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URBAN TRANSPORT DECARBONISATION STRATEGIES: SCENARIO ANALYSIS ON ROUTE BUS 368 IN CITY OF BUCHAREST

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This paper focuses on the impact of GHG emissions on air quality from Public Transport Operator in Bucharest, specifficaly for bus line 368, with a viewed to improving environmental conditions for city residents. The GHG emissions of the bus fleet on bus line 368 were estimated using the Jaspers Method and compared with a scenario in which more electric buses are introduced, analyzing the carbon footprint in both scenarios, diesel-only and diesel with electric buses. The study revealed that the electrification of the bus fleet attracts a lower specific carbon footprint, thus leading to better environmental life conditions.

Keywords: Air pollution; Transport emissions; Carbon footprint; GHG emissions.

Abbreviations

The following abbreviations are used in this manuscript:

GHG	Greenhouse Gases
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
N_2O	Nitrous oxide
CH_4	Methane
STB-S.A.	Bucharest Public Transport Company
UE	European Union

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JASPERS	Joint Assistance to Support Projects in European Regions
Web TAG	Web-based Transport Analysis Guidance
COVID-29	Coronavirus Disease 2019

1. Introduction

Air In the context of amplifying global challenges generated by the globalization process, air pollution and climate change emerge as major priorities on the sustainability and climate change agenda. By the World Health Organization, it's estimated that over 99% of the world's population gets exposed to air pollution above the limits set by air quality standards [1].

Recent scientific liters highlight the significant influence of air pollution on the proper functioning of the immune system, suggesting that chronic exposure to air pollutants may lead to immunological dysfunctions [2–4]. Many studies have found a correlation between the high levels of pollutants and the increased frequency of certain immune pathologies, including allergic diseases, bronchial asthma, and autoimmune diseases [5–7]. The primary sources of air pollution, mainly industrial activities, transport emissions, and fossil fuel-based energy production, are also contributing factors to climate change [8]. These processes generate significant emissions of carbon dioxide (CO_2), the main greenhouse gas involved in global warming [9]. The double impact of CO_2 highlights the deep link between air pollution and climate change, as sources of air pollutants are also major drivers of climate change at the global level.

The incomplete combustion of fuels in contained spaces is accountable for approximately 3.5 million deaths globally each year [10]. Global temperature rising because of high CO_2 levels boosts tropospheric ozone production by accelerating photochemical reactions and upping chemical reactivity, including by increasing water evaporation, which then adds to ozone production. Increased CO_2 levels are also associated with atmospheric flow changes, which can lead to the production of regional ozone. This complex mix of factors leads to higher public health risks, slower farming productivity, and ecosystem dysfunction [11, 12].

The transport sector accounts for a major fraction of air pollutant emissions, pointing to the urgent need to implement effective measures to mitigate these emissions in order to protect public health [13]. At the European Union level, transport contributes approximately 25% of total greenhouse gas (GHG) emissions, making it a key driver in the elaboration of climate change policies [14].

Based on Romania's fifth Biennial Report, coordinated by the Ministry of Environment, Water, and Forests, greenhouse gas emissions in 2020 were dominated by carbon dioxide (CO_2), which made up 67% of the total, followed by methane (CH_4) at 21%, nitrous oxide (N_2O) with 10%, and fluorinated gases with a contribution of 2% [15]. Higher carbon dioxide (CO_2) levels in the atmosphere really drive climate change, especially by making global warming more intense. Rising temperatures, combined with high CO_2 levels, also contribute to the formation of tropospheric ozone (O_3) in urban and industrial environments as a result of complex photochemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs), which is intensified by solar radiation. This chemical process has a big impact on public health, making respiratory and cardiovascular diseases more serious, especially for people who are already at higher risk [11].

The public transport operator for the municipality of Bucharest named STB - S.A. serves a total area of 1335 km², of which 240 km² is urban. STB - S.A. ensures the mobility of approximately 1.91 million passengers daily, with an operational structure that includes: a bus network consisting of 1640 vehicles distributed across 122 lines, of which 32 are regional; a trolleybus network consisting of 265 vehicles serving 13 lines; and a tram network consisting of 527 vehicles operating on 22 lines [16].

