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URBAN TRANSPORT IN WORLD METROPOLISES: A COMPARATIVE ANALYSIS AND KEY FEATURES OF ENERGY CONSUMPTION

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Most theoretical and empirical research on the subject of urban transport energy consumption has addressed the role of urban form and urban spatial structure (primarily population density and degree of centralisation), city size (population and/or area), the level of economic development, transport patterns, and transportation infrastructure. Our analysis encompasses a wide range of socio-economic, spatial, transport and infrastructure indicators, as well as energy efficiency and energy consumption indicators in a sample of 35 world cities, covering the period from 1960 to 2005. Comparative analysis indicates there are significant differences regarding the determinants of urban transport energy consumption, especially between the US and Australian automobile-dependent cities, on the one hand, and the wealthy Asian metropolises, on the other. Despite some recent positive trends (a decline in automobile vehicle-kilometres and reduction in urban transport energy consumption), a large number of cities in the developed world still rely predominantly on cars, while sustainable modes of urban transport play an almost negligible role. Due to trends of urbanization, demographic growth and a rise in living standards, the main focus of attention has shifted to metropolises in developing countries. In the long run, the urban form itself is particularly significant, not only because it critically influences transport demand, but also because of its inertness.

***Key words*: urban transport, world metropolises, energy consumption, comparative analysis, urban planning.**

INTRODUCTION

It is expected that by the middle of this century the intensified process of urbanization will lead to two-thirds of the world's population living in cities (United Nations Department of Economic and Social Affairs Population Division, 2015). The number of cities populated with more than one million inhabitants is growing steadily (especially in developing countries): while in 1950 there were only 75 such cities, now there are 548. The number of cities with more than 10 million inhabitants has doubled since 1995, and today there are as many as 33; by 2030 there will be 43, and these will be located mainly in developing countries (United Nations Department of Economic and Social Affairs Population Division, 2018).

Urbanization, accompanied by a demographic explosion, is also causing a dramatic increase in the consumption of resources and energy, as well as emissions of local and regional pollutants and CO_2. Cities account for 70% of the world's total consumption of resources, with some estimates suggesting that cities account for as much as 80% of worldwide energy consumption (OECD, 2010; UN-Habitat, 2018).

In the context of accelerated urbanization trends and growing environmental problems, urban transport is gaining importance. Not only does urban transport energy consumption represent a very significant part of the total city-level energy consumption, but forecasts suggest that in the future, urban transport CO_2 emissions from fossil fuel combustion will record the highest growth rate (International Energy Agency, 2009; UN-Habitat, 2011), as well as the transport sector itself globally (International Energy Agency, 2018).

The literature in this field is rich in studies and research that have sought to explain the relationship between urban form and urban travel characteristics (Acker, 2021; Ewing and Cervero, 2010; Leck, 2006; Milakis *et al*., 2015; Næss, 2012; Næss *et al*., 2019; Stead and Marshall, 2001; Stevens, 2017).

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The main conclusion is that the characteristics of urban form have a very significant impact on transport patterns in cities and, consequently, on the environmental effects of urban transport.

Many factors influence urban transport energy consumption (Creutzig *et al*., 2015). Most theoretical and empirical research has addressed the role of urban form and urban spatial structure (primarily population density and degree of centralisation) (Clark, 2013; Karathodorou *et al*., 2010; Kenworthy and Laube, 1999; Li *et al*., 2018; Liddle, 2013; Newman and Kenworthy, 1999; Rickaby, 1991; Zhao *et al*., 2017), city size (population and/or area) (Banister, 1992; Li *et al*., 2018; Shim *et al*., 2006), the level of economic development (Choi, 2013; Kenworthy, 2003; Wu *et al*., 2016), transport patterns and transportation infrastructure (Bongardt *et al*., 2013; Hu *et al*., 2010; Lin and Du, 2017; Vuchic, 2007).

The aim of this paper is to make a detailed analysis of the complex relationships that exist between the various elements of urban form, socio-economic factors and urban transport on the one hand, and energy consumption on the other, and also to examine the experiences of world metropolises characterized by different types of spatial development. Following this, the general policy implications that arise from this analysis will be highlighted.

MATERIALS AND METHODS

Our analysis encompasses a wide range of economic, spatial, transport and infrastructure indicators, as well as energy efficiency and energy consumption indicators (Table 1) in a sample of 35 world cities, and it covers a period of four and a half decades, more precisely from 1960 to 2005.

