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PRELIMINARY REPORT

The eko2 line in belgrade as a contribution to the development of e-mobility in the city

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Abstract: Buses powered by conventional fuel (diesel, CNG) are still the most common drive system in most cities of the world, including in Belgrade. The share of zero-emission buses, which primarily include electric-powered buses (E-bus), including the application of fuel cell and hydrogen technology, has a distinct upward trend in almost all developed cities of the EU and the world. Replacing conventional buses with zero-emission buses significantly contributes to the E-mobility strategy, which aims to decarbonize and reduce harmful gas emissions in cities originating from public transport vehicles. Electric buses have significantly higher energy efficiency compared to conventional buses, which is another reason for their use. The paper will present the environmental and energy effects of the use of electric buses in Belgrade on the EKO 2 line, which has been in operation since 2022, with an overview of the applied technology of E-bus, storing electricity, and charging infrastructure. At the end of the paper, a plan for the development of E-mobility of public transport in Belgrade is presented, which implies the introduction of a larger number of electric buses in the public transport system.

Keywords: E-mobility, E-bus, energy efficiency, ecology, development

INTRODUCTION

The transport sector takes an important place in meeting the needs of society in the transport of goods and passengers, but at the same time it is also a source of emissions of harmful gases and carbon dioxide as a result of the burning of fossil fuels. The use of fossil fuels is directly proportional to the industrial and economic development of a country, region or city [1]. In 2023, carbon dioxide (CO2) emissions originating from the transport sector amounted to 25% [2], as a result of the burning of fossil fuels, primarily oil derivatives, which is a share of about 57% of total oil consumption at the global level [3].

According to UITP data, in 2018 the share of diesel-powered buses in sales was around 80% [4], and in 2025 their share would be 15.6 % [5]. The system of public urban passenger transport is one of the most important functions of any city. Buses powered by diesel fuel are still the most represented drive system in most cities of the world, including in Belgrade, but with a constant trend of decreasing representation.

The use of fully electric buses for public urban transport should further reduce the level of emissions of harmful gases in cities, increase energy efficiency and contribute to the strategy of using zero-emission vehicles in cities, which is planned after 2050 [6,7]. The rapid development of battery technology and charging systems has contributed to the concept of electric buses being increasingly present in many cities since 2008, primarily in China, India, Europe, North and South America.

It can be considered that the concept of electric drive today has the greatest perspective for use in buses used in the public transport system, given that the performance of electric buses in terms of operational requirements (autonomy, transport capacity, charging time) has reached such a level that they can be a successful replacement for conventionally driven buses [8].

EU POSITION ON ELECTRIC MOBILITY IN PUBLIC TRANSPORT

In 2019, the European Union adopted Directive 2019/1161 (EU Directive 2019/1161) on clean vehicles (English: Clean Vehicle Directive), which in the sector of commercial vehicles (categories N2, N3, and M3) defines [9]:

- Zero-emission vehicles, which do not have internal combustion engines and whose CO2 emission does not exceed 1 g/kWh according to the criteria of EU Regulation 595/2009, i.e., 1 g/km according to the criteria of EU Regulation 715/2007. These vehicles include electric buses (with battery or supercapacitor), fuel cell buses, and trolleybuses when they work in autonomous mode and use electricity from the battery.
- Low-emission vehicles that use one of the alternative fuels defined by Directive 94/2014/EC.

These vehicles include hybrid-powered buses (Plug-in), standard hybrids, and CNG (compressed natural gas) buses.

According to the EU-Directive on clean vehicles 2019/1161, zero-emission vehicles represent an implementation strategy, so that from 2033, zero-emission buses (E-bus, fuel cells) should have absolute primacy in use in the public urban transport system of cities. According to the aforementioned Directive, all EU member states must, when procuring new buses, have a representation of buses with low and zero emissions according to the prescribed quota. For the period until 31.12.2025. year, the most developed EU countries (Germany, the Netherlands, Sweden...) had an obligation to purchase new buses with low and zero emissions, 44% of which 22% must be buses with zero emissions. EU member states that are less economically developed (Bulgaria, Romania, Croatia) had a set quota for the participation of buses with low and zero emissions between 28% and 32%.

