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Original Research

Belgrade's Urban Transport CO_2 Emissions from an International Perspective

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Abstract

Focusing on the implementation of increasingly strict energy and emission standards, the effect of the rapid increase in the use of motor vehicles on the degree of air pollution and energy consumption is completely neglected. All recent technological improvements and changes in the transport sector: substitution of fuels, increased use of diesel vehicles, direct gasoline injection, supercharging, electric vehicles, hybrid vehicles, etc., cannot offset massive growth in traffic, combined with significantly heavier, more powerful, more luxurious and thus more fuel-consuming vehicles. Hence, in this paper we focused on the carbon emissions and energy consumption of urban transport in Belgrade from an international perspective. Although the level of *automobile* CO_2 emissions in Belgrade is still very low at 228 CO_2 kg/per capita, due to the low volume of automobile passenger kilometres (1,502 pkm), the fact must not be overlooked that *automobile* mobility is of major importance to the total level of energy consumption in urban transport, and this can change surprisingly quickly. Only if Belgrade adopts transport and spatial development strategies similar to those applied by wealthy Asian metropolises at a similar stage of development is there high probability that its total urban transport CO_2 emissions will stop at a reasonable level of around 700-800 kg CO_2/per capita. Belgrade can prevent a dramatic increase in CO_2 emissions and energy consumption (and mitigate the negative local environmental effects of traffic congestion, traffic accidents, and air pollution), only if it:

1. Implements a more decisive strategy to limit private vehicle use while its level of car passenger km (PKT) is still relatively low.
2. Does not try to solve its transport problems only by trying to build urban road infrastructure (bridges and ring roads).
3. Concentrates on more CO_2 and energy-efficient urban transport systems, while at the same time ….
4. Developing urban rail systems (metro or LRT) with exclusive tracks that are immune to traffic congestion on urban streets.

Keywords: urban transport, carbon emissions, Belgrade, world metropolises

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Introduction

In 2009 transport became the highest single energy-consuming human activity: it was responsible for 27.3% of world energy-consumption (compared to 23% in 1973) [1].

Since transport predominantly (95%) relies on a single fossil resource – petroleum, this sector is responsible for 24% of world energy-related greenhouse gas (GHG) emissions, with about three-quarters produced by road vehicles.

Moreover, transport activity is expected to grow robustly over the next several decades, and by 2030 total carbon emissions are projected to be about 80% higher than current levels, doubling by 2050 [2-4].

The Stern review expects transport to be one of the fastest growing sectors in the future and among the last sectors to bring its emissions down to below current levels [5].

There are two main factors leading to such a huge increase in transport CO_2 emissions:

a) Dependency on the internal combustion engine, with no wide-scale economically viable alternative available in the coming decades.
b) A sharp increase in vehicle kilometres travelled (VKT), which seems to be an inherent feature of economic growth [6], although in previous years there has been growing evidence that in many cities (especially in developed countries) VKT has decoupled from GDP [7, 8].

This technological and economic dependency presents a challenging energy efficiency issue.

GHG emissions can be decomposed into:

1) Carbon intensity
2) Energy efficiency
3) Total transport demand [4]

Stern review underline that transport is one of the most expensive sectors to cut emissions from, because the low carbon technologies tend to be expensive and the welfare costs of reducing demand for travel are high. Transport is also expected to be one of the fastest growing sectors in the future. For these two reasons, studies point out that transport will be among the last sectors to bring its emissions down below current levels [5].

All recent technological improvements and changes in the (road) transport sector (substitution of fuels through increased use of diesel vehicles, direct gasoline injection, supercharging, electric vehicles, hybrid vehicles, etc.) cannot offset massive growth in traffic combined with growing demand for comfort (air conditioning, etc.), which is energy intensive [9].

For example, there is a reported continuous downward trend of fuel consumption due to the technological innovations introduced in modern passenger cars, as well as certain market shifts toward more fuel-efficient (diesel) vehicles [10]. Nevertheless, a large part of this benefit in fuel consumption and CO_2 emissions was counterbalanced by various factors, amongst which are stricter safety regulations, consumer demands, and improvements in vehicle comfort that have resulted in significantly heavier, more powerful, more luxurious, and thus more fuel consuming vehicles [9, 11]. Actually, an important factor that has accelerated the increase in transport energy use and carbon emissions is the gradual growth in size, weight, and power of passenger vehicles – especially in the industrialized world. For example, the U.S. Environmental Protection Agency has concluded that the U.S. new light-duty vehicle (LDV) fleet fuel economy in 2005 would have been 24% lower had the fleet remained at the weight and performance distribution it had in 1987. Instead, over that time period it became 27% heavier and 30% faster in 0-60 mph (0-97 km/h) time, and achieved 5% poorer fuel economy [12].

Also, since increased fuel efficiency, in fact, effectively decreases the unit cost of driving, energy effectiveness and reduced CO_2 emissions are seriously offset by increased demand for car travel. The latest research clearly shows that at least 60% of the potential energy savings from efficiency improvements is lost due to increased driving, which is called the “rebound effect” [13].

Hence, the overall picture shows only a modest improvement in fuel consumption and carbon emissions of the average vehicle [14].

Electric (and also hybrid) vehicles have been strongly promoted lately due to the fact that they have minor GHG emissions related to the vehicle technology itself, but their total GHG emissions are rather significant when the electricity they use has been produced in coal power plants. Hence their total carbon footprint when fuel production is included is actually very high [4]. This is of major significance since two thirds of global electricity is produced from fossil fuels [15].

Actually, worldwide travel studies have shown that the average time budget for travel is roughly constant worldwide, with the relative speed of travel determining distances travelled yearly [16]. As incomes have risen, travellers have shifted to faster – and more carbon and energy-intensive – modes [2].

Transport fuel use worldwide is currently dominated by petroleum, with more than 95% of fuel being either gasoline or distillate fuels such as diesel, kerosene, or jet fuel. A new analysis of fuel costs indicates that in the near term (and with oil prices around USD 60/bbl), most alternative fuels will be more expensive than gasoline or diesel [17]. While oil extraction is expected to peak and decline within this decade [18], the shortfall will likely be partially compensated for by non-conventional oil (such as tar sands) and other fossil resources such as gas-to-liquids and coal-to-liquids. On average, these fuels are more energy- and carbon-intensive than oil, caused by upstream emissions in the supply chain [19].

