

Article

The Importance of Introducing Zero- and Low-Carbon Solutions in Urban Bus Transport

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Abstract: The aim of this paper is to find the most important aspects of introducing zero-emission and low-carbon solutions in urban bus transport, as well as their availability. Beyond the economic aspects related to energy sources and consumption, the paper focuses on their impact on people and the environment. There is also an attempt to estimate the scale of the impact of changes in the structure of the energy sources of buses in urban transport compared with all the means of transport operating in a given area, as well as a justification for these changes. We also conducted a survey of bus passengers to check their awareness of the changes taking place and their attitude towards them.

Keywords: electromobility; bus transport; environmental issues; transportation economics; urban transport



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1. Introduction

The need to focus on the issue of energy sources in transport, particularly in urban areas, is determined by several factors. Most of the world's population lives in cities, and this trend, according to most studies available, will increase. Bertrand Delanoë, who was the mayor of Paris for over 10 years, is prompting the issue of urban logistics. He argues that it is at the level of cities, where more than half of humanity lives, that many current problems can be solved. Delanoë believes that by identifying people with local problems more easily, it is easier to deal with global problems, such as the environment and global warming, as they depend heavily on finding appropriate consumption patterns in urban areas [1]. Air pollution is one such, for which transport is largely responsible. However, it has a solution in the form of electromobility. Legal frameworks can be very useful in this case. For example, in 2018, Poland passed the “*Ustawa o Elektromobilności i Paliwach Alternatywnych*”, which can be translated as “Act on electromobility and alternative fuels” [2]. Article 68, point 4 is of particular relevance: “A local government unit referred to in article 36 paragraph 1, ensures the share of zero-emission buses in the fleet of vehicles used: (1) 5%—from January 2021; (2) 10%—from January 2023; (3) 20%—from January 2025”. It is also important for governments to source external funds, mainly from the EU, to help municipalities to reduce their own costs when modernizing bus fleets.

The fact that such purchases are made by a municipality, a subsidiary company or a budget establishment, etc., means a much more limited number of transactions than in the case of the passenger car market. Introducing appropriate solutions or increasing the ecological awareness of mayors can lead to improvements in air quality, as well as the elimination of other nuisance associated with the usage of diesel buses. The financing of public transport relies to a large extent on public funds. At the same time, public transport is used by crowds of people, which prompted us to ask passengers about their awareness and attitude to the changes in vehicle power supply. A questionnaire, which was conducted both on the Internet and directly, was addressed to people using public transport in such

cities as Warsaw, Kraków, Jaworzno, Zielona Góra and Inowrocław, where, statistically, the highest number is zero and low-emission buses. Most of the 102 responses concerned Warsaw (69%). In total, 78% of the respondents declared that they had higher education, while 75% were in the 18–45 age group.

2. Environmental Pollution and Transport Processes

The starting point for further considerations is the graphical presentation of the research results, showing changes in the emissions of individual harmful substances in chosen countries in recent years—Figure 1. Decreases of several dozen percentage points were achieved, while maintaining the economic growth and competitiveness of the European economy on the international stage. to the question of how this was achieved is not the focus of this article, but it is undoubtedly influenced by the modernization of technological processes, the imposition of emission standards on industry and transport, as well as the composition of pollutants emitted into the air. A further factor is the withdrawal of heavy industry from Europe to countries that provide cheaper labor and more liberal environmental laws.

