The Evolution of Energy Consumption in Electric Mobility in Bucharest in 2024: Between Efficiency and the Potential of Renewable Sources

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Abstract: *Globalisation has led to serious air pollution challenges, with significant consequences for the environment, human health, and climate, prompting a continuous worldwide search for emission reduction solutions. The transition to sustainable public transport represents one of the major priorities for European cities in the context of the current climate emergency and decarbonization targets. In Bucharest, the electrification of urban public transport has experienced progressive expansion, particularly through the introduction of electric buses in 2024. This article analyses the monthly electricity consumption of the electric vehicle fleet in 2024, focusing on the consumption trends of electric buses and the opportunities for renewable energy supply in an urban context, but also on the evolution of GHG emissions and carbon footprints for electric buses after upgrading.*

Keywords: *Renewable energy, public transport, electric bus fleet, carbon footprint, GHG emissions*

1. Introduction

Air pollution, particularly carbon dioxide (CO_2) emissions, constitutes a major environmental problem, with anthropogenic activities accounting for most emissions. The most significant sources of primary and secondary pollutants include industrial processes, the transport sector, and energy production [1].
These pollutants, with toxic effects on human health, account for up to 8.2% of total global greenhouse gas emissions [2] and contribute to the increase in global CO_2 concentrations, amplifying the climate change process.
Air pollution is associated with approximately 6.7 million premature deaths each year [3], and while the global average temperature has risen by about 0.85°C due to pollution [4], Europe's warming trend over the last three decades exceeded the global average, averaging 0.48°C, compared to the total global increase [5].
Greenhouse gas emissions from diesel use have been estimated to account for 26% of global black carbon emissions [6]. That is why specific measures are needed to mitigate these emissions by adopting the most advanced pollution control technologies and withdrawing high-emission diesel vehicles in service. As a result, the implementation of vehicle emission standards, fleets electrification, and quality requirements for alternative fuels in the European Union helped cut air pollution emissions from road transport [7,8].
Electrifying vehicle fleets offers high potential for reducing short-lived climate pollutants (SLCPs), particularly black carbon. According to Jacobson's estimates, replacing vehicles in the United States with electric, plug-in hybrid, or hydrogen-powered models from renewable energy sources (wind, solar, hydroelectric, etc.) could eliminate approximately 160 Gg/year of black carbon generated from fossil fuel combustion — equivalent to about 24% of national black carbon emissions (or 1.5% of global emissions) — and could reduce CO_2 emissions by about 26% nationally [9].
The targets set at European Union level for 2030 provide for a 55% net reduction in greenhouse gas emissions, and the target for 2050 is to become climate neutral [10].
In 2021, Romania was ranked 48th worldwide in greenhouse gas (GHG) emissions, with its contribution representing approximately 0.22% of the global total [11]. It is estimated that the transport sector is responsible for approximately 4.2 million premature deaths worldwide because

of outdoor air pollution [12]. Among the various pollutants it generates, carbon dioxide (CO_2) is the primary product of the complete combustion of carbon-based fuels and a major contributor to anthropogenic greenhouse gas emissions.
The transport sector is a major source of anthropogenic greenhouse gas (GHG) emissions, accounting for approximately 29% of total global emissions. These emissions consist mainly of carbon dioxide (CO_2), generated primarily by the combustion of fossil fuels in internal combustion engines, and are therefore a major contributor to climate change [13].
The Bucharest Public Transport Company (STB S.A.) operates an integrated network covering 1,335 km², of which 240 km² is within the urban area, serving approximately 1.071 million passengers daily. Its fleet comprises 1,640 buses operating on 122 routes, 265 trolleybuses on 13 routes, and 527 trams on 22 routes [14, 15]. This study presents a broad look at how improving Bucharest's urban transport system impacts the city, with more cars on the road causing traffic jams and air pollution. The analysis looks at the potential of renewing the fleet and upgrading transport infrastructure as ways to make public transport more attractive. Furthermore, the survey underlines the need of implementing urgent and specific measures and adopting sustainable environmental policy to mitigate the harmful effects of urban air pollution [16]. STB-S.A.’s fleet has been modernized by 43% over the last four years with electric buses, EURO 6 buses, new trams, and new trolleybuses, and in 2024, 58 out of 100 ZTE GRANTON electric buses entered service.

