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Modernization of the Public Transport Bus Fleet in the Context of Low-Carbon Development in Poland

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Abstract: The development of urban transport in recent years has become one of the most important issues related to improving the quality of life in Polish cities. Excessive pollution in the form of greenhouse gases and other harmful substances from buses affects people's health as does the excessive noise. This article analysed the measures being taken to reduce emissions, and the results showed that it is possible to reduce CO_2 emissions by more than 28 thousand megagrams (Mg) per annum. Policymakers in Poland should consider limiting electricity generation through coal combustion and recognize, at least temporarily, CNG/LNG-powered buses as low-carbon rolling stock and co-finance their purchase and the necessary infrastructure.

Keywords: emissions; buses; public transport; scenario analysis; Poland

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1. Introduction

As Polish society grows richer so does the number of private vehicles, especially in increasingly crowded cities, where people have to struggle with the negative health effects caused by pollution from this growing number of cars [1,2]. About 50,000 people die every year from poor air quality.

Public transport seems to offer a more rational use of the natural environment [3] because it reduces fuel consumption, exhaust emissions [4–6], and noise. The concept of sustainable public transport combines high-quality transportation with concern for the environment [7], so these vehicles should have a power source other than diesel or gasoline.

Quality of Life (QoL) should be understood as the set of factors that contribute to a person's general well-being, such as health, safety, intellectual and cultural preferences, financial security, family life and job satisfaction [8], or as McGregor et al. put it: "the level of satisfaction with an individual's conditions, relationships, and surroundings relative to the available alternatives" [9]. A QoL evaluation may help design transit-oriented development for various socio-economic groups [10], and for this the European Mobility Week campaign deserves attention: "Since 2002, it has sought to influence mobility and urban transport issues, as well as improve public health and quality of life. The campaign gives people the chance to explore the role of city streets and to experiment with practical solutions to tackle urban challenges, such as air pollution" [11]. Reducing CO_2 emissions from transport can, of course, enhance the quality of life, but there are other factors to consider such as access, amenities and safety [10].

As the local elections in 2018 made clear, public transport is an important issue for Poles, and it occupied a central position in the programmes of candidates for city president. Those who expressed concern about the systematic and planned development of urban transport, including former presidents, usually won in the first round or were elected in the second round [12]. Therefore, it is particularly important to reduce harmful emissions by developing low-carbon urban transport [13–15] because a large number of Polish cities have very poor air quality. According to the Barcelona Institute for Global Health, on the list of the 50 most polluted cities in the EU (European Union), as many as 15 are in Poland [16], and concentrations of harmful substances become particularly serious in winter, when emissions from heating buildings are added [17,18].

However, the idea of a zero-emission bus fleet is currently of particular scientific interest. Articles on the environmental impact of, for example, vehicles or cast iron parts [19,20] deal with recommendations for such a transition [21–24] and the results of simulation models are used to determine the electric energy consumption of electric buses [5] or the business and financing models for them [25].

This kind of scenario analysis, following assumed hypotheses, is widely used to predict the possible transformation of a system like an urban bus fleet [26–32]. For example, researchers use it for policy evaluation [33]. However, those studies focus mainly on prosperous countries; there is a greater need to pay attention to poorer countries that rely on coal-based energy. Therefore, the authors of this study decided to fill this research gap by focusing on a transition to a zero-emission bus fleet based on a Polish scenario analysis.

Section 1 presents the main problems related to the development of low-carbon transport in Poland. Section 2 indicates changes in urban transport in the context of low-carbon development. Section 3 presents possible ways of modernizing urban bus fleet. Section 4 contains a description of the research methodology. In Section 5 a scenario analysis was performed. Section 6 summarizes and refers to the most important results of the research conducted in the manuscript, including the reductions in CO_2 emissions that may take place by the end of 2024.