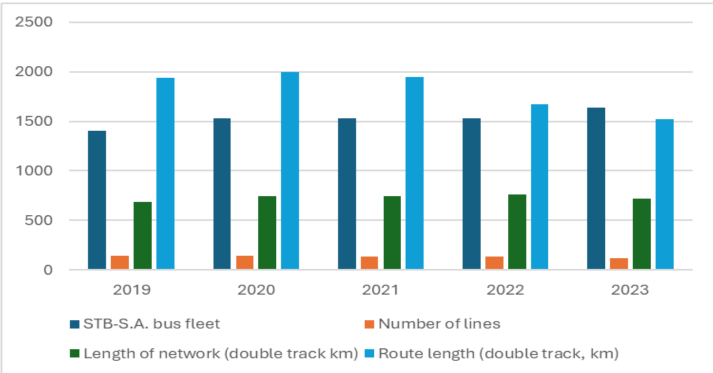

Fig. 1.1. Evolution of the STB-S.A. bus fleet between 2019 and 2023 [16].

The STB-S.A. bus fleet has benefited from European funds for the purchase of clean vehicles over the last four years, and the situation has significantly improved with the purchase of 130 hybrid buses and 100 electric buses [16]. The target for 2030 is to purchase a further 250 non-polluting buses, as set out in the PMUD [17]. The purchase of the 100 electric buses also involved an in-depth study on battery recharging options [18, 19].

2. Materials and methods

The aggregate assessment method of the Joint Assistance to Support Projects in European Regions (JASPERS) initiative [20] was applied to estimate greenhouse gas (GHG) emissions from the transport sector [21-26], using cumulative data on the annual mileage of vehicles in the bus fleet of the Bucharest transport network. The fleet bus of public transport operator from Bucharest is presented in Table 2.1.

Table 2.1.

STB – S.A. bus fleet in December 2024 [16].

Category	Bus type	Total fleet bus	Active fleet bus
Euro III	MERCEDES E3	498	319
Euro IV	MERCEDES E4	500	407
Euro VI	OTOKAR	400	375
Hybrid	MERCEDES HYBRID	130	124
Electric	ZTE GRANTON	100	59
Uncategorized	DAF, ROCAR, VOLVO	10	-
TOTAL		1638	1284

The emissions rate of each GHG per unit of fuel consumed (for gasoline and diesel consumption) is shown in Table 2.2. [24].

Table 2.2.

Emission factors for GHG calculation for the STB S.A. bus fleet. [24].

Gaz	Petrol[kg/l]	Diesel[kg/l]
CO_2	2.25	2.66
CO_{2e}	2.35	2.70

Jaspers uses the value of 0.517 kgCO_2/kWh, which is an official factor from JASPERS CBA Guidance, used in environmental assessments for European projects [25]. It is a conservative factor, but utile in estimates for traffic management's projects. The equivalent GHG factors for converting each greenhouse gas into CO_{2e} are shown in Table 2.3. For electric buses, we considered mileage (km) and energy consumption (kWh) using the conversion factors in Table 2.3. [24].

Table 2.3.

Equivalent GHG factors for converting each greenhouse gas into CO2e [24].

Gas	Conversion factor
CO_2	1
N_2O	298
CH_4	23

The WebTAG value is 1.1798 kWh/km [27]. In the ZTE Granton bus technical data sheet, the total capacity [kWh] is 383.23, and the bus range is 314.3 km, according to the SORT 1 - SORT UITP PROJECT report [28]. Producers do not recommend lowering the battery capacity below 75-80%. Under these conditions, the specific consumption calculated is 1.22 kWh/km.

Line 368 of STB-S.A. is a uniform and efficient bus line that covers a significant area of Bucharest, as shown in Fig. 2.1.