Finally, worldwide the transport sector’s energy and CO_2 trends are strongly linked to rising population and incomes. Another crucial aspect of the global transport system is that much of the world is not yet motorized (due to low incomes). The majority of the world’s population does not have access to personal vehicles, and many do not even have access to motorized public transport of any sort. As incomes in the developing nations grow, transport will grow rapidly. When these areas develop and respective populations' incomes rise, the prospects for vast expansion of motorization and increase in fossil fuel use and GHG emissions is very real [2]. And these prospects are exacerbated by evidence that the most attractive form of transport for most people as their incomes rise is the personal motorized vehicle, which is seen as a status symbol as well as being faster, more flexible, more convenient, and more comfortable than public transport.

If the aim is to achieve ambitious energy consumption and GHG reduction for transport within the next few decades, policies will have to be more determined: they should aim at reducing total consumption, which means reducing VKT, not just vehicle-specific consumption [6, 20].

Due to growth rates in the volume of traffic, it is unlikely that technical progress of engines will be sufficient to reduce overall emissions or even keep them at today's levels. For that reason, the focus is increasingly shifting to market-driven instruments, which, apart from creating incentives to develop and use low-emission technologies, can also reduce the demand for travel [21].

Joumard rightfully stresses that "only 40% of the effort required should focus on technology, while the remaining 60% should focus on managing demand for transport and the adoption of more sustainable modes of transport" [9].

Unfortunately, as the Intergovernmental Panel on Climate Change (IPCC) clearly points out regarding transport activity, projections foresee continued growth in global transportation carbon emissions in 2030 to about 80% above 2002 levels [2].

Cities contribute to climate change in three main ways: through direct emissions of GHGs that occur within city boundaries, through GHG emissions that originate outside of city boundaries but are embodied in civil infrastructure and urban energy consumption, and through city-induced changes to the earth's atmospheric chemistry and surface albedo [22].

Since more than half of the global population now lives in towns and cities, and UN-Habitat research forecast that this figure will rise to two-thirds by the year 2050 [23], one of the main issues concerning carbon emissions is how to limit rapidly rising urban transport.

In this paper we focus on a comparative analysis of carbon emissions in the urban transport of Belgrade and different world metropolises.

Materials and Methods

A well-to-wheels (WTW) analysis is a systematic approach for assessing energy consumption and GHG emissions related to different fuels and vehicle propulsion configurations. The whole WTW cycle is comprised of two independent stages. These include: I) a well-to-tank stage (WTT), which includes the recovery or production of the feedstock for the fuel, transportation and storage of the energy source through conversion of the feedstock to the fuel, and the subsequent transportation, storage, and distribution of the fuel to the vehicle tank, and II) a tank-to-wheels stage (TTW), which refers to the vehicle operation activities throughout its lifetime [24-28]. Regarding energy consumption and GHG emissions, the WTT part of the whole life cycle represents only about 15% of WTW total impact [29].

In our study we used only TTW because:

a) Although the entire WTW cycle includes WTT (which covers 15% of the whole WTW cycle), including WTT in calculations *on the level of world metropolises* is too difficult to perform (it is much easier to perform this kind of analysis/study on the national level).
b) Including WTT in our calculation cannot change our main results/conclusions of the study.
c) By using the results of previous, well known (and often quoted) research and papers in the literature [30-33] that cover the extended period from 1960-2005, we made our own research on Belgrade easily comparable.
d) Obtained results of this previous research that covers TTW (85% of the whole WTW cycle) are methodologically very precisely elaborated upon.

Following is a precise description of this TTW methodology used for obtaining energy used and CO_2 emisions on the metropolitan level.

Energy Consumption

All traction energy for all modes of public transportation was collected for this item. The data are collected by type of propulsion energy (typically diesel and electricity), but also petrol, LPG, or others. All data are converted to Joules for the totals using standard conversion factors as shown in Table 1.

The energy data are generally published in the operator's annual reports, or can be found with national public transportation regulating bodies or industry associations. Where the data were not published they were obtained through further investigation with the operators (often in the accounting sections because of the financial implications of fuel use).

Also, all public transportation data of all operators were included in all cities (this distinguishes this set of data from others, where often only the principal operator(s) of the central city in a metropolitan area is shown). In many cases, the serviced area of operators with a significant share of their operations inside the metropolitan area is larger. In these cases, where it was impossible to segregate out the portion of interest, the population of the larger service area was used to standardise the data.

CO_2 Emissions from Transportation

This item did not require collection by itself, as CO_2 emissions are linked to energy consumption, which is already available through the original data set. The conversion factor from joules of energy consumed to grams of CO_2 emitted depends on the type of fuel involved in the energy generation. In the case of propulsion by means of the internal combustion engine, this is a case of converting the fuel consumed into emitted CO_2. In the case of electric propulsion, however, additional information is required to account for the type of technology involved in power generation, the quality of the fuel in the case of coal, and for electric transmission network losses. The table below lists the conversion factors for fossil fuels (for propulsion via internal combustion engine) and for electric power according to the mix of generation plants (e.g., thermo, nuclear, and hydro power) existing in the supply grids for the metropolitan areas included in this study. Conversion factors from fuel types to energy are given in Table 1 while CO_2 emissions of different fuel used are in Table 2.

The data about average per capita emissions of CO_2 from passenger transport in each of the cities/regions have been calculated from the detailed energy data on private and public transport through standard grams of CO_2 per MJ conversion factors. For electrical end use energy in electric public transport modes in different cities/countries, reference was made to UN energy statistics showing the different contribution of various energy sources to electricity production (i.e., 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 [34]. 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.

