (1.21)	Tel Aviv (2.46)	Dakar (1.94)	Curitiba (2.43)	Manila (9.45)	Beijing (8.16)
Budapest (1.91)	Teheran (6.80)	Cape Town (2.90)	S. Paulo (15.56)	Bangkok (6.68)	Shanghai (9.57)
Krakow (0.74)	Riyadh (3.12)	Jo'burg (2.25)	Bogota (5.57)	Mumbai (17.07)	Guangzhou (3.85)
	Cairo (13.14)	Harare (1.43)		Chennai (6.08)	
	Tunis (1.87)			K. Lumpur (3.77)	
				Jakarta (9.16)	
				Seoul (20.58)	
				HCM City (4.81)	
Av. Pop. 1.29	**Av. Pop. 5.48**	**Av. Pop. 2.13**	**Av. Pop. 7.85**	**Av. Pop. 9.70**	**Av. Pop. 7.19**

Table 1. Cities in the Millennium Cities Database for Sustainable Transport by Region.

NOTES:
Lille, New Delhi, Turin, Lisbon, Buenos Aires, Rio de Janeiro, Brasilia, Salvador, Santiago, Mexico City, Caracas, Abidjan, Casablanca, Warsaw, Moscow, Istanbul were all included in the database, but were incomplete in their data at the end of the project and hence have been excluded from this analysis.

Population sizes are shown next to each city in millions with the average population size per city for the regional group shown at the bottom of each column.

Urban Form and Wealth		USA	ANZ	CAN	WEU	HIA
Urban density	persons/ha	14.9	15.0	26.2	54.9	150.3
Metropolitan gross domestic product per capita	USD	$31,386	$19,775	$20,825	$32,077	$31,579
Private Transport Infrastructure Indicators						
Length of freeway per person	m/ person	0.156	0.129	0.122	0.082	0.020
Parking spaces per 1000 CBD jobs		555	505	390	261	105
Length of freeway per $ of GDP	km/$1000	4.97	6.52	5.85	2.56	0.65
Public Transport Infrastructure Indicators						
Total length of reserved public transport routes per 1000 persons	m/1000 person	48.6	215.5	55.4	192.0	53.3
Total length of reserved public transport routes per urban hectare	m/ha	0.81	3.41	1.44	9.46	5.87
Ratio of segregated transit infrastructure versus expressways		0.41	2.00	0.55	3.12	3.34
Total length of reserved public transport routes per $ of GDP	km/$1000	1.55	10.90	2.66	5.99	1.69
Private Transport Supply (cars and motorcycles)						
Passenger cars per 1000 persons		587.1	575.4	529.6	413.7	210.3
Motor cycles per 1000 persons		13.1	13.4	9.5	32.0	87.7
Passenger cars per $ of GDP	cars/$1000	18.71	29.09	25.43	12.90	6.66
Motor cycles per $ of GDP	mc/$1000	0.42	0.68	0.46	1.00	2.78
Private Mobility Indicators						
Passenger car passenger kilometres per capita	p.km/person	18,155	11,387	8,645	6,202	3,614
Motor cycle passenger kilometres per capita	p.km/person	45	81	21	119	357
Passenger car passenger kilometres per $ of GDP	p.km/$1000	578.44	575.80	415.15	193.35	114.44
Motor cycle passenger kilometres per $ of GDP	p.km/$1000	1.43	4.11	1.0	3.70	11.32
Total private passenger kilometres per $ of GDP	p.km/$1000	579.86	579.91	416.14	197.05	125.76
Traffic Intensity Indicators						
Total private passenger vehicles per km of road	units/km	98.7	73.1	105.8	181.9	144.4
Total single and collective private passenger vehicles per km of road	units/km	98.9	73.3	106.1	183.1	149.6
Average road network speed	km/h	49.3	44.2	44.5	32.9	28.9

Table 2. Land use, transport infrastructure and private transport system characteristics in higher income regions, 1995.

Public Transport Supply and Service		USA	ANZ	CAN	WEU	HIA
Total public transport seat kilometres of service per capita	seat km/person	1,556.8	3,627.9	2,289.7	4,212.7	4,994.8
Total public transport seat kilometres per $ of GDP	seat km/$1000	49.60	183.46	109.95	131.33	158.17
Rail seat kilometres per capita (Tram, LRT, Metro, Sub. rail)	seat km/person	747.5	2,470.4	676.4	2,608.6	2,282.3
% of public transport seat kms on rail	%	48.0	68.1	29.5	61.9	45.7
Overall average speed of public transport	km/h	27.4	32.7	25.1	25.7	29.9
* Average speed of buses	km/h	21.7	23.3	22.0	20.2	16.2
* Average speed of metro	km/h	37.0		34.4	30.6	36.6
* Average speed of suburban rail	km/h	54.9	45.4	49.5	49.5	47.1
Ratio of public versus private transport speeds		0.58	0.75	0.57	0.79	1.04
Mode split of all trips						
* non motorised modes	%	8.1%	15.8%	10.4%	31.3%	28.5%
* motorised public modes	%	3.4%	5.1%	9.1%	19.0%	29.9%
* motorised private modes	%	88.5%	79.1%	80.5%	49.7%	41.6%
Public Transport Mobility Indicators						
Total public transport boardings per capita	bd./person	59.2	83.8	140.2	297.1	430.5
Rail boardings per capita (Tram, LRT, Metro, Sub. rail)	bd./person	21.7	42.5	44.5	162.2	238.3
Proportion of public transport boardings on rail	%	36.7%	50.7%	31.7%	54.6%	55.4%
Proportion of total motorised passenger kilometres on pub. transport	%	2.9%	7.5%	9.8%	19.0%	45.9%

Table 3 Public transport system characteristics and modal split in higher income regions, 1995.