As of January 1, 2026, the mentioned quotas have been increased by an average of 30% [9]. It is also important to mention the EU Directive 2014/94 [10], which refers to the use of alternative fuels in the transport sector, namely: Electricity, natural gas, biomethane, biofuels, hydrogen, synthetic diesel, liquefied petroleum gas, which should reduce the use of fossil fuels (diesel, gasoline) in the transport sector.

Tendencies of increasing use of zero-emission buses, which include electrically powered buses, trolleybuses and buses powered by fuel cells (fuel cells) and low emissions of harmful exhaust gases, which include CNG-powered buses, can be seen through the trend of the increase in the number of newly registered buses for public city transport for the EU 27 countries, i.e. for Norway, Iceland and Switzerland in 2023 and 2024. In 2023, the following were recorded: 6354 electric-powered buses, 4022 hybrid (diesel-electric) buses, 2883 CNG-powered buses, and 181 hydrogen-powered (fuel cell) buses, while the number of newly registered electric-powered buses in 2024 was 7779, which is an increase of 22.4% compared to 2023.

The growth trend of newly registered electric buses continued in 2025. Of the total of 12,165 newly registered E-buses, 11,605 were battery-powered, and 558 were fuel cell-powered. Compared to 2024, there was an increase of 56 % [5,11].

EXPERIENCES AND EFFECTS OF USING E-BUSES ON THE EKO 2 LINE IN BELGRADE

The public urban transport system in Belgrade has a total of 1481 rolling stock, of which the bus subsystem participates with 1289 vehicles in operation (about 87% of the total number of vehicles). Respectively, from the total number of buses that are in daily use, 516 buses belong to JKP GSP "Belgrade" and 773 buses belong to associations of private carriers [12]. Diesel-powered buses are the most prevalent and, as such, are one of the causes of urban pollution and exhaust gas emissions in Belgrade.

The main harmful emissions of IC engines using conventional fuel are: carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (CxHy), micro particles (PM10), smoke, and carbon dioxide (CO2) emissions. Starting from the fact that the buses of the city operator JKP GSP "Beograd" consumed about 14.1 million liters of Euro diesel and about 9.2 million kilograms of CNG (compressed natural gas) to achieve annual transport work in 2025 [13], leads to the conclusion that the effects of air pollution reduction in Belgrade can be significantly achieved by efficient energy and technical-technological management, as well as by successive renewal of the fleet with ecological vehicles with "zero" and low emission of exhaust gases in the bus subsystem of public city transport. In the area of Southeast Europe, the City of Belgrade is the leader in the implementation of the electric bus concept. A total of 15 E-buses from the Chinese manufacturer Higer are in operation on two city lines.

The first line, EKO 1 (Wolf Monument- Bellvil), on which only electric buses operate, was put into operation on September 1, 2016. year, while the second line EKO 2 (Dorcol / Sports center M.G. Muskatirović - Belgrade Waterfront) was put into traffic on January 24, 2022. year. The basic technical characteristics of E-bus (Figure 1) operating on the EKO 2 line are shown in Table 1.

Figure 1. E-bus Higer KLQ6125GEV3

Table 1. Technical characteristics E-bus Higer

Dimensions: length, width, height: 12.000x2.550x3.680 mm
Mass of empty vehicle: 12.120 kg
Number of places for sitting/ standing: 28/62
Number of doors: 3
Maximum speed: 70 km/h
Drive electric motor: Siemens 1DB2016 6NBO6 permanent magnet, central position
Max. power of the driving electric motor: 160/230 kW
Maximum torque: 2500 Nm
Drive controller: Siemens ELFA 3
Ultracapacitor: AOWEI
Capacity: 40 kWh
Charging time: 2-5 min

Figure 2. Route of the EKO2 line

Line EKO 2 is a typical city line. The average length of the line is 7.1 km, and the average transport speed is 13.8 km/h. The line connects the most attractive areas of the city: Belgrade on the water, Trg Slavija, Trg Republike, Kalemegdan, and Dorcol. 8 vehicles are operating on the line with an average arrival interval of 10 minutes [14].

The infrastructure (chargers) for fast charging of E-buses is installed at the terminus of the lines. The chargers are connected to the AC distribution network via

substations located in the immediate vicinity of the chargers. The high power of the charger enables the supercapacitor with a capacity of 40 kWh, which is built into the E-bus Higer, to be charged in just 2÷5 minutes. A view of the fast charger at the Dorcol terminus (Sports Center) is given in Figure 3. The basic characteristics of the charger are shown in Table 2.