For the years 1960 and 1990 (for 41 world metropolises) we used Kenworthy and Laube's 1999 International Sourcebook [30]; for 1995 (for 62 world cities) we used UITP Millennium Cities Database [31]; for 2005 (for 32 world cities) we used Newman and Kenworthy's The End of Automobile Dependence [33]. U.S. cities included are: Atlanta*, Chicago*, Denver*, Houston*, Los Angeles*, New York*, Phoenix*, San Diego*, San Francisco*, and Washington*; Western European cities: Graz*, Athens, Vienna*, Milan, Brussels*, Bologna, Copenhagen*, Rome, Helsinki*, Amsterdam, Lyon, Oslo*, Nantes, Barcelona, Paris, Madrid*, Marseilles, Stockholm*, Berlin*, Bern*, Frankfurt*, Geneva*, Hamburg*, Zurich*, Dusseldorf*, London*, Munich*, Manchester*, Ruhr, Newcastle, Stuttgart*, and Glasgow; Wealthy Asian cities: Osaka, Sapporo, Tokyo, Hong Kong*, Singapore*, and Taipei; Developing World metropolises: Manila, Bangkok, Mumbai, Chennai, K. Lumpur, Jakarta, Seoul, and Ho Chi Minh City; Australian cities: Sydney*, Melbourne*, Perth*, Brisbane*, and Adelaide; cities in transition: Prague*, Budapest, and Krakow; Chinese cities: Beijing, Shangai, and Guangzhou (*cities included in dataset for Table 7).

For *urban public transport* mobility in Belgrade (2011) we used data collected from public transport operators (24 hours/7 days per week) and statistical yearbooks for Belgrade [35] for each mode: bus, trolley bus, tram, and urban rail. VKT for different urban *public* transport modes in Belgrade for 2011 were: for buses 126,288,000, for trams 12,539,000, for trolley buses 5,781,000, and for urban rail (BG voz) 740,000. The load factor (ratio of passenger kilometres to available seat kilometres) for buses was 32.7%, for trams 19.3%, for trolley buses 25.1%, and for urban rail (BG voz) 35.1%.

Private car vehicle kilometres data were derived from major transport studies: 'Belgrade Transport Model' [36] and 'Study of the characteristics of transport demands,

Table 1. Conversion factors from fuel types to energy [30].

Fuel type	Conversion factor
Motor spirit (petrol/gasoline)	34.69 MJ/l
Automotive Distillate (diesel)	38.29 MJ/l
LPG	26.26 MJ/l
Electric power	3.60 MJ/kWh

Table 2. Grams of CO_2 per MJ of fuel used [30].

Fuel/Grid	CO_2 emissions (g/MJ)
Petrol(gasoline), diesel	72
LPG	65
Electric power	
Canada	66
USA	206
China	232
Japan	190
Austria	104
Belgium	110
Denmark	278
France	36
Germany (West)	184
Netherlands	195
Sweden	11
Switzerland	6
United Kingdom	230
Hong Kong	292
Indonesia	231
Japan	190
Korea (South)	146
Malaysia	241
Philippines	164
Singapore	292
Thailand	260
Serbia	207

transport supply, efficiency, and quality of the system of mass public transport of passengers in Belgrade' [37], plus surveys conducted by authorities (car occupancy was 1.31 passengers [36, 37]). Private car-fleet data were collected from the Ministry of the Interior and major vehicle insurance companies.

CO_2 emissions from urban transport were derived directly from total energy figures (both private transport and public transport) using conversion factors for the CO_2 equivalent of each fuel type, and a different conversion for each country's electricity depending on the mix of fuels used for generation.

For comparative analysis of the different scenarios of Belgrade's future urban transport CO_2 emissions we used the mobility levels of metropolises in countries in transition and in West European metropolises from the Millennium Cities Database [31]. For the calculation of Pearson's correlation coefficient we used statistical SPSS software.

Belgrade's Spatial Development

Belgrade can be divided into four concentric zones: central, middle, outer, and edge (Tables 3 and 4, Fig. 1).

In the last 20 years a distinctive feature of Belgrade has been the new, rapidly developing business district (NBD) of New Belgrade, in the vicinity of and spatially inter-connected with the Old City core (CBD) [39]. Hence, Belgrade's highly monocentric structure has become even more pronounced, since 28.2% of all (Master plan) work places are concentrated in the traditional CBD with an additional 7.4% in New Belgrade's NBD (just across the river) (Tab. 4 and Fig. 1).

It is evident that the average population density of the continually built-up area (CBA) of Belgrade (consisting of central, middle, and outer zones) is rather high (7,419 inhabitants/km^2) and that during 2002-11 major changes occurred in the outer and edge zones – with an increase of 87,000 inhabitants and 13.7 km^2 of net-urbanized area (whereas the middle zone gained only 9,500, the central zone lost 22,000 and the CBD lost 16,191 inhabitants) (Table 3).

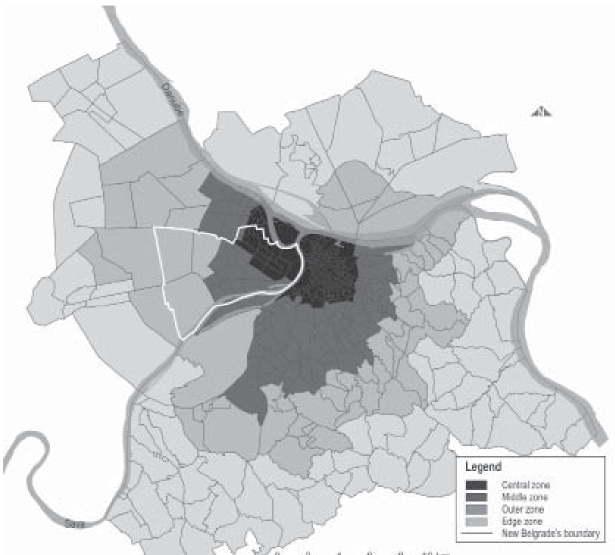

Fig. 1. Zones (and statistical circles) of Belgrade [38].

In short, the main characteristics of Belgrade's spatial development are high levels of population density (9,500-12,000 inhabitants/km^2 in its central and middle zone), and a very high level of centralization (28.2%) of employees in the CBD (Table 4) [39]. This is fertile ground for introducing high-capacity rapid rail rapid transit systems (light rail transit (LRT) or metro systems) [40]. Newman and Kenworthy point out that long-term data from cities around the world show that there is a fundamental threshold of urban intensity (residents and jobs) of around 35 per hectare to support public transit [41] – a threshold Belgrade evidently exceeds (Tables 3 and 4).