Overall Transport Energy Indicators		USA	ANZ	CAN	WEU	HIA
Private passenger transport energy use per capita	MJ/person	60,034	29,610	32,519	15,675	9,556
Private passenger transport energy use per $ of GDP	MJ/$1000	1913	1497	1562	489	303
Public transport energy use per capita	MJ/person	809	795	1,044	1,118	1,423
Public transport energy use per $ of GDP	MJ/$1000	26	40	50	35	45
Energy use per private passenger vehicle kilometre	MJ/km	4.6	3.9	5.0	3.3	3.3
Energy use per public passenger vehicle kilometre	MJ/km	26.3	14.9	22.0	14.7	14.4
Energy use per private passenger kilometre	MJ/p.km	3.25	2.56	3.79	2.49	2.33
Energy use per public transport passenger kilometre	MJ/p.km	2.13	0.92	1.14	0.83	0.48
Overall energy use per passenger kilometre	MJ/p.km	3.20	2.43	3.52	2.17	1.40
Public Transport Energy Use per Vehicle Kilometre by Mode						
Energy use per bus vehicle kilometre	MJ/km	28.8	17.0	24.1	16.3	17.3
Energy use per tram wagon kilometre	MJ/km	19.1	10.1	12.1	13.7	7.9
Energy use per light rail wagon kilometre	MJ/km	17.1	Not app.	13.1	19.5	11.7
Energy use per metro wagon kilometre	MJ/km	25.3	Not app.	10.6	11.6	10.0
Energy use per suburban rail wagon kilometre	MJ/km	49.9	12.1	48.8	15.4	10.4
Energy use per ferry vessel kilometre	MJ/km	846.5	170.5	290.8	120.7	601.7
Public Transport Energy Use per Passenger Kilometre by Mode						
Energy use per bus passenger kilometre	MJ/p.km	2.85	1.66	1.50	1.17	0.84
Energy use per tram passenger kilometre	MJ/p.km	0.99	0.36	0.31	0.72	0.36
Energy use per light rail passenger kilometre	MJ/p.km	0.67	Not app.	0.25	0.69	0.34
Energy use per metro passenger kilometre	MJ/p.km	1.65	Not app.	0.49	0.48	0.19
Energy use per suburban rail passenger kilometre	MJ/p.km	1.39	0.53	1.31	0.96	0.24
Energy use per ferry passenger kilometre	MJ/p.km	5.41	2.49	3.62	5.66	3.64
Greenhouse Indicators						
Total passenger transport CO_2 emissions per capita	kg/person	4,405	2,226	2,422	1,269	825
Total private transport CO_2 emissions per capita	kg/person	4,322	2,107	2,348	1,133	688
Total public transport CO_2 emissions per capita	kg/person	83	119	74	134	162
Percentage of total passenger transport CO_2 emissions from public transport	%	1.9	5.3	3.1	10.6	19.7

Table 4. Transport energy use and greenhouse characteristics in higher income regions, 1995.

Notes: The energy use of electrically powered modes is based on end use or actual delivered operating energy. The CO_2 emissions calculations for electrically powered modes take account of the fuel sources for electrical energy generation (hydro, nuclear, different grades of coal, gas etc) in each country as well as electrical energy generation efficiency in each country.

Urban Form and Wealth		EEU	MEA	LAM	AFR	LIA	CHN
Urban density	persons/ha	52.9	118.8	74.7	59.9	204.1	146.2
Metropolitan gross domestic product per capita	USD	$5,951	$5,479	$4,931	$2,820	$3,753	$2,366
Private Transport Infrastructure Indicators							
Length of freeway per person	m/ person	0.031	0.053	0.003	0.018	0.015	0.003
Parking spaces per 1000 CBD jobs		75	532	90	252	127	17
Length of freeway per $ of GDP	km/$1000	5.26	9.59	0.62	6.41	3.99	1.17
Public Transport Infrastructure Indicators							
Total length of reserved public transport routes per 1000 persons	m/1000 pers	200.8	16.1	19.3	40.2	16.1	2.3
Total length of reserved public transport routes per urban hectare	m/ha	10.67	2.18	1.15	2.39	2.50	0.32
Ratio of segregated transit infrastructure versus expressways		9.11	3.54	3.36	3.16	1.33	0.77
Total length of reserved public transport routes per $ of GDP	km/$1000	33.74	2.93	3.92	14.25	4.30	0.96
Private Transport Supply (cars and motorcycles)							
Passenger cars per 1000 persons		331.9	134.2	202.3	135.1	105.4	26.1
Motor cycles per 1000 persons		20.8	19.1	14.3	5.5	127.3	55.1
Passenger cars per $ of GDP	cars/$1000	55.78	24.49	41.04	47.89	28.08	11.03
Motor cycles per $ of GDP	mc/$1000	3.50	3.49	2.91	1.96	33.90	23.30
Private Mobility Indicators							
Passenger car passenger kilometres per capita	p.km/person	2,907	3,262	2,862	2,652	1,855	814
Motor cycle passenger kilometres per capita	p.km/person	19	129	104	57	684	289
Passenger car passenger kilometres per $ of GDP	p.km/$1000	488.57	595.37	580.35	940.48	494.13	344.05
Motor cycle passenger kilometres per $ of GDP	p.km/$1000	3.13	23.57	21.17	20.09	182.20	122.34
Total private passenger kilometres per $ of GDP	p.km/$1000	491.70	618.94	601.53	960.57	676.33	466.39
Traffic Intensity Indicators							
Total private passenger vehicles per km of road	units/km	168.8	180.7	144.1	58.4	236.1	117.2
Total single and collective private passenger vehicles per km of road	units/km	170.9	197.1	146.2	60.0	249.1	131.8
Average road network speed	km/h	30.8	32.1	31.5	39.3	21.9	18.7

Table 5. Land use and private transport system characteristics in lower income regions, 1995.

Public Transport Supply and Service		EEU	MEA	LAM	AFR	LIA	CHN
Total public transport seat kilometres of service per capita	seat km/person	4,170.3	1,244.6	4,481.2	5,450.3	2,698.8	1,171.3
Total public transport seat kilometres per $ of GDP	seat km/$1000	700.80	227.16	908.78	1932.77	719.01	495.01
Rail seat kilometres per capita (Tram, LRT, Metro, Sub. rail)	seat km/person	2,478.8	125.7	316.1	1715.5	402.4	44.6
% of public transport seat kms on rail	%	59.4	10.1	7.1	31.5	14.9	3.8
Overall average speed of public transport	km/h	21.4	20.9	18.4	31.4	18.0	13.6
* Average speed of buses	km/h	19.3	18.5	17.8	25.8	16.2	12.5
* Average speed of metro	km/h	29.5		32.4		33.9	35.4
* Average speed of suburban rail	km/h	37.6	36.6	41.0	34.4	33.0	
Ratio of public versus private transport speeds		0.71	0.68	0.60	0.80	0.81	0.73
Mode split of all trips							
* non motorised modes	%	26.2%	26.6%	30.7%	41.4%	32.4%	65.0%
* motorised public modes	%	47.0%	17.6%	33.9%	26.3%	31.8%	19.0%
* motorised private modes	%	26.8%	55.9%	35.4%	32.3%	35.9%	15.9%
Public Transport Mobility Indicators							
Total public transport boardings per capita	bd./person	711.5	151.8	265.1	195.4	231.0	374.9
Rail boardings per capita (Tram, LRT, Metro, Sub. rail)	bd./person	409.0	18.3	19.2	37.2	40.2	22.8
Proportion of public transport boardings on rail	%	57.5%	12.0%	7.2%	19.0%	17.4%	6.1%
Proportion of total motorised passenger kilometres on pub. transport	%	53.0%	29.5%	48.2%	50.8%	41.0%	55.0%

Table 6 Public transport system characteristics and modal split in lower income regions, 1995.

