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LIFE CYCLE COST (LCC) LEVEL OF AN URBAN TRANSPORT FLEET WITH DIFFERENTIATED SHARE OF BUSES WITH ALTERNATIVE DRIVE SYSTEMS

In recent years, there has been a significant increase in the number of buses operated by urban public transport companies powered by alternative fuels and equipped with alternative drive systems. In addition to economic factors, operators should also take environmental aspects into account when purchasing new vehicles. In this case, a useful criterion for selecting a vehicle is the Life Cycle Cost (LCC), which, in addition to the cost of purchasing a bus, takes into account the necessary expenses associated with its maintenance, operation, decommissioning, as well as emissions costs. This paper presents a study of the LCC values, estimated for the entire bus fleet based on several bus replacement variants, taking into account different shares of alternative buses in the transport fleet. Analyses have shown that replacing conventional buses by the compressed natural gas (CNG) powered buses will reduce life cycle cost by 27% compared to the LCC level in 2019. Increasing the share of electric buses in the fleet will significantly reduce the level of emissions of harmful substances contained in exhaust gases.

Keywords: *LCC, city bus, alternative drive*

1 Introduction

Urban transport vehicles with alternative drive systems are already widely used by city bus companies. According to definition contained in Art. 2(1) of the Act on Electromobility and Alternative Fuels, a zero-emission bus may be a bus powered by electricity generated from hydrogen in fuel cells installed in it or equipped only with an engine operation cycle that does not lead to greenhouse gas emissions, i.e. a vehicle with an electric battery or network drive (trolleybus). It follows from the cited Act that the definition of a zero-emission vehicle is not equivalent to the definition of an alternative drive vehicle. Vehicles powered by alternative fuels, according to Art. 1(11) of the same Act, include vehicles driven by electricity, hydrogen, liquid biofuels, synthetic and paraffin fuels, compressed natural gas (CNG), including biomethane derived, liquefied natural gas (LNG), including biomethane derived and liquefied petroleum gas [1].

The main barriers to a rapid increase in the share of alternative vehicles in fleets of urban public transport companies are the high purchase prices of such vehicles and costly infrastructure. The decision to replace conventional buses by buses running on alternative fuels or equipped with alternative drive systems is supported by lower emission of harmful substances and lower operating costs.

The Life Cycle Cost method is a useful tool to compare the production and operating costs of vehicles with different types of drive systems. This analysis also makes it easier to decide on choosing and buying a bus with a specific drive variant. The LCC estimation allows to distinguish the costs, starting from the production of a vehicle through its use and operation up to the total depreciation (economic or accounting life) or its disposal as waste (technical life). The Life Cycle Cost method shall include a detailed economic analysis, taking into account investment costs (purchase, registration and additional infrastructure), operating costs (fuel, electricity, repair and maintenance, insurance), end-of-life costs (recycling) and emissions costs. In the literature, there are many papers on analysis of the life cycle cost of city buses equipped with different types of drive systems. Papers [2-3] contain an analysis and comparison of the LCC of buses equipped with conventional and alternative drive systems for the assumed service life.

The aforementioned types of costs in the LCC structure may be extended by cost categories important for the researcher. Works [4-5] present an analysis of the Life Cycle Cost of a bus with an electric drive system, which includes different types of electric power supply and different types of charging systems. The presented results show that lower Life Cycle Cost values are obtained by charging the batteries at stations located at end stops (terminuses).

In many cases, the Life Cycle Cost of a vehicle is also considered from environmental aspects. This method estimates the economic factors associated with production and use of a vehicle and the costs of emissions. The environmental impact, manifested in emission of the harmful substances related to the production and distribution of fuel (energy), production of car parts and components, assembly of parts and components, operation

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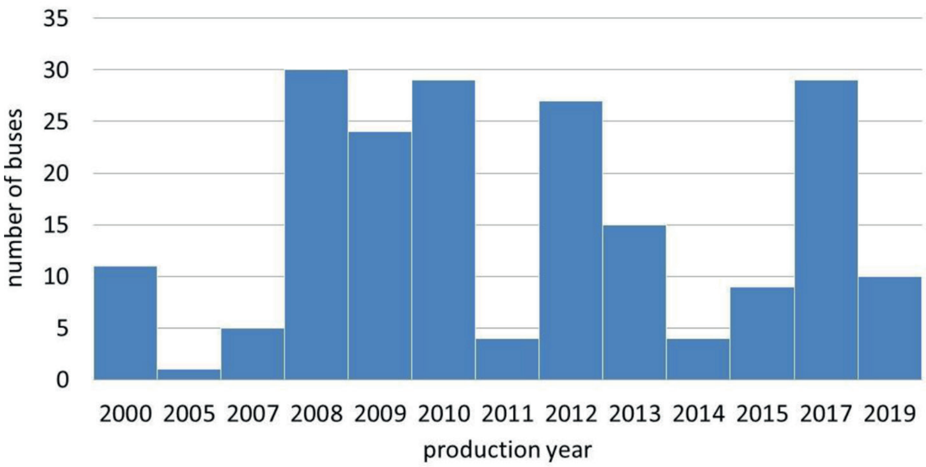

Figure 1 *Age structure of the bus fleet (based on [12])*

and use of a vehicle and its decommissioning, is expressed in monetary units and presented in the form of cost. The Life Cycle Cost analyses, including the costs of emissions of city buses equipped with conventional and alternative drives, are presented in papers [6-8].