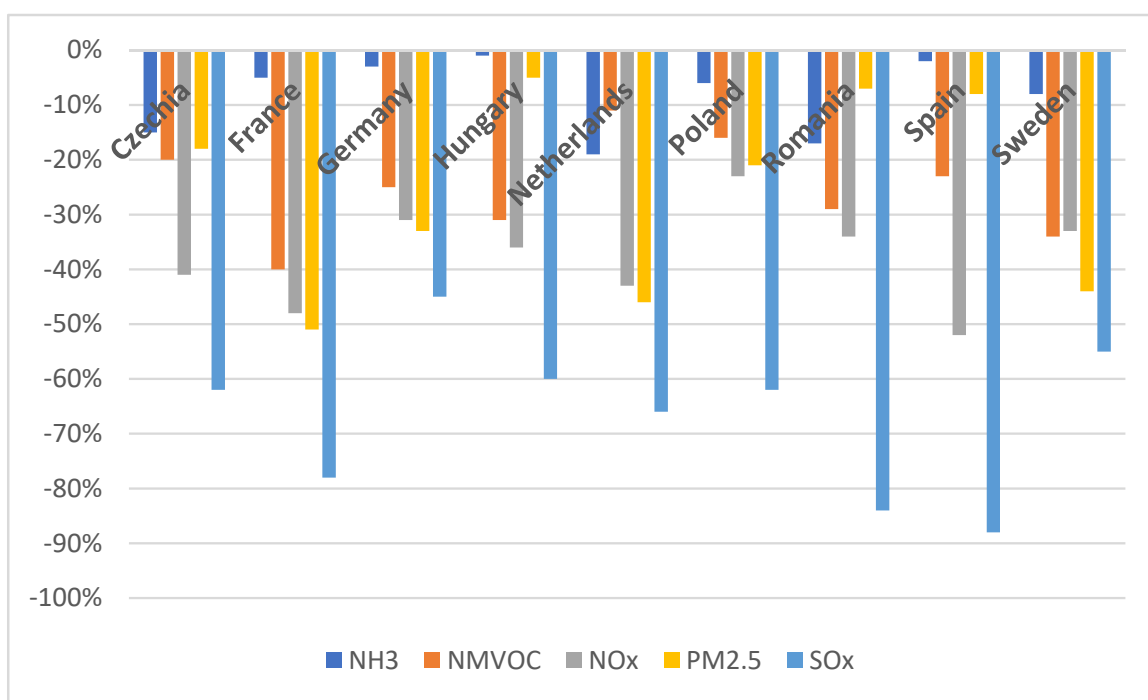


Figure 1. Changes in emissions of the main air pollutants in chosen countries from 2005 to 2019. Source: Emissions of the main air pollutants in Europe. <https://www.eea.europa.eu/ims/emissions-of-the-main-air> (accessed on 20 February 2022).

It is necessary to determine which sectors of human activity are most responsible for each time of pollution. According to our EEA research, the main cause of NH₃ emissions is “energy use in industry”, accounting for about 90%. The main causes of NMVOC pollution are “industrial processes and product use”, accounting for about 40%, followed by “energy use in industry” and “commercial, institutional and household”, which are both responsible for over a dozen percentage points, and “energy production and distribution” and “road transport”, each of which contribute less than 10% of the total emissions. In the case of NO_x, “road transport” is responsible for almost 40% and “energy production and distribution” for about 20%; other important polluters are “commercial, institutional and household”, “energy use in industry”, “non-road transport”, and “agriculture”. With particular matter 2.5, the picture is different: “commercial, institutional and household” are responsible for over 50%, followed by “industrial processes and product use”, responsible

for a dozen percentage points, and road transport, responsible for about 10%. For the last factor researched, SO_x , the share of “road transport” is irrelevant, with an almost 60% share of the energy total. The subject of this article is the share of road transport in the emissions of individual substances. According to a study by the European Environment Agency (EEA), road transport is heavily responsible for environmental pollution by the following substances: NMVOC (7.77% of total emissions), NO_x (36.48% of total emissions), and $\text{PM}_{2.5}$ (10.67% of total production). It should be noted that this study presents a comprehensive examination of road transport, which is understood as individual motorization, cargo transport, and passenger transport [3].

The emissions of non-methane volatile organic compounds, NMVOC, in chosen countries dropped significantly from 2005. NMVOCs cause cancer as a result of respiratory tract irritation and also cause heritable genetic damage. These compounds also indirectly affect the environment, leading to the formation of harmful secondary pollutants, such as ozone [4]. They also affect the natural environment, being one of the factors causing acid rain.