Transport Energy Indicators		EEU	MEA	LAM	AFR	LIA	CHN
Private passenger transport energy use per capita	MJ/person	6,661	10,573	7,283	6,184	5,523	2,498
Private passenger transport energy use per $ of GDP	MJ/$1000	1,119	1,930	1,477	2,193	1,471	1,055
Public transport energy use per capita	MJ/person	1,242	599	2,158	1,522	1,112	419
Public transport energy use per $ of GDP	MJ/$1000	209	109	438	540	296	177
Energy use per private passenger vehicle kilometre	MJ/km	3.1	4.2	3.7	3.7	2.6	2.7
Energy use per public passenger vehicle kilometre	MJ/km	11.8	16.1	16.9	9.5	11.9	10.6
Energy use per private passenger kilometre	MJ/p.km	2.35	2.56	2.27	1.86	1.78	1.69
Energy use per public transport passenger kilometre	MJ/p.km	0.40	0.67	0.76	0.51	0.64	0.28
Overall energy use per passenger kilometre	MJ/p.km	1.31	1.99	1.60	1.26	1.20	0.87
Public Transport Energy Use per Vehicle Kilometre by Mode							
Energy use per bus vehicle kilometre	MJ/km	14.2	20.6	18.0	18.1	14.4	9.8
Energy use per tram wagon kilometre	MJ/km	10.5	2.9	Not app.	Not app.	Not app.	Not app.
Energy use per light rail wagon kilometre	MJ/km	19.7	14.3	Not app.	Not app.	11.7	Not app.
Energy use per metro wagon kilometre	MJ/km	10.4	Not app.	12.7	Not app.	21.3	10.5
Energy use per suburban rail wagon kilometre	MJ/km	5.2	35.8	4.7	17.5	14.7	Not app.
Energy use per ferry vessel kilometre	MJ/km	84.2	54.0	Not app.	Not app.	25.0	297.6
Public Transport Energy Use per Passenger Kilometre by Mode							
Energy use per bus passenger kilometre	MJ/p.km	0.56	0.74	0.75	0.57	0.66	0.26
Energy use per tram passenger kilometre	MJ/p.km	0.74	0.13	Not app.	Not app.	Not app.	Not app.
Energy use per light rail passenger kilometre	MJ/p.km	1.71	0.20	Not app.	Not app.	0.05	Not app.
Energy use per metro passenger kilometre	MJ/p.km	0.21	Not app.	0.19	Not app.	0.46	0.05
Energy use per suburban rail passenger kilometre	MJ/p.km	0.18	0.56	0.15	0.49	0.25	Not app.
Energy use per ferry passenger kilometre	MJ/p.km	4.87	2.32	Not app.	Not app.	2.34	4.90
Greenhouse Indicators							
Total passenger transport CO_2 emissions per capita	kg/person	694	812	678	592	509	213
Total private transport CO_2 emissions per capita	kg/person	480	761	524	443	441	180
Total public transport CO_2 emissions per capita	kg/person	214	51	154	149	96	33
Percentage of total passenger transport CO_2 emissions from public transport	%	30.8	6.2	22.7	25.2	18.8	15.5

Table 7. Transport energy use and greenhouse characteristics in lower income regions, 1995.

Notes: The energy use of electrically powered modes is based on end use or actual delivered operating energy. The CO_2 emissions calculations for electrically powered modes take account of the fuel sources for electrical energy generation (hydro, nuclear, different grades of coal, gas etc) in each country as well as electrical energy generation efficiency in each country.

3.2.5 Modal share of trips by private motorised transport

The final variable that provides insight into private transport patterns is the percentage of all daily trips (all purposes) that are catered for by private transport (Tables 3 and 6). Not surprisingly, US (89%), ANZ (79%) and Canadian cities (81%) head the list. By contrast, their wealthier counterparts in Europe and Asia have only 50% and 42% respectively of all trips by private transport. This picture strengthens in the lower income cities where private transport caters for only between 16% (Chinese cities) and 36% (Asian cities) of all trips. The exception is the Middle Eastern cities where the proportion rises to 56%.

Despite the overwhelming visual and sensory impacts of traffic and its capacity to rapidly saturate the public space of a city, private transport is a minority player, relative to public transport and non-motorised modes, in 7 out of the 11 regions in this study. Because of their size, cars and other private transport vehicles have a huge impact, even at relatively low ownership levels, in urban environments not designed for them. This is true in most rapidly developing cities in the world and, of course, it has enormous social justice and equity implications. If urban transport priorities are primarily directed towards facilitating car travel through new freeways, parking facilities and so on, then this can threaten already viable urban transport systems that operate with comparatively low car use, high energy efficiency, low greenhouse impacts and provide effective transport services to the majority of people.

3.2.6 Non-motorised mode use

The most democratic and sustainable modes of urban transport, and the oldest, are foot and bicycle. Of course, here there are few fossil fuel implications outside of the embodied energy in human food, bicycles and pedestrian and bicycle infrastructure and likewise for greenhouse gases. There is an extraordinary range in the extent to which these energy-efficient, non-polluting and egalitarian modes are still used in cities today (Tables 3 and 6). In US cities, only 8% of all trips are made by foot and bicycle. Other auto cities are a little higher (respectively, 10% and 16% in Canadian and ANZ cities). Eastern and Western European, high and low income Asian, Middle Eastern and Latin American cities, all have very similar levels of non-motorised mode use ranging from 26% to 32% of all trips. The African cities have 41% walking and cycling, due to the majority low-income populations who rely heavily on walking, while the world leader is still the Chinese city with 65%.

It would appear very sensible from a social, environmental and economic perspective, and certainly from an energy and greenhouse perspective, to prioritise the protection and use of non-motorised modes by ensuring that facilities for pedestrians and bicycles are actively promoted and not eroded by motorisation. This is especially urgent in rapidly developing cities, especially in China where their pedestrian and cycling advantage appears to be under increasing threat from policies against bicycles and the sheer scale of motorisation (de Boom, Walker and Goldup, 2001; Kenworthy and Hu, 2002; Kenworthy and Townsend, 2002).

3.3 Energy Use

3.3.1 The oil problem in transport

The level of automobile dependence in a city has large implications for resource consumption, especially energy, as well as transport externalities such as greenhouse gas production. In this new century, when the world is likely to be affected by rapidly escalating oil prices and the fallout is felt everywhere from trucking industry blockades and protests, to the traumatic effect on many household budgets of rising fuel prices, energy will be back on the policy agenda. World oil production is predicted to peak by 2010 ("the big rollover") and then to enter a phase of irreversible decline, leading to shortage and supply interruptions, rapidly rising prices and a greater concentration of oil power in the Middle East. This will have profound implications for those sectors like transport that are utterly dependent upon conventional oil and cannot restructure overnight (Campbell, 1991; Campbell and Laherrere, 1995; Fleay, 1995). The relative certainty that this will happen can be seen historically in the accuracy of M. King Hubbert's original prediction of the US oil production peak in 1970 (Hubbert's bubble) (Hubbert, 1965). He predicted in the 1950s and 60s that world oil production would peak shortly after the year 2000, which is now being confirmed by many people based on much better, comprehensive data.

