iipp publishing

Journal of Quality and System Engineering

ISSN 2812-975X

1 (2022) 1

Journal homepage www.q-sci.rs

E-mobility in public transport in Belgrade experiences, challenges, and expectations

Slobodan Misanovic,

Project manager, JKP GSP Beograd, Knjeginje Ljubice 29, Beograd, Serbia

Abstract

The introduction of low and zero-emission buses in public urban transport systems has a constant tendency in many cities around the world as an effective way to reduce air pollution and decarbonization in the cities where they are used. For E-mobility in the cities, an important role is played by the increasingly widespread use of fully electric buses.The paper will present current directives in the European Union related to the implementation of low and zero-emission vehicles. Experiences in the application of fully electric buses in Belgrade from the aspect of environmental and energy benefits and tendencies of further development will be specially presented.

Key words

E-mobility
E-bus
Zero-emission vehicle
Environmental
Energy efficiency

Corresponding author

slobodan.misanovic@gsp.co.rs

Article info

Original Scientific Paper
Received 09.05.2022.
Accepted 18.05.2022.
Online available 20.05.2022.

1. Introduction

The transport sector occupies an important place in meeting the needs of society in the transport of goods and passenger transport, but it is also a source of emissions of harmful gases and carbon dioxide as a result of burning fossil fuels. The use of fossil fuels is directly proportional to the industrial and economic development of a country, region, or city [1]. According to Borovik, currently, 75% of the population in Europe lives in cities, which will lead to a further increase in carbon dioxide emissions and pollution related to traffic and transport [2]. In 2020, emissions of carbon dioxide (CO2) from the transport sector amounted to 24% [3], as a result of burning fossil fuels, primarily petroleum products, which accounted for 57% of total oil consumption globally [4]. Trends of population growth in the city also affect the increase in the number of vehicles, which imposes the growing importance of the use of alternative propulsion in vehicles (electric vehicles, hydrogen, natural gas, etc.) and the use of renewable energy sources. In the transport sector, the activity of passenger transport is very important.

The bus subsystem of public city transport in cities is one of the most important segments of the city's urban life. The use of fully electric propulsion in public transport buses should further reduce the level of emissions from urban traffic, increase energy efficiency and contribute to the strategy of using zero-emission vehicles in cities, which is planned after 2050 [5,6].

2. Legislation in EU countries in the application of alternative fuels and zero and low-emission vehicles

In 2014, the European Union adopted Directive 94/2014/EC on the increasing use of alternative fuels for commercial vehicles in the public sector for European Union countries [7]. Special emphasis is placed on the use of the following energy sources:

- Electricity

- Hydrogen
- Biofuels
- Synthetic fuels
- Natural gas (CNG, LPG), including biomethane
- Liquefied petroleum gas (LPG)

In 2019, the Clean Vehicle Directive 2019/1161 was adopted, which defines vehicles in the commercial vehicle sector (categories N2, N3, and M3) [8]:

"Zero-emission" vehicles, which do not have internal combustion engines and whose CO2 emissions do not exceed 1 g/kWh according to the criteria of Regulation EC 595/2009, or 1 g/km according to the criteria of Regulation EC 715/2007. Zero-emission vehicles include electric-powered buses (battery-powered or super-capacitor), fuel-cell-powered buses, and trolleybuses when operating in autonomous mode and using battery-powered electricity.

Low-emission vehicles that use some of the alternative fuels defined by Directive 94/2014/EC. Low-emission vehicles include CNG buses (compressed natural gas). PHEV (Plug-in) Hybrid buses, where most of the driving is done by an electric motor, are classified as low-emission vehicles regardless of fuel, whilst ''regular'' Hybrid buses can only be classified as low-emission vehicles when liquid biofuels, synthetic and paraffinic fuels are used and not blended with conventional fossil fuels (diesel/petrol). Clean Vehicle Directive 2019/1161, entered into force in August 2021 and is binding on EU members. It defines the representation of low and zero-emission buses (M3) in the procurement of new vehicles, as shown in Table 1.

For the period from January 1, 2026, to December 31, 2030, the representation in the procurement of buses (M3) with low and zero emissions will be proportionally increased by 44% compared to the previous period.

