Introduction

According to public information, Compania de Transport Public (CTP) Cluj-Napoca operates with 41 bus lines, providing transportation for 67.5% of the total number of passengers, by means of a fleet made up of 256 classical buses equipped with diesel engines meeting emission standards between Euro 0 and Euro 6, as well as a number of electric buses, with zero local pollution, on a road infrastructure of 567 km [1-3].

Regarding the Euro 6 emission standards, the new regulations make significant changes to the 50% reduction in the level of emissions measured for the following indicators: carbon dioxide (CO₂), nitrogen oxides (NOₓ), carbon monoxide (CO), and non-methane hydrocarbons (NMHCs). For electric propulsion systems, all of the above emission indicators are zero (local). The amount of CO₂ emitted per year from transport activity and calculated according to the amount of fuel consumed represents the carbon footprint of road transport. Approximately 25% of CO₂ emissions from road transport come from trucks, buses, and coaches, and this is expected to increase by about 10% by 2030 [4, 5]. The transport sector, with
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vehicles equipped with conventional fossil fuel engines, is responsible for more than 70% of air pollution in big cities [2]. Annually, the quantity of CO₂ emitted into the atmosphere has a mass four times the mass of the emitting vehicle [2]. The high degree of air pollution in the transportation sector results from the sector's direct dependence on fossil fuels. The negative impact on the environment in large urban agglomerations due to increased numbers of vehicles with classical propulsion systems is highlighted by European energy and environmental policies. Urban traffic is estimated to generate up to 40% of CO₂ emissions and up to 70% of other pollutant emissions [2, 6]. Around the world, approximately 3.7 million people in a billion die prematurely annually due to atmospheric pollution [7]. Cardiovascular, pulmonary, and cognitive diseases can be aggravated by the air-polluting emissions from the atmosphere.

The Green Vehicle Directive (2009/33/EC) [8] requires public transport operators, when purchasing new buses, to consider in their assessment of energy, environmental, and operational impact of at least the following: energy consumption, CO₂ and NOₓ emissions, NMHCs, and particulates. European Commission (EC) Regulation 443/2009 [9], which refers to the M1 vehicle category, aims to reduce emissions from new vehicles and imposes limits on CO₂ emissions to a value of 95 g CO₂/km by 2020, compared to the current standard of 130 g CO₂/km. European Union (EU) Regulation 2400/2017 [10], which implements EC Regulation 595/2009 [11] and amends Directive 2007/46/EC [12] and EU Regulation 582/2011 [13], indicates that emissions from trucks, coaches, and buses are currently about 25% of the total CO₂ emissions from road transport, and are expected to increase further in the future [14]. Reducing CO₂ emissions from heavy-duty vehicles and buses requires the implementation of effective measures to achieve the 60% reduction target by 2050.

Topal et al. [15] highlight that the increased pollutant emissions from classical road transport systems requires the development of sustainable transport systems with zero local pollutant emissions.

In the reduction of CO₂ emissions in Cluj-Napoca city, the chosen solution is to replace 11 diesel buses with electric buses. Thus, considering the desiderata [2, 16] for achieving this objective, Fig. 1 shows the advantages [2, 5] and disadvantages [2] of replacing diesel buses with electric buses for public transport.

Kivekas et al. [17] showed that in crowded urban areas, where driving cycles are demanding, traffic is heavy, and travel speeds are reduced, it is necessary to replace diesel buses with as many electric buses with low energy consumption as possible.

Topal et al. [15] proposed a new approach called the zero-emission bus purchase and operation model (ZEBusPOM) to move from the classical polluting public transport system to a sustainable system with zero local pollutant emissions according to the following algorithm:

1. Monitor the real-time operation of diesel/electric buses in urban traffic after a predetermined schedule, with passengers, under hot/cold weather conditions.
2. Develop a database with monitored results during the operation of diesel/electric buses.
3. Compare the two bus models in terms of energy efficiency.