Belgrade's Urban Transport CO_2 Emissions from an International Perspective

The degree of CO_2 emissions in urban transport resulting from the rapid increase in automobile passenger kilometres (Tables 5 and 6) is, unfortunately, usually neglected [42].

Previous years have seen growing evidence that in many cities in developed countries passenger kilometres travelled and energy consumption in urban transport has decoupled from GDP [7, 8]. In 1995-2005, for example, automobile passenger kilometres travelled in the U.S. stabilized at 18,000 pkm per capita, Australia at 12,000, Europe at 6,500, and wealthy Asian cities at 2,000 pkm/per capita [33]. Nevertheless, differences in passenger kilometres travelled remained extremelly pronounced.

Both load factors and the degree of mobility of different urban transport modes directly depend on:

– Income changes and economic development.
– Transport infrastructure investments and the choice of transport technology.
– Prices and economic instruments.
– Interdependence of transport and urban form, and the influence of urban planning policy [43].

As Kenworthy points out: "Meaningful results can be obtained from energy use per passenger km because this takes into account vehicle loadings. It is also the only way to fairly compare public and private transport energy efficiency." [44]. Taking into account these different load factors of urban transport modes, comparative analysis of the indicators of energy consumption per passenger kilometre of urban transport in world metropolises is given in Table 8 [30, 43].

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Table 9 shows indicators of mobility (expressed in passenger km/per capita) and CO_2 emissions in urban transport (in kg/ per capita) of different world metropolises [42, 43].

Table 3. Spatial distribution of population and densities of Belgrade's zones [38].

Zone	Net-urbanised area (km^2)		Population		Population densities (inhab./km^2)	
	year 2002	year 2010	year 2002	year 2011	year 2002	year 2011
CBD	3.640	3.640	50,447	43,697	13,841	11,989
Central zone	24.754	24.825	298,559 23,61%	276,635	12,061	11,143
Middle zone	57.064	57.665	533,401 42,18%	542,859	9,347	9,413
Outer zone	65.059	71.184	257,657 20,38%	314,319	3,960	4,415
Edge zone	79.935	87.526	174,810 13,82%	205,052	2,186	2,342
Master plan (MP)	226.812	241.20	1,264,427	1,338,865	5,575	5,551
Continuously built-up area (CBA)	146.877	153.674	1,089,617	1,133,813	7,419	7,378

Source: author's calculation

Table 4. Share of jobs of old CBD and New Belgrade's NBD (new business district) of all Belgrade's Master Plan area jobs in 2002 (in %) [39].

Area	Workplaces (in %)	Net-urbanised area (km^2)	Job densities	% share of jobs (in MP)	% share of jobs (in CBA)
CBD - Old Belgrade	28.2	3.640	33,457	28.20	29.69
NBD - New Belgrade	7.4	4.730	6,738	7.41	7.76
Total	35.6	8.370	18,379	35.61	37.45

The high value of Pearson's correlation coefficient (0.964) for *automobile* passenger kilometres per capita and total CO_2 emissions of urban transport (for our sample of 36 metropolises) illustrates the importance of *automobile* mobility in total CO_2 emissions in urban transport (Fig. 2).

Thus, it is apparent that the increase in the efficiency of motor vehicle fuel consumption – a thesis frequently promoted by supporters of an auto-dependent transport policy, such as Dunn [45] – does not decrease CO_2 emissions and save energy in urban transport. The most important role in this process is clearly played by: a) the rapid rise in level of mobility and b) the sharply increasing share of automobiles used in urban transport.

These are the main reasons why U.S. cities, with their highest level of motorized mobility in the world, also have the highest CO_2 emissions and energy consumption per capita ever registered in urban transport [42, 43].

At the same time, urban transport CO_2 emissions in developing world metropolises is almost insignificant today. Their CO_2 emission is 8.7 times lower than that of U.S. cities. However, due to the fact their populations will be four times larger than the population of the developed world metropolises by 2025 (doubling within 2000-25 from 735 million to 1.4 billion [46]), a further increase in motor vehicle use in developing countries will have devastating effects on global CO_2 emissions. If the developing metropolises follow the example of auto-dependent, low-density suburban development, unforeseeable consequences in the succeeding decades will ensue, with CO_2 emissions in urban transport 11 times higher.

Table 5. Passenger kilometres per capita in 24 cities (1960 and 1990) [30].

Cities	Automobile (pkm / per capita)		Public urban transport (pkm / per capita)	
	1960	1990	1960	1990
USA*	8,289	14,981	666	620
Australia	5,489	10,797	1,409	882
Western Europe	2,503	6,602	1,472	1,895

* data for 1960 are not available for Washington, Detroit, or Houston

Table 6. Urban transport in 63 cities (in passenger kilometres) (1995) [31].

Cities	Urban transport - total (pkm)	Private transport (automobile + motorcycle) (pkm)	Urban public transport (total) (pkm)	Urban public transport share in total pkm (%)
USA	18,743	18,200	544	2.9
W. Europe	7,804	6,321	1,483	19.0
wealthy Asian	7,340	3,971	3,369	45.9
developing c.	4,303	2,539	1,764	41.0
China	2,451	1,103	1,348	55.0
in transition	6,225	2,926	3,299	53.0
Belgrade*	6,066	1,502	4,563	75.2

* author's calculation for Belgrade for 2011

Table 7. Urban transport passenger kilometres per capita in 32 cities (1995 and 2005) [33].

Cities	Automobile (pkm / per capita)		Public urban transport (pkm / per capita)		Total transport (pkm / per capita)	
	1995	2005	1995	2005	1995	2005
USA	18,155	18,703	496	569	18,867	19,542
Australia	12,114	12,447	967	1,077	13,487	13,843
Europe	6,424	6,789	1,700	2,080	8,856	9,838
wealthy Asian	1,971	1,971	3,175	3,778	5,603	6,406
Prague	4,343	7,044	4,307	5,183	9,243	12,519

In short, it is obvious that a major decrease of CO_2 emissions of Belgrade urban transport are to be made in stopping its further increase in automobile mobility.