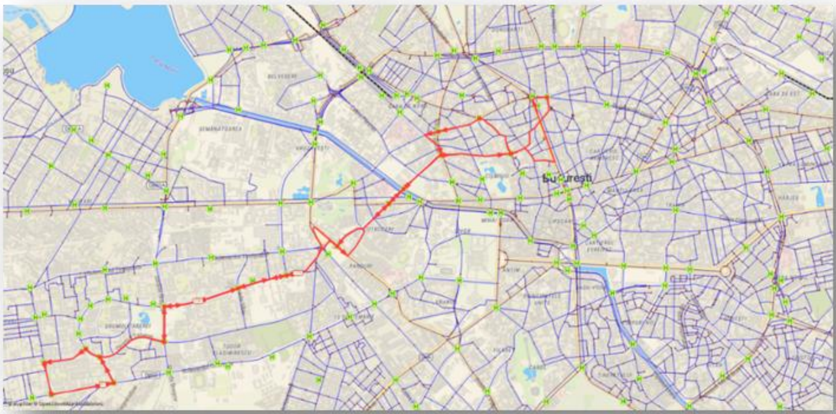

Fig. 2.1. Route map for STB-S.A. bus line 368 [16].

To evaluate the impact of introducing electric buses on the environmental performance of urban transport, we analyzed line 368, which operates a total of 15 buses, 7 of which are electric. We collected data from the STB-S.A., specifically from Traffic Planning and Dispatching Department for the working hours of buses on line 368 on weekdays and Saturdays/Sundays.

3. Results and discussions

In 2024, the fleet covered 967,733 km, both in the current scenario (with 7 electric buses) and in a scenario with diesel only buses. Fig. 3.1. represents the Jaspers spreadsheet for the STB-S.A. fleet with 7 electric buses and 8 diesel buses.

Assessment of GHG emissions using simple traffic data

Outputs

Total GHG Emissions (tCO2e)	909

Total GHG emissions for the whole of the traffic model 2024

	CONVENTIONAL FUELS					ELECTRIC		
Class	Car	LGV	OGV1	OGV2	PSV	Trolleybus	Elec Bus	Tram
GHG Emissions (tCO2e)	0	0	0	0	652	0	257	0

Sub-total GHG emissions for each of the vehicle classes for which data is provided below for 2024

Inputs

Year of Assessment	2024

The year which the traffic data represents

Annual vehicle kilometers travelled

The total annual vkm travelled by each vehicle class in the assessment year

	CONVENTIONAL FUELS					ELECTRIC			TOTAL
Vehicle Type	Car	LGV	OGV1	OGV2	PSV	Trolleybus	Elec Bus	Tram	
Vehicle KM					516,125		451,609		967,734

Speed Bands

User defined speeds bands for up to four categories of road, which the vkm data will be split across

Band	Description
18	Urban

Calculation of GHG emissions using simple traffic data

Table S1: Fossil Fuel Calculation by Speed Bands

Urban 25kph	Vehkm	Car-P	Car-D	LGV-P	LGV-D	OGV1	OGV2	PSV
		0	0	0	0	0	0	361288
Kg Emissions (2010 values)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	511508.3
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	26.9
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	26.9
	CO_2 Equivalent	0	0	0	0	0	0	520150
Emissions (2024)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	511508.3
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	26.9
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	26.9
	CO_2 Equivalent	0	0	0	0	0	0	520,150

Suburban 50kph	Vehkm	Car-P	Car-D	LGV-P	LGV-D	OGV1	OGV2	PSV
		0	0	0	0	0	0	103225
Kg Emissions (2010 values)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	82118.5
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	4.3
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	4.3
	CO_2 Equivalent	0	0	0	0	0	0	83506
Emissions (2024)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	82118.5
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	4.3
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	4.3
	CO_2 Equivalent	0	0	0	0	0	0	83,506

Rural 75kph	Vehkm	Car-P	Car-D	LGV-P	LGV-D	OGV1	OGV2	PSV
		0	0	0	0	0	0	51613
Kg Emissions (2010 values)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	47552.3
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	2.5
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	2.5
	CO_2 Equivalent	0	0	0	0	0	0	48356
Emissions (2024)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	47552.3
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	2.5
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	2.5
	CO_2 Equivalent	0	0	0	0	0	0	48,356