3. E-mobility, Examples of good practice in the use of electric buses in the world

The rapid development of battery technology and charging systems has contributed to the concept of electric buses since 2008 being more and more present in many cities, especially in China, Europe, and North and South America. It can be considered that the concept of the electric drive today has the greatest prospects for use in buses used in the public transport system, given that the performance of electric buses in terms of operational requirements (autonomy, capacity, charging time) has such a level that they can be a successful replacement for conventional buses [9].

Table 1. Representation in the procurement of new buses for the period August 2, 2021, to December 31, 2025, according to Directive 2019/1161

EU Country	Low-emission (M3)	Zero-emission (M3)
Luxemburg	45%	22.5%
Sweden	45%	22.5%
Denmark	45%	22.5%
Germany	45%	22.5%
Netherlands	45%	22.5%
Austria	45%	22.5%
Belgium	45%	22.5%
Italy	45%	22.5%
Ireland	45%	22.5%
Spain	45%	22.5%
Cyprus	45%	22.5%
Malta	45%	22.5%
France	43%	21.5%
Czechia	42%	21%
Lithuania	42%	21%
Finland	41%	20.5%
Hungary	37%	18.5%
Portugal	35%	17.5%
Latvia	35%	17.5%
Slovakia	34%	17%
Bulgaria	34%	17%
Greece	33%	16.5%
Poland	32%	16%
Estonia	31%	15.5%
Slovenia	28%	14%
Croatia	27%	13.5%
Romania	24%	12%

China is a world leader in the production of electric buses and their application in many public transport systems. According to data from May 2020, the total number of e-buses in China was about 420,000, which is 99% of the total number of e-buses in the world [10]. The introduction of electric buses in Chinese cities is a state project, as one of the measures to reduce air pollution, especially in large cities: Beijing, Shanghai, Shenzhen, etc. The city of Shenzhen is the first city in the world to have 16,500 electric buses in operation since 2018, making the bus subsystem of public city transport 100% "electrified" [9]. In 2020, the largest number of electric buses is in Guangdong Province, with 86,000 vehicles, followed by Shandong Province, with 45,000, and Jiangsu with 20,000 vehicles [11]. After China, the largest number of electric buses used in public transport systems is in Europe. The introduction of fully electric buses in Europe dates back to 2013, when in some cities: Rotterdam, Milan, Barcelona, Bremen, London, Copenhagen, Hamburg, etc., trial tests were conducted, usually with one or two E-buses. According to the official results of the ZeEUS project report published in October 2017, there were 859 electric buses in 90 cities in Europe [12]. A significant increase in the number of newly registered electric buses is present during 2020 and 2021.

According to the Chatrou CME Solutions report from January 2022 in the EU countries, the United Kingdom, Norway, Iceland, and Switzerland, the number of newly registered E-buses in 2021 was 2788, which is an increase of 48.6% compared to 2020 when the number of newly registered e-buses was 1875 vehicles. Except in the countries of Western Europe and the EU, the trend of introducing electric buses is present in the Russian Federation. In September 2018, the city of Moscow put into operation the first 15 electric buses. In 2019, the procurement of 285 electric buses manufactured by KAMAZ and GAZ was realized, which makes Moscow one of the leading cities outside China in terms of the number of electric buses. The trend of introducing electric buses in Moscow continued in 2020 when there were 600 E-buses on 24 city lines [13]. The trend of purchasing new E-buses continued in 2021 when the total number of electric buses reached the number of 1000 vehicles. Table 2 shows the cities in Europe where E-buses are widely used.