The purpose of this paper is to highlight the need to replace diesel buses with Euro 0 emission standards with electric buses with zero local pollution. This paper

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Fig. 1. Desiderata, advantages, and disadvantages of the solution for replacing electric buses for public transport.
reports research carried out on the quantity of CO\textsubscript{2} emissions reduced from urban traffic in Cluj-Napoca, Romania, following the replacement of 11 diesel buses with 11 electric buses. With this purpose, weather conditions (temperature and humidity) were considered for the investigated period (July-December 2018). The environmental data, along with statistics on fuel consumption (for diesel buses), energy consumption (for electric buses), and the distances traveled were the basis for assessing the amount of CO\textsubscript{2} reduced by the introduction of electric buses. At the same time, these data allowed evaluation of the optimal energy consumption of the electric buses according to temperature and humidity during the considered period.

### Material and Methods

#### Bus Technology Comparisons

At present, the CTP Cluj-Napoca fleet [3] has 40 Solaris Urbino 12e electric buses, of which 11 were purchased in May 2018 and 12 were purchased earlier this year (2019), and another 17 arrived in Cluj-Napoca.

### Table 1. Technical characteristics of considered buses.

| Parameters                        | Unit          | Renault R312 | Solaris Urbino 12e |
|-----------------------------------|---------------|--------------|--------------------|
| Length/width/height               | m             | 11.99/2.50/2.95 | 12.00/2.55/3.25    |
| Nominal/loaded weight             | kg            | 11550/19000  | 13000/19000        |
| Number of seats/total passenger capacity | –/–          | 28/107       | 23/70              |
| Engine/motor (tip)               | –/–           | Diesel Euro 0 | Electric asynchronous |
| Maximum engine power             | kW            | 180          | 160                |
| Maximum engine torque            | Nm            | 925          | 1450               |
| Batteries (type)                 | –/–           | –/–          | Lithium            |
| Battery capacity                 | kWh           | –/–          | 210                |
| Tank capacity                    | l             | 250          | –                  |
| Energy consumption summer/winter | kWh/km        | –/–          | 1.00/2.00          |
| Fuel consumption summer/winter   | l/100 km      | 34/37.4      | –                  |
| Autonomy (by producer)           | km            | 600          | 105                |
| CO emissions (Euro standard)      | g/kWh         | 12.30        | 0 local            |
| HC emissions (Euro standard)      | g/kWh         | 2.60         | 0 local            |
| NO\textsubscript{x} emissions (Euro standard) | g/kWh | 15.80 | 0 local |

### Table 2. Bus line characteristics.

| Parameters                        | Unit       | 27   | 28   | 30   | 32   |
|-----------------------------------|------------|------|------|------|------|
| Line length (tour-retour)         | km         | 9.700| 8.500| 17.700| 6.600 |
| Average time (tour-retour)        | min        | 41   | 36   | 78   | 35   |
| Number of stops (tour-retour)     | –          | 17   | 15   | 31   | 13   |
| Average distance between stops    | km         | 0.571| 0.567| 0.571| 0.510|
| Number of buses per line          | –          | 2    | 1    | 6    | 2    |
| Total number of lines (working days) | –          | 30   | 11   | 60   | 44   |
| Total number of lines (Saturday)  | –          | 22   | 10   | 30   | 24   |
| Total number of lines (Sunday)    | –          | 20   | 9    | 24   | 24   |
| Total distance per line (working days) | km  | 38121| 12249| 139122| 38042 |
| Total distance per line (Saturday) | km  | 5548 | 2210 | 13806 | 4118  |
| Total distance per line (Sunday)  | km         | 5238 | 2066 | 11470| 4277 |
| Total distance per line (July-December 2018) | km | 27   | 28   | 30   | 32   |
in mid-2019. The 11 electric buses that have been in the fleet since 2018 operate on lines 27, 28, 30, and 32 [2, 3]. The Solaris Urbino 12e buses already in operation have replaced the same number of diesel buses, Renault R312 type manufactured between 1990 and 1993, with Euro 0 emission standards. Not all diesel buses were replaced on the considered lines; some still run alongside the electric buses. The technical characteristics of the two types of buses are shown in Table 1 [18-23].

