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

Slobodan MIŠANOVIĆ, PhD
Senior Project Manager,
JKP GSP ”Beograd” - City Public Transport Company „Belgrade”
Member of UITP Bus Committee

Podgorica, 03.06.2022

Public city transport is the best promoter of E-mobility in cities especially for the bus subsystem

GOAL:

- Reduction of air pollution in cities (CO, NOx,CxHy, PM ....)
- Reduction of CO2 emissions (decarbonization), 24% of greenhouse gas (GHG) emissions in 2020, of which carbon dioxide is the most abundant and road transport
- Reduction of noise
- Increasing energy efficiency in the transport sector
- Reducing the use of passenger cars in cities
- Affirmation of the use of fully renewable energy sources (wind generators, photovoltaic cells)

FOCUS of E-mobility :

- **Replacement of diesel buses with electric buses (BEB, UC and FC)**
- **Afirmation Trolleybus subsystem (especially application of trolleybus with charging in motion)**

Replacement of diesel buses with Clean buses (EU position)

Clean Vehicle Directive (2019/1161)

DEFINITION OF CLEAN VEHICLE (Article 4):
For trucks and buses (N2, N3 and M3):

- A zero-emission HDV is a vehicle without an internal combustion engine, or with an internal combustion engine that emits less than 1g CO2/kWh (Regulation EC 595/2009), or that emits less than 1g CO2/km (Regulation EC 715/2007).
- A low-emission HDV is a vehicle that is powered by alternative fuels as defined as in the Directive 2014/94/EU).

E-bus (BEB,UCEB,FCEB) is considered to be zero-emission

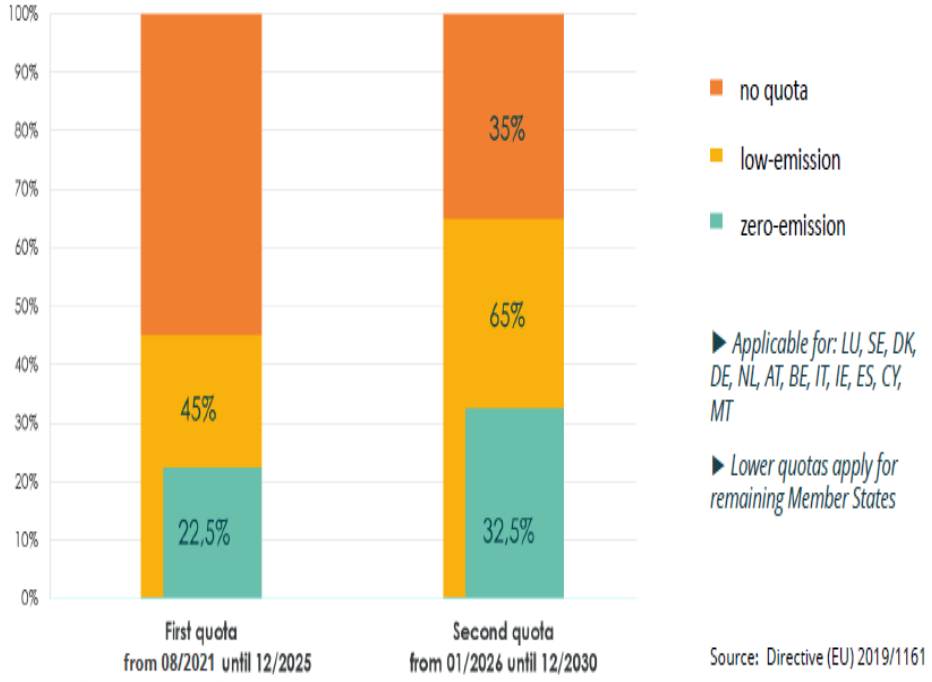
Trolleybus is considered to be zero-emission buses, provided they only run electricity, or they only use a zero-emission powertrain when they are not connected to the grid.

PHEV Hybrid buses, where a majority 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 be blended with conventional fossil fuels (diesel/petrol).**

‘Alternative fuels’ (Directive 2014/94/EU) should serve, at least partialy, as a substitute for fossil oil sources and include, inter alia:

- Electricity (>>> Plug-in Hybrid)
- Hydrogen (>>> Regarded as “Zero Emission” vehicle)
- Biofuels (liquid or gaseous fuel for transport produced from biomass)
- Synthetic and paraffinic fuels
- Natural gas, including biomethane, in gaseous form (CNG and LNG)
- Liquefied petroleum gas (LPG).