Table 2. Number and type of E-buses in some European cities

City	Number of E-bus	Manufacturer, type
Moscow (RU)	1000	Kamaz 12 m, Liaz 12m
London (UK)	728	BYD-ADL, dd
Pariz (F)	400	Bluebus, 12m
Milan (I)	265	Solaris, 12m
Warsava (P)	162	Solaris, 12m
Goteborg (S)	145	Volvo, 12m
Amsterdam (NL)	131	VDL, 18m
Berlin (D)	138	Solaris, 12m
Hamburg (D)	101	Mercedes, 12m
Bergen (N)	103	Yutong, 12m
Madrid (E)	81+56	Irizar, 12m

Electric buses are in operation in some cities in North and South America. In 2020, the total number of E-buses in the United States reached 2,800 vehicles [14], while at the end of 2021, the total number was 3,364, of which 169 were fuel cell-powered. At the end of 2021, there were 569 electric buses with batteries and 10 with fuel cells in operation in Canada [11]. In South America, the leader in the use of electric buses is Santiago de Chile with 776 vehicles [25]. Electric buses are widely used in Bogotá 655 as well as in Mexico City and Medellin [11]. As of 2020, there are 20 electric buses in the Uruguayan capital, Montevideo. South American cities: Buenos Aires, Panama City, and San Jose plan to buy electric buses in the near future [11].

4. E-mobility in Public Transport of Belgrade

In Belgrade the bus subsystem is the holder of the function of public transport. There are 1040 diesel buses in operation on week days. Buses of the largest carrier JKP GSP "Beograd" participate with 640 buses on weekdays and use about 31.29 million liters of Euro-diesel fuel for the realization of the planned annual transport work [9]. The reduction of air pollution in Belgrade from the impact of traffic can be significantly improved by energy, environmental and technical-operational measures in the bus subsystem of public city transport, and as one of the most efficient ways is the substitution with electric buses. It is for these reasons that the bus subsystem of public transport has gained in importance as the main promoter of new technologies in the implementation of the city's sustainable development strategy.

4.1. E-bus lines EKO 1 and EKO2

In Belgrade, the first line of public city transport EKO 1 (Vukov spomenik-Belvil), on which only fully electric buses operate, was put into operation on September 1, 2016. The introduction of five fully electric buses in regular traffic is a significant development project a new concept of environmentally and energy-efficient vehicles in public transport. City line EKO1 is a new line that is purposely designed and adapted for the operation of fully electric buses Higer KLQ6125GEV3, in order to maximize the energy and environmental benefits of E-buses in the central city area of Belgrade. Line EKO 1 is a diametrical city line that connects the old part of Belgrade with New Belgrade, passing through the central city zone. The average length of the EKO 1 line is 7.995 m. Observed by directions, the length of the route in the direction "A" is 7.477 m, where there are 15 stations with an average inter-station distance of 534 m. In the direction "B", the length of the route is 8.513 m, where 17 stations are positioned with an average inter-station distance of 532 m. On the EKO 1 line, there are 4/5 electric buses in operation, which work throughout the day with an arrival interval of 15 minutes.

The spatial position of the route of the EKO 1 line is shown in Fig. 1.

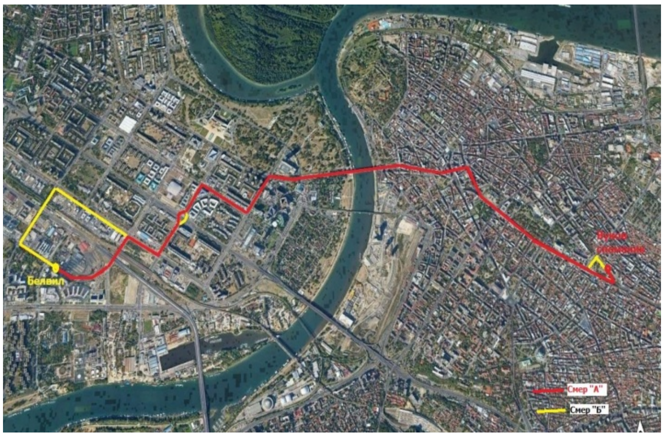

Fig. 1. Spatial position of the line EKO 1

Line EKO 2 (Dorćol/Sports and Recreation Center Milan - Gale Muškatirović-Belgrade on the water), on which electric buses operate, was put into operation on January 24, 2022. years. After the EKO 1 line, it represents continuity in the introduction of electric buses in the public city transport system of Belgrade. Line EKO 2 is a city diametrical line that provides passengers with good connections with urban areas of high attraction: Kalemegdan, Republic Square, Terazije, Slavija, Sava Promenade, TC Gallery. The average length of the line is 6.72 km. The number of stops in the "A" direction is 15, while in the "B" direction there are 16 stops. The average inter-station distance is 457 m. There are 8 electric buses in operation on the EKO 2 line, which work throughout the day with an arrival interval of 10 minutes. The spatial position of the route of the EKO 2 line is shown in Fig. 2.