Operating Lines of Tested Buses

The bus lines on which the electric buses are used are 27, 28, 30, and 32. According to data provided by CTP Cluj-Napoca [1, 24], the characteristics of these public transport lines are detailed in Table 2 and Fig. 2. To define the altitude of points for the bus line, we used the GpsPrune application [25], which is designed for viewing, editing, and converging coordinate data obtained by the global positioning system (GPS) (Fig. 3).

The altitude profile of a line is a very important parameter for an electric vehicle in terms of its autonomy. In [2], among other factors, the altitude characteristics of the public transport lines in Cluj-Napoca city were taken into consideration to study the designation of lines on which the electric buses would operate.
Environmental Data

Regarding the ambient data, the temperature in Cluj-Napoca in the time interval between 05:00, when the buses start working ($T_{5:00}$ ($^\circ$C)) and 23:00, when the buses finish working ($T_{23:00}$ ($^\circ$C)), was monitored for the whole considered period (July-December 2018). The temperatures were downloaded from rp5.ru [26] considering the temperature during each hour of the considered range. Since fuel/energy consumption is monitored as a statistical value per bus per day, the average daily temperature ($T_{\text{average}}$ ($^\circ$C)) was calculated from the relationship:

$$T_{\text{average}} (^\circ$C) = AVERAGE($T_{5:00}$:$T_{23:00}$) \quad (1)$$

The evaluation of recorded temperature for the considered period is represented in a boxplot (Fig. 4), which, based on the daily quantitative data of temperature variation, generated a statistical model for each monitored month. The main elements generated by the boxplot (Table 3) were mean ($\mu$), standard deviation (SD), minimum value (min), lower quartile (Q1) (delimits the lowest 25% of recorded values), median (med; delimits the lower 50% of recorded values, with 50% of the highest recorded values dividing the set of values into two equal parts), upper quartile (Q3) (delimits the highest 25% of recorded values), and maximum value (max).

Similar to temperature values, the daily average values for atmospheric humidity were downloaded and calculated and, after statistical processing, are presented in a boxplot (Fig. 5 and Table 4).

Electric Power Generation

Electric buses, propelled by electric motors powered by batteries recharged from the public electricity grid, have zero local pollutant emissions. Charging is carried out in loading stations located at the ends of the lines on which the buses run. There are slow charging stations (overnight), where batteries charge up to 100% of capacity in 4-6 hours, and fast charging stations, where batteries can be charged with a lot of energy in a short period of time (10 minutes), to extend the autonomy of electric buses in the intervals between runs.

This energy comes from both renewable sources (nuclear, geothermal, biomass, wind, solar, hydro) and polluting sources (coal, gas, oil) in different proportions, depending on a multitude of factors. The ElectricityMap Live [27] application and the monthly electricity market monitoring reports (Table 5) of the Romanian National Regulatory Authority for Energy (ANRE) [28-30]

![Fig. 4. Temperature values recorded for the considered period.](image)

![Fig. 5. Humidity values for the considered period.](image)

| Month     | $\mu$ (mean) | SD (standard deviation) | min (minimum value) | Q1 (lower quartile) | med (median) | Q3 (upper quartile) | max (maximum value) |
|-----------|--------------|-------------------------|---------------------|---------------------|-------------|---------------------|---------------------|
| July      | 20.88        | 2.09                    | 15.20               | 20.20               | 21.00       | 22.30               | 24.40               |
| August    | 22.90        | 1.54                    | 19.80               | 21.60               | 23.20       | 24.10               | 25.50               |
| September | 17.04        | 4.38                    | 8.00                | 14.40               | 18.60       | 19.60               | 23.70               |
| October   | 13.17        | 3.05                    | 5.90                | 11.60               | 13.40       | 15.10               | 19.10               |
| November  | 5.98         | 5.81                    | -7.00               | 2.00                | 5.00        | 7.80                | 17.60               |
| December  | -0.46        | 2.21                    | -7.20               | -1.80               | -0.20       | 0.90                | 3.60                |
show the quantity of CO₂ emissions between July and December 2018 (Fig. 6). These data are based on the national energy system production structure by the type of resource, from which the amount of energy consumed by electric buses to operate during the monitored period was obtained.