2. Changes in Urban Transport in the Context of Low-Carbon Development

When analysing low-carbon development, it is important to determine how greenhouse gas emissions per capita have changed in Poland compared to the EU average. In 2007–2018, average per capita greenhouse gas emissions in the EU decreased (Table 1) by almost 19%. A similar situation also took place in a large part of the EU countries. Over the same period, Poland did not reduce GHG (greenhouse gas) emissions [34]. It should be emphasized that the economic growth achieved in the analysed period did not prevent the EU countries from reducing greenhouse gas emissions per capita. On the one hand, many technological solutions were implemented in Poland during this period, which reduced energy consumption. However, the richer societies used more equipment that needed energy and the mobility of Poles increased, which contributed to an increase in transport emissions. It should also be emphasized that, statistically, Pole consumes less energy than a resident of the EU. However, the emission level per capita in Poland is higher than the EU average because it obtains most of its energy from high-emission coal-burning power plants [35].

Table 1. Final energy consumption in households and greenhouse gas emissions per capita in Poland and the EU 28 [36].

Specification	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2019/2007**
	Final Energy Consumption in Households per Capita (in kg of Oil Equivalent)													**%**
Poland	508	516	524	578	528	546	537	499	499	521	525	512	479	−5.7
EU 28	583	612	604	644	576	603	608	533	554	568	564	556	554	−5.0
	Greenhouse gas emissions per capita (in Mg CO_2 equivalent per capita)													2018/2007 (%)
Poland	11	10.8	10.3	10.9	10.8	10.6	10.6	10.2	10.3	10.6	11	11	no data	0
EU 28	10.6	10.4	9.6	9.8	9.5	9.3	9.1	8.7	8.8	8.7	8.8	8.6	no data	−18.9

Even though an efficient transport system plays an essential role in the development of a society and an economy, it contributes to air pollution and influences climate change through the emission of harmful gases, such as nitrogen oxides and particulate matter, such as PM2.5 and PM10 [37,38]. It also covers large areas of land that break up animal habitats, seal the earth's surface and contribute to excessive noise.

Low-carbon development has become an important financial problem for Poland [39] not only because of the threat of penalties related to having an insufficient share of RES (renewable energy sources) in total energy production, but also because excessive concentrations of pollutants may lead to financial penalties from EU institutions [40,41]. In the coming years, especially during the implementation of the current long-term EU budget (2021–2027), as much as 356.4 billion euro will be allocated to activities in the area of natural resources and the environment [42] such as investment in developing of low-carbon transport. Transport uses a third of the final energy in the EU, much of which comes from oil, accounting for almost 30% of total EU transport CO_2 emissions, 72% of which comes from vehicles. On the other hand, heavy vehicles (including buses) accounted for almost 19% of emissions [43]. From the point of view of people living in cities that have older buses, a greater problem than fuel efficiency is that these vehicles do not meet the emission standards for new buses.

However, bus emissions are not the only pollution source that must be addressed. In 2018, private vehicles accounted for 79.3% of Poland's total passenger transport compared to 12.9% for buses and coaches and 7.9% for trains [44]. Even though, a lot of papers have focused on reducing CO_2 emissions from cars [45,46] and trucks [20,47], this paper will focuses only on buses.

The European Commission presumes that the increase in the number of zero-emission fleet buses will increase to 17–22% by 2030 due to the expected tightening of CO_2 emission standards for this vehicle segment and support for measures to implement a charging infrastructure (BSL—Baseline scenario). The highest share of electric buses is forecast for the REG scenario (Figure 1). In the political scenarios for 2050, 92–98% of buses will be powered by electric motors [48]. It should be emphasized that buses are most often used in urban areas where electrification is more accessible. On the other hand, intercity coaches, like trucks, will have problems with access to battery charging stations [49].