EU-Minimum public procurement target for the share of Low-emission Buses in the total number of Buses at Member State level (*)



Source:UITP

Figure 1 Quotas for procurement of buses in EU, according to Clean Vehicle Directive

	Low-emission Buses (vehicle category M3)	
	From 2 Avgust 2021 to 31 Decembar 2025	From 1 January 2026 to 31 Decembar 2030
Luxembourg	45%	65%
Sweden	45%	65%
Denmark	45%	65%
Germany	45%	65%
United Kingdom	45%	65%
Netherlands	45%	65%
Austria	45%	65%
Belgium	45%	65%
Italy	45%	65%
Ireland	45%	65%
Spain	45%	65%
Cyprus	45%	65%
Malta	45%	65%
France	43%	61%
Czech	41%	60%
Lithuania	42%	60%
Finland	41%	59%
Hungary	37%	53%
Portugal	35%	51%
Latvia	35%	50%
Slovakia	34%	48%
Bulgaria	34%	48%
Greece	33%	47%
Poland	32%	46%
Estonia	31%	43%
Slovenia	28%	40%
Croatia	27%	38%
Romania	24%	33%

(*) Half of the minimum target for the share of clean buses has to be fulfilled by procuring zero-emission buses as defined in point 5 of Article 4. This requirement is lowered to one quarter of the minimum target for the first reference period if more than 80 % of the buses covered by the aggregate of all contracts referred to in Article 3, awarded during that period in a Member State, are double-decker buses.'.

Source: Directive (EU) 2019/1161

The ultimate goal in 2050 is 100% zero – emissions buses

Examples of good practice in the World:

China-Examples of good practice

In 2020, the largest number of electric buses is in China (350 000 E-buses); Guangdong Province, with 86,000 vehicles, followed by Shandong Province, with 45,000, and Jiangsu with 20,000 vehicles .

Shenzhen (China): Largest E-bus fleet in world , 16000 E-buses (BYD), 100% operation with E-bus

Santiago de Chile (Chile): Largest E-bus fleet in South America, 776 E-buses (BYD,Yutong),

Figure 2, E-bus depot in Shenzhen

Figure 3, E-bus BYD 12m in Santiago de Chile

Examples of good practice in the Europe:

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+86	Irizar,12m

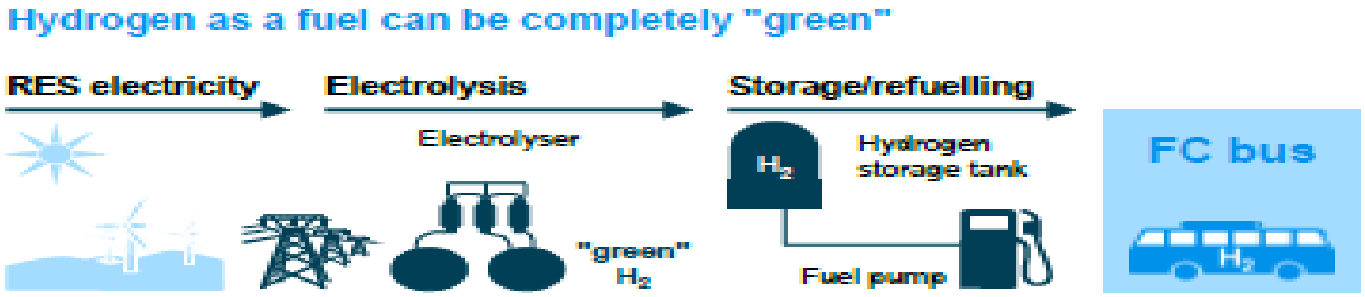
Newly registered E-buses in EU+UK+N+CH+Island