Reducing GHG emissions and dependence on fossil fuel markets and diversification of the energy supply can be achieved by using energy from renewable sources. Most public transportation systems use buses equipped with internal combustion engines that run on fossil fuels (as the main power source). The use of renewable sources has been universally accepted as a solution to replace fossil fuels in order to reduce global GHG emissions. However, this solution has many limitations in terms of environmental protection.

**Bus Monitoring Data**

Real-time monitoring of buses operating in Cluj-Napoca is done by the Thoreb tracking and traffic monitoring system [31], a GPS tracking system that allows for real-time surveillance of buses on a digital map based on the signals generated by GPS modules installed on the buses and transmitted to dispatchers using general packet radio service (GPRS) technology. At the same time, a range of data is collected on the technical condition of the buses, the distance traveled, fuel/energy consumption, number of passengers transported, etc., and transmitted to the dispatchers from the controller area network (CAN) bus.

**Diesel Bus Monitoring Data**

The data regarding the fuel consumption (l/100 km) of diesel buses for the considered period were taken from the opportunity study conducted by CTP Cluj-Napoca [3] and were evaluated using a boxplot (Fig. 7) based on estimated fuel consumption values, generating a statistical model for each monitored month. The main elements generated by the boxplot are presented in Table 6.
Replacing Diesel Buses with Electric Buses

Electric Bus Monitoring Data

The evaluation of recording of energy consumption in the considered period was done with a boxplot (Fig. 8) based on the initial data, generating a statistical model for each monitored month. The main elements generated by the boxplot are presented in Table 7.

Analysis of Monitoring Data

Diesel Bus Monitoring Data Analysis

The methodology for calculating CO₂ emissions for the assessed buses is based on the provisions of Directive 2009/33/EC [8], which promotes clean and energy-efficient vehicles and targets the increased use of green vehicles (in this case electric buses) by highlighting the energy and environmental impact.

In his study, Jovanovic [32] show that due to its extremely high share of regular diesel buses in urban public transport of Belgrade, CO₂ emissions are not as efficient as they should be and if urban transport supports rail use (electric propulsion system), the CO₂ emissions are much lower than emissions of regular buses (diesel propulsion system).

Kadiyala et al. [33] monitored the concentrations of pollutant emissions over a period of one year, recording other factors that are important in their production (weather conditions, annual monitoring period, source

Table 6. Boxplot analysis of fuel consumption of diesel buses (l/100 km).

| Month   | µ (mean) | SD (standard deviation) | min (minimum value) | Q1 (lower quartile) | med (median) | Q3 (upper quartile) | max (maximum value) |
|---------|----------|--------------------------|---------------------|---------------------|--------------|---------------------|---------------------|
| July    | 34.67    | 0.32                     | 34.00               | 34.40               | 34.80        | 35.00               | 35.20               |
| August  | 34.86    | 0.45                     | 34.00               | 34.60               | 34.80        | 35.20               | 35.60               |
| September | 34.78   | 0.77                     | 34.00               | 34.20               | 34.40        | 35.40               | 36.40               |
| October | 35.33    | 0.57                     | 34.20               | 35.00               | 35.40        | 35.60               | 36.40               |
| November | 36.72    | 1.31                     | 34.40               | 36.00               | 37.00        | 37.60               | 40.00               |
| December | 38.25    | 0.69                     | 37.20               | 38.80               | 38.00        | 38.80               | 40.20               |
of samples, etc.). Following the monitoring, the authors found that pollutant emissions increased proportionally with humidity in the ambient environment and decreased with ambient temperature decrease.

In their study, Hernandez-Paniagua et al. [34] used boxplot analysis to highlight the statistical values of pollutant emissions, comparing emissions from urban areas with diesel bus transportation with emissions from areas with trolleybus transportation (electric propulsion system).

Grijalva et al. [14] expressed the values of CO\textsubscript{2} emissions for diesel buses based on the well-to-wheels (WTW) and life cycle analysis (LCA) concepts, which examine the impact of CO\textsubscript{2} emitted into the atmosphere on the environment for all phases in the flow of power from extraction (oil well), refining, fuel transport, distribution, feed pump, tank, combustion process, power distribution to the propulsion system, and consumption on the wheels (Fig. 9).