The main sources of data used in this paper are as follows:

- data for 1960, 1970, 1980, and 1990 were taken and partially calculated from studies by Kenworthy and Newman (1989) and Kenworthy *et al*. (1999);
- 1995 data were taken and partially calculated from a study by Kenworthy and Laube (2001); and
- 2005 data were calculated from three sources: Newman and Kenworthy (2015), Kenworthy (2013) and McIntosh *et al*. (2014).

Comparative urban and transport data are not very often readily available. Some apparent limitations arise from difficulty with respect to the collection of different kinds of urban data, since they are often out of date. Still, this is not a major shortcoming in its usefulness. While it is important to have a more current perspective, the relative position between cities concerning many characteristics does not radically change over a ten-years period. Furthermore, these kinds of standardised data variables are most valuable and useful to "researchers and policy makers in coming to terms with the vast differences that exist between cities in basic patterns of land use, transportation and energy use" (Kenworthy *et al*., 1999).

One of the most valuable aspects of the data used in our analysis is its broad comparative perspective, which is not quite so dependent on absolutely current data. This set of data is unique "as there is nowhere else that one can find such a time series of data to work with which has been developed using the same definitions and methods" (McIntosh *et al*., 2014) spanning more than four decades.

Also, for the purpose of our analysis, the period 1960-1990 is of greatest significance, considering that the most important changes took place in many cities at that time which affected their urban form, transport patterns and energy consumption.

Table 1. List of indicators used in analysis

Economic indicator	Metropolitan GDP per capita
Spatial indicators	Urban density
	Urban job density
	Proportion of jobs in CBD
Infrastructure indicators	Length of road per person
	Parking spaces per 1,000 CBD jobs
Private transport indicators	Passenger cars per 1,000 persons
	Passenger car passenger kilometres per person
Public transport indicators	Total public transport passenger kilometres per person
	Total public transport vehicle kilometres of service per person
	Rail systems vehicle kilometres of service per person
	Total public transport vehicle kilometres of service per urban hectare
	Share of public transport in total motorised passenger kilometres
Energy efficiency indicators	Energy consumption per public transport passenger kilometre
	Energy consumption per bus passenger kilometre
	Energy consumption per private passenger kilometre
Energy consumption indicators	Private passenger transport energy consumption per person
	Public transport energy consumption per person
	Total transport energy consumption per person

In addition to the data included in our analysis, data for 2001 and 2012, published by the UITP (International Association of Public Transport), were considered but were not taken into account. There are two reasons for this. First, after a thorough analysis of key indicators, it was found that the methodology by which the data were collected was significantly different from that of the Newman and Kenworthy studies. Second, the quality of the data itself is questionable because of the large, illogical discrepancies between the 2001 and 2012 data for the same observation units.

On the other hand, the data provided by Newman and Kenworthy in their studies are highly precise and comparable and are used by many researchers in this field (Karathodorou *et al*., 2010; Lefèvre, 2010; Liddle, 2013; Liddle, 2015). Therefore, from the point of view of our analysis, the selected data set, although somewhat outdated, is arguably the highest-quality available cross-national, city-based data.

Although the mentioned studies individually contain data on a large number of world cities, time series are only available for a small group of cities for all six selected years. However, even for cities in this group, there are certain methodological discrepancies between the key indicators in different years. For many cities, it was simply not possible to make a quality time series, given that the methodology of statistical coverage within national censuses had changed at some point.

Our sample, therefore, includes only cities whose indicators are available and completely comparable throughout the time period of the analysis (Table 2). For many metropolises of developing countries, precise data for the period before 1990 are not available due to the lack of official statistics.

The urban area data in this paper refer to the net-urbanized area of the metropolitan area, which covers only a continuously built-up area within the city (following the methodology in Kenworthy *et al*. (1999)). In this way, the comparability of spatial indicators between different world cities is achieved. Accordingly, the population density and the job density calculated in relation to the net-urbanized area are referred to as the urban population density and urban job density.

In addition to the summary indicator, public transport data were broken down into bus and rail systems (where it was feasible to do so), which is very important, given the significant differences in the main characteristics of these modes of urban transport. Rail systems here include trams, light rail systems, subways and suburban rail.

As data for the metropolitan GDP per capita prior to 1990 are not known, we had to resort to their most accurate approximation. The use of national GDP per capita for these purposes (a method often used) would lead to major deviations from the real value, given that these cities/regions are, as a rule, economically much more developed than the rest of the territory. Therefore, this indicator was calculated based on the realistic assumption that the total share of the metropolitan GDP as part of the total national GDP did not change significantly compared to 1990. After obtaining the GDP calculated in this way, we used the relevant population of the city to obtain the metropolitan GDP per capita for the 1960s, 1970s and 1980s. Based on data in Kenworthy's paper (2013), we calculated the 2005 GDP per capita. For the purpose of the exchange rate conversion, official IMF data were used (International Monetary Fund).