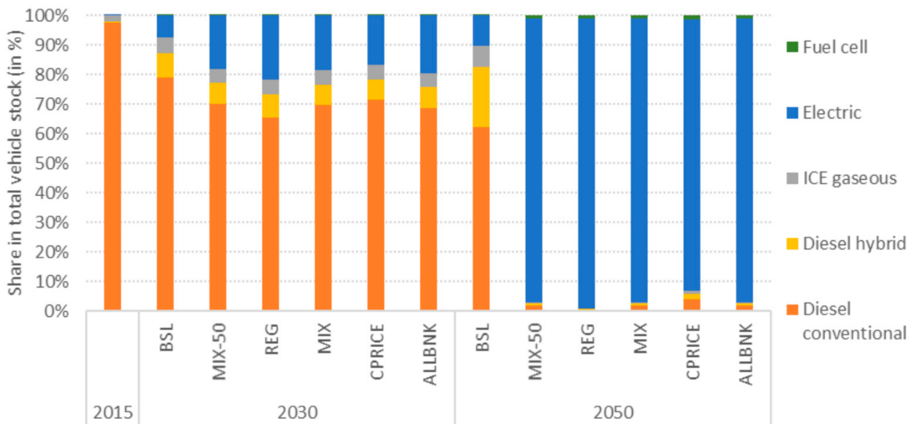

Figure 1. Shares in the bus vehicle stock by type of drivetrain in 2030 and 2050 [49]. BSL—(Baseline scenario) achieving the existing 2030 GHG emissions, renewables and energy efficiency of EU targets. The baseline scenario covers the transport policies adopted up to the end of 2019. MIX-50—An increased ambition scenario to achieve at least 50% GHG reductions. REG—A regulatory-based measures scenario that achieves around 55% of GHG reductions. MIX—Following a combined approach of REG and CPRICE, which achieves around 55% GHG reductions, both by expanding carbon pricing and with ambitious policies that are somewhat lower than those of REG. CPRICE—A carbon-pricing based scenario that achieves around 55% GHG reductions. It assumes the strengthening and further expansion of carbon pricing, via the EU ETS or other instruments, to the transport and buildings sectors, combined with low-intensity transport policies without intensifying energy efficiency and renewables policies. ALLBNK—The most ambitious scenario in GHG emissions reduction, based on MIX and further intensifying fuel mandates for aviation and maritime sectors in a response to an extended scope of GHG reductions covering all aviation and shipping.

An important element in developing the low-carbon public transport is increasing the share of electrically powered vehicles. In Poland, the share of energy generated from coal is on average about 80%, but preliminary data for 2020 shows that this share fell below 70%. Therefore, replacing the bus fleet with an electric one only changes the source of dust and greenhouse gases [49,50]. Only a significant increase in the share of renewable energy sources as part of total electricity production will result in lower carbon production [51,52]. The question is whether replacing the bus fleet given the current high level of energy generation makes sense from this point of view. Despite the limitations indicated above, the answer to this question is in the affirmative because electric buses usually replace old vehicles that do not meet current emission standards. Moreover, power plants that generate electricity are equipped with highly advanced technologies for capturing pollutants such as nitrogen oxides or suspended dust [53] and they are usually found at a considerable distance from city centers, which means that they have a smaller impact on human health.

3. Possible Ways of Modernizing Urban Bus Fleet

Diesel oil and gasoline are main energy sources for buses, but alternative drive systems are on the rise. Of the 12,129 buses in 2019, 1180 used alternative energy sources. A year earlier there were only 845 such vehicles [54].

These alternative sources comprise compressed natural gas (CNG), liquefied natural gas (LNG), electricity and hydrogen. The engines that run on LNG and CNG are the same. The liquefied gas evaporates in the fuel system and goes to the engine just as CNG does; the difference is in how the volume of natural gas is reduced. In CNG vehicles, gas is compressed at a pressure of 200 atmospheres, while in cryogenic LNG tanks it is a liquid cooled to below −120 °C. However, LNG technology has a refuelling advantage. Since LNG is a liquid, it can be refueled as quickly as diesel fuel in just a minutes [55,56]. In December 2020, there were 817 CNG/LNG buses in Poland, mostly CNG (95%). Table 2 presents their distribution by city.

Table 2. CNG/LNG urban buses in polish cities in December 2020. Selected cities are included [57].