The literature provides examples of Life Cycle Cost analyses developed not for a single vehicle but for the entire vehicle fleet. Paper [9] presents an estimation of the share of buses with hybrid and electric drive systems in the bus fleet, using optimization methods by minimizing the LCC, operating costs and emission costs. Paper [10] contains an analysis of the Life Cycle Cost of a truck fleet, in which the alternatively powered vehicles make up for 50% and 75% of the entire fleet. The results show that, despite the higher purchase price, a higher share of alternatively powered vehicles in the fleet leads to lower operating costs and significantly lower emissions of harmful substances in exhaust gases.

This paper presents 5 scenarios for the bus fleet modernization for Kielce in the period 2019-2030, each with different share of alternative buses. According to the adopted variants, the annual life cycle cost values for the entire bus fleet were estimated.

In the analysis presented, the LCC includes the following categories:

- purchase costs,
- operating costs,
- costs of repairs and maintenance,
- infrastructure costs,
- emission costs.

The presented research results may be used by city carriers and contribute to making a decision on purchase of alternative buses.

2 Characteristics of the Kielce public transport fleet

Kielce city transport network includes 66 day lines and two night lines. The total length of the city bus lines is 610 km and the length of the suburban bus lines is 145 km. Over 90,000 passengers use the Kielce public transport every day. The transport performance carried out during a year amounts to 12.54 million passenger kilometers [11].

At present, the Kielce transport fleet consists of 188 buses. The majority of them, i.e. 147, are small and medium buses (9 m, 10 m and 12 m). The number of 18 m articulated buses is 41. The average age of the fleet is 8 years. The age structure of the fleet is shown in Figure 1.

Most vehicles are equipped with diesel drive systems. Since 2017, Kielce has also been operating 25 buses with hybrid drive systems (combustion-electric). Currently, their share in the fleet amounts to 13%. It is planned to purchase 10 buses with engines fueled by compressed natural gas (CNG) in 2020. Currently, works related to the construction of the CNG supply station are underway [12].

3 Assumptions for the analysis

3.1 Bus parameters

In order to ensure that the average age of vehicles in use is not too high (in Kielce it was adopted at 8 years), it is necessary to replace end-of-life buses with new vehicles. The aim of the analysis was to develop variants of bus fleet modernization for Kielce. Based on these, it was determined how a given scenario would affect:

- the structure of the fleet,
- the emission level of harmful substances contained in exhaust gases - carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matters (PM_x) and volatile organic compounds (VOC),
- the Life cycle cost (LCC) for the entire bus fleet.

This analysis assumes that the buses have a service life of 15 years and an annual mileage of 60,000 km. All cost are displayed in euro according to the conversion rate published by the central bank of the Republic of Poland on 24 February 2020 (1 EUR = 4.28 PLN) [13]. It was assumed that the price of diesel oil was 1.15 €/dm^3, compressed natural gas (CNG) - €0.68/Ndm^3 and electricity - €0.15/kWh [14]. In the paper, the aforementioned prices of fuels,

Table 1 Bus data adopted for the analysis

	Diesel	Diesel Euro 6	CNG	EV (200 kWh)	HEV (11.6 kWh)
Purchase price [€]	210 300	210 300	240 000	590 000	350 500
Maintenance cost [€/ year] [15]	3 500	3 500	3 700	3 000	3 700
Cost of replacing a battery pack [€] [16]				140 200	8 130
Average fuel consumption [17]	53.2 dm^3/100km	50.0 dm^3/100 km	50.9 kg/100km	140 kW/100 km	46.5 l/100km

Table 2 Bus replacement schedule under scenario no. 1

		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Number of buses to be exchanged		10	1	0	5	30	24	29	4	27	15	4
Number of purchased buses	Diesel (Euro 6)	-	-	-	-	30	24	29	4	27	15	4
	CNG	10	1	0	5	-	-	-	-	-	-	-
Share of low-emission buses in the fleet		19%	19%	19%	22%	22%	22%	22%	22%	22%	22%	22%

energy and the cost of replacing batteries in EV and HEV vehicles were treated as fixed prices. Table 1 shows the other data adopted for the analysis.