Highway 100kph	Vehkm	Car-P	Car-D	LGV-P	LGV-D	OGV1	OGV2	PSV
		0	0	0	0	0	0	0
Kg Emissions (2010 values)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CO_2 Equivalent	0	0	0	0	0	0	0
Emissions (2024)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	CO_2 Equivalent	0	0	0	0	0	0	0

TOTAL		Car-P	Car-D	LGV-P	LGV-D	OGV1	OGV2	PSV	TOTAL
Kg Emissions (2010 values)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	641179.1	641179
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	33.7	34
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	33.7	34
	CO_2 Equivalent	0	0	0	0	0	0	652012	652012
Emissions (2024)	CO_2	0.0	0.0	0.0	0.0	0.0	0.0	641179.1	641179
	N_2O	0.0	0.0	0.0	0.0	0.0	0.0	33.7	34
	CH_4	0.0	0.0	0.0	0.0	0.0	0.0	33.7	34
Emissions	CO_2 Equivalent (t)	0	0	0	0	0	0	652	652

Table S2: Electricity Vehicle Emissions

Trolleybus	1.9	kWh/km
Electric Bus	1.1	kWh/km
Tram	1.6	kWh/km

TOTAL		Trolleybus	Elec Bus	Tram	TOTAL
	vkm	0	451609	0	
	kWh	0	496769.9	0	
Emissions (2024)	CO2 (t)	0	257	0	257

Fig. 3.1. Jaspers spreadsheet for the STB-S.A. fleet with 7 electric buses and 8 diesel buses. [20].

Table 3.1. presents GHG emissions evolution in the two scenarios, diesel-only and diesel + electric buses, for the year 2024.

Table 3.1.

GHG emissions with and without 7 electric buses on line 368 in 2024.

Bus type	CO_2 [kg]	CH_4 (kg)	N_2O [kg]	CO_{2e} [kg]	Specific CO_{2e} [kg/km]
Diesel only buses (15)	1,192,481	63	63	1,213,000	1.25
Diesel (8) + electric (7) buses	641,000	34	34	909,000	0.94

With the introduction of seven electric buses (approximately 47% of the fleet), emissions decreased significantly at 641,000 kg CO_2; 34 kg CH_4; 34 kg N_2O; 909 tons of CO_2e, representing a total reduction of 304 tons CO_2e, as shown in Fig. 3.2.

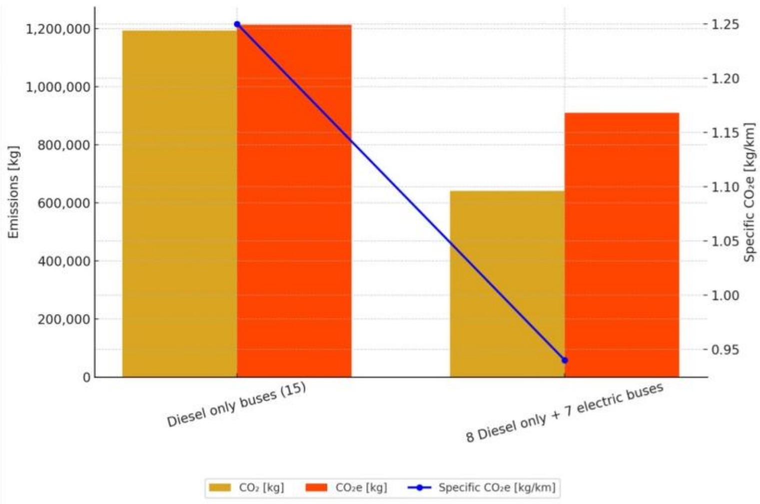

Fig. 3.2. GHG evolution in the two scenarios for line 368, with and without the 7 buses.

