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ORIGINAL SCIENTIFIC PAPER

TTW (Tank to Wheel) and WTW (Well to Wheel) Analysis Using Electric Buses on the Line Eko 1 in Belgrade

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Abstract: The bus subsystem is the holder of the public transport function in many cities with a dominant representation of diesel-powered buses. In the last few years, electric buses (E-bus) have been increasingly used in many cities around the world (China, Europe, South America), making them the main alternative to conventional buses (diesel, CNG). The main advantages of using electric buses compared to conventional buses are higher energy efficiency, zero pollution emitted at the local level, more favorable carbon dioxide emissions observed at the regional or national level depending on the method of obtaining electricity, lower noise level. Since 2016, five electric buses have been operating in Belgrade on the EKO 1 line (Vukov spmenik-Belvil). The paper will present the environmental benefits of the use of electric buses observed through TTW (Tank to Wheel) and WTW (Well to Wheel) analysis, compared to diesel and CNG buses.

Keywords: E-bus, TTW (Tank to Wheel) and WTW (Well to Wheel) analysis.

INTRODUCTION

The transport sector has an important role in meeting the needs of society in the transport of passengers and goods and is a significant generator of greenhouse gas emissions and carbon dioxide as the major cause of the environmental damage. Emissions from the road vehicle (passenger cars, busses, coaches, trucks), the principal source of emitted hazardous substances in the urban environment [1]. The products of combustion in the vehicles equipped with an internal combustion engine, which exhaust system are discharged into the atmosphere, harmful substances comprise a plurality of which are usually: carbon monoxide (CO), unburned hydrocarbon radicals (CxHy), nitrogen oxide (NOx) and particulate matter with diameters: PM 2.5 PM5, PM10, sulfur compounds, aldehydes, benzene, etc.

In 2012 according to a report of the World Health Organization (WHO) announced that 3.7 million people worldwide die each year as a result of air pollution. According to the same report, more than 5600 people die prematurely in the Republic of Serbia as a result of air pollution [2,3].

Buses used in public city transport are mostly represented with diesel engines. Diesel engines emit large amounts of suspended particles and nitrogen oxides, especially during cold engine operation, at full load, and subsequent fuel injection into the engine. Numerous studies conducted worldwide have shown that the impact of suspended particles as a result of air pollution is directly related to the higher likelihood of lung cancer in humans [3,4] as well as the increased rate of morbidity and mortality due to cardiovascular and respiratory diseases [3,4,5].

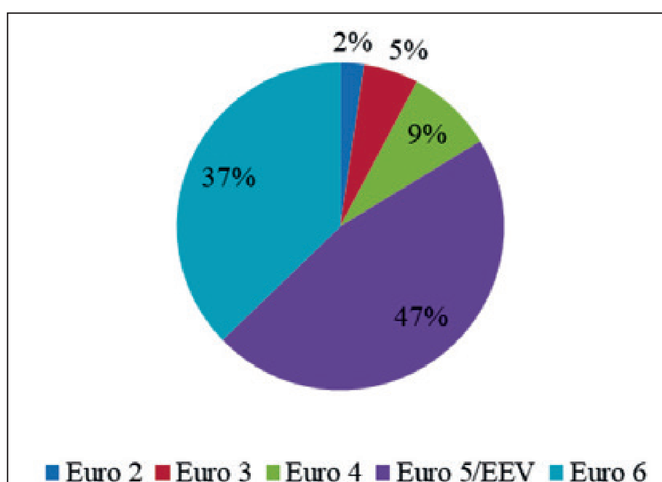

Figure 1. The structure of the bus fleet in JKP GSP Beograd (31/12/2020) [6]

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 week-days and use about 31.29 million liters of Euro-diesel fuel for the realization of the planned annual transport work [6]. In the last 3 years, a significant modernization of the bus subsystem was performed with 244 new buses that meet the EURO 6 norm. Observed according to the emission norms (EURO), the structure of the bus fleet is shown in Figure 1.

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. For these reasons, the bus subsystem of public urban passenger transport is gaining in importance as the main promoter of new technologies in the implementation of the city's sustainable development strategy.

EKO 1 (Vukov spomenik-Belvil) E-BUS LINE

In Belgrade the first line of public transport EKO 1 (Vukov spomenik-Belvil), where traffic only fully electric buses, put into operation on 1 September 2016. The introduction of five fully electric buses Higer KLQ-6125GEV3, in regular traffic is a significant development project of the expert team of JKP GSP "Belgrade" which is supported by the City of Belgrade and represents the beginning of using a new concept of environmentally and energy-efficient vehicles in public transport. passengers. City line EKO1 is a new line that is purposely designed and adapted for the operation of fully electric buses Higer KLQ6125GEV3, 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 spatial position of the route of the EKO 1 line is shown in Figure 2.