The CNG-fueled vehicles and those equipped with electric drive systems require additional infrastructure. For electric buses, there are two main battery charging methods: fast charging by means of a pantograph located at terminuses or stops and slow charging by means of a plug-in, carried out mainly at depots. The cost of installing a pantograph charger was assumed to be PLN 500,000, while the cost of a plug-in charger was assumed to be €23 365[18]. It was assumed that the cost of building a compressed natural gas supply station would amount to €21 million. A CNG station has fast and slow refueling points [19-20].

The GREET program (Greenhouse gases, Regulated Emissions and Energy use in Transportation Model) was used to estimate emission of the harmful exhaust gas compounds. The program was developed by Argonne National Laboratory (ANL) as a part of a project run by the United States Department of Energy. The GREET program makes it possible to estimate the environmental impact of the life cycle of vehicles equipped with conventional and alternative drive systems. The GREET database contains parameters of 80 different vehicles. Thanks to the interactive interface and the graphical toolkit, simulations can be carried out easily. The program uses data provided by the U.S. Environmental Protection Agency (EPA) [21]. The calculations bring the following data:

- value of energy from combustion of fuel (oil, petrol, gas, coal) and from renewable sources (biomass, wind, solar radiation, water),
- emission level of greenhouse gases (CO_2, CH_4, N_2O), harmful compounds contained in exhaust gases (CO, NO_x, PM_x, SO_x, aliphatic and aromatic hydrocarbons),
- water consumption.

In the GREET program, the life cycle of a vehicle is divided into the stage of fuel production (including acquisition and refinement of crude oil, production, distribution and storage of fuel), the stage of vehicle production (production of parts and components and assembly of the vehicle) and the stage of vehicle operation and use. The program enables emissions of harmful substances and greenhouse gases to be estimated at each of the above-mentioned stages. The emission values of carbon dioxide (CO_2), nitrogen oxides (NO_x), particulate matters (PM_x) and volatile organic compounds (VOC) are presented in the form of costs, in accordance with the rates contained in the European Parliament and of The Council Directive [22].

3.2 Fleet modernization scenarios

The analysis period is 11 consecutive years, i.e. 2019-2030. As mentioned earlier, the vehicle fleet currently (at the end of 2019) consists of 188 buses and this was adopted as a fixed value for the following years. For each of the years covered by the analysis, the total Life Cycle Cost (LCC) and level of emissions for the entire bus fleet were estimated. The assumed service life of vehicles is 15 years, meaning that they must be taken out of service upon reaching this age and new vehicles must be purchased in

Table 3 *Bus replacement schedule under scenario no. 2*

		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Number of buses to be replaced			1	0	5	30	24	29	4	27	15	4
Number of purchased buses	Diesel (Euro 6)	-	-	-	-	-	-	29	4	27	15	4
	CNG	10	1	0	5	30	24	-	-	-	-	-
Share of low-emission buses in the fleet			19%	19%	22%	38%	50%	50%	50%	50%	50%	50%

Table 4 *Bus replacement schedule under scenario no. 3*

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Number of buses to be replaced	10	1	0	5	30	24	29	4	27	15	4
Number of purchased CNG buses	10	1	0	5	30	24	29	4	27	15	4
Share of low-emission buses in the fleet	19%	19%	19%	22%	38%	51%	66%	68%	82%	90%	93%

Table 5 *Bus replacement schedule under scenario no. 4*

		2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Number of buses to be replaced		10	1	0	5	30	24	29	4	27	15	4
Number of purchased buses	CNG	5	1	0	2	15	12	15	2	13	8	2
	EV	5	0	0	3	15	12	14	2	14	7	2
Share of low-emission buses in the fleet		19%	19%	19%	22%	38%	51%	66%	68%	82%	90%	93%
Fast chargers (pantograph)		2	2		2	8	8	8	2	8	6	2
Slow chargers (plug-in)		4	1		6	12	12	14	2	14	7	2

their place. The replacement of vehicles was considered according to 5 scenarios.

In **scenario no. 1**, the minimum share of low-emission buses in the fleet by 2025, i.e. 20%, was adopted. Kielce currently operates 25 buses with a hybrid drive system (HEV), which accounts for 13% of the fleet. This variant assumes replacement of 7% of the oldest buses with conventional drive systems by buses with CNG fueled engines. Once the target share of low-emission buses is reached, the remaining vehicles to be replaced can be substituted by conventional buses. However, they will have diesel engines meeting the EURO 6 emission standard (Table 2). Scenario no. 1 also assumes the construction of a compressed natural gas supply infrastructure.

Scenario no. 2 assumes a 50% share (until 2025) of low-emission buses. In 2019, the share of hybrid buses (HEV) in the fleet of the Kielce carrier amounted to 13%. This variant includes the purchase of CNG buses so that they account for 37% of the fleet (Table 3). It is also necessary to build infrastructure designed for refueling buses with compressed natural gas (CNG) engines. Once the 50% share of low-emission buses is achieved, the remaining vehicles to be replaced due their service life end will be substituted by conventional buses with diesel engines meeting the EURO 6 emission standard.