City	Amount	Share in the Bus Fleet *
Warsaw	201 CNG, 35 LNG	12%
Tychy	135 CNG	75%
Rzeszow	102 CNG	48%
Czestochowa	49 CNG	25%
Radom	37 CNG	22%
Tarnow	33 CNG	35%
Gdynia	32 CNG	13%
Myslowice	30 CNG	No data
Bielsko-Biala	26 CNG	No data
Lubin	25 CNG	No data
Other cities	112 CNG	-

* estimated value.

In electric buses, there are two ways to charge the storage battery: standard charging and fast charging [58]. Standard charging uses moderate charging power, especially over night at the bus depot and during longer breaks. This results in a large battery capacity and increased weight when the bus has to run all day [59]. Fast charging is used between runs. It significantly reduces the capacity of the battery and thus its weight [60]. Fast charging can be used with a special pantograph, the design of which allows the driver to connect the vehicle to the power supply safely without leaving the vehicle. Moreover, there is also a wireless solution—inductive charging [61]. Unfortunately, fast charging requires the bus schedule to allow for sufficient charging time in certain locations [22]. In December 2020, Poland had 416 electric buses in operation (Table 3).

Table 3. Electric urban buses in Polish cities in December 2020.

City	Amount	Share in the Bus Fleet *
Warsaw	161	8%
Zielona Gora	43	48%
Krakow	29	5%
Jaworzno	24	35%
Poznan	21	6.5%
Other cities	138	-

* estimated value.

In hydrogen-powered buses, electricity is generated by synthesising oxygen from the air and hydrogen from a set of cylinders in the presence of a catalyst. Heat and water vapor are side effects of this reaction [62], and the refueling time is quite short [63]. In January 2021, though, there was not a single hydrogen bus among the city fleets in Poland.

According to the European Environment Agency, transport in 2017 was responsible for 24.6% of greenhouse gas (GHG) emissions in the EU 28. Overall, road transport was responsible for 71.7% of emissions, of which trucks and buses accounted for 26.3% [64]. No wonder that measures are being taken to reduce the contribution of harmful substances [65].

The new EU directive 2019/1161 requires a special share of "clean vehicles" in contracts organized from mid-2021. A clean vehicle means zero emission (electric and hydrogen) or low emission (CNG/LNG). In the case of Poland, the goals to be achieved are at least 32% of "clean vehicles" for 2021–2025 orders and at least 46% from 2026 to 2030. The directive applies to purchase, rental, hire, instalment and public transport service contracts [66]. Unfortunately, the Ministry of Climate and Environment in Poland would like to focus only on zero-emission vehicles and exclude low-carbon vehicles. Meanwhile, the introduction of CNG/LNG-powered vehicles, as the literature suggests, might produce emission savings [26]. At the beginning of 2021, the ministry consulted on an amendment to the act on electromobility. The Chamber of Commerce for Urban Transport pointed out that the new regulations were more restrictive than in the EU directive and ignored the issue of CNG/LNG-powered buses [67,68]. This calls into question current investment in rolling stock and infrastructure. As mentioned earlier, there are currently over 800 CNG/LNG buses, 416 electric buses, and no hydrogen buses. Due to the pandemic, local governments responsible for urban transport have reduced their budgets, which means they will have difficulties meeting the proposed EU goals because electric and hydrogen-powered buses are more expensive than CNG/LNG buses (Table 4).

Table 4. Cost of buying a bus [57].

Type of a Bus	Price in PLN
CNG/LNG	1,100,000
Electric	2,100,000
Hydrogen	3,000,000

The Polish government will subsidize purchases; however, it will be delivered through a competition. For instance, the National Fund for Environmental Protection and Water Management prepared the "Green Public Transport" program, under which an electric bus, hydrogen bus or trolleybus can be co-financed at 80, 90 and 80% of the eligible cost, respectively. Furthermore, this program can also finance 50% of the infrastructure costs needed to service vehicles. Those interested must meet the criteria set out in the terms of the program [69].

It is also important to emphasize that Poland is the largest European producer of electric city buses. In 2020, Solaris had a European market share of 20%. In 2020, the company delivered a total of 457 electric buses having a length of 12 or 18 m—almost three times as many as in the previous year when 162 Urbino electric models were delivered [70].