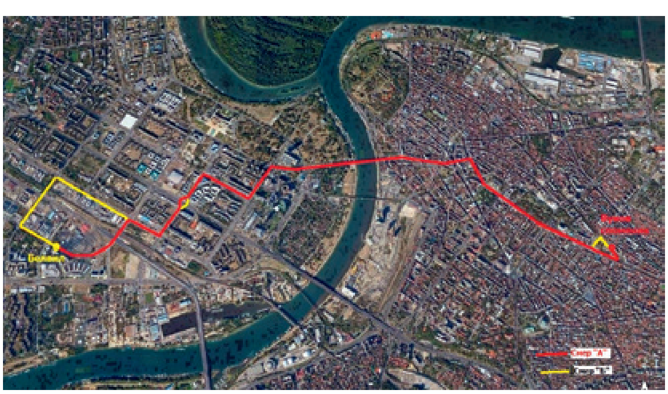

Figure 2. Spatial position of the line EKO 1

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 [7].

The fully electric bus Higer KLQ6125GEV3 is a modern low-floor solo city bus that meets all technical requirements in accordance with European Commission Directive 2007/46 (Directive EC /2007/46) and Regulation 136/2014 (Regulation EU 136/2014) which refers to the fulfillment of technical conditions for buses for public urban passenger transport, including electric buses. The e-bus uses a supercapacitor to store electricity with a capacity of 20 kWh [8]. The E-bus charging system is with fast charging which is performed at the initial-final stops (terminals) where 150 kW chargers are installed.

Electric bus Higer KLQ6125GEV3 in the charging phase is shown in Figure 3. The basic technical characteristics are shown in Table 1.

Figure 3. E-bus Higer KLQ6125GEV3

Table 1. Technical characteristics E-bus

Type	Electric KLQ6125GEV3
Length/width/ height	12000/2550/3680 mm
Curb weight	12540 kg
Passengers	82+1
Max.speed	70 km/h
Charging time at the terminus	5-10 minutes
Supercapacitor	AOWEI 20 kWh
Traction motors	Siemens (x2) 1PV5135
Power	2x90 kW (peak) 2x67 kW (nominal)
Torque	2x430 Nm
Traction control	Siemens 10DT6

RESULTS OF TTW (TANK TO WHEEL) AND WTW (WELL TO WHEEL) ECOLOGICAL PERFORMANCES E-BUS COMPARED TO DIESEL AND CNG BUSES ON LINE EKO 1

Electric buses are classified in the category of zero-emission vehicles, since they use electricity for propulsion. In this sense, aspects of the environmental impact of the immediate environment can be analyzed, where vehicles are in operation (local level), which in the literature is called "tank to wheel", TTW (Tank to Wheel) and environmental impact on the wider environment that is a region or country known as a ''source to wheel'' 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 [8].

The environmental impact at the local level is minimal, as the only negative impact on the environment comes from the formation of microparticles and dust due to contact of tires and roads, from the friction of brake linings and evaporation of working fluids (transmission lubricating oil, antifreeze, etc.). which can be ignored. The TTW analysis of electric buses can be viewed in the context of the environmental effect achieved by replacing buses using diesel fuel or CNG, by quantifying the amount of pollutants that will not be emitted into the atmosphere as a result of vehicle substitution.

The method of production and transmission of electricity is essential when analyzing the impacts of the environmental performance of electric buses on a regional or national level, or WTW analysis. Analysis of WTW carbon dioxide emissions is important to consider and compare the emission levels emitted by buses with different propulsion systems, including purely electric buses. The aspect of carbon dioxide emissions that occur in the phase of electricity production is especially important here, considering that electricity is obtained from various sources. In the Republic of Serbia, most of the electricity is obtained from thermal power plants with a share of about 70% [9].