Relating total emissions to distance traveled, specific emissions of 1.25 kg CO_2e/km are attained in the diesel-only scenario, compared to 0.94 kg CO_2e/km in the scenario with seven electric vehicles. This reduction of approximately 25% in emissions highlights the positive impact of partial electrification on urban air quality and carbon footprint reduction associated with public transport, as illustrated in Fig. 3.3.

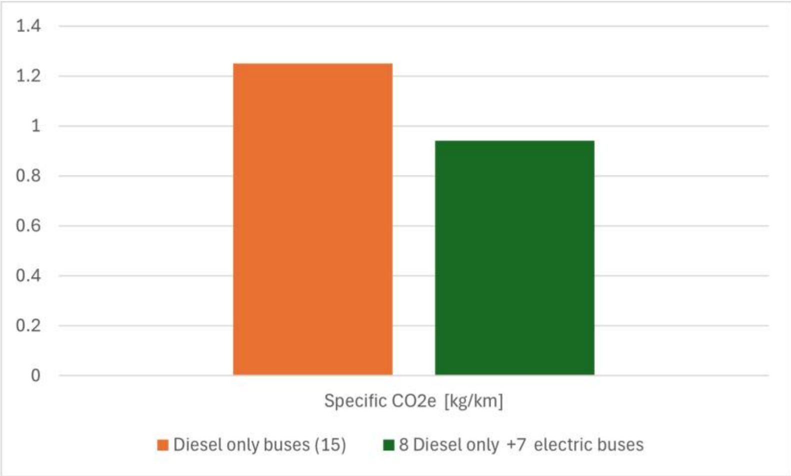

Fig. 3.3. The specific carbon footprint for the two scenarios for line 368, with and without electric buses.

In conclusion, the obvious advantages of partial electrification of the bus fleet are evident, and the evolution of specific indicators provides a solid basis for sustainable urban mobility planning.

We have developed a scenario in which 5 more electric buses will be introduced on line 368 in 2025. The scenarios includes: exclusively diesel operation, the integration of seven electric buses, and expansion to 12 electric buses out of a total of 15. The results are presented in Table 3.2., Figs. 3.4. and 3.5., assuming that all 15 buses will travel the same distance in 2025 as they did in 2024.

Tabel 3.2. GHG emissions evolution for the scenario with and without the introduction of 5 additional electric buses on line 368 compared to 2024.

2025 Scenario	**Electric bus**	**Diesel bus**	**CO_2 [kg]**	**CH_4 [kg]**	**N_2O [kg]**	**CO_2e [kg]**	**CO_2e specific [kg/km]**
Diesel only buses (15)	0	15	1,192,480	63	63	1,213,000	1.25
Diesel + 7 electric buses	7	8	641,000	34	34	909,000	0.93
Diesel + 12 electric buses	12	3	238,500	13	13	683,000	0.70

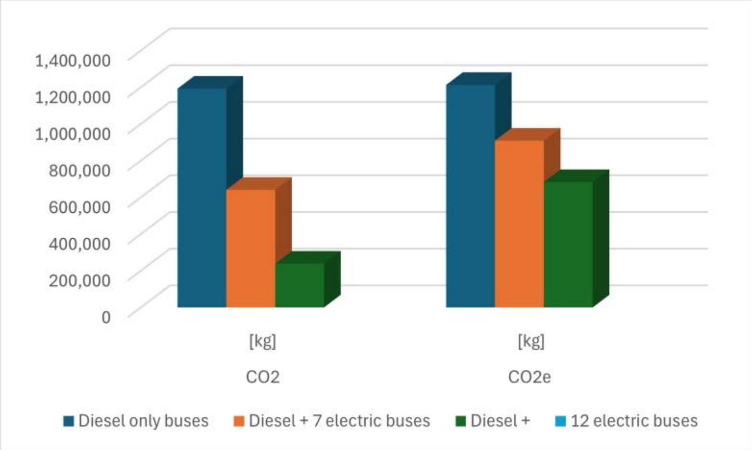

Fig. 3.4. GHG emissions for the scenario with and without the introduction of 5 additional electric buses on line 368, compared to 2024.