Results and Discussion

Different Scenarios for Belgrade's Future Urban Transport CO_2 Emissions

Compared to other world metropolises, Belgrade has a relatively low level of CO_2 emissions in urban transport today. Unlike metropolises of Eastern European countries [47], in Belgrade (due to the economic crisis) neither the level of private motorization (300 cars per 1,000 people), nor automobile passenger kilometres have changed much during the last 15 years (the only change being that old vehicles have been replaced by second-hand cars imported from Western Europe). Nevertheless, although the level of *automobile* CO_2 emissions in Belgrade is very low (228 CO_2 kg/per capita, due to the low volume of automobile passenger kilometres: 1,502 pkm), the fact must not be overlooked that *automobile* mobility is of major importance to total level of energy

Table 8. Energy consumption of urban transport in 63 cities (in MJ/passenger km) (1995) [31].

Cities	Private transport (automobile + motorcycle) (MJ/pkm)	Bus (MJ/pkm)	Tram (MJ/pkm)	Metro (MJ/ pkm)	Energy use ratio of different transport modes		
					Private tr. / Bus	Bus / Metro	Private tr. / Metro
USA	3.25	2.85	0.99	1.65	1.1	1.7	1.97
W. Europe	2.49	1.17	0.72	0.48	2.1	2.4	5.2
wealthy Asian	2.33	0.84	0.36	0.19	2.9	4.4	12.3
developing	1.78	0.66	-	0.46	2.7	1.4	3.9
China	1.69	0.26	-	0.05	6.5	5.2	33.8
in transition	2.35	0.56	0.74	0.21	4.2	2.7	11.2
Belgrade*	2.10	0.44	0.375	0.16**	4.8	2.75*	13.1*

* author's calculation for Belgrade for 2011 **Urban rail (BG voz)

Table 9. Urban transport CO_2 emissions (in kg/ per capita) and average daily motorized mobility in 63 cities (in pkm / per capita) (1995) [31].

Cities	Average daily motorized mobility		Daily private mobility (automobile + motorcycle)			Urban transport CO_2 emissions (in kg)	
	pkm/per capita	Ratio world metropolises/ USA cities (=1)	pkm/per capita	Ratio world metropolises/ USA cities (=1)	Private mobility share in pkm/per capita (%)	CO_2 kg /per capita	Ratio world metropolises/ Belgrade (=1)
USA	51.3	1	49.9	1	97.2	4,405	11.28
W. Europe	21.4	2.4	17.3	2.9	80.8	1,269	3.25
wealthy Asian	20.1	2.55	10.9	4.6	54.2	825	2.11
developing c.	11.8	4.36	7.0	7.1	59.3	509	1.30
China	6.7	7.65	3.0	16.6	44.8	213	0.54
in transition	17.1	3.01	8.0	6.2	46.8	694	1.78
Belgrade*	16.6	3.09	4.1	12.2	24.8	390.6	1

* author's calculation for Belgrade for 2011

consumption in urban transport, and it can change surprisingly quickly.

In Prague, for example, although the city is strongly public-transport oriented with annual transit boarding per capita ever-rising and among the highest in the world [33] (in 1995-2005 automobile passenger kilometres rose extremely quickly – from 4,343.5 to 7,044.5 passenger kilometres per capita, or more than 62%) [48]. Hence, in 2005 energy consumption of Prague's urban transport (20,403 MJ/person) surpassed by 22% the level of the urban transport energy consumption of West European metropolises in 1995 (16,793 MJ/person).

In Table 10 we gave different scenarios for Belgrade's future urban transport CO_2 emissions: a) current CO_2 emissions, b) CO_2 emissions when Belgrade reaches the automobile mobility level of cities in countries in transi-

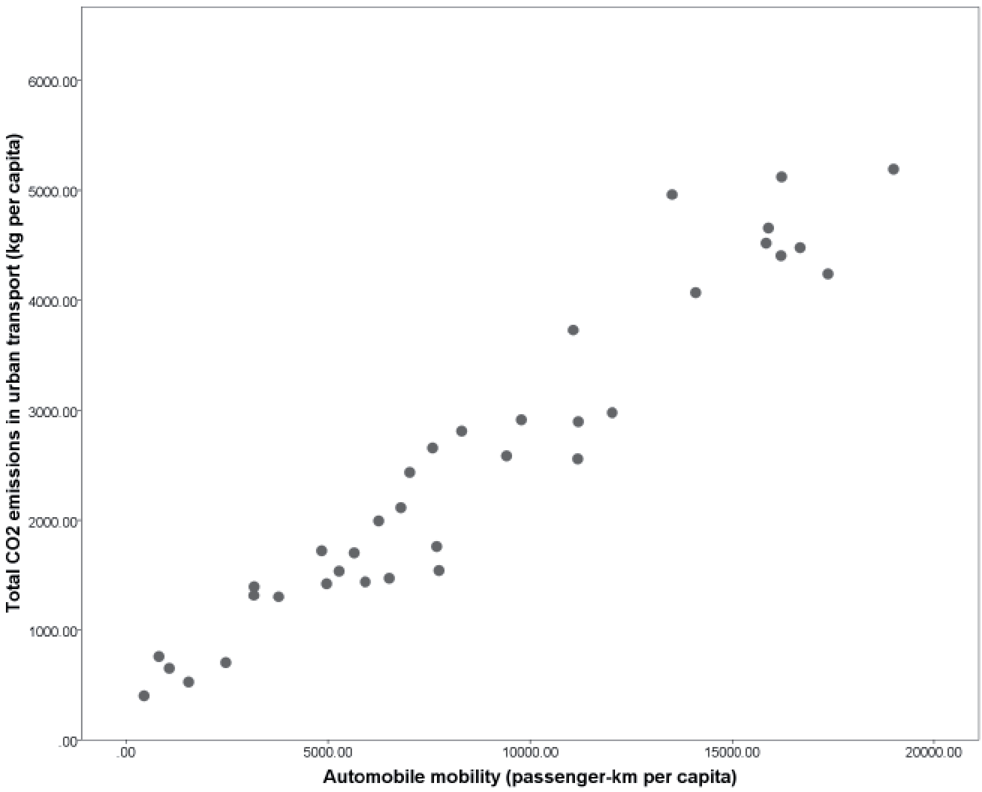

Fig. 2. Correlation between automobile mobility and CO_2 emissions in urban transport.