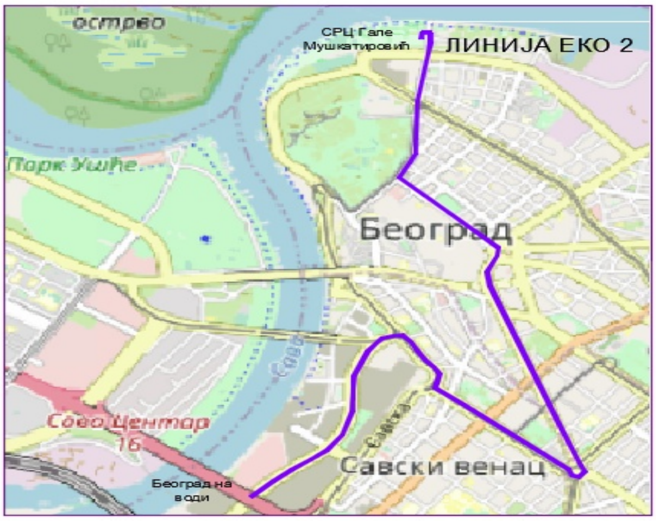

Fig. 2. Spatial position of the line EKO 2

4.2. E-bus Higer KLQ6125GEV3

The fleet of Higer KLQ6125GEV3 electric buses has a total of 15 vehicles. The first series of 5 vehicles were procured in 2016 and the second series of 10 vehicles were procured in 2021.

The fully electric bus Higer KLQ6125GEV3 is a modern low-floor standard city bus that meets all technical requirements in accordance with Directive EC/2007/46. The E-bus use super capacitor technology to store electricity with a capacity of 20/40 kWh. Electric bus Higer KLQ6125GEV3 is shown in Fig. 3 and Fig. 4.

Fig. 3. Higer KLQ6125GEV3, from 2016.

Fig. 4. Higer KLQ6125GEV3, from 2021.

The basic technical characteristics are shown in Table 3.

Table 3. Technical characteristics Higer KLQ6125GEV3

	Higer KLQ6125GEV3, Production from 2016.	Higer KLQ6125GEV3, Production from 2021
Length/width/height	12000/2550/3680 mm	12000/2550/3680 mm
Curb weight	12540 kg	12190 kg
Passengers	82+1	90+1
Doors	2x2	3x2
Max. speed	70 km/h	70 km/h
Supercapacitor	AOWEI 20 kWh	AOWEI 40 kWh
Charging time	5-10 minutes	5-10 minutes
Traction motors	Siemens(x2)1PV5135, asynchronous	1DB2016 6NB06, permanent magnet
Power	2x67kW,2x90kW, 2x150kW	160 kW/230kW
Max. Torque	2x430 Nm	2500 Nm
Inverter	DC/AC 430-585 V	DC/AC 600-720 V
Traction control	Siemens 10DT6	Siemens ELFA 3

4.3. Infrastructure for charging

The E-bus charging system is with fast charging which is performed at the initial-final stops (terminals) where chargers are installed. On the EKO 1 line, the power of the charger at the terminal is 150 kW.

Fig. 5. Line EKO 1, Terminal Belvil

Two chargers with a total power of 2x400 kW are installed on the EKO2 line at each terminal.