NO_x . Since 2005, there has been a significant decrease in NO_x emissions and other ozone precursor pollutants in the road transport sector, despite an overall increase in transport activity in this sector over the period considered. These emission reductions have been achieved mainly as a result of installing three-way catalysts in gasoline-powered cars (in accordance with European emission standards) [3].

Particulate matter, including fine $\text{PM}_{2.5}$, is also harmful to the health of people exposed to it. Fine dust with a diameter below $2.5\ \mu\text{m}$ is the most dangerous. It reaches the alveoli and even penetrates into the blood vessels and, from there, into the bloodstream. It is equally harmful to the respiratory system and the cardiovascular system. Numerous scientific studies have linked exposure to particulate pollutants to various problems, including the premature death of people with heart or lung disease. Increased symptoms, such as respiratory tract irritation, coughing or breathing difficulties, have been observed in people exposed to fine particulate matter. These dusts are also harmful to the environment. The particles can be carried over long distances by the wind and then settle on the ground or water.

Depending on their chemical composition, the effects of this settlement may include: the acidification of lakes and streams, changes in the nutrient balance in coastal waters and large river basins, the depletion of soil nutrients, and the destruction of forests and agricultural crops, contributing to acid rain [5].

The harmful effects of the substances cited above appear to be indisputable and significant. Therefore, legislators have forced vehicles introduced to the market to meet increasingly stringent standards for emissions and exhaust-gas content. The changes in the values determined by individual standards are presented in Table 1.

The fact that the standards regarding the content of exhaust gases in new vehicles are being raised suggests that over the years, emissions of harmful substances by road transport will decrease. Particularly significant progress has been achieved in the emission of nitrogen oxides, with five emissions at EuroIV that are five times lower than EuroV and almost nine times lower than EuroIV. However, it is important to set this against the constant increase in transport needs and, thus, the increase in the number of vehicles and the number of kilometers they cover.

Taking into account their age, most of the vehicles currently used meet EuroIII standard or higher. However, even a small emission, in the case of a large number of emitters, may cause a dangerous concentration of harmful substances.

Table 1. EU emission standards for diesel engines—test under stable conditions.

Standard	Date	Test	CO ^a	Hc ^b	NO _x ^c	PM ^d
g/kWh						
Euro I	1992, ≤85 kW	ECE R-49	4.50	1.10	8.00	0.612
	1992, >85 kW	ECE R-50	4.50	1.10	8.00	0.36
Euro II	1996.10	ECE R-51	4.00	1.10	7.00	0.25
	1998.10	ECE R-52	4.00	1.10	7.00	0.15
Euro III	1999.10 EEV only	ESC & ELR	1.50	0.25	2.00	0.02
	2000.10	ESC & ELR	2.10	0.66	5.00	0.10
Euro IV	2005.10	ESC & ELR	1.50	0.46	3.50	0.02
Euro V	2008.10	ESC & ELR	1.50	0.46	2.00	0.02
Euro VI	2013.01	WHSC	1.50	0.13	0.40	0.01

^a carbon monoxide ^b hydrocarbons ^c nitrogen oxides ^d particulate matter. Source: Emission Standards, EU: Heavy-Duty Truck and Bus Engines, www.dieselnet.com/standards/eu/hd.php (accessed on 10 March 2020).

It should be remembered that, in addition to harmful substances, internal combustion engines also emit noise, which is a factor that negatively affects human and animal health, as well as quality of life. All these environmental factors constitute a very strong basis for introducing quick and decisive changes in the structures of public transport fleets. It should be remembered that in addition to the issues related to quality of life and sustainable development, there are also issues related to energy security and, ultimately, from the perspective of the next decade, economic benefits.