The WTW concept is a method of analysis for evaluating the environmental impact of the extraction, distribution, supply and transformation the propulsion energy into kinetic energy for vehicles. CO\textsubscript{2} emissions are not only the result of the fuel burned in internal combustion engines (ICE). These emissions are produced in all the stages mentioned above. For real, correct and complete evaluation of the emissions that result from the operation of the diesel buses we must consider the equivalent CO\textsubscript{2} emission values and results in all the stages between the process of extraction of the raw material and until the power supply of the vehicle.

In conclusion, we can say that the net value of CO\textsubscript{2} emissions result from the operation of diesel buses is equal to the CO\textsubscript{2} emissions generate by ICE, plus the contribution of CO\textsubscript{2} emissions resulting directly or indirectly from the extraction of raw materials up to the energy conversion.

Thus, for a diesel bus, CO\textsubscript{2} emissions are calculated by considering the average fuel consumption and the distance traveled over a period of time, but also the coefficient corresponding to the WTW stages.

The estimation of the amount of CO\textsubscript{2} emitted by diesel buses for a distance traveled over a period of time is from Equation (2):

$$Q^\text{diesel}_{\text{CO}_2} (\text{kg}) = n^\text{buses}_{\text{diesel}} \cdot W^\text{diesel}_{\text{WTWCO}_2}(\text{kgCO}_2\text{eq}/\text{l}) \cdot \sum_{m=1}^{100} \frac{c^\text{m}_{\text{diesel}}(l/100\text{ km}) \cdot d^\text{m}_{\text{diesel}}(\text{km})}{100\text{ (km)}}$$

...where $Q^\text{diesel}_{\text{CO}_2}$ (kg) is the total amount of CO\textsubscript{2} emitted in the atmosphere by the diesel buses evaluated during the considered period, $n^\text{buses}_{\text{diesel}}$ is the number of buses, $m$ is a month in the assessment period, $i$ is total months of the considered period, $c^\text{m}_{\text{diesel}}(l/100\text{ km})$ is average fuel consumption and the distance traveled over a period of time

| Month   | $\mu$ (mean) | SD (standard deviation) | min (minimum value) | Q1 (lower quartile) | med (median) | Q3 (upper quartile) | max (maximum value) |
|---------|--------------|-------------------------|---------------------|---------------------|--------------|---------------------|---------------------|
| July    | 1.13         | 0.07                    | 0.98                | 1.09                | 1.14         | 1.18                | 1.27                |
| August  | 1.18         | 0.05                    | 1.10                | 1.14                | 1.17         | 1.22                | 1.29                |
| September | 1.07         | 0.07                    | 0.97                | 1.00                | 1.08         | 1.12                | 1.29                |
| October | 1.15         | 0.11                    | 0.94                | 1.07                | 1.15         | 1.23                | 1.42                |
| November | 1.45         | 0.24                    | 0.96                | 1.31                | 1.45         | 1.59                | 1.93                |
| December | 1.81         | 0.17                    | 1.52                | 1.69                | 1.79         | 1.92                | 2.20                |

Table 7. Boxplot analysis of power consumption of electric buses (kWh/km).
Consumption for diesel buses in the considered month, \(d_m\) (km) is the distance traveled by a diesel bus for the considered month, and \(f_{\text{WTWCO}_2}^{\text{diesel}}\) (kgCO\(_2\)eq/l) is the amount of CO\(_2\) emitted to produce a liter of fuel based on the WTW concept.