Fig. 6. Line EKO2, Terminal Belgrade Waterfront

5. Energy and environmental benefits of E-bus operation on EKO 1 and EKO 2 lines

Electric buses are classified in the category of zero-emission vehicles, as they use electricity for propulsion. In this sense, one can analyze the aspects of the environmental impact on the immediate environment, where vehicles are in operation (local level), which in the literature is called TTW (Tank to Wheel), and the environmental impact on the wider environment. that is, a region or state known as a source-to-point analysis, WTW (Well to Wheel). In the case of TTW analysis, the electric bus propulsion system has no emissions: carbon monoxide, nitrogen oxides, hydrocarbons, and microparticles. TTW analysis (from tank to point) and WTW analysis (from source to point) refer to line EKO 1 where electric buses are in operation, in order to perform a comparative analysis of environmental performance with buses that use diesel fuel or CNG. Measurement of fuel consumption for buses of standard length using diesel fuel and CNG was done based on monitoring the results of diesel fuel consumption on buses IK-112N (EURO 4) and KPG on buses MAZ-203 CNG, which was performed in the period 12.08 - 5.10.2017 [9], when due to infrastructural works in Roosevelt Street or in other periods of the year in case of short-term interruptions of electricity supply in the charger zone, the operation of electric buses was temporarily replaced with diesel-powered buses and CNG-powered buses. The effects of the operation of buses of different propulsion systems on the achieved emissions of harmful gases and carbon dioxide on the line EKO 1, on an annual level are shown in Table 4. [9].

The UITP Environmental methodology was used to calculate CO, CxHy, CH4, NOx, PM10, and CO2 emissions from diesel and CNG buses. Table 4 shows that Higer KLQ6125GEV3 electric buses operating on the EKO 1 line annually have an indirect impact on the environment observed at the macro-level (Republic of Serbia) through the emission of 389.5 tons of carbon dioxide generated in the production of electricity.

Table 4. Summary analysis of the TTW and WTW for buses of different propulsion systems on line EKO 1 in Belgrade, (annual period of operation) [9]

Line EKO 1	Unit	E-bus Higer KLQ6125GEV3	IK-112N	MAZ-203 CNG
Number buses in operation		5	5	5
Mileage	km	62750	62750	62750
Average electricity consumption	$kWh \cdot km^{-1}$	1.493		
Average consumption of diesel	$L \cdot (100km)^{-1}$		47.05	
Average consumption of CNG	$kg \cdot (100km)^{-1}$			49.84
Emission CO	kg	-	2183.6	2347.1
Emission CxHy	kg	-	300.2	93.9
Emission CH_4	kg	-	-	293.4
Emission NO_x	kg	-	1910.6	158.5
Emission PM_{10}	kg	-	16.4	5.8
Emission CO_2, TTW	**t**	-	**388.2**	**397.1**
Emission CO_2, WTW	**t**	**389.5**	**443.3**	**465.9**

Energy. In the Republic of Serbia, the production of electricity was mostly obtained from thermal power plants, about 70%. Compared to the carbon dioxide emissions from diesel-powered buses observed at the state level (WTW analysis), which amounts to 443.3 tons, it turns out that it is 12.1% lower for electric buses. An even more favorable case is the analysis of CO2 emissions compared to buses on CNG, where it is 16.4% lower for electric buses. The energy efficiency of E-bus is expressed as the ratio of consumed electricity and distance traveled energy 1.493 kWh·km^{-1} is many times higher compared to diesel bus (4.705 kWh·km^{-1}) and CNG buses (6.243 kWh·km^{-1}).

Although the EKO2 line has been in operation for a little over three months, based on the initial tests, it can be concluded that the energy efficiency of E-buses purchased in 2021 is significantly better than the vehicles purchased in 2016. Consumption of E-buses from 2021 is about 20% lower compared to vehicles from 2016. New vehicles are characterized by better performance of the inverter-electric motor drive system, higher operating voltage, lower electrical losses in the drive system and auxiliary devices, and lower vehicle weight. Assessment of the effects of electric buses on the EKO2 line from the point of view of emissions of harmful gases and carbon dioxide can be done as a quantification of emissions that would occur if instead of electric buses on the EKO 2 line run diesel-powered buses that meet EURO 6 standard. Table 5 gives an estimate of TTW and WTW emissions for buses of different propulsion systems on the EKO 2 line.

Table 5. Summary analysis of the TTW and WTW for buses of different propulsion systems on line EKO 2 in Belgrade, (annual period of operation)

Line EKO 2	Unit	E-bus Higer KLQ6125GEV3	Diesel bus (EURO 6)
Number buses in operation		10	10
Mileage	km	65.000	65.000
Average electricity consumption	kWh·km^{-1}	1.246	
Average consumption of diesel	L·(100km)$^{-1}$		42.8
Emission CO	kg	-	4109.8
Emission CxHy	kg	-	164.3
Emission CH_4	kg	-	-
Emission NO_x	kg	-	472.6
Emission PM_{10}	kg	-	10.3
Emission CO_2, TTW	**t**	-	**731.6**
Emission CO_2, WTW	**t**	**674.05**	**835.5**

The analysis concludes that the emission of carbon dioxide CO_2 (WTW) in electric buses is lower by 19.3% compared to diesel buses.