2. Materials and methods

Using data collected from the Technical and Operations Departments of STB - S.A., we have analysed the monthly electricity consumption of the electric vehicle fleet and associated maintenance units of STB S.A. in 2024, focusing on the evolution of electric bus consumption and opportunities for renewable energy supply in an urban context. The introduction of electric buses has provided an overview of the energy consumption of urban mobility systems and the potential for integrating renewable energy sources into the power supply infrastructure. In 2024, the bus fleet of public transport operator in Bucharest in presented in Figure 1.
The ZTE Granton bus specifications indicate that the total battery capacity is 383.23 kWh, providing a range of 314.3 km, according to the SORT 1—SORT UITP Project report [17]. Producers recommend maintaining the battery state of charge above 75-80%.

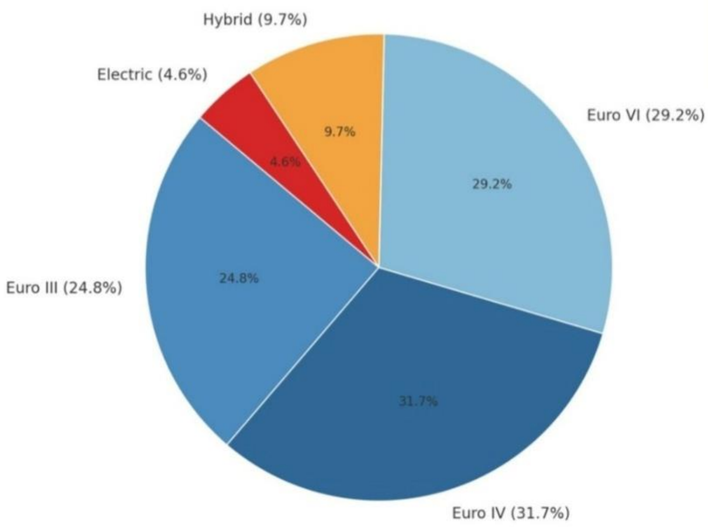

Fig. 1. STB-S.A. bus fleet percentage in December 2024 [14]

2.1 Electricity consumption for the bus fleet of the public transport operator in Bucharest

The evolution of energy consumption and specific energy for electric buses in 2024 is presented in Table 1 and Figure 2, based on the collected data.

Table 1: Energy consumption and specific energy for bus fleet of public transport operator in 2024

Month	KWh	kWh/km
January	258.574	1.478
February	138.198	0.79
March	233.771	1.336
April	220.219	1.258
May	228.976	1.308
June	259.361	1.482
July	302.992	1.731
August	279.418	1.597
September	259.352	1.482
October	231.209	1.321
November	300.614	1.718
December	326.608	1.866

The highest consumption (both total and specific) is recorded in the cold months **(December, January, November)** and in the middle of summer (July–August) due to increased energy consumption for heating systems for passenger comfort and to maintain the battery at optimal temperatures (in winter) and because of high consumption from using air conditioning in the summer.

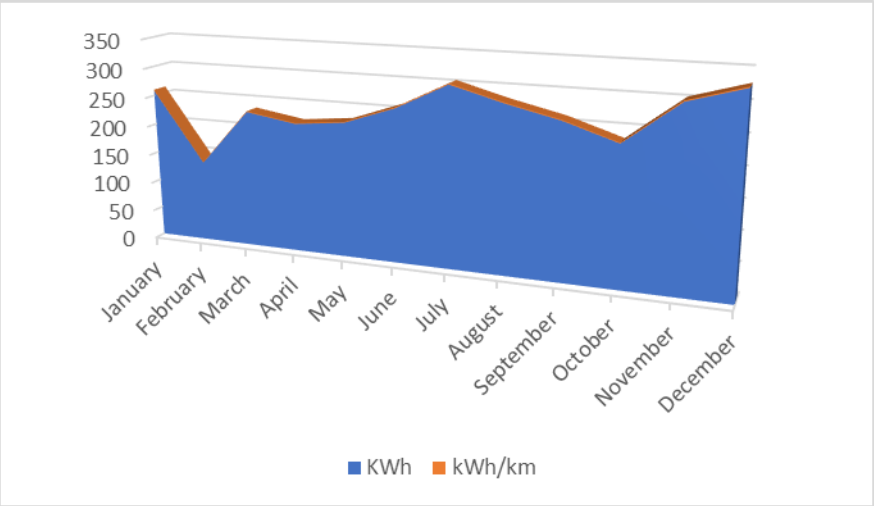

Fig. 2. STB-S.A. bus fleet energy consumption and specific energy in 2024

Seasonal averages for specific consumption of electric buses in 2024 are presented in Table 2.