Scenario no. 3 assumes a gradual replacement of buses with conventional drive systems with buses equipped with engines powered by the compressed natural gas (CNG) (Table 4). This variant, like the previous ones, assumes the need to build a CNG refueling station. Under this scenario, at the end of 2030, the share of alternatively powered vehicles will amount to 93%.

Scenario no. 4 assumes the replacement of end-of-life conventional buses with buses with electric drive systems (EV) and CNG buses. The assumption is that in 2030 buses of both types will have an equal share in the fleet (Table 5). Scenario no. 4 includes the construction of a compressed natural gas supply station and charging points for electric buses (chargers in the depot and at bus stops). As a result of the modernization of the fleet at the end of 2030, the share of alternatively driven vehicles will amount to 93%.

Scenario no. 5 assumes a gradual replacement of conventional buses with buses equipped with electric drive systems (EV). This variant assumes the need to adapt the

***Table 6** Bus replacement schedule under scenario no. 5*

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Number of buses to be replaced	10	1	0	5	30	24	29	4	27	15	4
Number of purchased EV buses	10	1	0	5	30	24	29	4	27	15	4
Share of low-emission buses in the fleet	19%	19%	19%	22%	38%	51%	66%	68%	82%	90%	93%
Fast chargers (pantograph)	4	2	6	4	20	16	20	2	18	10	2
Slow chargers (plug-in)	10	1	2	3	30	24	29	4	27	15	4

battery charging infrastructure, consisting of chargers at bus stops and in the depot (Table 6). According to scenario no. 5, in 2030 the share of alternative vehicles in the bus fleet will amount to 93%.

4 Life Cycle Cost (LCC) model

The presented Life Cycle Cost (LCC) analysis covers the economic and environmental aspects of buses throughout their life cycle. An LCC model in the following form was used for calculations:

$$LCC = \sum_{n=1}^{N} (C_A + C_F + C_M + C_B + C_{Inf} + C_E), \quad (1)$$

where:
$n \in (1,2, \ldots, N)$ - number of vehicles,
LCC - life cycle cost,
C_A - costs of purchase,
C_F - costs of fuel,
C_M - costs of maintenance,
C_B - costs of replacing a battery pack,
C_{Inf} - costs of infrastructure,
C_E - costs of emissions.

The purchase costs C_A were expressed as follows:

$$C_A = \sum_{n=1}^{N} \sum_{k=1}^{K} \left(\frac{P_a}{O_i}\right), \quad (2)$$

where:
$k \in (1,2, \ldots, K)$ - type of a vehicle drive system,
$i \in (1,2, \ldots, I)$ - age of a vehicle,
P_a - purchase price,
O_i - service life.

Costs of fuel C_F:

$$C_F = \sum_{n=1}^{N} \sum_{k=1}^{K} \left(\frac{f_c}{100} \cdot P_f \cdot D\right), \quad (3)$$

where:
f_c - average fuel consumption [dm^3/100km, kWh/100km],
P_f - unit price of fuel/energy [PLN/dm^3, PLN/kWh, PLN/dm^3],
D - annual mileage [km].

The costs of maintenance C_M include the costs of insurance and periodic inspections, the costs of replacement of tires and service fluids and the costs of required repairs and removal of defects. In the analysis, the costs of repairs and use take the following form:

$$C_M = \sum_{n=1}^{N} \sum_{k=1}^{K} \left(\frac{M}{O_i}\right), \quad (4)$$

where:
M - annual costs of repairs and maintenance of the vehicle.

The operating experience gained so far has shown that energy storage devices have a much shorter service life than buses. It was assumed that a battery pack should be replaced every 6 years, therefore, during the service life of a bus it would be necessary to replace the energy storage device twice. The costs of battery replacement C_B were expressed as follows:

$$C_B = \sum_{n=1}^{N} \sum_{k=1}^{K} \left(\frac{P_B \cdot B \cdot A_{i,k}}{O_i}\right), \quad (5)$$

where:
P_B - price of battery replacement [PLN/kWh],
B - energy capacity of batteries [kWh],
$A_{i,k}$ - number of vehicles with i - age and k - type of drive system.

Buses equipped with the CNG engines require construction of special infrastructure. It consists of pumps and specially adapted refueling and storage equipment for compressed natural gas. For electric buses, the infrastructure includes battery charging stations. The cost of infrastructure C_{Inf} can be expressed as follows:

$$C_{Inf} = \sum_{n=1}^{N} \sum_{k=1}^{K} \left(\frac{P_C \cdot L_{j,k}}{A_{i,k}}\right), \quad (6)$$

where:
$j \in (1,2, \ldots, J)$ - number of charging/refueling stations,
P_C - price of building a charging/refueling station,
$L_{j,k}$ - number of stations intended for k - type of drive system,
$A_{i,k}$ - number of vehicles with i - age and k - type of drive system.