3. City Buses in the Context of Electromobility

One of the solutions for reducing these problems seems to be the use of hybrid buses. Thanks partially to work on electric motors, they burn less fuel and are able to emit less pollution from exhaust gases. In long-term operations, they achieved fuel combustion results up to about 1/3 lower than those of buses with only diesel drive [6]. They are also positive in terms of noise emissions. Moreover, they are also chosen from the practical perspective of their operation, since they do not need to be charged from the grid, which, considering the source of electricity in Poland, is sometimes considered controversial. This undoubtedly offers advantages in terms of operational reliability, since there is no risk of the vehicle stopping due to the depletion of batteries during passenger transport, as these are most often hybrid electric vehicle (HEV) units. Power from two sources is used to drive this type of vehicle: an internal combustion engine and an electric engine. It is also possible to travel with only on one of the engines. The battery can store energy taken from the internal combustion engine, recovered from rolling, or generated during braking of the vehicle. In addition, there are hydrogen-powered buses and PHEVs, i.e., hybrids loaded from the network.

Although the discussion over which type of drive is the most advantageous is still not closed, it is worth focusing on the type based only on batteries charged from the network. It is often indicated as the best choice in terms of “green transport”, when “green energy”, i.e., from renewable energy sources, is used for the power supply. The issue is less clear when using the so-called “gray energy” derived from fossil fuels.

Almost 80% of the capacity achievable jointly by commercial, wind, and other renewable power plants in the KSE (KSE—Krajowy System Elektroenergetyczny—National Power System—a system of electricity generation, transmission, distribution, storage and use devices operating in Poland) comes from the burning of fossil fuels, of which over 93% arise through the burning of hard coal and lignite [7].

Reliability requires checking which harmful substances are associated with production and emission. The results are presented in Table 2. At the same time, it should be noted

that results showing the diversity of particulate matter depending on the particle size are not available.

Table 2. Emission factors for individual substances in g/kWh for end consumers of electricity in 2018 in Poland.

Sulfur oxides (SO _x /SO ₂)	0.681
Nitrogen oxides (NO _x /NO ₂)	0.631
Carbon monoxide (CO)	0.275
Particulate matter	0.036

Source: CO₂, SO₂, NO_x, CO and PM emission factors for electricity based on the information contained in the national database on emissions of greenhouse gases and other substances for 2018. The National Center for Balancing and Management of Emissions, Institute of Environmental Protection—National Research Institute KOBIZE, IOŚ—PIB, Warszawa, 2019, p. 4.

The emission of harmful substances and resource-consuming electricity generation processes causes raises doubts in Poland over the investment in electric vehicles, including electric buses. The arguments presented by the opponents of electric vehicles relate to both purely economic aspects and those related to ecology. The economic aspects depend on several factors. The fundamental factor is undoubtedly the recent volatility of oil prices in global markets, which have ranged from USD 21.51 to USD 74.34 per barrel on the New York Mercantile Exchange (NYMEX) over the past three years [8].

The price of a barrel of Brent crude, recorded in London in the period from 2017 to April 2020, ranged from USD 14.85 to USD 86.07 [9]. In addition, there is a risk factor associated with changes in exchange rates. In the years 2017–2020, the USD/PLN pair ranged from 3.31 PLN for 1 USD to 4.31 PLN for 1 USD.

Another problem concerns the costs of electricity production, specifically the costs of the raw materials it involves. In Poland, coal used in the energy sector is listed on the Polish Power Coal Market Index PSCMI1, where prices from 2017 to March 2020 ranged from PLN 198.38 to PLN 268.38 per ton.

The next aspect is the cost of emission allowances. Taking into account SPOT prices, EEX, Primary Market Auction on, for example, the European Energy Exchange AG, which is located in Leipzig, in the period from April 2017 to April 2020, emission prices ranged from EUR 4.49 per ton of CO₂ to 28.04 Euro per ton [10]. In Poland, as in the case of the oil market, one must take into account the volatility of the exchange rate of EUR against PLN, which in the years 2017–2020 ranged from PLN 4.13 for EUR 1 to PLN 4.63 for EUR 1. In addition to these factors, which are beyond the government's control, there are national conditions in the form of the tax system. The components of the fuel price in Poland are clearly illustrated in Figure 2. In turn, in the case of electricity prices, one should remember the activities of the Energy Regulatory Office regarding the acceptance of electricity tariffs, which must, on the one hand, take into account the costs and profitability of energy companies, and, on the other hand, take into account the interest of the recipient under market conditions with low competitiveness [11].