Table 2: Seasonal averages for specific consumption of electric buses in 2024

Season	Month	Specific energy consumption [kWh/km]
Winter	December-February	1.38
Spring	March-May	1.30
Summer	June-August	1.60
Autumn	September November	1.51

Figure 3 highlights the impact of seasonal weather conditions on the energy performance of electric buses. They are more efficient in periods with moderate temperatures and less efficient in winter and summer, which require additional battery power for air conditioning and heating.

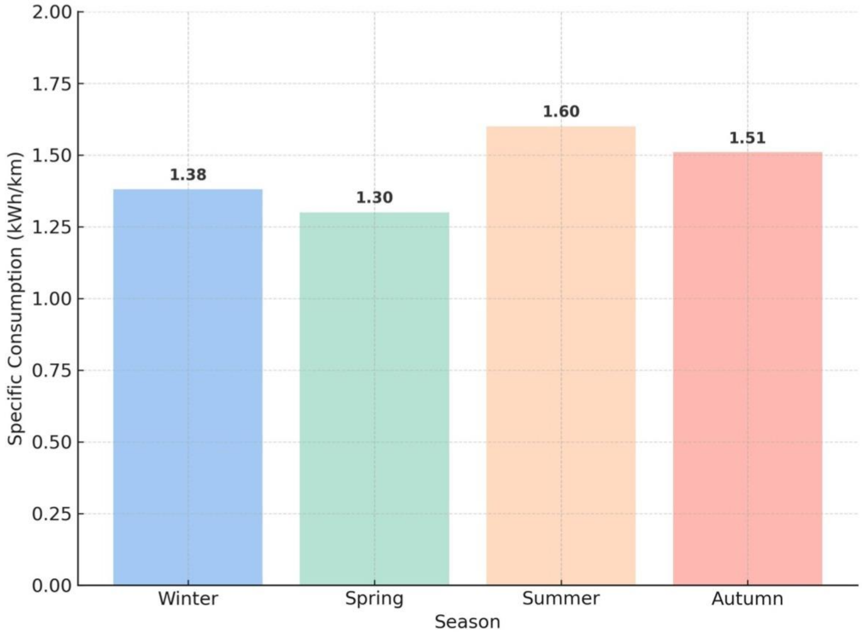

Fig. 3. Seasonal specific energy evolution of the public transport operator in Bucharest 2024

The consumption of electric buses in Bucharest varies between 1.30 and 1.60 kWh/km depending on the season. The climate and the use of HVAC (heating/cooling) systems are the main factors causing the variation.

A comparison of specific energy consumption for transport fleets in some different European countries is presented in Table 3 and Figure 4.

Table 3: Specific energy consumption comparison in European cities [14, 18-28]

Country	Specific Consumption (kWh/km)
Romania (Bucharest, 2024)	1.46
UK (Enviro400EV test)	0.67
UK (real-world depots)	1.11
Germany (Berlin BVG)	0.90
France (Paris)	1.23
Spain (Madrid EMT)	1.00
Spain (other lines)	2.10
Italy (Turin GTT)	1.35
Portugal (Lisbon Carris)	0.75
Portugal (TCB)	1.00
Poland (Warsaw MZA)	1.03

A comparative analysis of specific energy consumption in European countries reveals notable regional differences. In Bucharest (1.46 kWh/km), consumption is above the European average (1.2–1.3 kWh/km), mainly due to traffic congestion, climatic conditions, and the use of heating, ventilation, and air conditioning systems.