The Higer KLQ6125GEV3 electric buses operate exclusively on the city line EKO 1. Measurement of fuel consumption for buses of standard length using diesel fuel and compressed natural gas (CNG) was done based on monitoring the results of diesel fuel consumption on buses IK-112N (EURO 4) and CNG on buses MAZ-203 CNG which are performed in the period 12.08.-5.10.2017. year, when due to infrastructural works in Roosevelt Street, the operation of electric buses was temporarily replaced with buses with diesel fuel and buses with CNG [8]. Example of comparison of estimated emissions of harmful gases and carbon dioxide from the point of view of TTW and WTW analysis on line EKO 1 of electric bus Higer KLQ6125GEV3, the bus with diesel fuel IK-112N (EURO 4) and bus with compressed natural gas MAZ-203 CNG in which the Cummins ISL G powertrain, which meets the 2010 EPA/CARB and EURO 6 exhaust emission standards, is installed, is shown in Table 2 on an annual basis [8].

The UITP Environmental methodology was used to calculate CO, CxHy, CH_4, NOx, PM_{10} emissions from diesel and CNG buses [10]. The emission calculation was obtained on the basis of input data on diesel fuel consumption expressed in $L \cdot (100km)^{-1}$, CNG consumption in $kg \cdot (100km)^{-1}$, maximum emission values of CO, CxHy, CH_4, NOx, and PM_{10} expressed in $g \cdot kWh^{-1}$ depending of the level emission norms of engine, according to the ETC TEST test (Directive 2005/55/EC, European regulation no.595/2009) and the specific fuel consumption expressed in $g \cdot kWh^{-1}$.

Carbon dioxide (CO_2) emissions for diesel-powered buses and CNG buses according to TTW analysis were obtained using equation 1.1 [8,9].

Table 2. Summary analysis of the TTW and WTW for buses of different propulsion systems on line EKO 1 in Belgarde, (annual period of operation) [8]

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·km-1	1.493		
Average consumption of diesel	L·(100km)-1		47.05	
Average consumption of CNG	kg·(100km)-1			49.84
Emission CO	kg	-	2183.6	2347.1
Emission CxHy	kg	-	300.2	93.9
Emission CH4	kg	-	-	293.4
Emission NOx	kg	-	1910.6	158.5
Emission PM10	kg	-	16.4	5.8
Emission CO2, TTW	t	-	388.2	397.1
Emission CO2, WTW	t	389.5	443.3	465.9

$$m_{CO_2} = m_{fg} \cdot g_c \cdot \frac{44}{12}, \qquad (1)$$

m_{CO_2} - mass of formed carbon dioxide, g,
m_{fg} - mass of fosil fuel that burns, g,
g_c - carbon content in the fuel, %,
44 - molar mass of carbon dioxide, $g \cdot mol^{-1}$,
12 - molar mass of carbon, $g \cdot mol^{-1}$.

The value of carbon dioxide (CO_2) emissions, if calculated according to the WTW analysis, was obtained by increasing the carbon dioxide emission value obtained by TTW analysis by an increase factor of 14.2% for diesel fuel and 17.3% for CNG, which are the most realistic for the Republic of Serbia. In the case of electric buses, the calculation of CO_2 emissions according to the WTW analysis was obtained using equation 1.2 [8]:

$$CO_{2_{WTW}} = \frac{E_{ebus_L}}{\eta_{ch}} \cdot LCA_{co_2} \cdot f_{gpee}, \qquad (2)$$

CO_{2WTW} - carbon dioxide emissions acording to WTW analysis, $g \cdot km^{-1}$,
E_{ebusL} - electricity consumption of E-bus, $kWh \cdot km^{-1}$,
η_{ch} - charger efficiency coefficient (~0.95),
LCA_{CO2} - emmision factor of the total cycle of electricity production in Republic Serbia, adopted 774 $g \cdot (kWh)^{-1}$ [8,9],
f_{gpee} - coefficient of loses in electricity transmission.

CONCLUSION

The introduction of electric buses in regular operation is a significant development step in the improvement of the public city transport system in Belgrade. The analysis of the environmental performance (TTW, WTW) of the E-bus on the EKO 1 line compared to diesel and CNG buses have proven the advantages of using this new bus concept. It is obvious that the mentioned emissions of harmful exhaust gases are not present during the operation of the electric buses on the EKO 1 line in Belgrade. Although the environmental performance of conventionally powered buses (diesel, CNG) has been significantly improved, the presence of harmful emissions is still present and the best way to reduce the environmental impact of the bus subsystem is to replace it with electric buses. Compared to the carbon dioxide emission from diesel buses, the annual level (WTW analysis) of 443.3 tons can be concluded to be 12.1% lower for electric buses. Compared to CNG-powered buses, the annual CO2 emission of electric buses is lower by 16.4%. The city of Belgrade attaches great importance to this issue and the next step will be the introduction of a new line EKO 2, on which 10 E-buses will work, which is planned for the end of 2021.

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