Figure 3. Fast charger /Dorcol terminus/

Tabela 2. Technical characteristics of the charger

Input voltage .....3x380 V
Max.Power ..... 400 kW
Max.output voltage.....750 V DC
Charging efficiency 97%
Charger contact height .... 4.5-4.6 m

The introduction of E-buses into regular operation on the EKO 1 and EKO 2 lines in Belgrade is interesting for the analysis of the environmental effects compared to buses with other propulsion systems (diesel, KPG). In this sense, aspects of the impact on the environment of the immediate environment, where the vehicles are in operation (local level) can be analysed, which in the literature is called "Tank to Wheel-TTW" and the environmental impact on the wider environment, i.e. the region or the country, which is known as the analysis Well to Wheel-WTW. In the case of the TTW analysis, the propulsion system of electrically powered buses has no emissions: CO, NOx, CxHy, PM10, which makes them environmentally most suitable for working primarily on central city lines and traffic roads with the highest vehicle frequencies, thus contributing in the best way to reducing the impact of harmful exhaust gas emissions.

The environmental impact at the local level is minimal, considering that the only negative impact on the environment comes from the formation of microparticles and dust due to the contact of tires and the road, from the friction of brake linings, and the evaporation of working fluids (transmission lubricating oil, antifreeze, etc.), which can be ignored. The way electricity is produced and transmitted is essential when analyzing the environmental performance impacts of electric buses on a regional or national level, i.e., WTW analysis.

The analysis of WTW carbon dioxide emissions is important to understand and compare the level of emissions emitted by buses with different propulsion systems, including purely electric buses. The aspect of carbon dioxide emission that occurs during the electricity production phase is particularly important here, given that electricity is obtained from different sources [8,15].

The analysis WTW of CO2 emissions from electric buses is based on the fact that the production of electricity in the Republic of Serbia is predominantly from thermal power plants, with a representation of around 70%. The rest of the production comes from hydroelectric power plants, about 27%, and solar panels and wind generators, 3%. Given that the share of electricity production from thermal power plants is 70%, the standard CO2 emission factor (g/kWh) in electricity production is 774 g/kWh [8].

The results of measuring the average energy consumption for buses with different drive systems on the EKO 2 line are shown in Table 3.

Table 3. Energy consumption on the EKO2 line for buses with different drive system

Drive system	Average consumption (L/100 km)	Average consumption (kWh/km)	Average consumption (kg/100km)	Emissions CO2 (WtW) (g/km)
E-bus 12m, Higer KLQ6125 GEV3	-	1.15	-	952.4
Diesel bus 12m, Higer KLQ6129 GQ2 (Euro 6)	46.1	4.6	-	1394
CNG bus 12m (Euro 6)	-		47.0	1399

In the case of E- buses, the average consumption of electricity is 1.15 kWh/km [16], the CO2 emission (WTW), including transmission losses in the network, is 952.4 g/km [8,17]. Under the same operating conditions on the EKO2 line, the diesel-powered bus has a consumption of 46.1 l/100 km [18] and a CO2 emission (WTW) of 1394 g/km. A bus on CNG with an expected consumption of 47 kg/100 km [18] would achieve a CO2 emission (WTW) of 1399 g/km [17]. From this calculation, it can be concluded that the level of CO2 emission (WTW) is about 31.6% lower for an electric bus compared to a diesel bus, or 31.9% lower compared to a CNG bus. The "Tank to Wheel" (TTW) analysis of electric buses can be seen in the context of the environmental effect achieved by replacing buses using diesel fuel by quantifying the amount of pollutants that will not be emitted into the atmosphere as a result of vehicle substitution. In a specific example, one diesel-powered bus on the EKO2 line would have annual emissions of: 164.2 kg CO, 14.2 kg CxHy, 43.8 kg NOx, 1.09 kg PM10 [17].