3.3.2 Private transport energy use

The urban data here reveal an extraordinary imbalance in transport energy consumption (Tables 4 and 7), with US cities leading the world at over 60,000 MJ per person of energy used for cars and motor cycles. This is twice as high as their nearest rivals, the Canadian and Australian cities, and 4 to 6 times more than their biggest competitors in the global economy, the western European cities and wealthy Asian cities, such as in Japan. Even cities in the Middle East, where most oil is produced, only use 10,600 MJ per person, despite some relatively conspicuous consumption in cities such as Riyadh (25,082 MJ per person). The rapidly industrialising Chinese cities consume a mere 2,500 MJ per person in private transport, which means that a US city of 400,000 people consumes in one year, the same amount of private transport energy as a Chinese Mega-city of 10 million people.

We can also examine which cities are the most intensive in their use of transport energy relative to wealth. For every $1,000 of GDP generated by the city, we find that three groups of cities stand out as being the most intensive in transport energy consumed. These are the US and the Middle Eastern cities (1,900 MJ/$1000GDP), and the African cities (2,200), again highlighting the high consumption and private transport orientation of a wealthy minority against a backdrop of pervasive poverty in African cities. The outstanding cities are again the Western European cities and wealthy Asian cities who consume only 489 and 303 MJ/$1,000GDP respectively. All the other regions fall between these extremes with an average of 1,364 MJ/$1,000GDP.

As different countries stake out their claims on ever diminishing and more costly conventional oil, especially those who so far have not yet shared the benefits that flow from this valuable non-renewable resource, oil is likely to become a major destabilising geo-political and economic issue early in this century. Despite claims to the contrary by US, British and Australian governments, the recent conflict in Iraq probably bears at least partial testament to

this. There are likely to be big shake-ups in the transport industry, especially in relation to private transport, as a result of these global political and resource realities.

3.3.3 Public transport energy use

The use of energy in public transport systems in world cities (Tables 4 and 7) is small compared to private transport, regardless of the significance of the transport task undertaken by public transport (see later). Also, in the more significant public transport environments where rail modes are found, public transport energy use is in the form of electricity, which is often generated without oil (gas, hydro-electric, nuclear), and of course can also come from renewable sources. In the US, ANZ, Canadian, Western European and Middle Eastern cities, public transport energy use per capita does not exceed 7% of the combined private and public transport energy use (average of 4%). The biggest contribution is in Latin American cities (23%), with the other five regions averaging 17%.

3.3.4 Energy efficiency differences between private and public transport

It is also clear from the data in Tables 4 and 7 how relatively energy-inefficient private transport is compared to public transport. Energy consumed per passenger km in public transport in all cities is between one-fifth and one-third that of private transport, the only exception being in the US cities where large buses dominate public transport and attempt to pick up passengers in suburbs designed principally around the car. In US cities, public transport energy use per passenger kilometre stands at 65% that of cars. Part of the reason for this is that in US cities the public transport vehicles have the highest use of energy per vehicle kilometre of all cities (26 MJ/km, with most other regions under about 16 to 17 MJ/km, down to a low of 10 MJ/km in African cities).

Examining the overall energy efficiency of motorised transport in the world's cities (private and public transport combined), we find that the Canadian cities are the least efficient at 3.5 MJ per passenger km. This is followed closely by US cities at 3.2 MJ per passenger km. These results reflect the large private vehicles in use in North America, especially 4WD sports utility vehicles (SUVs), their low use of motor cycles and their high levels of private versus public mobility. The private vehicles in US and Canadian cities consume about 5 MJ/km, whereas most other regions are under 4 or even 3 MJ/km, despite generally worse levels of congestion in these latter areas.

By contrast to North America, ANZ cities average 2.4 MJ per passenger km for their total motorised transport system, while all the lower income regions range between 0.9 (China) and 2.0 MJ per passenger km. All these lower income cities have a more significant role for energy-efficient public transport in their overall mobility, some have high use of motor cycles and many operate fleets of mini-buses, which are relatively energy-efficient (especially with high loadings).

3.3.5 Energy use of different public transport modes

As indicated above, we can examine energy use on a per vehicle km or per passenger km basis. The former is an indication of the inherent energy use of the particular vehicle, the technology it exploits and the environment in which it operates (congestion etc). In the case of rail modes, the data are reported on a per wagon km basis, not train km. Energy use per

passenger km is an indication of the mode's efficiency in carrying people, based on the kind of loadings that the mode achieves in different cities. Tables 4 and 7 contain these data for buses, trams, light rail (LRT), metro systems, suburban rail and ferries. Not all modes are present in some regions and the averages for a particular mode are taken from the cities in the region where the mode is found. All energy data are based on end use or actual delivered operating energy. The primary energy use for electric rail modes in each city will vary according to the overall efficiency of electrical generation in each country including power station efficiencies and transmission losses. The use of primary energy in modal energy efficiencies for electrical modes would have necessitated a fuller accounting of the energy used in producing and delivering petrol, diesel and gaseous fuels if a genuine comparison were to be made.

It is difficult to discuss the energy use per vehicle kilometre for public transport modes in any detail because of the huge variety of vehicle types, sizes and ages that lie behind the averages. A few general points can be made.

• As with cars, buses in US and Canadian cities are the most energy consumptive (between 24 and 29 MJ/km, compared to an average of 16 MJ/km in all other regions and only 10 MJ/km in Chinese cities).

• Big differences can occur in vehicular energy use in suburban rail operations depending on whether diesel systems are present (these have higher energy consumption than electric systems).

• There are 29 cases where rail modes are represented in the two tables and in 24 cases the energy use per vehicle km for the rail systems is lower than that of the respective bus system in the region.

• Ferries clearly have the highest use of energy per km due to the frictional forces involved in their operation through water. However, there is a huge variation based on vessel size (eg double-deck ferries in Hong Kong, down to small long tail boats in Bangkok) and speed of operation. The average operational energy use across the nine regions where ferries exist is 277 MJ/km, but figures range from 846 in US cities to only 25 in low-income Asian cities.

More meaningful results can be obtained from energy use per passenger km because this takes into account vehicle loadings and is a measure of the success in public transport operations. It is also the only way to fairly compare public and private transport energy efficiency.

• Except for trams and light rail in Eastern European cities, rail modes use less energy than buses per passenger km in each region.

• Across all regions buses average 1.05 MJ per passenger km. This is compared to 0.52 for trams, 0.56 for LRT, 0.46 for Metro and 0.61 for suburban rail. In summary, there is, on average, not a huge difference in energy efficiency between the different rail modes, and rail systems in world cities on average use about half the energy of buses per passenger kilometre.

• Urban rail modes, taken together across regions, are on average 4.6 times less energy consuming than the average car (0.54 compared to 2.45 MJ/passenger km).