In this paper, Life Cycle Cost includes environmental costs in the form of emission costs calculated in accordance

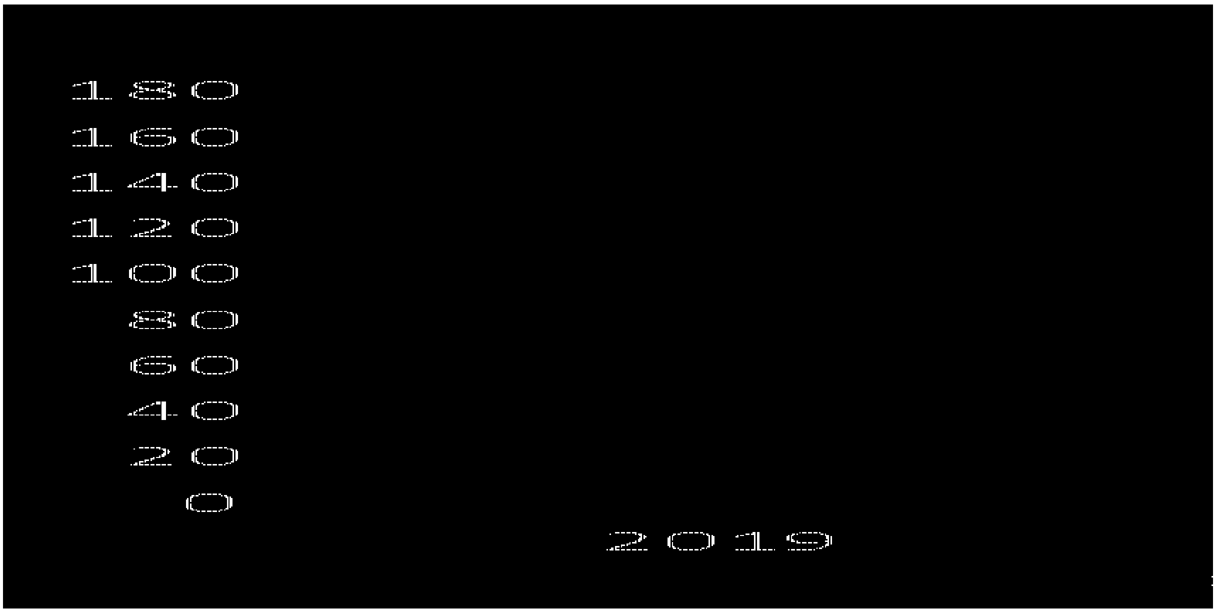

Figure 2 *Fleet structure for the variants described above*

with the rates set out in the European Parliament and of The Council Directive [21]. The costs of emissions C_M take the following form:

$$C_A = \sum_{n=1}^{N} \sum_{k=1}^{K} \sum_{z=1}^{Z} \left(\frac{P_z \cdot E_z \cdot D}{O_i} \right), \qquad (7)$$

where:
$z \in (1,2, \ldots, Z)$ - harmful substance contained in exhaust gases (e.g. CO_2, NO_x, etc.),
P_z – costs' rate per emission [PLN/kg],
E_z - emission level [kg/km],
D - annual mileage [km].

5 Results of the analysis

5.1 Changes in the structure of the fleet

In 2019, vehicles meeting the European exhaust emission standards of EURO 3 and EURO 4 made up for a significant part of the fleet. Between 2021 and 2024, buses over 10 years of age will account for around 70% of the fleet. In the years 2024-2026, there will be the largest number of buses to be replaced due to their age. During that period it will be necessary to purchase as many as 83 vehicles.

The fleet structure for the analyzed variants is shown in Figure 2.

In scenario no. 1, the assumed 20% share of the low-emission buses in the transport fleet will be reached in 2023. A total of 41 buses with alternative drive systems will be purchased.

In scenario no. 2, the envisaged 50% share of alternative buses will be achieved a bit later, i.e. in 2025. There will be a total of 95 vehicles with alternative drives then. Successive replacement of "old" conventionally powered buses will result in only 14 such buses remaining in 2030 and their share in the fleet will fall to 7%.

According to scenarios no. 1 and 2, in 2030, a significant part of the fleet will still be made up of buses equipped with diesel internal combustion engines. In scenarios no. 3, 4 and 5, the share of buses with alternative drive systems will reach 93% in 2030.

5.2 Emission levels and costs

The main reasons for replacing vehicles with conventional drive systems are economic and ecological aspects. Despite the fact that modern emission reduction systems, such as exhaust gas recirculation system (EGR), selective catalytic reduction system (SCR) with a catalyst, AdBlue (urea water solution) or particulate filter (DPF) are installed in buses, road transport still largely contributes to increase in emissions of nitrogen oxides, carbon dioxide and suspended particulates PM_x in cities.

Figure 3 shows the level of CO_2 emissions in the period under consideration for the simulated scenarios.