Based on the data on power consumption on the EKO 2 line, it follows that the E-bus "Higer KLQ-6125GEV3" has more than 4 times higher energy efficiency than the diesel and CNG-powered buses. The high energy efficiency of electric-powered buses is a consequence of the greater degree of beneficial effect of the drive system inverter-electric motor (0.92÷0.95) compared to IC motors in buses with conventional drive, as well as the possibility of recuperating electrical energy

during the braking and deceleration phase. The effect of recuperation on the EKO2 line reaches up to 40% of the total energy consumed [16]. Electric buses have a significantly lower level of emitted noise. Compared to diesel-powered buses at a speed of 30 km/h, the emitted noise level of the E-bus is 8 dB lower. Compared to the KPG bus, the emitted noise level is lower by about 6 dB [8].

DIRECTIONS FOR FURTHER DEVELOPMENT OF E-MOBILITY IN THE PUBLIC TRANSPORT OF BELGRADE

An intense trend of increasing the number of electric buses in the public transport system of Belgrade is expected in 2027. As is known, the Republic of Serbia, i.e., the City of Belgrade, will host the World Exhibition EXPO 27. During the event, which will last from May 15 to August 15, 2027. Eight (8) lines will be established that will transport visitors from different parts of the city. It is planned that electric buses will operate on the lines. Table 4 shows the lines on which the E-bus will operate during the EXPO27 event [19].

Electric buses will be equipped with batteries with a large capacity of 420÷500 kWh and will be charged at the depot during the night with chargers with a power of 120÷150 kW. In addition to battery buses, buses with supercapacitors will be used as an electrical energy storage system, which will be charged at the terminus using 400 kW fast chargers. After the EXPO 2027 event, electric buses will be implemented in the existing bus subsystem of Belgrade. It is planned to replace diesel-powered buses with electric buses that will operate on central city lines such as lines 26, 27E, 35,... It is planned to establish new circular lines through New Belgrade, on which 25m long electric buses (Figure 4) will operate, with a capacity of 210 passengers, as well as new lines that will connect Block 20 with the EXPO exhibition complex.

The introduction of 90 new electric-powered buses into operation will result in a significant improvement in the environmental performance of the public transport system, which contributes to the sustainable development of the city's transport system as a whole.

CONCLUSION

The introduction of electric buses into the public transport system in Belgrade represents a significant qualitative shift from a technological and, especially, environmental point of view. JKP GSP "Beograd" represents a

Figure 4. Two-articulated E-bus, 25m

Tabela 5. Technical characteristics of 25m E-bus
- vehicle length: 25.0 m
- vehicle width: 2.55 m
- radius: max. 25 m
- powertrain: electric, synchronous motors, 2x160 kW
- passenger capacity: 210 passengers
- seats: 50
- places to stand: 160
- storage system: Ultracapacitor, 144 kWh
- charging strategy: fast, 400-600 kW

Tabela 4. Planned lines during EXPO 2027

Name of Line	Number E-bus in operation	Type of E-bus	E-bus Technology/Charging type
EXPO 1, Aerodrom N.Tesla-EXPO	6	12m	Battery/ slow at depot
EXPO 2, Beograd na vodi-EXPO	13	12m	Ultracapacitor/ fast at terminal
EXPO 3, Borča-EXPO	24	12m	Battery/ slow at depot
EXPO 4, Vukov spomenik-EXPO	15	12m	Ultracapacitor/ fast at terminal
EXPO 5, Ustanička-EXPO	14	12m	Battery/ slow at depot
EXPO 6, Blok 20-EXPO	10	12m	Ultracapacitor/ fast at terminal
EXPO 7, Blok 45-EXPO	6	24m	Ultracapacitor/ fast at terminal
Fider 1, EXPO žel.stanica-EXPO	2	24m	Ultracapacitor/ fast at terminal
Total	90		

good example of practice in the region when it comes to the promotion and application of electric buses. Measures to improve the bus fleet from the aspect of environmental requirements include the planned renewal of the fleet with vehicles that meet the highest environmental standards, primarily vehicles with zero and low emissions of harmful gases, and the withdrawal of diesel-powered vehicles from use.

The greater presence of electric buses is imposed as a realistic option in the medium term for significantly reducing harmful gas emissions on the streets of Belgrade, which will contribute to improving the quality of the environment and reducing the costs that the local community allocates for eliminating the consequences of its damage. The environmental benefits of the operation of electric buses in Belgrade are the best argument and support for the further development of this concept in Belgrade. The long-term strategy involves the exclusive use of electric vehicles in accordance with EU directives and good practices of public urban transport companies from Europe and the world.

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