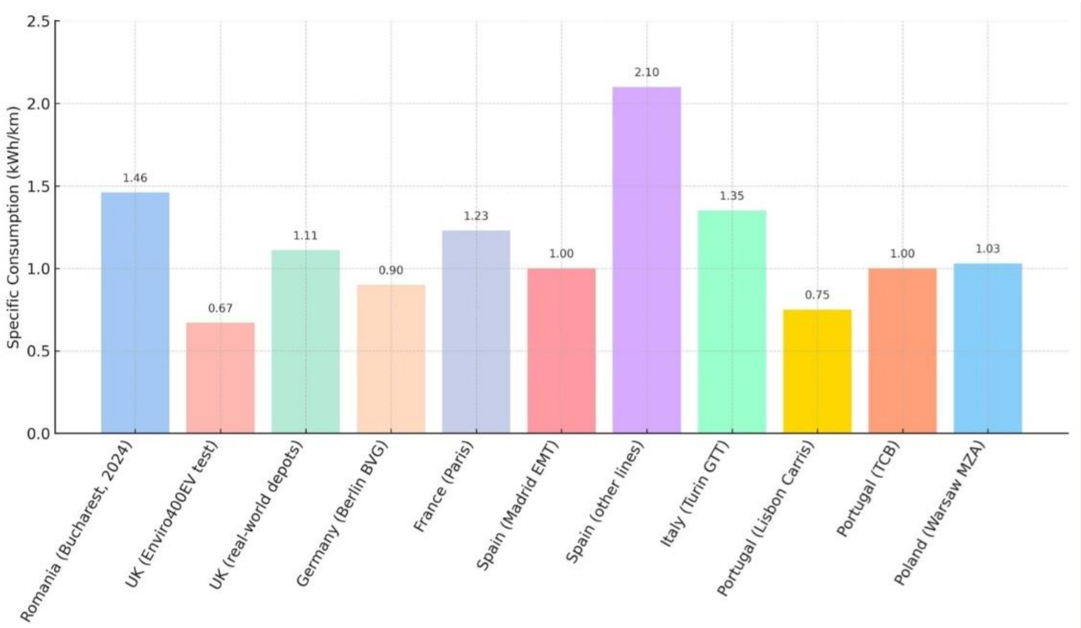

Fig. 4. Comparison of specific energy consumption of fleet bus in different European cities [14, 18-28]

The United Kingdom reports values of up to 0.67 kWh/km in standardized tests, although actual figures are closer to 1.1 kWh/km. Germany (0.9 kWh/km) and France (1.23 kWh/km) demonstrate efficient operation, supported by advanced infrastructure and a temperate climate. Southern European cities such as Madrid (1.0-2.1 kWh/km) and Turin (1.35 kWh/km) show greater seasonal variability, largely influenced by high cooling demand during the summer. Portugal has some of the best results (0.5-0.75 kWh/km in Lisbon), while Poland (about 1.03 kWh/km on average) experiences significant seasonal fluctuations, with winter peaks of up to 3 kWh/km. Overall, Romania is more in line with the higher consumption trends in Southern and Eastern Europe, emphasizing the importance of optimizing the vehicle fleet and infrastructure, energy-efficient vehicle technologies, and improving operational practices.

2.2 Status of charging stations for electric buses in Bucharest

Twenty slow charging stations have been installed within the URAC to serve 20 electric buses from the existing transformer stations on the low voltage network. The charging stations have a power of 90 kW, a supply voltage of 400 V AC—alternating current—and a maximum current consumption of 165 A, all provided by the electric bus provider [14]. The maximum power that can be absorbed for charging electric buses is 2000 kW, in accordance with the existing Technical Connection Certificate. The electrical power supply of URAC, who provides manufacturing and repair services for the STB-S.A. tram fleet, is provided by the national distribution network and operates at a voltage of 10 kV.

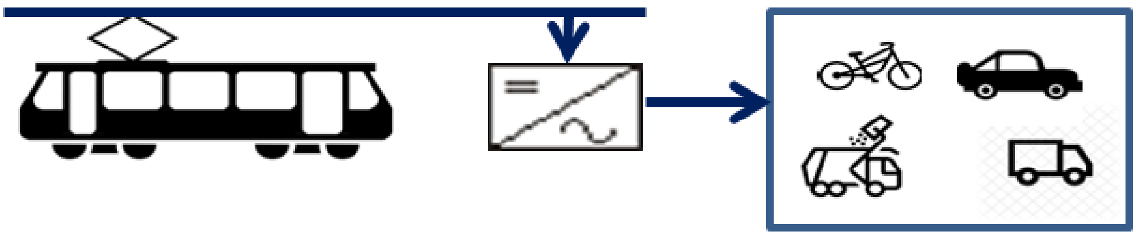

Fig. 5. Power supply for electric vehicles from the tram traction network

These charging stations at URAC are a temporary solution, as three depots are currently being upgraded to provide charging facilities for electric buses: Berceni, Bujoreni, and Bucurestii Noi, with a total installed power of 4950 kW and a total power of 90 kW.