6. Further directions of development of E-mobility in Belgrade

In its development plans, the City of Belgrade pays special attention to the strategy of introducing environmentally-friendly vehicles for public city transport. Procurement of new electric buses and their significant presence in the JGT system is a policy of e-mobility development in Belgrade, which together with the trolleybus and tram subsystem of public transport and affirmation of non-motorized movements (cycling, pedestrian zones) should contribute to improving environmental quality. In Belgrade. According to the plan for the procurement of vehicles for public transport for the period 2022-2025, which was made by JKP GSP "Belgrade" and adopted by the Secretariat for Public Transport, the procurement of 15 E-buses of standard length and 25 articulated e-buses of 18 meters, and 80 trolleybuses with batteries that have a range of 10 km This procurement plan for E-buses is part of the action plan "Air Quality Plan in Belgrade" adopted by the Belgrade City Assembly in 2021

7. Conclusions

One of the most significant contributions of E-mobility in cities is the growing use of electric buses. The trend of introducing E-bus is constantly growing in all development regions of the world. The introduction of electric buses on the EKO1 and EKO2 lines in Belgrade is a significant development project that has proven that the introduction of electric buses can contribute to reducing the level of air pollution in Belgrade and increase energy efficiency by buses. Further introduction of electric buses and renewal of the trolleybus subsystem with modern trolleybuses with autonomy will enable the expansion of the network of lines, primarily in the central city zone, where zero-emission vehicles will work.

8. Reference

[1] Werner Z.: Alternative World Energy Outlook 2005 a possible path towards a sustainable future, Conference ”The soul of the empire”, workshop 3: ”Mankind on a hot tin roof. Kyoto heretics braving the greenhouse effect”, Rimini, 28-30 October, 2005.

[2] Borowik, L., & Artur.: Modernization of a trolleybus line system in Tychy as an example of eco-efficient initiative towards a sustainable transport system. Journal of Cleaner Production, pp. 188-198, December 2015.

[3] International Energy Agency: Transport-improving the sustainability of passenger and freighttransport.2020, https://www.iea.org/topics/transport

[4] International Energy Agency: Global Energy Review 2020: The impacts of COVID-19 on global energy, https://www.iea.org/reports/global -energy-review-2020/oil#a

[5] EC 2011a - European Commission White Paper, Road to a Single European Transport Area e Towards a Competitive and Resource Efficient Transport System, Brussels: EC, 2832011 COM (2011) 144 Final, 2011.

[6] Clean Buses – Experiences with Fuel and Technology Options, Clean fleets,February 2014,

[7] Directive 94/2014/EC: On the deployment of alternative fuels infrastructure, 22 October 2014, L 307/1.

[8] Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019

[9] Mišanović S.: Energetske i ekološke performanse autobusa na električni pogon u sistemu transporta putnika, doktorska disertacija, Fakultet inženjerskih nauka Univerziteta u Kragujevcu, 2021.

[10] MarketWatch(2021), China Electric Bus Report 2019:By Key Players, End-User,Type,Market Share,Forecast to 2025.Retrived fromhttps://www.marketwatch.com/press-release/china-electric-bus-market-report-2019-by-keyplayers-end-user-type-market-share-forecast-to-2025-2021-02-12

[11] ASSURED project, Clean Bus Report, 2022.

[12] ZeEUS, E-bus report #2, An updated overview of electric buses in Europe, 2017.

[13] ГУП Мосгортранс: Электробус для Москвы, апрель 2020, (презентација у PPT).

[14] Sustainable Bus (2021). Zero emission buses in the USA:+24% in 2020.2,800 delivered or ordered. Retrived from https://www.sustainable-bus.com/news/zero-emission-buses-north-america-2020/.