• The above averages do, however, mask some exceptional energy performance by specific rail modes in particular regions. For example, light rail in low-income Asian cities and metro systems in Chinese cities consume only 0.05 MJ/passenger. This is 57 times more efficient than an American urban bus and 76 times more efficient than a Canadian car per passenger

km. These high efficiencies are mainly due to some exceptional loading levels on these systems.
• In every region, ferries are by far the most energy consumptive public transport mode. In fact, in 6 out of the 9 regions where ferries are featured, their energy use per passenger kilometre exceeds that of private transport.

3.4 Greenhouse Gas Emissions (CO_2) from Passenger Transport

Tables 4 and 7 show the average per capita emissions of CO_2 from passenger transport in each of the regions. The data have been calculated from the detailed energy data on private and public transport in this study through standard grams of CO_2 per MJ conversion factors. For electrical end use energy in electric public transport modes in different countries, reference was made to UN energy statistics showing the different contribution of various energy sources to electricity production (ie thermal, nuclear, hydro, geothermal). The data also showed the relative contribution of different feedstock to the thermal power plants and the overall efficiency of electrical energy production in the country (http://unstats.un.org/unsd/energy/balance/default.htm referenced 13/08/03). This combination of data was used to ensure the correct multiplier for end use electrical energy and to calculate the kilograms of CO_2 from end use electrical energy consumption by each of the transit systems in each city.

The results show a similar pattern to that of private passenger transport energy use per capita because of the general dominance in most cases of energy use for private transport in cities. US cities generate an average of 4,405 kg of CO_2 per person from passenger transport, while the next highest group, the Canadian cities produce roughly half that level (2,422 kg). Australian cities are a fraction lower (2,226 kg). From there on the figures are much lower, starting with the Western European cities (1,269 kg) and followed by the high income Asian cities (825 kg). In terms of the group of lower income cities, the figures range from 812 kg in Middle Eastern cities down to a mere 213 kg in Chinese cities. In terms of regional extremes, the US cities are producing 21 times more CO_2 per capita from passenger transport than are the Chinese cities.

The other interesting factor in these tables is the proportion of per capita CO_2 that is attributable to public transport. Again not surprisingly, the US are the lowest at only 1.9%, while the Eastern European cities are the highest at 30.8% due to the fact that they have the most extensive and well-utilised public transport systems in the world. The other high income regions (ie apart from the USA) have cities where public transport contributes on average 10% to passenger transport CO_2 emissions. In the other lower income cities (ie outside Eastern Europe) the average is 18%. In most cities then, public transport is by far the minor player in CO_2 emissions due partly to its comparatively low share of trips, but also because of its greater efficiency in moving people.

There are, however, exceptions to this, as revealed in Figure 1. This shows the total per capita emissions of CO_2 from passenger transport in all 84 cities, divided into private and public transport (public transport is the top portion of the graph). The data show an extraordinary range in CO_2 emissions from a low in Ho Chi Minh City of 71 kg per capita per annum up to

Atlanta's figure of 7,455 kg per capita (a 105-fold difference). In addition, it can be seen that in a handful of cities, public transport is one half or more of total per capita CO_2 emissions, whereas the average for the entire sample of cities is 13%. Figure 2 shows this more clearly with Manila, Dakar, Bogota and Cracow all having between 51% and 78% of total CO_2 emissions from passenger transport coming from public transport.

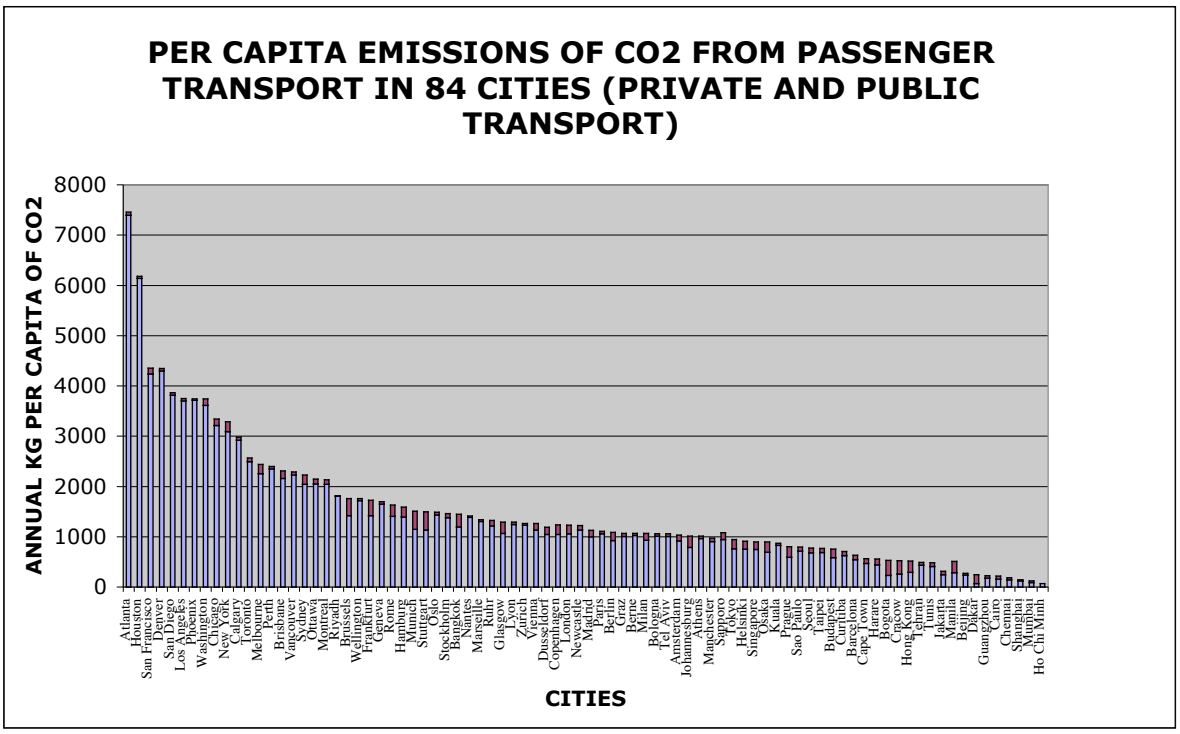

Figure 1. Per capita passenger transport emissions of CO_2 in 84 cities worldwide.