Table 10. Different scenarios of Belgrade's future urban transport CO_2 emissions [35].

	Automobile (pkm)	Urban Public Transport (pkm)	Total (pkm)	Automobile (CO_2 kg /per capita)	Urban Public Transport (CO_2 kg / per capita)	Total (CO_2 kg /per capita)
Belgrade today	1,502	4,563	6,066	227.7	162.9	390.6
Belgrade – "East EU" scenario	2,907	4,563	7,470	491.9	162.9	654.8
Belgrade – "West EU" scenario	6,202	4,563	10,765	1,128.6	162.9	1291.5

Source: author's calculation according to [35]

tion, and c) CO_2 emissions when Belgrade reaches the automobile mobility level of cities in Western Europe.

Belgrade's urban transport CO_2 emissions will be 1.8 times higher when the city reaches the automobile mobility level of metropolises in countries in transition recorded in 1995 (Tables 8 and 9). When the automobile mobility level of metropolises in West European countries recorded in 1995 is reached (Tables 8 and 9), it will be 3.3 times higher. Hence, *traffic limitation strategies* (like those applied in Singapore, Hong Kong, London, etc.) are of the utmost importance.

Belgrade's urban *public* transport share in total urban transport CO_2 emissions (approximately 41.7%) is the highest in our sample of cities. Even urban public transport modes that use electricity (trams, trolleys, urban rail; due to extremely high dependency on coal for electricity production) are causing serious negative environmental effects [49, 50]. But the most important fact is that due to its extremely high share of regular *buses*, urban public transport of Belgrade is not as CO_2-efficient as it should be (Tables 11 and 12). If urban form (high population densities and concentration of jobs in the CBD) supports rail use, its CO_2 emissions are much lower than emissions of regular buses; even the old Russian urban rail proved to have 4.5 times lower CO_2 emissions, while recently imported and tested Swiss (Flirt) urban trains have even 12.6 times lower CO_2 emissions than buses in Belgrade.

Unfortunately, the public transport strategy has concentrated on buses, which are incapable of accommodating the rapidly rising transport demand, and on the introduction of parking zones in the central area of the city.

Although express buses have been strongly promoted [32], Belgrade is completely unsuitable for this type of transport strategy (especially in its central zone) due to a) its spatial structure and b) its narrow, inadequate street network [51].

The recent construction of an inner semi-ring road and additional bridges over the Sava River has been done without an accompanying strategy of land-use changes and without considering infrastructure-induced mobility (so-called hidden transport demand [52]). Hence, these huge investments are merely a temporary antidote, and not a long-lasting, valid solution.

It is usually completely overlooked that with its strong public transport (bus) orientation, insufficient street capacities (about 67% of the primary urban street network are single lane per direction [53]), as well as its frequent and heavy road congestions, Belgrade has for a very long time been ready not only for a much stricter private motor vehicle limitation strategy, but also for a rail (metro or LRT) system with completely separated, exclusive right of way [42, 53].

As Vuchic points out, a transit mode is defined by its three basic characteristics: a) right-of-way (ROW)

Table 11. Urban public transport share in total urban transport CO_2 emissions (in %) (1995) [35].

Cities	Urban transport energy consumption (MJ/per capita)			Urban public transport share in Total urban transport CO_2 emission(in %)
	Total (kg CO_2/per capita)	Private (automobile + motorcycle) (kg CO_2/per capita)	Urban public transport (kg CO_2/per capita)	
USA	4,405	4,322	83	1.9
W. Europe	1,269	688	162	10.6
wealthy Asian	825	688	162	19.7
developing c.	509	441	96	18.8
China	213	180	33	15.5
in transition	694	480	214	30.8
Belgrade*	390.6	227.7	162.9	41.7

* author's calculation for Belgrade for 2011

Table 12. Belgrade's urban public transport CO2 emissions for 2011 (% share).

	Bus	Tram	Trolleybus	Urban rail (BG voz)
% share	77.3 %	16.8 %	3.5 %	2.4 %

Source: author's calculation

category, b) system technology, and c) type of service. Transit modes vary with each of these characteristics. Belgrade has struggled with the strategic decision of choosing between a metro, light rail, or express-bus option; however, contrary to the common belief that technology mostly determines modal characteristics, the ROW category has a major influence on both performance and costs of modes [40].

In past decades different *rail* proposals have substituted each other, from metro (in 1958, 1968, 1976, 1982, and 2004), to light rail (in 2006) [54]. It is usually stressed that for the construction of a new urban rail system, more than five million people and a GDP per capita above US$ 1,800 are needed for such a project to be economically viable [55]. But, as Vuchic rightly points out, it is not such a simple, straightforward relationship [40], since high population densities and the high level of job concentration in the CBD are even more important.

In this respect, especially encouraging was the recent introduction (2011) of *BG voz*, a 25 km line of urban rail system (with 7 km running through tunnels under the central part of the city at 15-minute intervals during rush hours) that serves the city of Belgrade. This first urban rail line runs through six Belgrade municipalities: Zemun, Novi Beograd, Savski Venac, Vračar, Zvezdara, and Palilula, with over 700,000 inhabitants in total (the residential areas of these municipalities through which the line runs have approximately 200,000 inhabitants).

In short, a variety of measures can counter rising CO_2 in the urban transport sector. The most obvious choice for Belgrade is: a) measures that limit the use of motor vehicles and promote improvement of their technical efficiency, b) the promotion of public transport, walking, and cycling, and c) spatial planning measures aimed at reducing the total demand for transport in the city.

Of great importance here are precisely defined phases of implementation of these urban transport policy measures. The phase in which restrictive instruments on private transport and measures for the promotion of urban public transport are introduced is crucial. While the degree of private car use is still relatively modest, it is very likely that the applied package of measures will obtain the desired results.