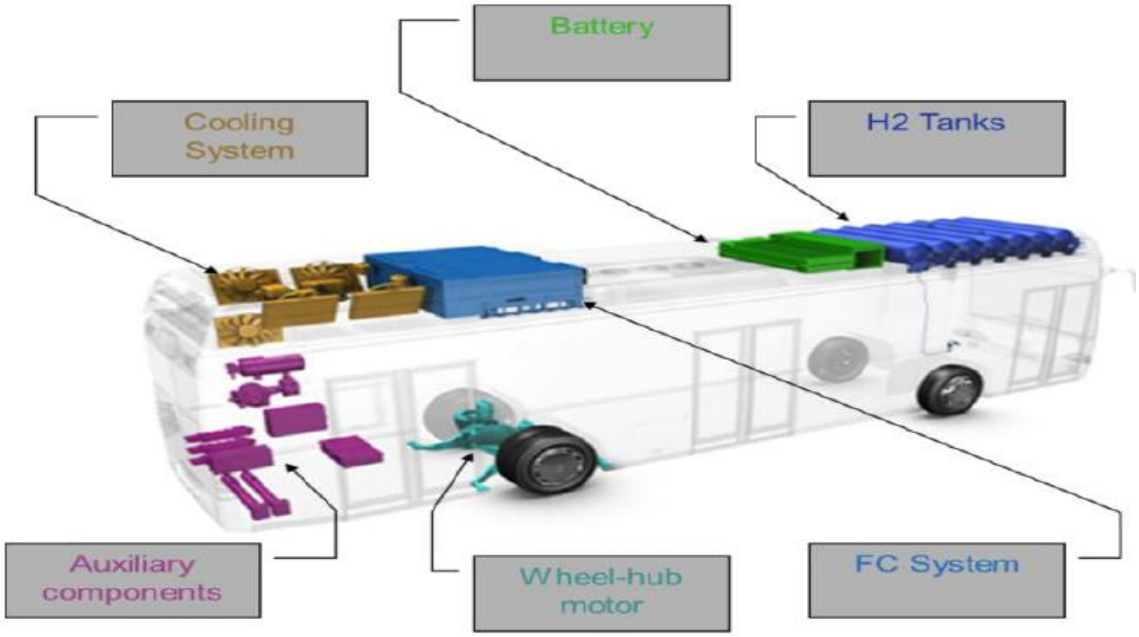
2021.Year 2788 E-buses

2020.Year 1875 E-buses

- Many tenders for the purchase of E-bus launched in 2021 (Barcelona 78, Stockholm 75, Helsinki 76, Malmo-Hassleholm 122, Paris 113, Basel 65.....)

- **Significant increase in sales of fuel cell buses, The JIVE /JIVE 2 (Joint Initiative for Hydrogen Vehicles across Europe) projects are the flagship fuel cell bus projects in Europe aiming to deploy over 300 buses in 18 cities &regions by the end of 2022**





ELECTRIC BUS MARKET

- Electric buses as a relatively new technology, have a tendency to constantly improve and strain primarily electricity storage systems (batteries, capacity up to 400 kWh for 12m E-bus and ultracapacitors 40 kWh), chargers "slow" with electric power 60÷80 kW, "fast" with power 400÷600 kW), traction control system, optimization of energy consumption, reduction of empty vehicle weight. FC buses (trend of decreasing prices FC buses, with a charge of 40 kg H2 autonomy of about 500 km.
- At the moment, all the world's bus manufacturers have E-buses of different lengths in their production program: midi (8÷9 m), standard (11÷13 m), articulated (18÷19 m) and double-articulated. 24÷27 m) and they become part of the standard offers on the bus market (Figures 4,5,6)

Figure 4, E-bus BYD 12m

Figure 5, E-bus Solaris Urbino 18m

Figure 6, E-bus Hess 24m

- The most represented manufacturers of electric buses that are currently present on the European market are BYD, VDL, Solaris & bus, Volvo, Kamaz, GAZ, Yutong, Ebusco, Optare, Caetano, Skoda, Irizar, Van Hool.
- Leading manufacturers of equipment and systems for charging electric buses are ABB, Siemens, Shunk, Jema Energy, Bombardier Primove.

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 work- days and use about 31.29 million liters of Euro-diesel fuel for the realization of the planned annual transport work. Also 150 tram and 90 trollly are in operation during work-day.
- If analyze the most important and most frequent corridors in the city of Belgrade, where public transport buses operate every day, concluded that especially in peak load, buses that use diesel fuel significantly increase the concentration of harmful gas emissions.