RESULTS

The comparative analysis indicates that there are significant differences in spatial and transport parameters, as well as energy consumption, in the urban transport of world cities.

Urban densities and job densities are significantly lower in cities in the US, Australia, and Canada than other cities in our sample. The US and Australian cities have an average of about 10 times lower densities than the wealthy cities of Asia and the metropolises of developing countries (Table 3). Western European cities are located somewhere in the middle, with about 5,000 inhabitants/km^2. Although their urban density declined by about 30% over the observed period, this can be explained by the intensification of peri-urban development as well as by general trends in population decline. Obviously, the activity density (jobs and persons) in wealthy Asian cities, cities in developing countries and those in the metropolises of Western Europe is extremely compatible with high-capacity transit systems. On the other hand, higher densities have the effect of reducing the overall transport demand in the city.

Table 2. World cities included in analysis

USA	Western Europe	Australia	Canada	Asia (wealthy)	Developing countries
Chicago	Brussels	Brisbane	Calgary	Hong Kong	Bangkok
Denver	Copenhagen	Melbourne	Montreal	Singapore	Jakarta
Houston	Frankfurt	Perth	Ottawa	Tokyo	Kuala Lumpur
Los Angeles	Hamburg	Sydney	Vancouver		Manila
New York	London				Seoul
Phoenix	Munich				Surabaya
San Diego	Paris				
San Francisco	Vienna				
Washington	Zurich				

During the period analyzed, in almost all world cities, the relative share of jobs in CBDs (central business districts) declined, and many of them that had prevalent monocentric characteristics started to develop polycentric or even dispersed employment patterns. Job centralization is most prevalent in Western European cities (about 19%), Canadian cities (17.5%) and metropolises in developing countries (about 16%) (Table 3).

Cities in the US, Canada and Australia are characterized by the highest values of private urban transport infrastructure indicators: the length of urban roads per capita and number of parking spaces in CBDs (Table 4). The length of urban roads per capita in Australian cities is five times greater than that of wealthy Asian cities and even 10 times that of metropolises in developing countries. Numerous studies have revealed a positive link between the construction of new road infrastructure and the increased number and length of automobile travel (Cervero, 2002; Cervero and Hansen, 2002; ECMT, 1998; Goodwin, 1996). In addition, the construction of city roads reduces opportunities for walking and cycling (Litman, 2001).

The number of parking spaces per 1,000 jobs in CBDs in US cities is twice as high as in Western European cities, three times that of the metropolises of developing countries and even five times higher than wealthy Asian cities. The availability of parking space in the central areas to a large degree determines the use of different modes of urban transport, especially when commuting.

The level of motorization has seen a huge growth in almost all world cities, in parallel with the increase in the standard of living. Cities in Australia and the US have an extremely high number of cars per 1,000 persons, namely 647 and 626 respectively. It is worrying that in the observed period the level of motorization has tripled in the cities of Western Europe and the cities of developing countries (1980-1995).

Table 3. Evolution of urban density, urban job density and proportion of jobs in CBD in world cities, 1960, 1970, 1980, 1990, 1995 and 2005
(Source: adapted according to Kenworthy et al., 1999; Kenworthy and Laube, 2001; Kenworthy and Newman, 1989; Newman and Kenworthy, 2015)

Cities	Year	Urban density (persons/ha)	Urban job density (jobs/ha)	Proportion of jobs in CBD (%)
USA	**1960**	17.2	8.0	16.34
	1970	16.7	7.5	13.66
	1980	14.5	7.4	12.03
	1990	15.0	8.5	10.30
	1995	15.9	8.0	9.49
	2005	16.2	-	8.80
Western Europe	**1960**	70.9	41.1	23.74
	1970	65.8	37.5	21.50
	1980	55.1	32.6	20.10
	1990	49.7	31.7	18.82
	1995	51.4	30.7	20.44
	2005	52.1	-	19.01
Australia	**1960**	19.5	7.4	26.35
	1970	15.2	6.6	21.93
	1980	13.7	5.5	16.60
	1990	13.0	5.4	13.70
	1995	13.3	5.7	13.33
	2005	14.0	-	13.17
Canada	**1960**	36.5	6.6	-
	1970	30.1	10.6	26.43
	1980	26.3	12.5	23.10
	1990	26.7	13.3	19.65
	1995	26.4	12.6	18.01
	2005	25.6	-	17.49
Asia (wealthy)	**1960**	95.1	-	-
	1970	166.8	80.6	29.70
	1980	149.3	71.0	19.40
	1990	152.8	87.5	17.80
	1995	167.2	84.0	12.33
	2005	-	-	-
Developing countries	**1980**	153.7	50.8	-
	1990	166.4	65.1	25.65
	1995	161.3	73.2	15.83