This large number of variables makes it difficult to make decisions based on the economic factors associated with the cost of the transport process itself. To this, other operating components, such as durability, failure rate, service cost, energy recovery, etc, can be added. Each entrepreneur providing transport services must individually weigh these factors, taking into account the human resources, equipment, and conditions through which it makes specific orders and provides services. From a general perspective, holistic considerations related to social justice issues should be considered in the context of the external costs generated by transport.

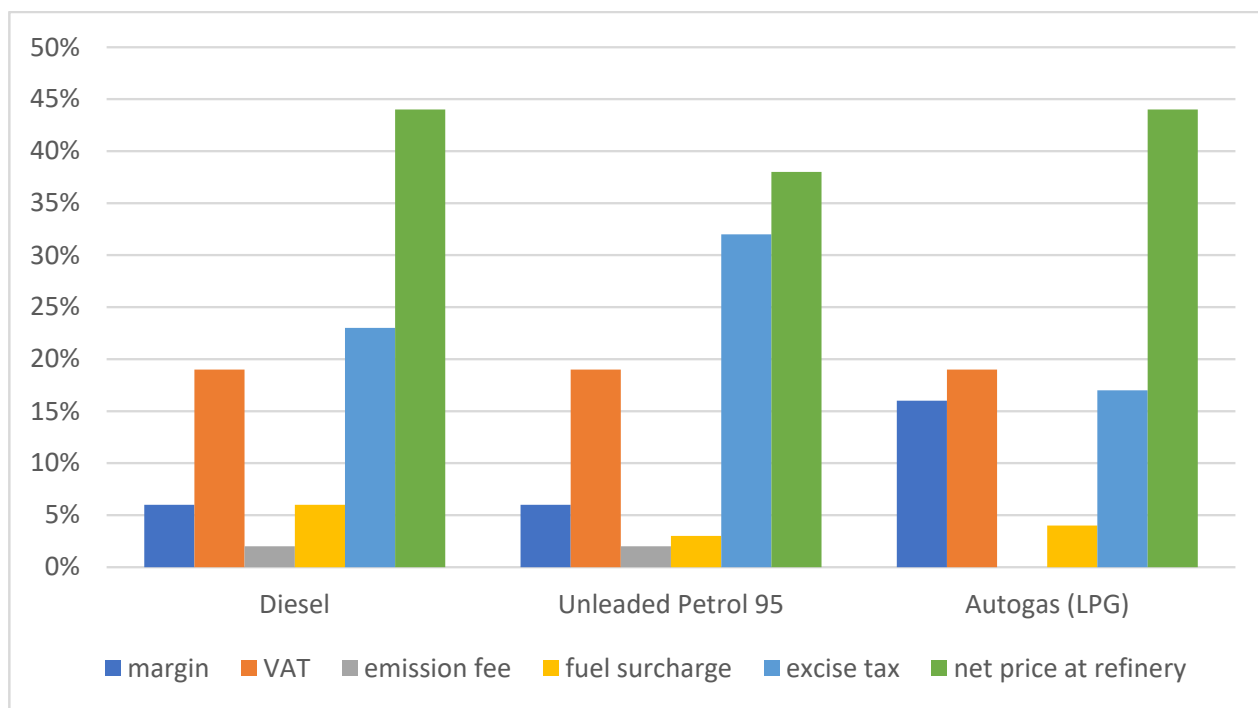


Figure 2. Constituent fuel prices in Poland in the first quarter of 2020. Source: Own study based on Polska Organizacja Przemysłu i Handlu Naftowego (POPiHN), fuel-price structure, http://www.popihn.pl/struktura_ceny_paliwa.php (accessed on 3 April 2020).