The carbon dioxide emission values for the period 2019-2023 are similar for all of the bus replacement variants considered. This is a consequence of the small number of new buses, since only 16 will be replaced by 2023. A faster reduction in the CO_2 emission will take place from 2024 onwards. Between 2024 and 2030, the level of carbon dioxide emission for the analyzed scenarios will vary considerably. The lowest level of CO_2 emission will occur for scenarios no. 4 and 5, which assume the purchase of electric buses. Successive replacement of "old" buses also affects the level of emissions of other harmful compounds, such as NO_x, VOC and PM_x. Figure 4 shows the values of emissions of NO_x, VOC and PM_x.

The emission reduction values of the analyzed exhaust gas components are presented in Table 7.

Scenario no. 1 assumes the lowest share of low-emission vehicles in the transport fleet (20%) among the

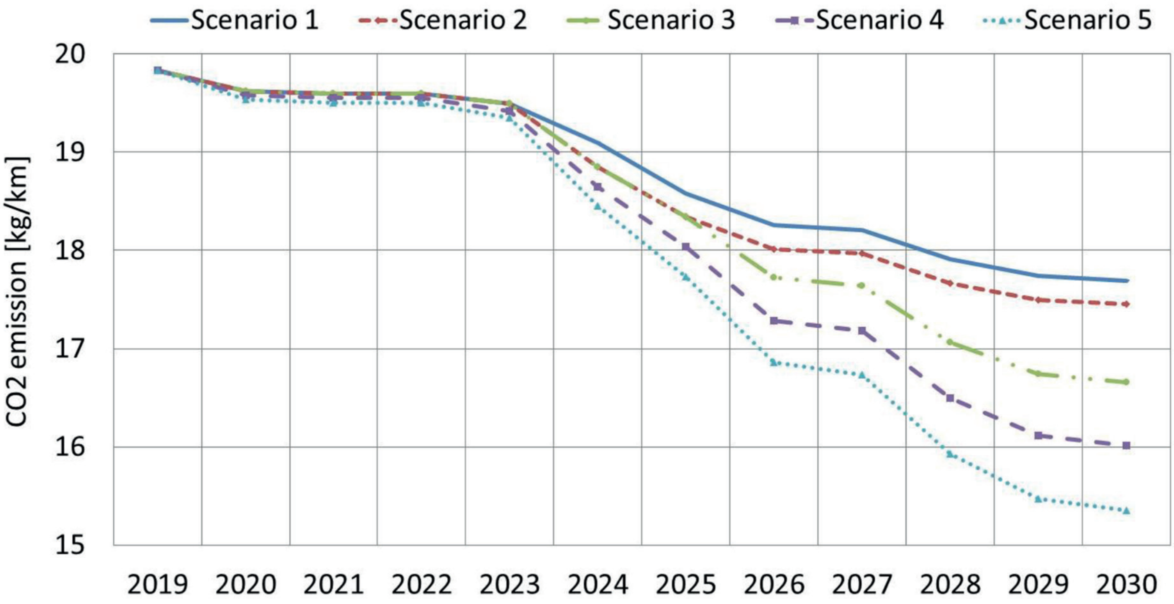

Figure 3 *Level of CO_2 emissions*

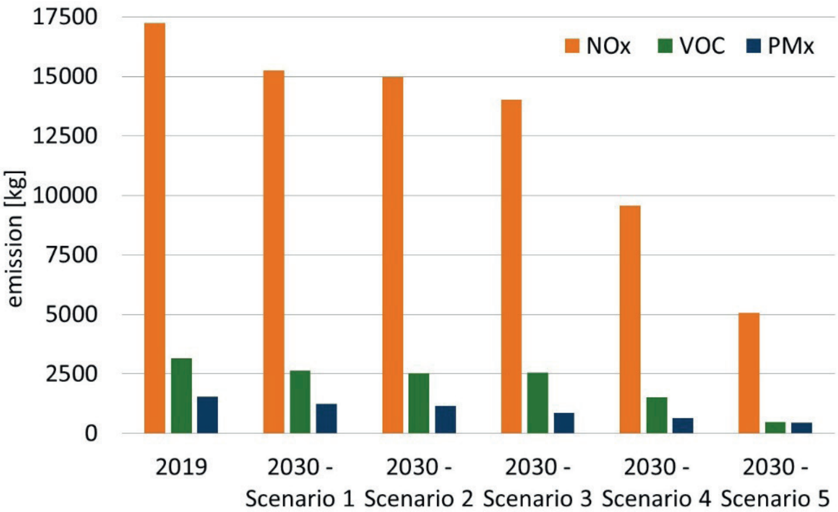

Figure 4 *Emission values of NO_x, VOC and PM_x for the variants considered*

Table 7 *Emission reduction values compared to base year 2019*

	2030 - scenario 1	2030 - scenario 2	2030 - scenario 3	2030 - scenario 4	2030 - scenario 5
CO_2	11%	12%	16%	19%	23%
NO_x	12%	13%	19%	44%	71%
LZO	7%	7%	8%	44%	83%
PM_x	19%	25%	44%	57%	71%

considered variants. In this scenario the CO_2 and NO_x emissions will decrease by relatively small values of 11% and 12%, respectively by 2030, compared to 2019 values. The PM_x and VOC emissions will also decrease by 19% and 7%, respectively (Table 7). Scenario no. 3, which assumes the replacement of buses with a conventional combustion engine by vehicles with CNG engines, will allow a significant reduction in particulate matter emissions. Compared to 2019, the value of PM_x emission in 2030 may be 44% lower.