Table 4. Evolution of metropolitan GDP per capita, infrastructure and mobility of private urban transport in world cities, 1960, 1970, 1980, 1990, 1995, and 2005
(Source: adapted according to Kenworthy, 2013; Kenworthy et al., 1999; Kenworthy and Laube, 2001; Kenworthy and Newman, 1989; Newman and Kenworthy, 2015 and the author's calculations)

Cities	Year	Metropolitan GDP per capita (in $)	Length of road per person (m per capita)	Parking spaces per 1,000 CBD jobs	Passenger cars per 1,000 persons	Passenger car passenger kilometres per person (pkm per capita)
USA	**1960**	4,648	7.44	360.1	372.7	8,606
	1970	6,905	7.48	448.3	458.0	10,255
	1980	15,119	6.84	399.0	534.4	12,839
	1990	26,785	6.42	434.4	595.7	15,718
	1995	31,425	6.24	536.2	569.5	17,434
	2005	54,655	5.85	415.0	625.8	18,100
Western Europe	**1960**	1,547	1.51	128.2	126.0	2,723
	1970	3,535	1.73	155.2	243.5	4,480
	1980	17,018	2.22	187.6	333.6	5,677
	1990	32,285	2.42	218.7	398.0	6,648
	1995	40,532	2.57	202.7	405.9	6,444
	2005	51,551	2.48	226.4	402.8	6,628
Australia	**1960**	2,211	8.68	293.0	217.4	5,610
	1970	3,652	8.28	258.4	313.3	8,035
	1980	11,307	8.58	314.3	444.3	10,121
	1990	19,761	8.20	378.1	488.2	10,604
	1995	20,226	8.57	367.2	590.9	12,114
	2005	36,648	7.58	297.8	646.7	12,447
Canada	**1960**	3,638	4.90	-	270.3	-
	1970	5,134	4.90	453.2	357.5	-
	1980	13,159	6.47	360.2	454.5	8,326
	1990	23,216	5.38	385.5	531.3	9,589
	1995	21,167	5.57	427.9	545.9	9,102
	2005	38,603	5.58	355.6	531.5	9,046
Asia (wealthy)	**1960**	639	-	-	21.9	-
	1970	1,859	2.15	53.7	66.9	1,136
	1980	8,880	1.94	67.1	87.5	1,593
	1990	21,331	1.76	79.9	123.1	2,385
	1995	32,324	1.76	103.6	156.5	2,860
	2005	25,973	-	-	-	1,975
Developing countries	**1980**	-	0.58	-	47.5	1,495
	1990	2,861	0.72	192.3	102.4	1,640
	1995	5,538	0.85	166.1	158.3	3,016

Although the increase in passenger kilometres is not as pronounced as in 1960-1990, the automobile-dependent cities of the US, Australia and Canada continue to have comparatively greater private mobility than other metropolises. By comparison, this number is nine times higher in US cities (18,100 pkm per capita) than in the wealthy Asian metropolises (1,975 pkm per capita).

The supply of public transport is also significantly different among world cities. The largest supply per capita and urban hectares is in wealthy Asian cities, Western European cities and the metropolises of developing countries. However, while developed cities in Asia and Western Europe have a significant share of rail systems, in poor metropolises buses account for the largest volume of vehicle-kilometres per capita. Therefore, they also have the highest public transport mobility - especially wealthy Asian cities (3,786 pkm per capita) (Table 5).

A very significant long-term benefit of high-capacity transit systems is that they direct urban development towards their corridors. This creates the necessary conditions to prevent the process of urban sprawl. Therefore, the development of transit systems must be closely linked to urban planning and transport policy (Lefèvre, 2010).