For a proper delimitation of the CO\(_2\) emissions value, which can be used for both buses (diesel and electric), it was considered that the CO\(_2\) emissions for WTW concept is formed by CO\(_2\) emissions from the well-to-tank (WTT) section – the stages corresponding to the processes of extraction, transport and distribution of the fuel \(f_{\text{WTTCO}_2}^{\text{diesel}}\) (kgCO\(_2\)eq/l) [14, 35] and the tank-to-wheels (TTW) section – the stages corresponding to the processes of the fuel supply and the fuel conversion \(f_{\text{TTWCO}_2}^{\text{diesel}}\) (kgCO\(_2\)eq/l) [36], according to Equation (3):

\[
f_{\text{WTWCO}_2}^{\text{diesel}}(\text{kgCO}_2\text{eq/l}) = f_{\text{WTTCO}_2}^{\text{diesel}}(\text{kgCO}_2\text{eq/l}) + f_{\text{TTWCO}_2}^{\text{diesel}}(\text{kgCO}_2\text{eq/l})
\] (3)

In order to assess the amount of CO\(_2\) emitted in the atmosphere by the diesel buses during the considered period, their fuel consumption is converted to the distance traveled (l/100 km) in equivalent energy consumption (kWh/km). In this respect, considering the lower heating value (LHV) of 43100 kJ/kg [37] for diesel fuel and converting this into kWh (1 kWh = 3600 kJ), 12 kWh/kg is obtained, equivalent to 10 kWh/l (1 kg = 1.2 liters of diesel). The equivalent energy consumption based on the LHV of the fuel is an abstract value that allows for a comparison between energy efficiency and the emissions of the diesel and electric buses. The total amount of CO\(_2\) emission for each diesel bus in a month is calculated as the product of the amount of fuel and the sum of conversion factor corresponding to the entire cycle of LCA. The equivalent consumption per km for each month of the monitored period results from the ratio between the total amount of CO\(_2\) emissions for each diesel bus and the distance traveled in that month.

The results using Equation (2) and the conversion factors specified above are presented in Table 8.

### Electric Bus Monitoring Data Analysis

For electric buses powered by the national electricity grid, the WTW concept comprises the following steps: oil well, transport, distribution, production of electrical energy (power generation), transport and distribution of electricity (power transmission and distribution), charging the battery, powering the engine, power delivery system, and energy consumption at wheels (Fig. 10) [6, 30, 37-39].

The WTW concept consists of WTW and TTW sections. To assess the amount of CO\(_2\) emitted into the atmosphere to produce the energy consumed during of the amount of fuel and the sum of conversion factor corresponding to the entire cycle of LCA. The equivalent consumption per km for each month of the monitored period results from the ratio between the total amount of CO\(_2\) emissions for each diesel bus and the distance traveled in that month.

The results using Equation (2) and the conversion factors specified above are presented in Table 8.

### Table 8. Consumption of equivalent energy for diesel buses.

| Parameters                               | Unit   | July   | Aug    | Sept   | Oct    | Nov    | Dec    |
|-----------------------------------------|--------|--------|--------|--------|--------|--------|--------|
| Fuel consumption (cd\(_m\))            | l/100 km | 34.80  | 34.80  | 34.40  | 35.40  | 37.00  | 38.00  |
| Equivalent energy consumption (LHV\(_{\text{diesel}}\) = 43100 kJ/kg) | kJ/km  | 12499  | 12499  | 12355  | 12715  | 13289  | 13648  |
| Equivalent energy consumption (1 kWh = 3600 kJ) | kWh/km | 3.472  | 3.472  | 3.432  | 3.532  | 3.691  | 3.791  |
| Distance traveled/month (d\(_m\))      | km     | 46432  | 47315  | 43946  | 47315  | 45578  | 45682  |
| Fuel consumption/month                  | l      | 15973  | 16655  | 15117  | 16750  | 16864  | 17359  |
| Equivalent energy consumption/month    | kWh    | 161209 | 164275 | 150824 | 167107 | 168248 | 173190 |
| WTT factor \(f_{\text{WTTCO}_2}^{\text{diesel}}\) (see [14]) | kgCO\(_2\) eq/km | 0.162  | 0.162  | 0.162  | 0.162  | 0.162  | 0.162  |
| WTT factor \(f_{\text{WTTCO}_2}^{\text{diesel}}\) (fuel consumption) | kgCO\(_2\) eq/l | 0.460  | 0.460  | 0.465  | 0.452  | 0.432  | 0.421  |
| TTW factor \(f_{\text{TTWCO}_2}^{\text{diesel}}\) (see [36]) | kgCO\(_2\) eq/l | 2.4416 | 2.4416 | 2.4416 | 2.4416 | 2.4416 | 2.4416 |
| CO\(_2\) emissions (buses/month)        | kg     | 46344  | 48322  | 43941  | 48467  | 48468  | 49693  |
| Total CO\(_2\) emissions \(Q_{\text{CO}_2}^{\text{diesel}}\) | kg     | 285235 |
| Total CO\(_2\)/km                      | kg CO\(_2\) eq/km | 0.998  | 1.021  | 1.000  | 1.024  | 1.063  | 1.088  |
the considered period, only CO₂ emissions are considered in the WTT section, whose values are given in Table 9 [14, 40-42]. The electric buses with zero local pollution are much more efficient also from the point of view of energy efficiency, having much lower energy consumption.