Scenarios no. 4 and 5, in which the purchase of electric buses is assumed, are characterized by even lower emissions of harmful substances contained in exhaust gases. In 2030, according to scenario no. 4, the level of CO_2 emission will drop by 19%, the level of NO_x and VOC emissions by 44% and the level of PM_x emissions by 57% compared to 2019.

Among the considered variants, the lowest emission of the analyzed harmful substances contained in exhaust gases is provided by scenario no. 5, according to which

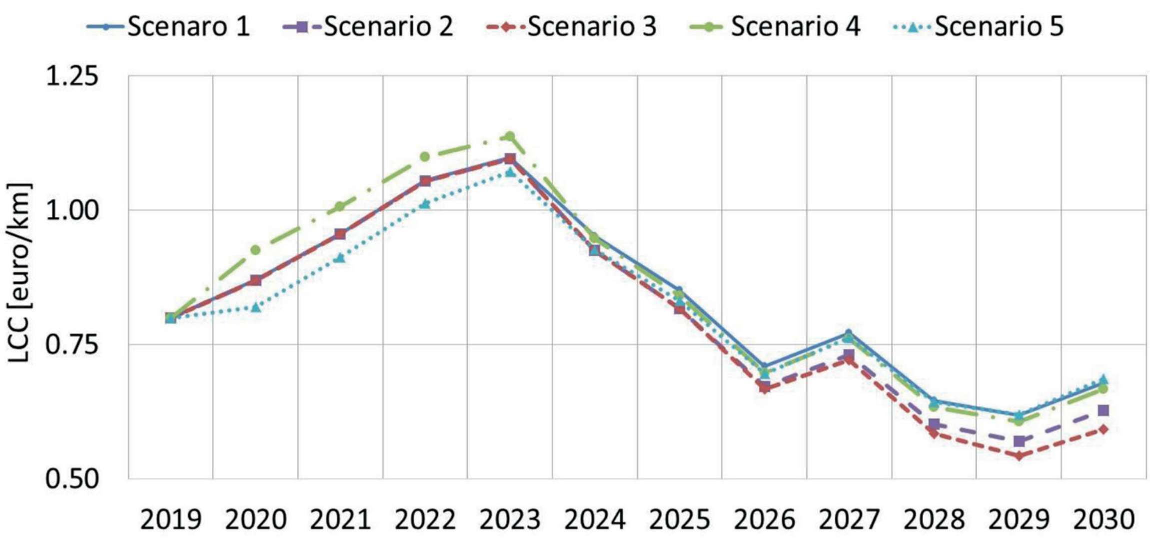

***Figure 5** Change in LCC in the analyzed period*

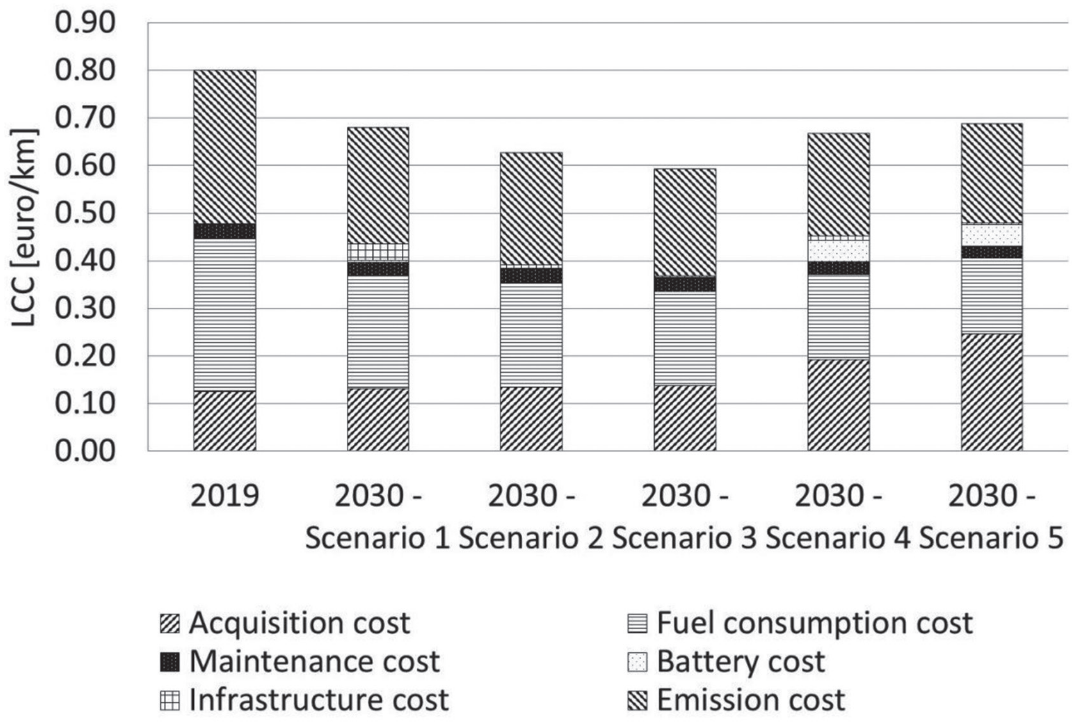

***Figure 6** The LCC summary*

in 2030 CO_2 emissions will drop by 23%, NO_x and PM_x emissions by 71% and the VOC emissions by 83%.

5.3 Life Cycle Cost (LCC) values

An important factor determining the choice of the strategy for modernization of the bus fleet (in accordance with the assumed scenarios) is the cost of purchase of a new vehicle. The cost of purchasing a bus with an engine fueled by compressed natural gas is 10% higher than for a bus with a conventional internal combustion engine. For electric buses, the cost of purchase is 64% higher than for buses with conventional drives.

An important issue related to purchase of alternatively fueled vehicles or vehicles equipped with alternative drive systems is a need to provide appropriate infrastructure. Conventional and hybrid vehicles do not require additional infrastructure outlays.

In the case of operation of electric buses, it is necessary to incur additional costs related to construction of the battery charging stations. In turn, the use of buses with CNG engines requires the construction of storage facilities for compressed gas and refueling stations. This involves significant costs. In the LCC method, infrastructure costs are spread over all vehicles using it. The LCC values in the analyzed period, estimated in accordance with the considered variants of bus fleet modernization, are presented in Figure 5.

Until 2023, LCC values are similar for all of the scenarios analyzed, as a relatively low number of vehicles would be replaced during that period. The higher LCC values for modernization following scenario no. 3 are due to the need to provide infrastructure for electric and CNG buses. Moreover, in this period the operation of the largest number of vehicles used so far will come to an end. This will result in an increase in the LCC value.