Therefore, it is important to use this advantage to reduce CO_2 emissions further while supporting the Polish economy by purchasing vehicles from domestic manufacturers.

4. Methodology

The methodology was adapted to the goal and scope of research, which included analysis of the existing literature, a scenario, source documents, mathematical statistics, tables and charts. These methods contributed to the achievement of research goal.

The literature analysis was carried out earlier. To carry out a scenario analysis, it was necessary to start with determining the total number of city buses. On average, over the last few years there were approximately 12,000 registered and performing buses in Poland [54]. Then attention was focused on the number of vehicles that ran on a particular fuel: diesel oil, CNG/LNG, electricity or hydrogen as well as hybrids. In 2020, the share of electric buses was about 3.5%. Diesel buses dominated with more than an 86% share. CNG and LNG buses had less than a 7% share, and the share of hybrid buses was less than 3.5% [57]. There were no hydrogen-powered buses [71–74], but one manufacturer made them available to carriers for testing. Taking this division into account, it is possible to focus on the CO_2 emissions for each of the given types of vehicles. In 2020, the previously described buses emitted over 1 million Mg CO_2, from the source to the wheels and 831.5 thousand Mg of CO_2, from the tank to the wheels, which is important for the health of city residents because harmful gases and dust get into the air with the CO_2 emissions (Table 5). The next step is to determine the average number of kilometers that the buses travel during a year. According to the Central Statistical Office, it is 72,590 km [54]. There is also a need to clarify the share of renewable energy in Poland's total energy production. In 2020, it was 18% and, based on the available statistical data and planned investments in RES, 20% is expected for 2024. With this data, we move on to establishing assumptions for individual scenarios.

Table 5. Greenhouse gas emissions and number of buses for scenarios I-III [75,76].

Description	Diesel Buses	CNG-Powered Buses	LNG-Powered Buses	Hydrogen Buses	Electric Buses		Hybrid Buses
					Electricity Generated from Conventional Raw Materials (Coal, Gas)	Electricity Generated from Renewable Energy	
Greenhouse gas emissions from the tank to the wheels (expressed as $CO_{2\,eq}$ in g/km)	1004	1014	1014	0	0	0	552
Greenhouse gas emissions from the source to the wheels (expressed as the $CO_{2\,eq}$ in g/km)	1222	1171	1171	320	720	20	672
The share of buses in December 2020 (%)	86.33	6.51	0.29	0	2.84	0.62	3.41
The number of buses (December 2020)	10360	781	35	0	341	74 *	409
Buses participation (scenario I—pessimistic)	80.11	7.47	1.01	0.93	5.48	1.37	3.63
Buses participation (scenario II—realistic)	76.43	8.02	1.29	1.33	7.05	1.79	4.09
Buses participation (scenario III—optimistic)	73.02	8.37	1.55	1.75	8.67	2.19	4.45
Number of buses (scenario I—pessimistic)	9614	896	121	112	657	164 **	436
Number of buses (scenario II—realistic)	9171	962	155	160	846	215 **	491
Number of buses (scenario III—optimistic)	8762	1004	186	210	1040	263 **	535

* theoretical number of buses powered by electricity generated on the basis of renewable energy, calculated on the basis of the 18% share of renewable energy for 2020. ** theoretical number of buses powered by electricity generated from renewable energy, calculated on the basis of a 20% share of renewable energy for 2024.

There are many barriers that hinder the development of low-carbon city bus transport, such as high costs and the need to build infrastructure for battery chargers [23,77,78]. Despite the difficulties, a particularly rapid increase in the number of electric buses is taking place in wealthy countries such as China, Germany and the U.K. [24,79].