The total amount of CO₂ emissions for each electric bus over a month is calculated as the product of energy consumption and the conversion factor corresponding to the WTT section. The equivalent consumption per km for each month of the monitored period results from the ratio between the total amount of CO₂ emissions for each electric bus and the distance traveled in that month.

The estimation of CO₂ emitted for production, transport, and charging electric buses to cover the traveled distance over the considered period is derived from Equation (4):

\[
Q_{\text{CO}_2}^{\text{electric}} (kg) = n_{\text{electric buses}} \cdot f_{\text{WTRCO}_2}^{\text{electric}} (kgCO_2/kWh) \cdot \sum_{i=1}^{i_{\text{months}}} [c_{e_i}(kWh/km) \cdot d_{m_i}(km)]
\]

...where \( Q_{\text{CO}_2}^{\text{electric}} (kg) \) is the total amount of CO₂ emitted into the atmosphere by the production of energy consumed by electric buses during the considered period, \( n_{\text{electric buses}} \) is the number of evaluated electrical buses, \( m_{\text{months}} \) is a month during the assessment period, \( i \) is the total number of months for the considered period, \( c_{e_i}(kWh/km) \) is the average energy consumption of an electric bus for the considered month, \( d_{m_i}(km) \) is the distance traveled by an electric bus for the considered month, and \( f_{\text{WTRCO}_2}^{\text{electric}}(kgCO_2/kWh) \) is the amount of CO₂ emitted to produce 1 kWh of energy based on the WTT section (see Table 5).

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Table 9. Energy consumption for electric buses.

| Parameters                              | Unit | July    | Aug     | Sept    | Oct     | Nov     | Dec     |
|-----------------------------------------|------|---------|---------|---------|---------|---------|---------|
| Energy consumption (\( c_{e_i} \))      | kWh/km | 1.14    | 1.17    | 1.08    | 1.15    | 1.45    | 1.78    |
| Distance traveled/month (\( d_{m_i} \)) | km    | 46432   | 47315   | 43946   | 47315   | 45578   | 45682   |
| Energy consumption/month                | kWh   | 52932   | 55359   | 47462   | 54412   | 66088   | 81314   |
| CO₂ emissions (WTT section see Table 5) | gCO₂/kWh | 256.92  | 281.45  | 292.87  | 305.95  | 335.04  | 339.37  |
| WTT factor (\( f_{\text{WTRCO}_2}^{\text{electric}} \)) (WTT section see Table 5) | kgCO₂/kWh | 0.257   | 0.282   | 0.293   | 0.306   | 0.335   | 0.339   |
| CO₂ emissions (buses/month)             | kg    | 13599   | 15581   | 13900   | 16647   | 22142   | 27596   |
| Total CO₂ emissions (\( Q_{\text{CO}_2}^{\text{electric}} \)) | kg    | 0.293   | 0.329   | 0.316   | 0.352   | 0.486   | 0.604   |
| Total CO₂/km                           | kg CO₂/km | 0.293   | 0.329   | 0.316   | 0.352   | 0.486   | 0.604   |

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Fig. 11. Energy consumption (kWh/km) vs. temperature (°C) and humidity (%).
Results and Discussion