Different modes of urban transport have very different energy efficiency, expressed here in MJ per passenger kilometre. Due to its significantly higher capacity and load factor, public transport is a much lower energy consumer than automobiles (Table 6). This difference is most pronounced in wealthy Asian cities, where automobiles consume five times more energy per 1 passenger kilometre than public transport. This is, of course, a consequence of high-capacity rail systems and the extremely high load factor that characterizes these metropolises, which is strongly influenced by high urban densities. Following these, cities in Western Europe and developing countries have the lowest energy consumption of public transport.

Table 5. Public transport supply and mobility, and the share of public urban transport in the total motorised pkm in world cities, 1960, 1970, 1980, 1990, 1995, and 2005
(Source: adapted according to (Kenworthy and Newman, 1989; Kenworthy et al. 1999; Kenworthy and Laube, 2001; McIntosh et al., 2014; Newman and Kenworthy, 2015)

Cities	Year	Total public transport vehicle km of service per person (vkm per capita)	Rail systems vehicle km of service per person (vkm per capita)	Total public transport vehicle km of service per urban hectare (vkm per ha)	Total public transport passenger km per person (pkm per capita)	Share of public transport in total motorised pkm (in %)
USA	**1960**	28.91	6.86	561	560	8.4
	1970	24.48	7.14	475	399	4.7
	1980	30.67	8.36	497	533	4.5
	1990	31.36	10.92	501	551	3.6
	1995	31.69	12.21	533	503	3.0
	2005	42.37	15.68	733	601	2.9
Western Europe	**1960**	78.36	59.40	5,420	1,860	41.4
	1970	73.33	50.81	4,540	1,538	26.8
	1980	78.39	53.04	4,158	1,665	23.4
	1990	91.60	62.27	4,354	1,937	23.1
	1995	99.87	67.94	5,103	1,834	22.4
	2005	119.34	80.96	6,274	2,290	23.8
Australia	**1960**	81.25	44.98	1,610	1,539	21.4
	1970	60.55	24.43	934	1,192	12.9
	1980	57.58	26.25	819	906	8.3
	1990	61.50	28.40	840	1014	8.9
	1995	57.36	29.05	789	966	7.6
	2005	58.94	30.18	856	1,075	8.1
Canada	**1960**	32.77	-	861	335	-
	1970	26.57	-	714	328	-
	1980	55.10	6.18	1,509	857	10.1
	1990	54.03	10.38	1,466	862	8.8
	1995	47.19	10.17	1,252	884	9.0
	2005	51.41	12.31	1,310	1,007	10.4
Asia (wealthy)	**1960**	-	27.40	-	-	-
	1970	-	33.10	-	3,483	77.9
	1980	102.47	26.73	16,295	3,217	67.0
	1990	114.57	39.57	19,475	4,020	64.1
	1995	117.28	42.33	21,803	4,141	61.5
	2005	-	-	-	3,786	43.5
Developing countries	**1980**	-	-	-	1,371	45.5
	1990	108.00	2.83	19,772	1,871	38.3
	1995	155.07	-	29,379	1,822	38.7

It is clear that public transport has the greatest potential for reducing the overall energy consumption of urban transport, since it can carry the largest number of passengers, while being several times more energy efficient than private transport.

The values of the spatial, economic, infrastructural and transport indicators analyzed here are reflected in the per capita energy consumption of urban transport (Table 7). Although in a slight decline after 1990, the energy consumption of US cities is still at a persistently high level compared to other world metropolises - US cities consume three times as much energy in transport than Western European and over eight times as much as wealthy Asian cities. Behind them are cities in Australia and Canada. The largest share of energy consumption, of course, comes from consumption in private urban transport.

DISCUSSION

In terms of urban transport energy consumption, US and Australian cities (and to a certain extent Canadian)

Table 6. Energy efficiency of private and public urban transport in world cities, 1960, 1970, 1980, 1990, 1995 and 2005 (Source: adapted according to Kenworthy et al., 1999; Kenworthy and Laube, 2001; Kenworthy and Newman, 1989; McIntosh et al., 2014; Newman and Kenworthy, 2015)