The graphic clearly indicates a progressive decrease in all emission indicators as the number of electric buses expands. CO_2e falls from over 1,213 tons in the scenario without electric buses to approximately 630 tons in the scenario with 12 electric buses. Total CO_2e follows a similar trend, indicating a concrete reduction in all emissions from the bus fleet with 530 tons of CO_{2e}.

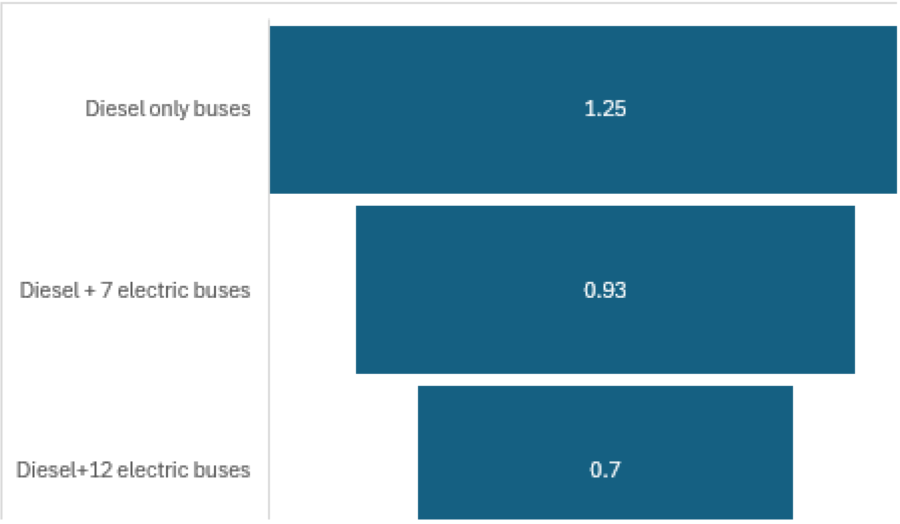

Fig. 3.5. Specific carbon footprint for the scenario with and without the introduction of 7 additional electric buses on line 368, compared to 2024.

Specific CO_2e most accurately reflects the environmental efficiency of each scenario: from 1.25 kg/km in the baseline scenario to 0.70 kg/km in the advanced scenario. This representation highlights the environmental benefits of the transition to electric mobility, supporting the necessity of investments in electric urban fleets for reducing greenhouse gas emissions in the transportation sector.

4. Conclusions

By introducing 7 electric buses, the middle scenario ("Diesel + electric", 7E+8D) reduces total emissions to 909 tons of CO_2e, with a specific carbon footprint of 0.94 kg CO_2e/km, which means an absolute decrease of approximately 25% in total CO_2e emissions and a significant improvement in environmental efficiency. The highest decarbonization scenario, involving 12 electric buses and only 3 diesel buses, generates a drastic reduction in total emissions to 683 tons of CO_2e and a specific value of 0.70 kg CO_2e/km, equivalent to a reduction of approximately 43% compared to the baseline scenario. Therefore, gradual progress in the electrification of public transport is proving to be an effective climate change mitigation strategy, with tangible benefits for air quality and public health. These results highlight the need to accelerate investments in electric mobility infrastructure and optimize the fleet mix in large cities, to achieve the target from in Sustainable Urban Mobility Plan. The target is to continuing the modernization of the charging infrastructure for electric buses(Berceni, Bucurestii Noi and Bujoreni depots) to allow the new onebuses purchased to be operational; extending dedicated bus lanes to prevent traffic jams and reduce fuel and energy consumption; improving traffic management systems to reduce congestion and save energy, especially during peak hours; congestion charges or restricted access to city centers for polluting vehicles; developing ambitious environmental policies that take into account the circular economy, the metabolic transition, and EU regulations.

Making public transport more attractive and efficient, especially by upgrading the vehicle fleet, will provides Bucharest not only economic and social benefits, but also real improvements in quality of life.

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