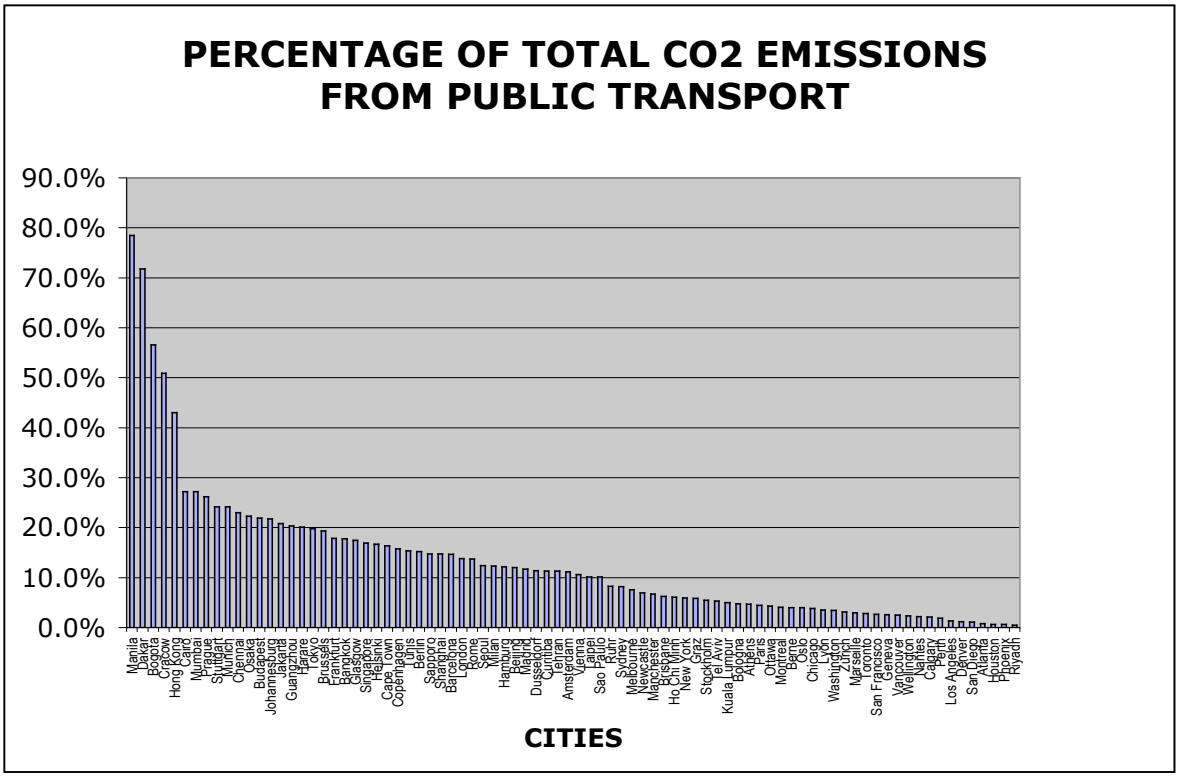

Figure 2. Percentage of total per capita passenger transport CO_2 that comes from transit.

After that, Hong Kong is the only standout city with over 40%, while the rest of the sample plunges to below 30%, ending with 0.5% in Riyadh and 0.6% in a handful of US cities.

3.5 Public Transport Patterns

After examining the broad patterns of private transport and the resulting energy use and greenhouse data, we need to better understand some of the factors that lie behind these patterns. The first important area is the extent and quality of public transport in cities.

3.5.1 Public transport service levels

Public transport service supply in annual seat kms per capita measures the amount of service provided by public transport, taking into account the different size of public transport vehicles (from mini-buses to double-deck trains). Public transport service levels are by far weakest in Chinese cities, Middle Eastern cities and US cities. Chinese cities still rely very heavily on non-motorised modes, though this is falling rapidly, and their public transport systems have consequently never been very well developed (only 4% of service is by rail). Public transport in Middle Eastern cities relies quite heavily on mini-bus systems that restrict transit supply (only 10% of transit service is rail-based). US cities, although having had some extensive transit systems earlier in the 20th century (eg Los Angeles' large rail system), have had a long history of decline in public transport. This has only begun to change a little in the last 5 years and 48% of service is now rail-based in the cities in this study. The western and eastern

European cities, high-income Asian cities, Latin American and African cities provide the highest levels of public transport service. There are qualitative differences, however, with the European and Asian cities being more rail-oriented and offering services that compete with cars in quality, reliability and speed (46% to 62% is rail-based service). By contrast, African cities have 31% of service on rail, while Latin American cities have only 7%, notwithstanding Curitiba's fine bus-way system.

If we average the seat kms per capita of service across the high and low-income regions, we find that there is overall only a small difference (3,336 in high-income regions and 3,203 in low-income regions). However, it is clear that the quality of the public transport service provided, as measured by the proportion of service that is by rail modes, is very much higher in the richer regions (51% compared to 21%). This helps to explain the data in the next section on transit usage. We also find of course that, relative to wealth (per dollar of GDP), low income cities provide a very much larger amount of transit service. High-income cities provide 126 seat kms per $1000 of GDP earned, while low income cities provide 831, or more than 6.5 times greater service levels. That these low-income cities do not appear to reap the transit usage rewards from this high service provision, is a very important point that is discussed in the following sections.

3.5.2 Public transport usage levels

There are two clear extremes in public transport use. The US cities stand out globally with the lowest rate of trips per capita on public transport (59 per annum), while the eastern European cities are clearly the world leaders with 712 trips per person per annum (12 times more). This is also reflected in the overall modal split for all trips, where US urban residents use transit for only 3% of daily trips and Eastern European city residents use transit for 47% of all trips. The other high users of public transport, either in terms of trips per capita or modal share of trips (but not always both) are high and low income Asian cities, western European cities, Latin American, African and Chinese cities. For example, Chinese cities, despite poor transit service, have high per capita usage due to captive riders (375 trips per capita), but the overall share of total trips is low (19%). This is due to very high walking and cycling (65% of total trips). African cities have only mediocre trips per capita on public transport (195 trips per capita) but the share of trips is quite high at 26% (due to the lowest overall daily trip rate of all cities).

ANZ cities, Canadian cities and Middle Eastern cities are comparatively low users of public transport in a global sense, regardless of the measure used. However, Canadian cities distinguish themselves within the most auto-orientated cities with transit use levels that are broadly speaking double those of the US and ANZ cities. This relative success of Canadian cities in public transport is discussed elsewhere (Raad and Kenworthy, 1998).

Although some low-income cities enjoy comparatively healthy public transport use for their very low level of service (eg in China), this will not be sustainable as incomes and aspirations rise. Lower income cities will need to start preparing to attract 'choice' public transport riders, not just captive riders, otherwise public transport will rapidly lose riders to cars and motor cycles. The comparative data in this study suggests that many low- income cities could be in a dangerous situation regarding their ability to resist further rapid motorisation. As incomes rise

and non-motorised transport appears less attractive, cars and motor cycles will be the only options for people unless public transport systems are increased and improved in quality and can offer alternative, competitive mobility. This will generally mean moving towards more extensive rail systems, or at least fully segregated busways. If not, transport energy use and greenhouses gases in particular will rise rapidly.

3.5.3 Importance of rail and comparative modal speeds

The data in this paper highlight the importance of urban rail systems in developing competitive public transport systems, reducing energy use and minimising greenhouse gases from transport due to their positive effect on overall public transport performance. Not only are they the most energy-efficient modes, but they are the most effective at capturing modal share from private transport. In the high income cities, only the European and Asian cities have public transport systems that capture a healthy share of the overall transport market and these are the cities where urban rail systems are most developed, especially in relation to their private transport equivalent, the urban freeway. The ratio of fully segregated transit infrastructure to urban freeways in these rail-oriented cities is over 3 compared, to 0.4 and 0.5 in US and Canadian cities and 2 in ANZ cities. In the lower income sample, by far the healthiest performing transit systems, by whatever measured used, are in the Eastern European cities where segregated transit infrastructure is some 9 times higher than urban freeways (see further discussion in next section).