Table 1. Traffic corridors with the higest frequencies of buses for public transport

Street	Bus lines	frequency [buses/hour]
Brankova	15,16,27E,35,43,65,67,71,72,75,77,84,95,704,706,707,EKO1	**127.6**
Boulevard Despot Stefan	16,27E,32E,35,43,58,95,96	63
Kneza Milosa	23,37,51,52,53,56,56L,58,74	67
Boulevard Z.Misica (Fair)	23,37,51,52,53,55,56,56L,58,88,89,91,92,511,551,553	**97**
Glavna (Zemun)	17,45,73,83,84,704,705,706,706E,707	63
Boulevard Oslobodjenja	30,31,33,39,42,47,48,59,78	77

NOx emissions

Euro 3

=

Euro 6

PM_{10} emissions

Euro 3

=

Euro 6

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

E-mobility in Belgrade PT

First E-bus Line (opened to regular operation 1st September 2016.)

EKO 1 (Vukov spomenik-Naselje Belvil)

Figure 7, Route of Line EKO 1

- **A central city line, so that the environmental impact of the "0" emission is the biggest.**
- **The high attractiveness of line from the aspect of passenger requirements.**
- **Suitability of the line or terminal from the aspect of providing energy requirements for chargers**
- **One of the first lines in Europe where the E-bus is working exclusively**
- **The mean length of the EKO 1 line is 8 km. (Direction ''A'' 7,47 km, Direction ''B'' 8.5 km). The line with a flat configuration with a slight climb**

Figure 8, E-bus Higer KLQ6125GEV3

Higer KLQ6125GEV3
- **Capacity: 80 passengers**
- **2x Siemens, electric motors, asynhronic Power: 2x67kW , 2x90 kW, 2x150 kW**
- **Torque: 2x430 Nm**
- **RPM: 10 000 min-1**

Ultracapacitors technology for storage electricity

- **Principle: Electric-static**
- **Capacity: 20 kWh**
- **Flexibility for rapid charging and discharging**
- **High efficiency: 92-98%**
- **Acceptable mass: 900 kg**
- **Temperature range: -40 to +65 C**
- **Charging time defined by factor C >10**
- **The possibility of accepting the entire electrical energy in the recuperation phase**
- **Can withstand deep discharge**
- **Suitable for recycling**
- **Life time, at least 10 years, the real 15 years**

Charging system : fast-charging at terminials.

The advantages of the pantograph charging system

- **The acceptable charging time 5-10 min**
- **The possibility of attaching the charger to tram/trolly network (DC) or public distribution network (AC)**
- **Power of charger ≥ 150 kW**
- **E-bus can be in operation full working time (patricularly important in summer/winter conditions with the use of air-conditioning or heating system)**

EXPLOITATION INDICATORS ON THE LINE EKO 1

- Number E-buses in operation: **4**
- Working hours per vehicle per day: **16÷18 h**
- Average daily mileage per vehicle: **190÷215 km**
- Transport speed*: **14.4 km·h^{-1}**
- Daily number of passengers transported per vehicle: **900÷1200 passengers**
- Avarage Consumption*: **1,23 kWh · km^{-1} (summer period, incrise +24%, winter period +35%)**
- Reliability of work on the line: **97.5%**