Since 2023, the LCC value has been gradually decreasing due to the replacement of old buses with new ones. Among the analyzed scenarios, the lowest LCC values are found in scenario no. 3, which provides for replacement of buses with conventional engines by vehicles fueled by CNG gas. The LCC value determined for 2030, estimated according to assumptions of variant no. 3, is 27% lower than the LCC level in 2019. The structure of individual LCC components in 2030, based on selected variants, is shown in Figure 6.

The Life Cycle Cost values, estimated based on scenarios assuming a 20% and 50% share of low-emission buses in fleet, set for 2030, are 19% and 20% lower than the LCC level in 2019, respectively. In both variants, the largest share in the LCC is represented by emission costs - 38%. The costs of fuel consumption, which account for 36% of LCC, are also a significant share.

The highest LCC values are found in variants no. 4 and 5, which provide for the purchase of electric buses. The Life Cycle Cost values estimated for variants no. 4 and 5 have the lowest share of fuel consumption costs and emission costs among the LCCs calculated based on the other scenarios. However, the high purchase price, the costly infrastructure and the need to replace batteries make the LCC level estimated for variants no. 4 and 5 significantly higher than for the others. In 2030, according to scenario no. 5, the cost of purchasing a vehicle is 36% of the LCC and the costs of the battery replacement are 7% of the LCC. For variant no. 5, the share of bus purchase costs is 29% of LCC and the cost of the battery replacement is 7% of LCC. The Life Cycle Cost values estimated for variants no. 4 and 5 are 18% and 14% lower than the LCC values in 2019, respectively.

6 Conclusions

With a view to purchasing buses that are alternatively powered or equipped with alternative drive systems, several aspects should be taken into account, such as the purchase costs, operating costs and emission level. Urban public transport companies face the choice of buying alternative or conventional buses and are guided mainly by economic aspects. In general, the costs of purchasing such a vehicle are much higher than the costs of purchasing a bus with a conventional drive system. Unlike the conventional and hybrid vehicles, electric and CNG-fueled buses require infrastructure. However, alternative buses are characterized by the lower operating costs and significantly lower emissions of harmful substances in exhaust gases, such as CO_2, NO_x or PM_x.

The analyses show that the lowest emission level and operating costs can be achieved by increasing the share of electric buses in the fleet. Among the scenarios analyzed, the lowest Life Cycle Cost (LCC) values are represented by the variant that provides for the replacement of buses with conventional drive by the CNG-fueled vehicles.

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