Assumptions for the scenario analysis were based on the available statistical data such as plans for purchasing low-carbon buses, which was possible because the authors collected this information from local government co-financing programs for ecological buses. For example, data for "Green Public Transport", mentioned earlier, was obtained during autumn 2020 from the research of experts at scientific and local government institutions and enterprises [80]. In April and May 2021, foresight research was conducted among representatives of transport sector enterprises, local governments, scientific circles and non-governmental organizations, from which were able to define individual scenario assumptions and indicate how the number of city buses should change (e.g., electric or hybrid). When developing assumptions for individual scenarios, the authors used their own experiences gained during, for example, application evaluations for co-financing innovative projects and investment in for various institutions, including the European Commission, Regional Operational Program, and National Centre for Research and Development. During the research, three scenarios were proposed that indicate the likely development of the number of city buses by the end of 2024. All scenarios assumed the following:

- The number of buses will be close to the average from recent years, i.e., 12,000. It does not provide for changes in the number of buses because the analysis covers a relatively short period of time.
- Each bus will cover an average distance of 72,590 km as before. Currently, there are no data available that would allow determining the average distance covered during a year.
- CO_2 emission levels will stay at the current level.
- The share of hybrid buses will grow very slowly due to difficulties in obtaining funding for their purchase.
- The share of electricity generation based on renewable energy sources will increase from 18% in 2020 to 20% in 2024.
- A slow increase in the share of buses powered by natural gas (LNG and CNG) due financing issues related to the relatively high emissions of greenhouse gases and other pollutants.

5. Results and Discussion

For Scenario I (pessimistic) it was assumed that investments in new, "greener buses" will run more slowly than predicted by the plans and assumptions currently available. This situation may be due to the lack of agreement between the Polish government and the European Union on the allocation and financial resources to help improve the economy after the coronavirus pandemic. Another reason might be delays in vaccine deliveries. In the case of Scenario II (realistic) it was assumed that all planned activities related to investment in developing bus transport will be implemented, orders for, and deliveries of, low-carbon buses is to be uninterrupted, and the ordered buses will be put into use (Table 6). However, there may be minor delays in implementing tenders for the purchase of vehicles. In Scenario III (optimistic), it was assumed that replacing diesel-powered buses will be faster due to the mobilization of additional funds, which are not included in current assumptions for the development of urban transport in the coming years.

Table 6. CO_2 emissions for scenarios I–III.

Description		Number of km Traveled per Year	Greenhouse Gas Emissions from the Tank to the Wheels (Expressed as $CO_{2\,eq}$ in Mg)			Greenhouse Gas Emissions from the Source to the Wheels (Expressed as the $CO_{2\,eq}$ in Mg)		
			Scenario I (Pessimistic)	Scenario II (Realistic)	Scenario III (Optimistic)	Scenario I (Pessimistic)	Scenario II (Realistic)	Scenario III (Optimistic)
Buses with diesel engines			700,672	668,386	638,578	852,810	813,513	777,233
CNG-powered buses			65,951	70,809	73,901	76,163	81,773	85,343
LNG-powered buses			8906	11,409	13,691	10,285	13,175	15,811
Hydrogen buses		72,590	0	0	0	2602	3717	4878
Electric buses	Electricity generated from conventional raw materials (coal, gas)		0	0	0	34,338	44,216	54,355
	Electricity generated on the basis of renewable energy		0	0	0	238	312	382
Hybrid buses			17,470	19,674	21,437	21,268	23,951	26,098
Total			793,000	770,278	749,606	997,704	980,658	964,099

Based on the scenario analysis, it was calculated that by investing in low-carbon city buses, it will be possible to reduce CO_2 emissions by over 34 thousand Mg from the source to the wheels) and almost 46 thousand Mg from the tank to the wheels in the case of the realistic scenario (Table 7). However, even in the case of a slower pace of investment, which was assumed in pessimistic Scenario (I), there will be significant reductions in CO_2 emissions—almost 29 thousand Mg from the tank to the wheels and over 20 thousand Mg from the source to the wheels. Reductions in greenhouse gas emissions will take place in Poland as a result of EU regulations that will enforce compliance with low-carbon solutions and an increasingly aware society that will put pressure on the authorities to ensure that they do. In the case of the optimistic scenario, it will be possible to reduce CO_2 emissions by over 62.6 thousand Mg from the source to the wheels and almost 46.4 thousand from the tank to the wheels. However, for such a significant reduction, it will be necessary to mobilize additional funds to increase investment in low-carbon buses.