Cities	Year	Energy consumption per public transport passenger kilometre (MJ/pkm)	Energy consumption per bus passenger kilometre (MJ/pkm)	Energy consumption per private passenger kilometre (MJ/pkm)
USA	**1960**	1.45	1.48	4.90
	1970	1.91	2.02	5.16
	1980	1.91	2.13	4.76
	1990	1.91	2.43	3.66
	1995	2.19	2.79	3.16
	2005	2.14	-	2.84
Western Europe	**1960**	0.40	0.71	1.93
	1970	0.51	0.91	2.05
	1980	0.62	0.96	1.88
	1990	0.67	1.30	3.38
	1995	0.74	1.33	2.61
	2005	0.77	-	2.38
Australia	**1960**	1.06	1.04	2.70
	1970	0.79	1.19	2.76
	1980	0.99	1.53	2.86
	1990	1.02	1.74	2.90
	1995	0.99	1.77	2.55
	2005	0.97	-	2.89
Canada	**1960**	0.88	1.58	-
	1970	1.56	1.77	-
	1980	1.37	1.56	4.05
	1990	1.35	1.74	3.29
	1995	1.18	1.56	3.50
	2005	1.21	-	3.19
Asia (wealthy)	**1960**	-	-	-
	1970	0.33	0.64	3.63
	1980	0.49	0.74	2.91
	1990	0.43	0.84	3.02
	1995	0.46	0.78	3.14
	2005	0.70	-	3.62
Developing countries	**1990**	0.70	0.74	3.17
	1995	0.87	0.85	2.17

Table 7. The evolution of urban transport energy consumption in world cities, 1960, 1970, 1980, 1990, 1995 and 2005 (Source: adapted according to (Kenworthy et al., 1999; Kenworthy and Laube, 2001; Kenworthy and Newman, 1989; Newman and Kenworthy, 2015)

Cities	Year	Private passenger transport energy consumption per person (MJ per capita)	Public transport energy consumption per person (MJ per capita)	Total transport energy consumption per person (MJ per capita)
USA	**1960**	45,276	715	46,041
	1970	58,573	589	59,162
	1980	66,538	834	67,373
	1990	62,265	852	63,117
	1995	55,287	834	56,121
	2005	51,038	1,008	52,047
Western Europe	**1960**	9,884	756	10,744
	1970	14,129	826	15,035
	1980	17,162	1,013	18,241
	1990	24,974	1,241	26,216
	1995	16,650	1,300	17,951
	2005	15,288	1,720	17,008
Australia	**1960**	18,898	1,451	20,349
	1970	27,168	843	28,011
	1980	35,801	812	36,613
	1990	37,754	904	38,659
	1995	31,044	875	31,920
	2005	35,972	1035	37,008
Canada	**1960**	-	467	-
	1970	-	463	-
	1980	42,240	1,175	43,366
	1990	38,209	1,161	39,332
	1995	31,987	1,046	33,033
	2005	28,568	1,187	29,756
Asia (wealthy)	**1960**	-	-	-
	1970	8,641	907	9,772
	1980	11,180	1,137	12,318
	1990	13,915	1,396	15,311
	1995	8,306	1,722	10,028
	2005	6,077	2,691	8,768
Developing countries	**1990**	12,272	1,327	13,598
	1995	8,009	1,632	9,641

represent a rather specific, even extreme, type of development. Newman and Kenworthy have called such metropolises automobile-dependent cities (Kenworthy and Newman, 1989). Automobile dependency is largely a consequence of public policy, namely, transport and spatial planning measures that have consistently favored car use and encouraged spatial expansion. At the same time, it has been completely neglected that traffic problems, such as congestion, cannot be solved solely by the construction of new urban roads, which again stimulates even more rapid growth of private mobility and intensification of dispersed spatial development (Frederick, 2016; Geels *et al*., 2012; Kakar and Prasad, 2020; Kasraian *et al*., 2016; Kenworthy, 2017; Litman, 2004: Litman, 2007; OECD, 2018).

Although very diverse, Western European cities are significantly different from US and Australian automobile-dependent cities. In contrast to their spatial development, which is largely the outcome of macroeconomic policy (see: Jovanović, 2005), the far more significant role of spatial planning is noticeable in the development of Western European cities. The ambitious post-war development plans for Paris and London, although completely different in terms of their success, best bear witness to this. Jovanovic (2008) summarizes that "precisely the European way of regulatory urban planning and the continued subsidization of public urban transport has significantly contributed to the development of European metropolises in a 'more sustainable' way...".

However, there are indications that in many metropolises of the developed world, characterized by automobile dependence, saturation has occurred, and that the trend of exponentially increasing private mobility has at least slowed, if not stopped, in recent years. Many studies indicate that the peak of car use was reached at the beginning of the 21st century, both nationally and in the cities themselves (Millard-Ball and Schipper, 2011; Newman and Kenworthy, 2011; Puentes and Tomer, 2008).