As part of the European project, it has been found that, following the modernization of the drive systems installed on electric vehicles, energy consumption has decreased, and it has been calculated that the average hourly consumption and maximum hourly consumption for the 38 existing electrical substations. Using this energy resource for charging electric vehicle batteries is associated with additional energy losses, which can reach approximately 40% of the total energy used. That's why an energy balance should be made to see if this solution is feasible given the transport infrastructure that's about to be upgraded.

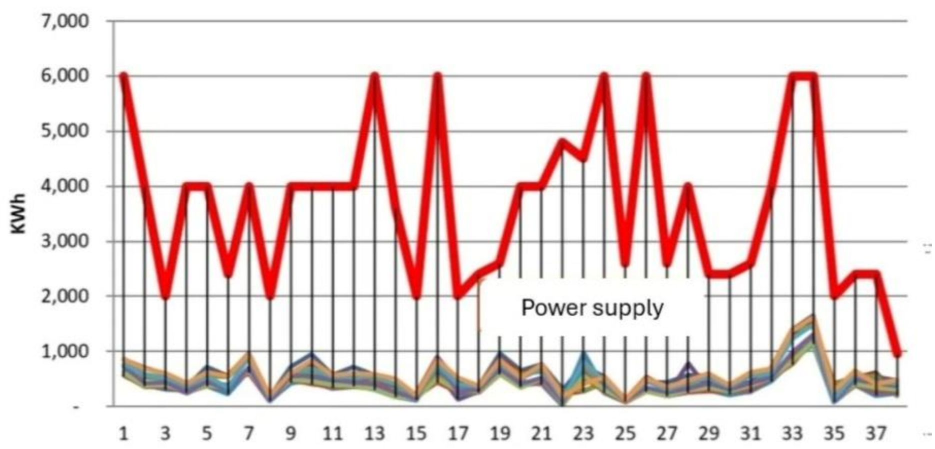

Fig. 6. Maximum hourly consumption and installed power (KWh) / (KVA)

In order to utilize this energy resource, additional energy loss may occur during the charging of electric vehicle batteries, which may represent up to approximately 40% of the total energy used; based on the specifics of the existing transport infrastructure and the location of the stations, an energy balance should be done to see if this solution is feasible for the transport infrastructure that's going to be upgraded.
The upgraded infrastructure for environmentally friendly transport operates in accordance with European standards in vigour - European Directive 2009/33/EC promoting clean and sustainable transport, which started in 2024.

2.3 Emissions estimation and the carbon footprint for the bus fleets of the public transport operator in Bucharest

The bus fleet emissions were estimated using Joint Assistance to Support Projects in European Regions (JASPERS) method [15], applied for estimating the greenhouse gas (GHG) emissions in the transport sector [17, 29-33], drawing upon cumulative records of the annual mileage of the bus fleet operating in the Bucharest public transport network. According to the JASPERS Cost-Benefit Analysis (CBA) Guidance, the standardized emission factor for electricity generation in Romania is 0.517 kg CO_2 per kWh, which was applied in this study to estimate associated greenhouse gas emissions [31].
The introduction of electric buses in 2024 reduced emissions by 12 kilotons of CO_2e compared to 2023, representing a 13% decrease in these types of emissions compared to the previous year. In 2024, electric buses accounted for approximately 3.47% of the total distance travelled by the entire bus fleet.
A relevant comparison can be made between 2023 and 2024. Although the reduction per kilometer may seem moderate, over the typical long distances of urban transport systems, it substantially reduces total greenhouse gas emissions.
With the introduction of electric buses in 2024, specific emissions per kilometer were 1.234 kg/km, a reduction of 2.68% compared to the previous year, which is illustrated in Figure 7.