In this context it can be concluded, as Jovanović [38] points out, that Belgrade can prevent a dramatic increase in CO_2 emissions (and mitigate the negative local environmental effects of traffic congestion, traffic accidents, and local air pollution) only if it:

- Implements a more decisive strategy of limiting private vehicles use, while its level of car passenger km (PKT) is still relatively low (as was done in wealthy Asian metropolises at a similar stage of development).
- Does not try to solve its transport problems only by building a network of urban road infrastructure (bridges and ring roads).
- Continues to provide priority movement for buses (a dominant form of public transport), while …
- Strongly orienting itself toward the development of urban rail systems (metro or LRT) with separate, exclusive tracks that are completely immune to traffic congestion on urban streets [38].

In short, if Belgrade adopts a transport and spatial development strategy like the one wealthy Asian metropolises applied at a similar stage of development [43, 56], there is a good chance that its total urban transport CO_2 emissions will stop at a reasonable level of around 700-800 kg CO_2/per capita.

Conclusions

It is evident that the strongly promoted thesis that significant reductions of CO_2 emissions in the sphere of urban transport could be made by increasing the efficiency of motor vehicles has not provided the planned results. This is clearly proven in the huge CO_2 emissions in the urban transport of U.S. cities.

The most important role in this process is definitely played by a) the dramatically increasing level of personal mobility and b) the sharp rise of automobile use in urban transport.

These are the main reasons why U.S. cities, which have the highest level of motorized mobility and use of automobiles in the world, also have the highest level of CO_2 emissions in urban transport ever recorded.

If the metropolises of developing countries follow the example of the auto-dependent, low-density suburban development of U.S. cities, as imposed by globalization, there will be unforeseeable consequences in the succeeding decades as it will result in 11-times higher CO_2 emissions in their urban transport in 2025 (compared to 2000).

Obviously, Belgrade is now at a major crossroads. Although the level of *automobile* CO_2 emissions in Belgrade is still very low (228 CO_2 kg/per capita, due to the low volume of automobile passenger kilometres: 1,502 pkm), the fact must not be overlooked that *automobile* mobility is of major importance to the total level of energy consumption in urban transport, and it can change surprisingly quickly. Only if it adopts a transport and spatial development strategy similar to that applied by wealthy Asian metropolises at a similar stage of development is there a very high possibility that its total urban transport CO_2 emissions will stop at a reasonable level of around 700-800 kg CO_2/per capita.

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References

1. OECD/IEA. Key World Energy Statistics. OECD/IEA, **2011**.
2. METZ B., DAVIDSON O.R., BOSCH P.R., DAVE R., MEYER L.A. (Eds.). Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, **2007**.
3. IEA. World Energy Outlook. IEA, **2008**
4. CREUTZIG F., MCGLYNN E., MINX J., EDENHOFER O. Climate policies for road transport revisited (I): Evaluation of the current framework. Energy policy. **39** (5), 2396, **2011**.
5. STERN N. The Economics of Climate Change: Stern Review. Cambridge University Press: Cambridge, **2007**.
6. RAUX C. The potential for CO_2 emissions trading in transport: the case of personal vehicles and freight. Energy efficiency. **3** (2), 133, **2010**.
7. KENWORTHY J. Decoupling urban car use and metropolitan GDP growth. World Transport Policy and Practice, **19** (4), 7, **2013**.
8. NEWMAN P., KENWORTHY J. 'Peak Car Use': Understanding the Demise of Automobile Dependence. World Transport Policy and Practice. **17** (2), 31-42, **2011**.
9. JOUMARD R. The stakes of air pollution in the transport sector, from the French case. *Atmospheric Environment*. **39**, 2491, **2005**.
10. ACEA–Association Des Constructeurs Européens D'automobiles. ACEA' s CO2 commitment, **2002**. Available at: http://www.acea.be/acea/ brochure_co2.pdf. Accessed February 13, 2015.
11. MEHLIN M., GUEHNERMANN A., AOKI R. Preparation of the 2003 review of the commitment of car manufacturers to reduce CO_2 emissions from M1 vehicles. Final Report of Task A: Identifying and assessing the reasons for the CO_2 reductions achieved between 1995 and 2003. Berlin: German Aerospace Center, Institute of Transport Research, **2004**.
12. HEAVENRICH R.M. Light-Duty Automotive Technology and Fuel Economy Trends, 1975 Through 2005. U.S. Environmental Protection Agency Report EPA-420-R-05-001. US EPA, **2005**.
13. FRONDEL M., RITTER N., VANCE C. Heterogeneity in the rebound effect: Further evidence for Germany. Energy Economics. **34**, 461, **2012**.
14. FONTARAS G., SAMARAS Z. A quantitative analysis of the European Automakers' voluntary commitment to reduce CO_2 emissions from new passenger cars based on independent experimental data. Energy Policy. **35**, 2239, **2007**.
15. EIA – U.S. Energy Information Administration. International Energy Outlook 2013. Washington DC: EIA, **2013**.
16. SCHAFER A. Regularities in Travel Demand: An International Perspective. Journal of Transportation and Statistics. **3** (3), 1, **2000**.
17. IEA–International Energy Agency. Transport, Energy and CO_2 – Moving Toward Sustainability. OECD/IEA, **2009**.
18. IEA–International Energy Agency. World Energy Outlook. Paris: International Energy Agency, **2010**.
19. CHARPENTIER A., BERGERSON J., MACLEAN H. Understanding the Canadian oil sands industry's greenhouse gas emissions. Environmental research letters. 4, **2009**.
20. JOVANOVIĆ M. Kuznets curve and urban transport - the scope of I+M programs. Glasnik srpskog geografskog društva (Bulletin of the Serbian Geographical Society). **92** (4), 127, **2012**.
21. Federal Environmental Agency. Reducing CO_2 emissions in the transport sector – A description of measures and update of potentials. Berlin: Federal Environmental Agency, **2003**.
22. OECD. Cities and Climate Change. Paris: OECD, **2010**.
23. UN-Habitat. Urban patterns for a green economy: leveraging density. UN-Habitat, **2012**.
24. MACLEAN L. H., LAVE L. Evaluating automobile fuel/propulsion system technologies. Progress in Energy and Combustion Science. **29**, 1, **2003**.
25. PASAOGLU G., HONSELAAR M.,THIEL C. Potential vehicle fleet CO_2 reductions and cost implications for various vehicle technology deployment scenarios in Europe. Energy Policy, **40**, 404, **2012**.
26. THIEL C., PERUJO A., MERCIER A. Cost and CO_2 aspects of future vehicle options in Europe under new energy policy scenarios. Energy Policy, **38**, 7142, **2010**.
27. THIEL C., SCHMIDT J., VAN ZYL A., SCHMID E. Cost and well-to-wheel implications of the vehicle fleet CO_2 emission regulation in the European Union. Transportation Research Part A, **63**, 25-42, **2014**.
28. ELGOWAINY A., ROUSSEAUA A., WANG M., RUTH M., ANDRESS D., WARDD J., JOSECK F., NGUYEND T., DAS S. Cost of ownership and well-to-wheels carbon emissions/oil use of alternative fuels and advanced light-duty vehicle technologies. Energy for Sustainable Development, **17**, 626, **2013**.
29. PRIEUR A., TILAGONE R. A detailed Well to Wheel Analysis of CNG compared to diesel oil and gasoline for the French and the European markets. SAE Technical Paper 2007-01-0037, **2007**.
30. KENWORTHY J., LAUBE F, NEWMAN P., BARTER P, RAAD T., POBOON C., GUIA B. An International Sourcebook of Automobile Dependency in Cities. Un. Press of Colorado: Boulder, **1999**.
31. KENWORTHY J.R., LAUBE F. The Millennium Cities Database. UITP, Brussels, **2001**
32. World Bank. Cities on the Move. World Bank: Washington DC, **2002**
33. NEWMAN P., KENWORTHY J.R. The End of Automobile Dependence. Island press: Washington, **2015**.
34. United Nations. Energy Balances 2012. United Nations: New York, **2015**. Available at: http://www. http://unstats.un.org/unsd/energy/balance/default Accessed September 23, 2015.
35. Institute For Informatics And Statistics. Statistical Yearbook of Belgrade 2012. Institute for Informatics and Statistics, **2013**.
36. Faculty Of Transport And Traffic Engineering. Belgrade Transport Model. Faculty of Transport and Traffic Engineering: Belgrade, **2007** [In Serbian].
37. Faculty Of Transport And Traffic Engineering. Istraživanje karakteristika transportnih zahteva, transportne ponude, efikasnosti i kvaliteta sistema javnog masovnog transporta putnika u Beogradu (Study of the characteristics of transport demands, transport supply, efficiency and quality of the system of mass public transport of passengers in Belgrade). Faculty of Traffic and Transport Engineering – Institute SF: Belgrade, **2002** [In Serbian].