Analysis consumption electricity of E-bus*

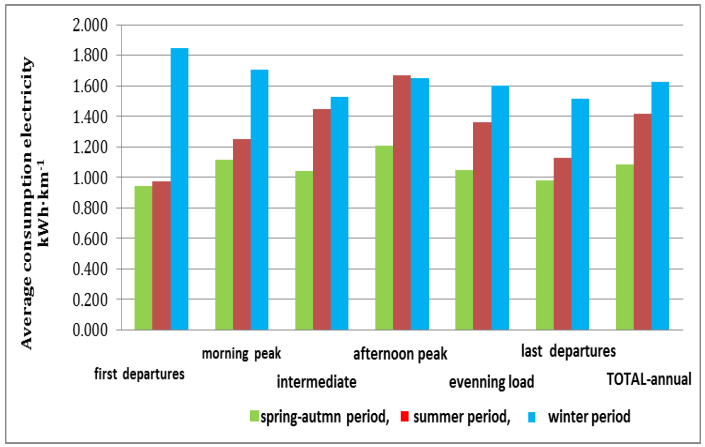


Figure 9.Consumption electricity, direction A, EKO 1 line

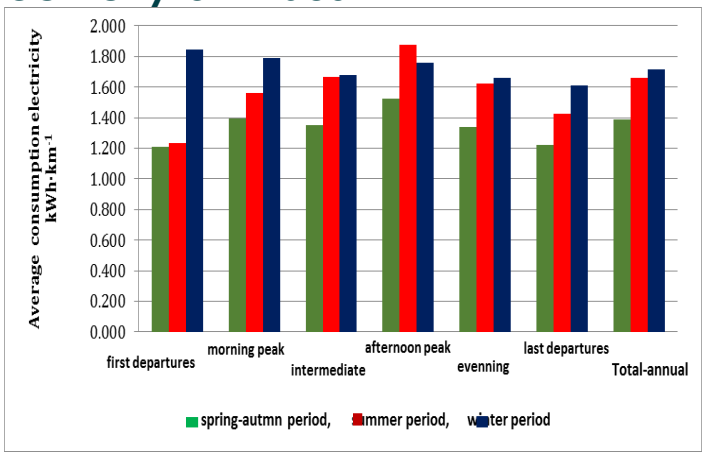
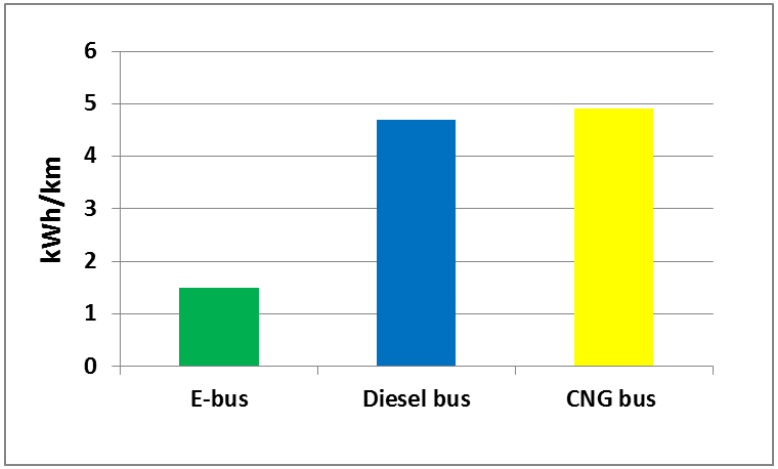


Figure 10. Analisyis electricity, direction B, EKO 1 line

Comparison of energy efficiency of different drive systems for a city bus of 12m*



Analysis ecological performances of E-bus on line EKO1

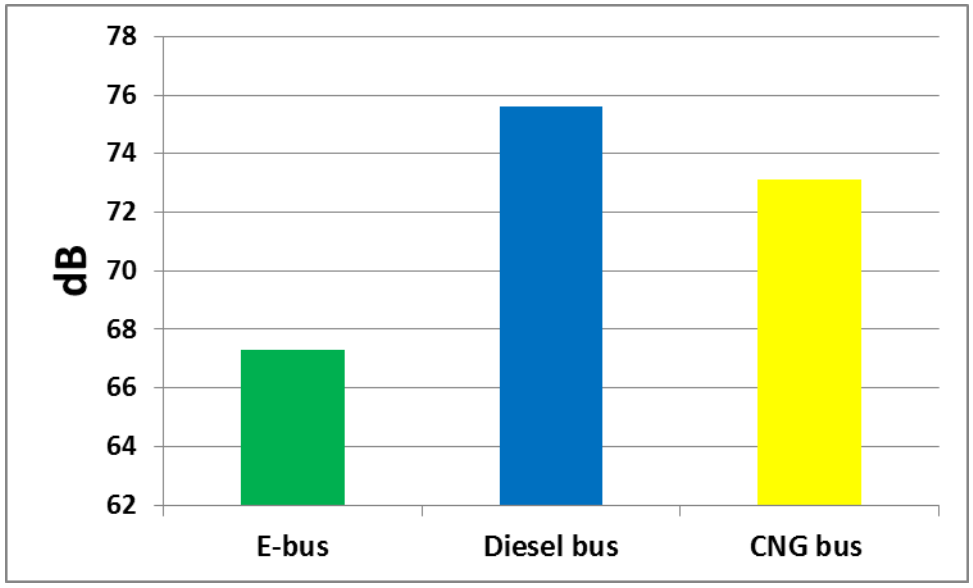
Table 1 Summary analysis of the TTW and WTW for buses of different propulsion systems on line EKO 1 in Belgrade, (annual period of operation)*

Line EKO 1	Unit	E-bus Higer KLQ6125GEV3	IK-112N Disesel	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

* Source:
Misanovic S.: Energy and environmental performance of E-bus in the passenger transport system, doctoral dissertation, Faculty of Engineering, University of Kragujevac, 2021