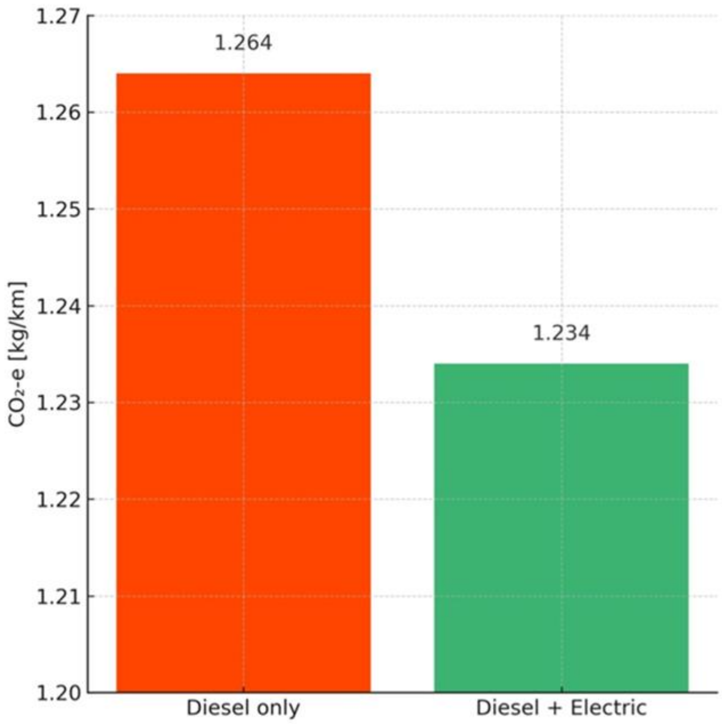

Fig. 7. Specific CO2e emissions per km in 2024

The estimated greenhouse gases and carbon footprint obtained during the analyzed period (2021-2024) after the introduction of electric buses in 2024, are presented in Table 4.

Table 4: Estimated GHG emissions for bus fleet of public transport operator in 2021-2024

Year	CO_2 [kg]	N_2O [kg]	CH_4 [kg]	CO_{2e} [kg]
2021	86,118,608.29	4532.55	4532.55	87,573,559.51
2022	81,739,580.79	4302.08	4302.08	83,120,549.50
2023	83,963,198.9	4419.11	4419.11	85,381,735.05
2024	72,176,673.81	3798.77	3798.77	74,485,933.81

For Bucharest case (Romania), indirect greenhouse gas emissions were calculated using the national average emission factor for electricity for 2024, quantified at 232 g CO_2e per kWh (i.e., 0.232 kg CO_2e/kWh) [34]. Table 5 and Figure 8 present a comparison between CO_2e/kWh values in Romania and those reported for other European countries.

Table 5: CO_2e/kWh for Romania compared with other states of European Union [34]

Country	Current Emissions [gCO_{2e}/kWh] in 2024
Romania	232
Austria	37
Portugal	94
Greece	251
Spain	113
Italy	295
Sweden	15
Lithuania	470

The table highlights the significant differences between countries in terms of carbon intensity of electricity production. Romania performs in the middle of the ranking — well ahead of countries with a coal/gas-based energy mix, but far behind countries with green or nuclear energy.