The following problems can be identified here. Firstly, power plants are usually located away from places with large population densities. It is known that high concentrations of and long-term exposure to power-related substances is harmful to humans. Furthermore, emissions from new or modernized blocks are achieving increasingly positive parameters. This includes the requirements of horizontal documents ordering increases in the share of renewable energy sources and minimizing emissions of harmful substances, such as “Europe 2020, European strategy for smart, sustainable and inclusive growth” [12] or “A Clean Planet for all European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy” [13]. These will most likely result in an increase in the share of renewable energy sources in the energy mix in Poland. It is also necessary to take into account the very conscious and rational operations of enterprises which, by deciding to replace their vehicles, create or modernize a base specially designed for electric buses. These buses are equipped not only with obvious chargers, but also with photovoltaic installations, allowing them to obtain energy and fill the battery overnight. Practice also shows the need to install charging points on loops so that vehicles can be reliably used throughout the working day. The availability of vehicles and competition among their manufacturers are also important. These processes usually have a positive effect on the price and quality of goods sold. It should be emphasized here that all major bus manufacturers present on the EU market offer low- or zero-emission models.

4. The Social Aspect of Changes

Each change, whether revolutionary or evolutionary, is associated with its impact on the environment and vice versa. Cost-effective, carbon-neutral, and sustainable cities need to be supported by changing political, technological, and market conditions. The most important process is to actively involve citizens and increase the social acceptance of highly profitable buildings and new technologies in cities. Therefore, the question is what kind of determinants are recognized and accepted by citizens [14]. This prompted us to check

how the changes in the operation of city buses are perceived by the inhabitants of cities in Poland, given the aim of modernizing the fleet to reach low or zero emissions.

The most popular non-diesel types of bus drive that the passengers had the opportunity to use were HEV, over 45%, followed by CNG, over 30%, BEV, almost 25%, and PHEV, almost 20%. People are often afraid of change and technical innovation. In addition, there are several known cases of electric bus fires and the suspension of their use [15]. This is why answers to the question over whether “there are power sources for public transport vehicles which, being relatively new or not very popular, cause fear of use” are so important. In total, 83.3% of the respondents did not feel afraid of using vehicles with engines other than those powered by diesel or gasoline. Furthermore, 16.7% of respondents were afraid of using hydrogen-powered buses, 10.8% feared those powered by CNG, and only 5.9% were afraid of using HEV and BEV buses. The respondents also answered the question of “if there are, what are the advantages of electric vehicles in public transport?”: 55.9% answered, “no direct emissions from the vehicle”, 50% answered, “low noise emissions”, and only 5.9% answered that “there are no advantages”.

From the point of view of shaping transport and energy policy, the attitudes of residents to changes in transport, their willingness to change their own habitual choices of means of transport, as well as their willingness to assume the financial costs associated with the modernization of the fleet, are of key importance. The distribution of answers is illustrated in Figures 3 and 4.