Table 7. Differences in CO_2 emissions for Scenarios I–III by the end of 2024 compared to 2020.

Description		Greenhouse Gas Emissions from the Tank to the Wheels (Expressed as $CO_{2\,eq}$ in Mg)	Greenhouse Gas Emissions from the Source to the Wheels (Expressed as the $CO_{2\,eq}$ in Mg)	GHG Emissions Difference from Tank to Wheels 2024/2020 (Expressed as the $CO_{2\,eq}$ in Mg)			GHG Emissions Difference from Source to Wheel 2024/2020 (Expressed as the $CO_{2\,eq}$ in Mg)		
				Scenario I (Pessimistic)	Scenario II (Realistic)	Scenario III (Optimistic)	Scenario I (Pessimistic)	Scenario II (Realistic)	Scenario III (Optimistic)
Buses with diesel engines		755,041	918,984	−54,369	−86,655	−116,463	−66,174	−105,470	−141,751
CNG-powered buses		57,486	66,387	8465	13,323	16,414	9775	15,386	18,956
LNG-powered buses		2576	2975	6330	8833	11,115	7310	10,200	12,835
Hydrogen buses		0	0	0	0	0	2602	3717	4878
Electric buses	Electricity generated from conventional raw materials (coal, gas)	0	17,822	0	0	0	16,516	26,394	36,533
	Electricity generated on the basis of renewable energy	0	107	0	0	0	131	205	274
Hybrid buses		16,388	19,951	1082	3286	5049	1317	4000	6146
Total		831,492	1,026,227	−38,492	−61,214	−83,885	−28,523	−45,569	−62,128

6. Conclusions

Reducing emissions of greenhouse gases and other harmful substances from buses is of particular importance for improving the quality of life of city residents. There are quite strict regulations on this matter at the European Union and national level, and Poland seems to be a country particularly worth analysing as it has a large number of city buses and is one of the leading producers of electric buses in Europe. The scenario analysis carried out in this article regarding the prospects of developing of low-carbon urban bus transport showed that a reduction in the range of 38.5–83.9 thousand Mg CO_2 from the tank to the wheels and in the range of 28.5–62.1 thousand Mg CO_2 from the source to the wheels is possible. It should be noted that to obtain a greater reduction additional funding would be needed for increased investment in low carbon buses. Recognition of CNG/LNG-powered buses as low-carbon rolling stock during the transition period and co-financing of the purchase for public transport carriers will also be helpful. Other studies also indicated this [26,81], and because of these it is possible to reduce CO_2 emissions and use money more efficiently than for the purchase of low-carbon buses.

Another form of needed assistance for urban transport operators is support in preparing cost/benefit analyses of plans to make the transition to zero-emission rolling stock. It seems that further research should focus on ways to increase ridership. As a result, it will be possible to increase the positive environmental effect.

It should be emphasized that the reduction in CO_2 emissions would be much higher if coal-burning electricity generation were reduced. The calculated reductions in greenhouse gas emissions in the three scenarios assumed they would be much higher if electricity in Poland were produced to a greater extent on the basis of RES, which is possible especially in rural areas. Therefore, the article showed that reducing CO_2 emissions and their accompanying harmful gases and dust calculated are of particular importance for improving urban air quality.

In addition to increasing the financing related to replacing a city's bus fleet and limiting the use of fossil fuels in electricity generation in Poland, other measures should also be taken to develop low-carbon city bus transport. The most important of them include:

- ongoing monitoring and adaptation of the bus system to the needs of users (location of stops, routes for individual lines);
- introducing zones in city centers that ban cars with engines that do not meet the latest ecological standards, while simultaneously expanding parking lots on the outskirts where it would be possible to leave non-ecological cars and use ecological urban transport;
- implementation of educational activities to promote low-carbon transport;
- radical limitation and the future banning by local governments of the purchase of buses with internal combustion engines;
- increasing parking fees in city centers;
- expansion of pedestrian infrastructure, especially in the vicinity of bus stops;
- expansion of bus lanes infrastructure; and
- blocking some roads to passenger car traffic.

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