It can be said that whilst there clearly are cities in the world (eg in Latin America, Africa and China), that achieve healthy public transport use with little or no rail systems, they rely mostly on poor captive riders, not choice riders, as in wealthier cities with high transit use. As incomes rise and car ownership levels grow, the public transport systems of these low-income, bus-based cities tend to get hit hardest for market share, because they cannot compete in speed or comfort with private transport. Motor cycles in particular tend to compete heavily with bus systems that are engulfed in traffic (Barter, 1998).

This is seen in the comparative operating speeds between modes. There are no regions where the average speed of bus systems exceeds 26 km/h and the overall average across the 11 regions is only 19 km/h. In Chinese cities buses operate at an average 12.5 km/h, or about the same speed as cycling. On the other hand, metro systems operate between 30 and 37 km/h (average 34 km/h). Suburban rail systems across the regions average 42.9 km/h. When these speeds are compared to general road traffic speed, which averages 34 km/h across all regions, it can be seen that only rail systems can compete.

Any city wishing to rebuild its public transport base, save energy, reduce greenhouse emissions or prevent a dramatic collapse in transit ridership as incomes rise and competition from motor cycles and automobiles sets in, needs to seriously consider some form of segregated rail system. At the very least, cities need highly effective busway systems, such as in Curitiba and São Paulo in Brazil. A strategy of ensuring competitive transit speeds appears to be integral for urban public transport in any city.

The positive greenhouse argument still applies to urban rail notwithstanding the source of electrical energy in particular cities (eg from inferior brown coal or lignite in Melbourne).

This is because the amount of automobile travel displaced by effective rail systems outweighs the negative effect of poor power station performance. Of course, it also remains possible that thermal power generation can move to less CO_2 intensive feedstocks.

3.6 Transport Infrastructure Provision

Underlying the patterns of urban transport, energy use and greenhouse emissions are significant differences in the extent and type of infrastructure for private and public transport. Different priorities in transport infrastructure facilitate different movement patterns.

3.6.1 Public transport infrastructure

In accord with the data in the previous section, Western European, high income Asian and Eastern European cities, and to a lesser extent the ANZ cities, are the only regions that have significant reserved alignments for public transport. This consists mainly of railways, but also a few physically segregated busways. All of the lower income city regions, apart from Eastern Europe, have comparatively scarce reserved public transport facilities that provide unimpeded paths for transit vehicles. Chinese cities stand out as being particularly low in this factor and in the wealthier auto regions, US cities are clearly the lowest in segregated facilities for transit, though Canadian cities are not far behind. Overall, the data again highlight that the wealthier regions generally have an edge in the provision of better quality transit systems with an average of 113 metres per 1000 persons of reserved public transport routes compared to 49 in cities in poorer regions. The only positive thing that can be said is, that relative to their city GDPs, poorer cities have more than the double the reserved transit rights-of-way of their wealthier neighbours (10.0 km versus 4.6 km per $1000 of GDP).

3.6.2 Private transport infrastructure

Urban freeways

The private transport corollary of fixed route transit is the urban freeway. US cities, without any surprise, have the highest availability of freeway per person in the world, followed by ANZ and Canadian cities with 83% and 78% as much respectively. Outside of these three regions freeway provision falls away rapidly, especially in Latin American and Chinese cities (only 2% of the US level). The other 8 regions altogether average only 0.028 metres of freeway per capita compared to 0.156 in US cities (18% of the US level).

It is not surprising that cities with the highest freeway provision also have the highest average speed of general traffic (44 to 49 km/h in US, ANZ and Canadian cities). The other cities with considerably lower freeway provision achieve only 29 km/h average road system speed. It has been understood in a systematic way since as early as 1974, how urban freeway provision is directly associated with higher car and energy use in cities (eg Watt and Ayres, 1974). The mechanism for this, in terms of longer travel distances rather than savings in time, has been explained elsewhere (eg Newman and Kenworthy, 1984, 1988, 1999).

In terms of the commitment to freeways relative to wealth, the data reveal that lower income cities have marginally higher provision of freeways per $1000 of GDP than high- income cities (4.5 km compared to 4.1 km). In fact, Eastern European, Middle Eastern and African cities exceed the US figure in kilometres of freeway per $1000 of GDP generated. It seems

clear that poorer cities are giving priority to freeway construction to perhaps an even greater extent than wealthier cities.

Congestion

Freeways and congestion issues are often linked together in discussions, especially in relation to efforts to save energy and reduce emissions. The tables provide some different measures of congestion in cities, since increasing urban traffic congestion is frequently cited as being responsible for huge wastage of energy resources and extra emissions in cities. The results in this study run directly counter to this assertion. They indicate that as congestion increases, there is less car use, more motor cycle use, more public transport use and more use of non-motorised modes. Conversely, lower congestion reflected in higher average speed of traffic, is associated with more car use, less motor cycle use, less public transport use and less use of non-motorised modes.

Overall, the results suggest that congestion acts as a brake on per capita car use. Congestion encourages greater motor cycle use, and works in favour of public transport, but only where these options offer speed advantages with respect to cars stuck in congested conditions, and where parking is limited. This is often the case in more congested high-income cities, since they commonly have urban rail systems, or less frequently, busways. The results suggest that rather than saving energy and lowering emissions, reduced congestion, reflected in higher traffic speeds, increases energy use and emissions (including greenhouse gases) through its tendency to favour cars, increase urban sprawl and travel distances, and reduce the viability of other modes. Cities should not be in any rush to reduce congestion in order to save energy or reduce greenhouse gases. Rather they should be looking to strategically improve the transit and non-motorised mode alternatives to avoid congestion.

Parking

Parking in the central business districts (CBD) of cities is another indicator of private transport infrastructure, which varies dramatically across regions. Parking supply in central areas is an important factor in modal split to public transport for trips to this most critically space-constrained section of any city. The availability of parking, much more than price, tends to determine the attractiveness of car commuting to the central city. High levels of parking will encourage the least energy-efficient trips to work, while well-loaded, radial rail systems will use the least energy for this critical trip purpose.

The highest providers of parking are the US, ANZ and, perhaps surprisingly, the Middle Eastern cities, all having over 1 parking space for every 2 jobs. It must be said, however, that the Middle Eastern cities are greatly affected by Riyadh which is a world extreme, having some 1,883 spaces for every 1000 jobs, due to its huge on-street parking supply. Teheran has only 22 spaces per 1000 jobs and Tel Aviv, the next highest after Riyadh has 467. By and large, other cities do not come close to these regions in CBD parking supply, ranging from averages of 17, 75 and 90 spaces in Chinese, Eastern European and Latin American cities respectively, up to 390 in Canadian cities.