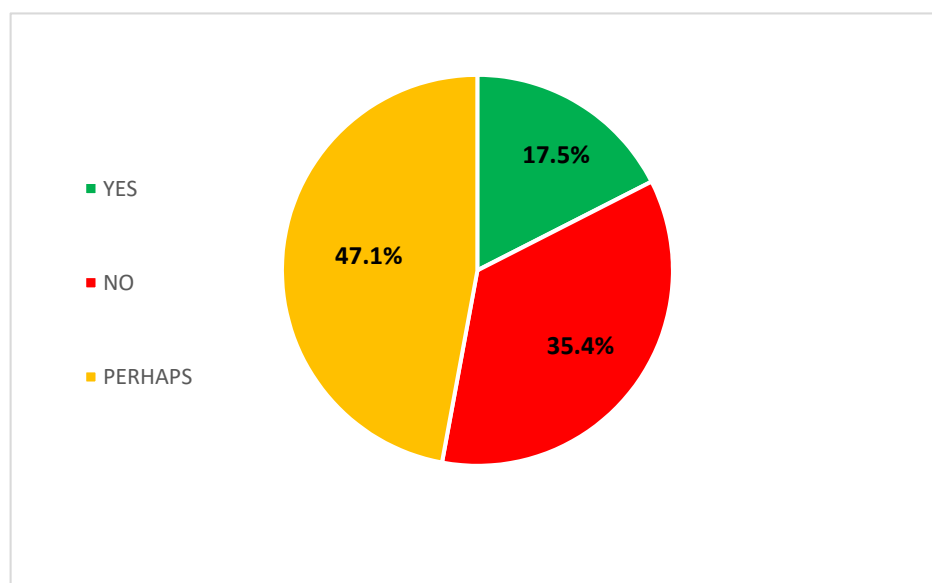


Figure 3. Would you be willing to pay more for a service provided with zero-emission or low-emission transport? Source: Own studies.

It can be seen that the passengers were strongly divided in their opinions. However, although almost half of the passengers did not want to pay more for the transport service, over 50% did not rule out doing so. Over 17% declared their willingness to pay more when transport was more environmentally friendly; this topic probably requires further research in order to determine the real values acceptable to passengers, so that price pressure does not discourage the use of public transport. These results can be compared to other studies about the general opinions about whether Poland’s contribution to climate change is so low that its reduction would not significantly translate into global change. In 2016, 43.6% of respondents thought so, whereas in 2018, this percentage was lower, with only 37.3% of respondents saying “yes” [16].

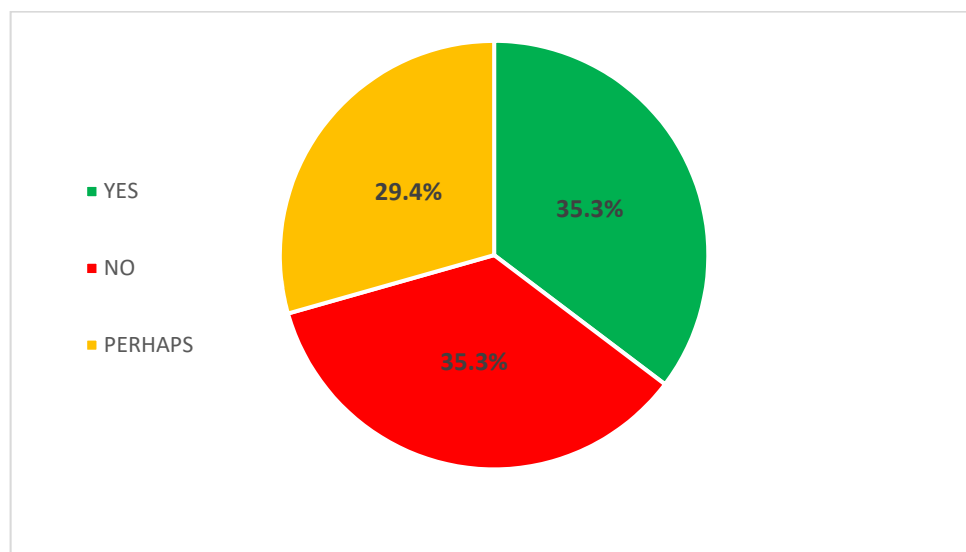


Figure 4. If public transport (bus) was provided by low-emission or non-emission transport, would it encourage you to use public transport more often? Source: own studies.

It should be also remembered that public transport needs support from public funds, which may come from relatively high parking fees, so that it can offer an appropriate standard of both security reliability and aesthetics, combined with affordable prices [17]. The results regarding the question, “would environmentally friendly transport encourage people to use the public transport more often?” was also positively received. As many as 35.3% of the respondents answered “yes”, and another 29.4% did not rule it out. This shows that it is worth responding to this significant social group. It should be mentioned here that 76% of the respondents had higher education, which, in our opinion, may slightly overestimate the percentage of people who welcome new ecological solutions and are willing to make sacrifices for the sake of the environment.

These research results in Poland should be considered relatively positive in the face of changes and based on the experience of other studies, according to which Polish consumers are more skeptical about electromobility [18].