Analysis level of noise E-bus /diesel/CNG

The noise level when moving the bus at a speed of 30 km/h



Line ''VRABAC'' (pedestrian zone in city center)

Figure 13. Route of line ''Vrabac''

- Opened to regular operation 30st August 2019.
- Intended for elderly citizens and tourist who visit city center
- Served by mini electric vehicles ''Guevara'', capacity 6-8 passengeres
- Lenght of rute: 2.2 km
- 3 vehicles in operation
- Working time: 8 a.m to 10 p.m
- Arrival interval: 10 minutes

Figure 14. mini electric vehicles ''Guevara''

Figure 15. station ''Kulturni centar''

EKO 2 (Belgrade waterfront- Gale Muskatirovic, sport-centar)

Second E-bus Line opened to regular operation 24 January 2022.)

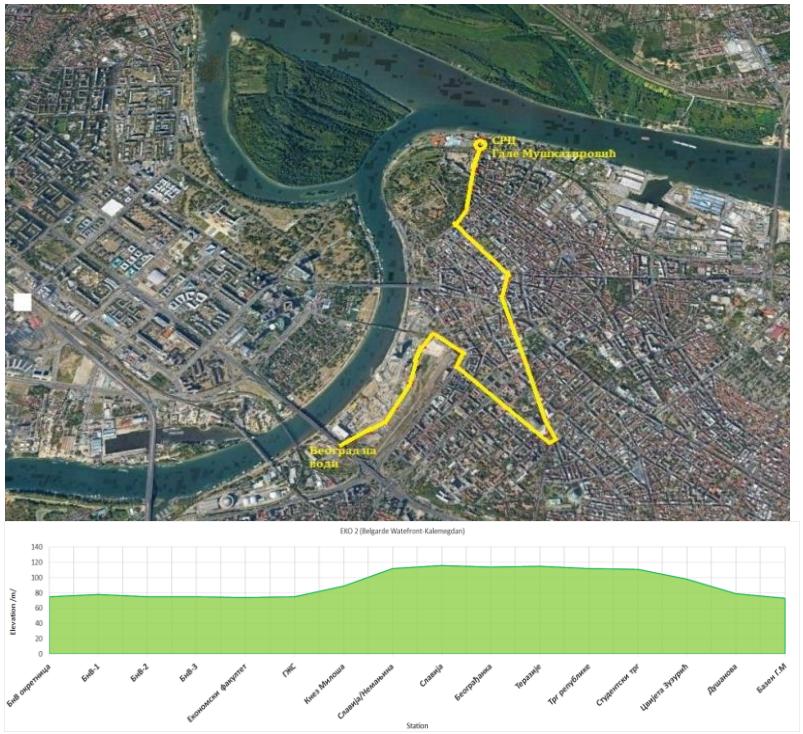


Figure 15. Route of line EKO2

- central city line,
- The high attractiveness of line
- The mean length of the EKO 1 line is 6.4 km.
- 8 e-buses in operation
- Interval: 10 min
- Transport capacity: 540 passengeres/h
- expected electricity consumption (daily level): 1.24 kWh/km,

New e-buses

Higer KLQ6125GEV3
- Capacity: 90 passengers
- Siemens, electric motor with permanent magnet
- Power: 160 kW
- Torque: 2500 Nm
- RPM: 3500 min-1

Advanced Ultracapacitors technology for storage electricity

- High efficiency: 95-98%
- Capacity: 40 kWh
- High efficiency: 95-98%
- Acceptable mass: 1300 kg
- Temperature range: -40 to +65 C
- Charging time defined by factor C >10

Charging system:

- 2 fast chargers AC/DC on each terminals, power 2x400 kW
- Eficiency: ≥ 0,96
- The acceptable charging time 5-10 min

AC/DC Chargers on Terminal: Gale Muskatirovic,sport-center 2x400 kW

Table 2. 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	$kWh \cdot km^{-1}$	1.246	
Average consumption of diesel	$L \cdot (100km)^{-1}$		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

FUTURE PLANS 2022-2025

E-buses Procurement:

15 E-bus (12m)
25 E-bus (18m)

Trolleybuses (CiM) Procurement:

20 Trolleybuses (18m)
60 Trolleybuses(12m)

Tender preparation in progress

New E-bus lines:
replacement of diesel buses
on city centarl lines

the proposal, Lines: 31,77,83....

- extension of existing trolleybus lines
- removed contact networks from the central zone

Thank you for your attention