As a result of data processing, Fig. 11 shows the variation in energy consumption of diesel and electric buses considered over the set period, depending on ambient temperature and atmospheric humidity. The obtained results (see Fig. 11) highlight the significant influence of ambient temperature and atmospheric humidity on energy consumption. Thus, it can be seen that the humidity curve approaches the energy consumption curve. The increased energy consumption in the summer months (July and August) is due to air-conditioning (AC) in electric buses. The replaced diesel buses did not have AC, so they did not consume extra fuel during this period. Compared to climatic conditions in the summer and early autumn, in winter, when the ambient temperature falls below freezing and the humidity is high, energy consumption can double. Due to this, there may be situations where electric buses cannot be used during the working day because of the drastic decrease in autonomy. In such situations, it is necessary to introduce fast charging stations at some stops on the line or reduce the working hours of electric buses by half.

For the evaluated electric buses, the distribution of energy consumption during the considered period (July-December 2018) depending on ambient temperature and ambient humidity are shown in Figs 12 and 13, respectively. The maximum point concentration (zoom image) indicates an optimal energy consumption (1.125 kWh/km) relative to the optimal ambient temperature (21.2°C) and ambient humidity (68.5%).

The energy efficiency of the electric buses is influenced by a number of external factors such as: the mass of the buses that depends on the number of passengers transported, the consumption generated by the auxiliary systems that depends on the climatic conditions (high temperatures – cooling system with AC, low temperatures – the heating system), the altitude profile of the urban route traveled by buses, etc.

In order to assess the results of CO₂ emissions from the production of electricity required for the operation of electric buses during July-December 2018, we analyzed the structure of types of electricity delivered in Romania in that period, for which these emissions were evaluated monthly. After analyzing the recorded data, we found that replacing diesel buses with electric buses had an immediate effect on eliminating local emissions in the circulation areas of Cluj-Napoca. At the same time, the emission of CO₂ generated by the production of electric power consumed by electric buses is 2.605 times lower than that generated by diesel buses (Fig. 14, see Tables 8 and 9).

The experimental data recorded for the monitored period include the climatic characteristics, from the point of view of the ambient temperatures and humidity, for the hot season (July-September) and for the cold season (October-December).
Conclusions

By replacing diesel buses with electric buses in the passenger fleet, Cluj-Napoca aims to develop sustainable urban public transport with clean vehicles. The purpose of this study is to demonstrate that by replacing a number of diesel buses with a maximum pollution factor (Euro 0 emission standards) with electric buses that do not emit local pollutants, the total amount of CO$_2$ emissions is significantly reduced (emissions are generated only when producing the necessary electricity to charge the buses).

In addition to reducing pollutant emissions from public transport, replacing diesel buses with electric buses has immediate advantages (reduced environmental noise, reduced shocks caused by thermal engines transmitted to the infrastructure, increased local/national/international confidence and visibility of areas that adopt such a modern solution, etc.) and medium- and long-term benefits (reduced operating costs and maintenance due to the reliability of electric buses based on the simple construction of the powertrain, and the possibility of reducing the cost of bus trips, so that as many citizens as possible will stop using personal vehicles in the city, resulting in less traffic and further reduction of pollution).

The energy efficiency of the electric buses depends on the specific conditions of each urban system in which these buses are integrated and operate, but regardless of these specific conditions there is a common positive impact, namely that the local emissions generated by the operation of these buses are zero. For the production of electricity, according to the analysis of the life cycle and the stages of the WTW concept, it can be said that the real impact on the environment depends on the renewable sources (nuclear, geothermal, biomass, wind, solar, hydro) and on the pollutants sources (coal, gas).

According to the research carried out in this paper, it was found that at the national level between 50 and 65% of the energy resources used to obtain electricity are renewable.

In addition, due to the specific conditions of the free market for electricity trading, in the national system, there is the possibility for the operator of the electric bus fleet to buy electricity labeled “green” electricity (obtained from renewable primary sources) in order to minimize the total amount of CO$_2$ emissions for each electric bus.

The fact that the purchase prices of electric buses are high is still a disadvantage, but national/international financing programs for the purchase of clean electric vehicles could facilitate the acquisition of clean vehicles.

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Conflict of Interest

The authors declare no conflict of interest.

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