Newman and Kenworthy point out possible reasons for the decline in car use in cities: the effect of the so-called Zahavi's constant, revitalization of public transport, stopping the process of dispersed urban development, aging of urban populations, and higher fuel prices (Newman and Kenworthy, 2011). Due to the increasing traffic congestion in automobile-dependent cities, the influence of Zahavi's constant, i.e., limitations of the so-called travel time budget, are becoming increasingly apparent. Also, as there is an exponential link between car use and public transport (an increase in passenger kilometres by public transport per capita causes a dramatic decrease in passenger kilometres by car per capita), the revitalization of public transport has played a significant role in reducing automobile dependence in many developed cities (Newman and Kenworthy, 2015). This relationship is something that transport planners often tend to disregard.

In the same period, there are indications of a break in the usual positive link between economic growth and urban mobility. In most cities in the developed world, there has been a significant reduction in vehicle-kilometres by car per unit of real GDP (an average of 21%), which means that despite the strengthening of their economies, car use is reduced. In some cities there is even an absolute reduction in the distance traveled by car (Kenworthy, 2013).

However, despite all these positive trends (decline of automobile vehicle-kilometres and reduction of urban transport energy consumption), a large number of cities in the developed world still rely predominantly on cars, while sustainable modes of urban transport play an almost negligible role.

The wealthy Asian metropolises are the complete opposite of the US and Australia's automobile-dependent cities. Singapore, Hong Kong and Tokyo are the best examples of sustainable urban development and energy efficient cities (Leung *et al*., 2018). A key feature of their development is the exceptional coordination of urban planning and transport strategies, as well as innovative solutions to transport problems (Diao, 2018; M. Jovanović, 2014; Wen *et al*., 2019).

Furthermore, the wealthy Asian metropolises are among the most densely populated cities in the world (Table 3). These extremely high population densities are not merely the outcome of the process of urbanization, accelerated economic development and the natural limitations of spatial expansion, but rather they are largely the result of strategic spatial and transport planning. This has provided the high load factor of economically very efficient high-capacity public transport systems (Jovanović, 2009). At the same time, the exceptionally high load factor (often over 100%) has led to the high energy efficiency of public transport, expressed in energy consumption per passenger kilometre.

The planned development of the 'new towns' has left a great mark on the spatial development of these metropolises, which originated from Howard's 'garden city'. However, these 'new towns' have largely fulfilled the principle of self-sufficiency, which, with the coordinated development of rail transport, effectively reduced the need for car use and travel in general (Diao, 2018; Jovanović, 2009).

Also, these cities have a very restrictive car ownership and car use policy. In Hong Kong, for example, the motorization rate has been successfully limited by various fiscal measures that have raised car registration prices and costs. Singapore is considered to be the world's best example of implementing measures to limit the use of motor vehicles. The congestion pricing system was introduced in 1975 and was quite innovative - in the form of permits that vehicle owners had to buy in order to enter the central city area. The effects were visible very quickly. In just one year, the number of cars entering the central zone in the peak hour decreased from 43,000 to 11,000 (Seah, 1980), and the speed of vehicle movement doubled (Chin, 1996). The modal share of public transport in travel, which stood at 46% in the 1970s, jumped to 67% two decades later (GTZ, 2012). These measures were aided by fiscal instruments such as restricting car ownership, introduced in 1990 (Vehicle Quota System) (Barter, 2005). Potential buyers took part in auctions to obtain a license that allowed motor vehicle registration. In ten years, this system managed to reduce the annual growth rate of motorization from 4.2% to 2.8% (Timilsina and Dulal, 2010). Following Singapore's example, many cities, such as Hong Kong, London and Stockholm, have successfully introduced congestion charge systems.

Unlike the developed world metropolises, cities in developing countries are in the early stages of the urban development cycle. Their urban form is compact, and population densities are high (Table 3). A large number of them have pedestrian characteristics, so non-motorized modes of transport have a large share in the overall mobility. In such circumstances, the choice of transport strategy and the construction of transport infrastructure is of the utmost importance, as it can decisively determine the further course of urban development.

Although the motorization rate is low due to the low standard of living compared to the wealthier cities in the world, in parallel with economic development the number of cars and the length of travel itself is growing rapidly. Some forecasts suggest that, thanks to rapid economic development, the mobility of motorized transport in these countries will increase as much as four times by the middle of the 21st century (Schafer and Victor, 2000).

As the share of car use is still at a relatively low level, their energy consumption is significantly lower than other cities in the world. Nevertheless, current processes of dramatic demographic growth, rapid urbanization and economic development place these metropolises at the heart of the global agenda for sustainable urban development. Already today, the population of these metropolises is much greater than the population of cities in developed countries (United Nations Department of Economic and Social Affairs Population Division, 2018). However, their urban sustainability problems should not be viewed solely as a consequence of accelerated urbanization and a population explosion, but more as an unintended outcome of poor urban planning and governance (Rode and Burdett, 2011).