38. JOVANOVIĆ M. Urban transport energy consumption - Belgrade case study. Thermal Science. **19** (6), 2079, **2015**.
39. JOVANOVIĆ M., RATKAJ I. Functional Metamorphosis of New Belgrade. disP - The planning review, **50** (4), 54, **2014**.
40. VUCHIC V. Urban Transit Systems and Technology. John Wiley & Sons, **2007**.
41. NEWMAN P., KENWORTHY J. Urban Design to Reduce Automobile Dependence. Opolis, **2** (1), 35-52, **2006**.
42. JOVANOVIĆ M. Međuzavisnost koncepta urbanog razvoja i saobraćajne strategije velikog grada (Interdependence of Urban Transport Strategy and Spatial Development of a Metropolis). Faculty of Geography Belgrade: Belgrade, **2005** [In Serbian].
43. BARTER P. An International Comparative Perspective on Urban Transport and Urban Form in Pacific Asia. Murdoch University: Perth, **2000**.
44. KENWORTHY J. Transport Energy Use and Greenhouse Gases in Urban Passenger Transport Systems: A Study of 84 Global Cities, Third Conference of the Regional Government Network for Sustainable Development, Notre Dame University, Fremantle, Western Australia, September 17, **2003**.
45. DUNN J. Driving Forces; The Automobile, Its Enemies and the Politics of Mobility. The Brookings Institution: Washington DC, **1998**.
46. United Nations. World Urbanization Prospects: the 2009 revision. United Nations: New York, **2010**.
47. CHATELUS G. Central and Eastern European countries. In: Transport: New Problems, New Solutions. ECMT: Paris, **1996**.
48. KENWORTHY J. Total Daily Mobility Patterns and Their Policy Implications for Forty-Three Global Cities in 1995 and 2005. World Transport Policy and Practice. **20** (1), **2014**.
49. OKA S., GRUBOR B., DAKIĆ D., ILIĆ M., MANOVIĆ V., ERIĆ M., PAPRIKA M., OKA N., BELOŠEVIĆ S., MLADENOVIĆ R., CRNOMARKOVIĆ N. Investigation of the suitability of Serbian lignite Kolubara and Kovin for burning in CFBC boilers. Termotehnika. **1-4**, 83, **2004**.
50. BRNABIC A. Serbian Energy and Climate Policy: a Critical Perspective. SÜDOST EUROPA Mitteilungen, **2014**.
51. JOVIĆ J., ĐORIĆ V. Traffic and environmental street network modelling: Belgrade case study. Transport. **25** (2), 155, **2010**.
52. CERVERO R., HANSEN M. Induced Travel Demand and Induced Road Investment: A Simultaneous Equation Analysis. Journal of Transport Economics and Policy. **36** (3), 469, **2002**.
53. JOVANOVIĆ M. Sustainable urban transport and spatial development of Belgrade. In: Sustainable urban & transport planning – SUTP 2013. MARTINS N. (Ed.). UNIDO: Belgrade, 75, **2013**.
54. KORICA R., FURUNDZIC D. Metro or Light Rail: Belgrade Transport Proposals, Proceedings, Real Corp 2011-Change for Stability: Lifecycles of Cities and Regions, Essen, Germany, 613, **2009**.
55. LOO B., LI D. Developing metro systems in the People's Republic of China: Policy and gaps. Transportation. **33**, 115, **2006**.
56. JOVANOVIĆ M. Gradski saobraćaj i životna sredina (Urban Transport and Environment). Faculty of Geography Belgrade: Belgrade, **2014** [In Serbian].