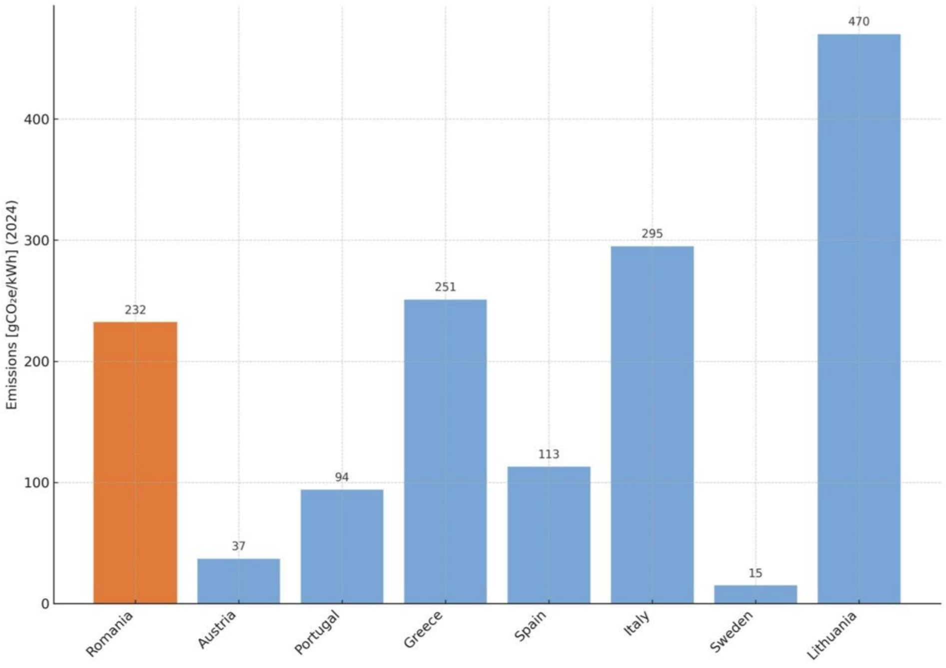

Fig. 8. CO_{2e}/kWh comparison between Romania and European countries

3. Discussion

Projections suggest that by 2030, electric buses will represent over 30% of the national fleet, consistent with Romania’s obligations under the European Green Deal and the “Fit for 55” package, which foster the shift towards sustainable, low-emission mobility [16].
If the number of electric buses doubles (from 58 to 100), then total energy consumption also doubles (assuming approximately constant mileage per bus) is presented in table 6 and Figure 9. We’ve considered two scenarios: a static scenario (no increase), a dynamic scenario (with small increase, 1% per year). Monthly electricity consumption data for 2024 indicated an average of 1.46 kWh/km, which was used as the reference factor for estimating annual fleet demand and projecting scenarios for 2025–2030.

Table 6: The evolution of electricity consumption of the electric bus fleet in two scenarios

Year	Constant	1%/YEAR
2025	5.24	5.24
2026	5.24	5.29
2027	5.24	5.34
2028	5.24	5.39
2029	5.24	5.44
2030	5.24	5.5

The sensitivity scenario was applied to take account of potential variations in energy demand by introducing an annual growth rate of 1%. According to this assumption, the annual electricity consumption of 5.24 GWh in 2025 increases to approximately 5.50 GWh by 2030.

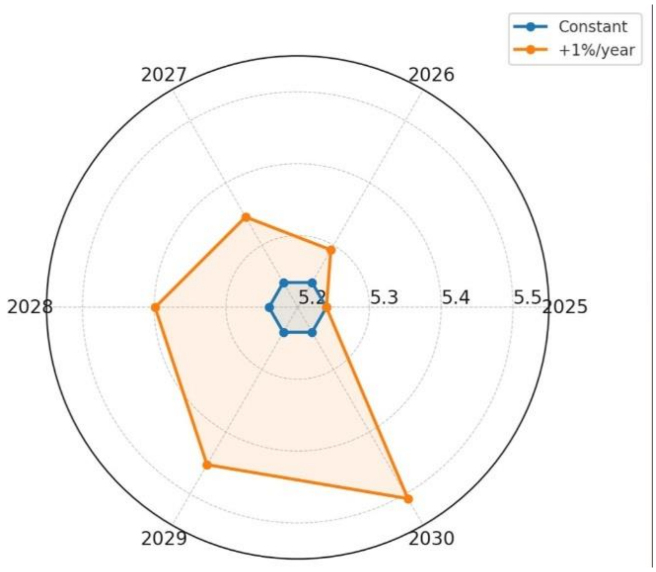

Fig. 9. Comparison of the static scenario (no changes) and the dynamic scenario (1% annual growth) of electricity consumption based on data from 2024

Blue line (constant) = 5.24 GWh/year, constant over the period 2025-2030.
Orange line (+1 %/year) = increases from 5.24 GWh in 2025 to 5.50 GWh in 2030.
For the period 2025–2030, we have modeled a scenario that predicted the replacement of 50 diesel buses with electric buses each year, contributing to the gradual transition to a low-emission fleet. By 2030, almost 80% of the Bucharest operator's bus fleet would be modernized, with an estimated reduction of over 11 kilotons of CO_2e compared to 2024 levels, as shown in Figure 10.