Regarding policy implications, the effects of various instruments on energy consumption in urban transport are very often analyzed within the ASIF methodology. They represent different aspects that can be influenced by urban and transport policy: activity (A), structure/modal share (S), energy intensity (I) and fuel type (F).

Throughout history, the emphasis has often been on the implementation of new transport technologies, as well as on the improvement of existing ones (Webb, 2019). These are measures that improve the efficiency of the vehicles themselves (mainly automobiles), the quality of fuel and the quality of road infrastructure. A well-known example is the implementation of increasingly stringent automobile standards in the United States since the 1960s, which significantly reduced the emission of local air pollutants per vehicle-kilometre traveled, but unfortunately not the emission of CO_2. However, as there was a tremendous increase in mobility by private modes of transport in the same period, these effects were almost nullified (Jovanovic, 2012). The same can be expected with other technological innovations with regard to fuel or the vehicles themselves - if these improvements cause energy savings, they often lead to greater car use (a well-known Jevons paradox). Investigating this effect in road transport, one meta-analysis shows that the short-term reduction in expected benefits from technological improvements is 10-12%, and in the long-term as much as 26-29% (Dimitropoulos *et al*., 2018). Also, the positive effects on the environment of many new technologies are not so clear when the entire process of their production and consumption is taken into account. The use of an electric car, for example, which is based on energy obtained from non-renewable sources, is not effective from the point of view of sustainable urban development.

Most authors agree that measures affecting components I and F will, at least in the foreseeable future, have the least effect on reducing energy consumption and CO_2 emissions in urban transport (Banister, 2011; Lefèvre, 2009; Næss and Vogel, 2012). The scope and outlook of new transport technologies are perhaps best illustrated by the fact that, despite high expectations, electric vehicles have failed to significantly replace the internal combustion engine - today, their total number in use is only 0.2% of the total passenger vehicles (OECD/IEA, 2017).

This is especially true for the metropolises of developing countries. Given their level of economic development and living standards, it cannot be expected that new technology, such as electric vehicles, will be widely available in the near future. It is estimated that, in relation to developed countries, the market penetration of new transport technology in developing countries lasts on average 10 years longer, e.g. since the launch of the electric car, it has taken more than four decades for it to reach a somewhat significant market share in the least developed countries (Assmann and Sieber, 2005).

Thus, although all components of the ASIF framework should be taken into account in order to reduce the energy consumption of urban transport, it is obvious that, especially in the metropolises of developing countries experiencing the greatest changes, the focus should be on reducing demand and changing the modal share in favor of walking, cycling and public transport.

It is obvious that the reduction of energy consumption in urban transport can be achieved by implementing various urban planning/land use and transport policy instruments (Banister, 2011; Bongardt *et al*., 2010). Among these, measures that reduce the need for urban transport (reducing the total vehicle-kilometres or the total passenger kilometres) are the most significant, especially ones resulting in increasing urban densities. Urban planning arguably has a key role in achieving sustainable urban transport (Hickman *et al*., 2013), as it affects the spatial distribution of activities and determines their proximity to urban residents (i.e., accessibility).

Future research should focus on identifying the determinants of urban transport energy consumption and their significance using econometric methods (i.e., panel analysis), in order to fully understand their effect. Finally, given the significant number of studies in this field with similar hypotheses, it would be very useful to conduct a meta-analysis.

CONCLUSION

A comparative analysis of the urban transport energy consumption of world metropolises indicates that there are significant differences, especially between the US and Australia's automobile-dependent cities, on the one hand, and the wealthy Asian metropolises, on the other. Although due to numerous factors, the trend of increasing private mobility and energy consumption slowed down in the first decade of the 21st century, the modal share of public transport and other sustainable modes of urban transport is still underwhelming.

In the long run, the urban form itself is particularly significant, not only because it critically influences transport demand, but also because of its inertness. Therefore, a substantial decrease in urban transport energy consumption in the mature cities of the developed world, at least in the near future, is not likely due to the radical interventions and high economic costs it entails.

Global urban transport energy consumption will be greatly determined by the type of urban development that is prevalent in the 'young' cities of the developing world, especially those with a relatively low motorization rate and private mobility, as urban planning and transport policies are much more effective in these conditions.

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