The experience of rapidly developing low income cities with dense urban forms, such as in China, suggests that orderly urban transport development depends upon controlling the rate of

motorisation, while building public transport infrastructure to effectively balance investment in new roads and parking areas. Certainly, no city in the world, not even Los Angeles, has ever been able to supply enough roads and parking to meet demand. Compact, dense cities have particularly severe limits on how much space they can devote to cars without destroying their urban fabric and quality of life.

4. URBAN FORM

It has been widely demonstrated how important urban form is in helping to explain the macro patterns of urban transportation, especially the level of auto dependence and transport energy use (Newman and Kenworthy, 1989, 1999; Kenworthy and Laube, 1999; Cervero, 1998). Tables 2 and 5 provide data on urban density, the most significant measure of urban form that has been found in the above studies. The data show how the higher car and energy use cities, and the highest greenhouse gas producers, are low in population density, while the higher density cities have reduced car and energy use per person and lower transport greenhouse gases. Average densities range from lows of 15 per ha in the US and ANZ cities up to 150 to 200 per ha in the Asian cities, including Chinese cities. On average, the lower income cities are more than double the density of the wealthier cities (109 versus 52 persons per ha).

In the high-income cities, 82% of the variance in car passenger kms per capita and 78% of the variance in per capita private passenger transport energy use is explained by urban density. In the low-income cities, where other factors such as extreme variations in income affect the outcome, still 47% of their variation in per capita car use and 44% of the variance in per capita private passenger transport energy use, is explained by urban density.

Any city wishing to attend to issues of managing the automobile, minimizing car and energy use and reducing its greenhouse gas output must address urban form and its effects on urban transportation. The best policy response seems to be one of selective density increases and mixing of compatible land uses, especially around areas of high public transport accessibility. As well, centralisation of jobs in the CBD, but also in satellite sub-centres built at transit nodes, appears to be an effective strategy. Urban growth boundaries or green belts to minimise spread of the city, also appear to be important.

It is widely recognised today that the most effective way of building a ‘transit metropolis’ is to tightly integrate dense, mixed-use development around stops on a fixed-route transit network, thus maximising walk-up patronage and multiple trip making. This is the approach from Curitiba and Ottawa with their busways, through the urban rail systems in European cities, and in the modern Asian cities such as in Japan, Hong Kong and Singapore (Cervero, 1998). Bus or light rail feeders to the main rail system are also widely exploited.

Favourable urban form is a critical factor in creating sustainable and energy efficient and greenhouse minimising urban transport systems. Many cities in the west that are trying extremely hard to reduce their car use and increase their public transport and non-motorised mode use, are faced with trying to increase densities. Many lower income cities, especially those in Asia already have very dense and centralised patterns of urban land use, which places them in an ideal situation to minimise their future dependence on private transport and fossil

fuels. Their density makes them ideal environments for effective public transport and their mixed land uses combined with their density, means that walking and cycling will remain the most convenient mode for many trips due to short trip lengths. However, motorisation is tending to disperse urban land uses, so concerted policy attention is needed to ensure that this inherent urban form advantage does not deteriorate.

5. CONCLUSIONS

World oil production is likely to peak some time in the first decade of this century. Thereafter total production will decline and the highly oil-dependent transportation sector will have to make a series of sweeping adjustments, which will be felt acutely in cities. Likewise, the imperative to reduce greenhouse gas emissions and minimise the possibility of destructive global warming will likely be felt more acutely throughout the world. It is important to understand therefore global patterns of urban transport, how dependent different cities are on energy to run their transport systems, how they produce different levels of CO_2 emissions, and some of the underlying reasons for these patterns.

A large comparison of transport patterns in cities from around the world, demonstrates clearly some of the problems associated with automobile dependence, in particular high energy usage and CO_2 emissions. Conversely, these patterns demonstrate the energy and greenhouse gas reduction potential and other benefits of managing and reducing the role of the automobile in urban transport systems and enhancing the role of public transport and non-motorised modes. Motor cycles are also relatively energy and greenhouse-efficient modes, but they are associated with a raft of other problems such as high local smog emissions, noise and traffic danger, that their energy and greenhouse savings come with other unacceptable environmental burdens.

The level of transport energy use and greenhouse gas emissions from transport in cities can be linked directly and indirectly to a host of factors. Excluded from the significant factors is the level of wealth in cities, which is often thought to be a key driver of higher car and energy use, but which in this study has been shown not to have a significant relationship with these variables. The significant factors underlying automobile dependence and energy use include the extent and quality of the public transport system, especially the kilometres of dedicated transit right-of-way and the amount of service provided by urban rail systems. Lower income cities have a particular problem in this respect. They provide comparatively high levels of transit service, but little of it is rail. Most of it is inferior bus service that operates within general road traffic congestion, which is losing to market share to cars and motor cycles. Their level of transit use is low compared to many wealthier cities that anchor their transit systems heavily around speed-competitive rail systems.

Urban freeways and high levels of parking in the CBD are associated with higher energy use and greenhouse emissions in cities. In particular, low density sprawling, heavily zoned land use is shown to be particularly strongly associated with high transport energy use and CO_2 emissions. This is primarily because higher densities are also associated with healthy levels of transit use and high usage of non-motorised transport. US cities, followed a long way behind by Canadian and Australian cities, are the heaviest transport energy users and greenhouse gas

producers from transport in the world, while Chinese cities are the lowest (US cities are 24 times higher than Chinese cities in per capita passenger transport energy use and 21 times higher in CO_2 emissions).

Public transport energy use per capita is always only a fraction of private transport energy use, never exceeding 23% of the total passenger transport energy use in any region, regardless of the extent of service and usage. In terms of CO_2 emissions per capita, the Eastern European cities experience the highest contribution from public transport at 31%.

Transport energy use (and by implication CO_2) is of course dependent upon the modal share between private, public and non-motorised modes, but also upon the relative energy efficiency between modes. The data here show that energy consumption per passenger km is in every region significantly higher for cars than public transport. Rail modes (trams, light rail, metro and suburban rail) are in virtually every instance more energy efficient that buses in the respective regions. They also have the advantage that in most cases, except selected suburban rail systems, they operate on electric power, which can be and is generated from non-fossil fuel and renewable energy sources. Ferries are found to be the highest energy consuming modes, exceeding even that of cars in some regions.

The results point clearly to the energy and greenhouse conservation potential of compact, mixed land use cities, with extensive transit systems operating on a backbone of rail. Compact land uses can be combined with attractive environments for walking and cycling, which will save further energy and CO_2 emissions. Strict limitations on freeway construction and parking in the central area of cities will assist in creating less auto-dependent cities with lower built in energy demand and less greenhouse emissions from passenger transport. Attempting to get rid of congestion through freeway building and other means, rather than building up the non-auto modes to help people avoid congestion, will not save energy or reduce CO_2 emissions but will increase these factors in cities, and result in other negative environmental impacts.

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