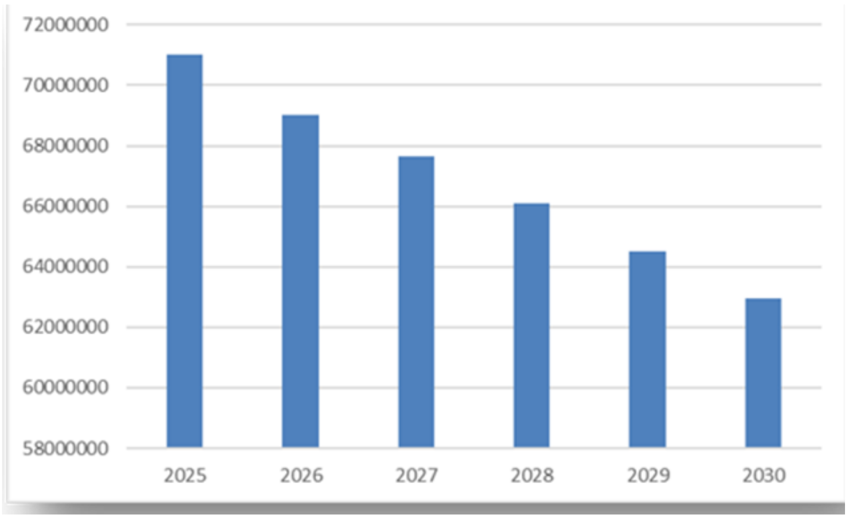

Fig. 10. Estimated GHG and carbon footprint scenario with 50 electric buses replacement in public transport operator between 2025-2030

The decreasing greenhouse gas emissions tendency at both local and European level corresponds to the initiatives of most Romanian municipalities, which are developing Sustainable Energy Action Plans (SEAPs) [35] or Climate and Sustainable Energy Action Plans (CSEAPs) [36] to build coherent and tangible inventories and decisions for reducing urban emissions.
Cutting down on local air pollution by getting rid of PM, NOx, and VOC emissions will directly contribute to long-term health benefits, like respiratory and cardiovascular diseases and other health issues directly linked to air pollution. This is in coherence with Romania's pledges as part of the European Green Deal and the "Fit for 55" framework, that promote the transition to transport based on low emissions [37] by achieving the 2030 target of additional procurement of 250 non-polluting buses, as stipulated in the P.M.U.D. [38].

The transport sector significantly affects air quality due to internal combustion engine vehicles, which emit pollutants such as PM, NOx, CO, and VOCs, contributing to urban environmental quality decline and detrimental health effects. That is why the electric buses represent a concrete solution for cutting greenhouse gas emissions and reducing air pollution.

4. Conclusions

The introduction of 58 electric buses into Bucharest's public transport fleet generated a quantifiable decarbonization impact, saving 13% of carbon dioxide equivalent emissions in comparison with 2023.
Moreover, the specific carbon footprint of electric bus operations decreased by approximately 2.68%, representing a total reduction of approximately 11 kilotons of CO_2e, partly attributable to the decline of diesel-only buses.
The specific annual average electricity consumption for Granton buses is approximately 1.46 kWh/km in 2024, which represents the reference factor for the future consumption forecasts and for fleet energy performance assessment.
The data provides a solid basis for sustainability reports and strategies to expand the electric fleet, especially as charging stations for electric buses are being completed at the Bujoreni, Berceni, and Bucurestii Noi depots. This will allow the deployment of the remaining electric buses purchased in 2023.
Sustainable and resilient future recommendations for public transportation:

- Gradual phase-out of Euro III-V vehicles, supported by binding requirements or stimulus packages for their removal from service.
- The completion of the modernization of the charging infrastructure for electric buses to allow the new electric buses to start operating.
- The expansion of electromobility (replacing trams, introducing new, environmentally friendly electric buses and trolleybuses)
- Developing more ambitious environmental policies that consider the circular economy and EU regulations
- Reducing operating costs by granting subsidies for energy used in electric traction and preferential energy tariffs for public transport operators.

Future prospects:

- Expanding GHG emissions calculations using the JASPERS method for all electrified public transport in Bucharest
- Quantifying electricity consumption for electric bus charging stations to estimate the carbon footprint for these terminals
- The estimation of black carbon (BC) emissions, which also include $PM_{2,5}$, and short-lived climate pollutants (SLCPs), such as CH_4, using adequate calculation methods
- Scenario screening for the alternative options, such as hydrogen, as an energy source for buses, which represent a promising solution for conventional electrification, especially on extended routes or in heavy-duty conditions, where electric charging infrastructure deployment is challenging.

Upgrading the public transport fleet in Bucharest will increase the attractiveness and efficiency of the mobility, bring socio-economic gains while generate significant benefits for the city's environment.

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
NOx Nitrogen oxides
PM Particulate matter
VOC Volatile Organic Compounds

BC Black Carbon
SLCP Short-lived climate pollutant emissions
STB S.A. Bucharest Public Transport Company
URAC Repair Work and Central Factory
UITP The International Association of Public Transport
UE European Union
JASPERS Joint Assistance to Support Projects in European Regions
Web TAG Web-based Transport Analysis Guidance
PMUD Sustainable Urban Mobility Plan
HVAC Heating, Ventilation, and Air Conditioning

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