5. Possible Impact of Changes

The scale of the impact of bus rolling stock replacement remains an open issue in individual communes. For example, in Szczecin, the total number of registered passenger cars in mid-2019 was almost 231,000 [19], and the number of buses at the disposal of Szczecin carriers was 204 [6]. Even when adding the number of vehicles rented for transport from other entities and vehicles shared with the neighbouring commune, this number does not reach 300. In Kraków, in 2019, there were 493,000 registered cars, passenger cars, and buses [20], 512 Miejskie Przedsiębiorstwo Komunikacyjne Spółka Akcyjna (city bus carriers) [21], and 80 vehicles operated by Mobilis sp. z o. o. [22], the second enterprise operating buses. In Bydgoszcz, at the end of 2018, almost 209,000 passenger cars were registered [23], and the number of the buses in the enterprises servicing public transport was 157 units [24]. This means that the number of buses was around one per thousand vehicles in a given area. Even assuming that one bus consumes about 55 to 65 L of diesel per 100 km, which is several times more than an average passenger car, it is still difficult to determine a diametrical change in the emission of harmful substances into the atmosphere in a given city.

It seems reasonable to take a step-by-step approach to low-carbon standards, especially in urbanized areas, which should ideally be supported by a municipal and governmental transport policy with an emphasis on internal and intergenerational justice. One of the ways to achieve this would be internalization of transport costs.

Buses in large municipalities in Poland are usually used for 10 to 20 years. Therefore, purchasing decisions cannot be made solely based on the legal situation as it is today, but should also anticipate changes, at least over the next decade. At the same time, bus carriers should lobby municipal authorities not only for funds for the purchase of vehicles or the rate per vehicle-kilometer, but also for the fastest possible implementation of the system—a transport policy that would promote and reward public transport. In support of the assumption about the important role of communes in shaping transport realities in their respective areas, one can cite the Act of Self-Government “Ustawa o Samorządzie Gminnym z 8 Marca 1990 roku” [25]. In addition to its provisions, which can also be indirectly attributed to the goals related to the introduction of solutions in the field of electromobility (e.g., health care), the act indicates that commune governments have an obligation to protect the environment by providing local public transport or roads and spatial order. The last two issues, often overlooked in the solutions on transport rolling stock, are extremely important because they often determine the extent of transport needs, how to meet them, and also determine the elongation of roads.

Decision-makers or administration, broadly understood, should consider currently available sources of financing, such as funds from regional operational programs or co-financing from the CUPT (The Center for European Union Transport Projects, or Centrum Unijnych Projektów Transportowych), a state budget unit that manages funds from the European Union, supervised by the ministry responsible for transport. These funds are focused on the purchase of low- or zero-emission vehicles, which carriers use.

The replacement of buses by local government units or their related entities also has aesthetic and managerial aspects. Of course, it should not be understood solely as a PR procedure designed to build the image of communes that care about the environment and its inhabitants. Communes should take the lead on pro-ecological solutions. It is difficult to justify the actions of municipalities, such as convincing residents to change to vehicles with alternative power sources, if the communes themselves continue to use conventional sources. Of course, this relatively new technology raises questions about reliability, battery life, risk of fires, and the method and costs of disposal and recycling. However a conscious society should minimize the presence of substances and factors harmful to health wherever possible, especially when these activities do not constitute a significant economic burden that would inhibit the development of similar activities in other areas.

6. Summary

Currently, the trend of supporting local governments in the implementation of low- or zero-emission transport is becoming increasingly visible. Co-financing comes either from central funds or from regional disposers of EU funds. The condition of support is that municipalities or enterprises demonstrate activity and adequate substantive preparation to be able to effectively apply for funds that significantly reduce the cost of purchasing this type of rolling stock. From the perspective of municipalities, this makes zero-emission transport a cheaper alternative to the purchase of conventional vehicles. There is also a gradual increase in awareness of the need to reduce the concentration of harmful substances and factors (e.g., noise, congestion), which especially onerous in heavily urbanized areas. The most important activities in this area include: the replacement of buses by municipalities and related entities or the provision of services for them, the promotion of the use of public transport, a policy of internalizing the external costs of transport at the commune and state level, the freeing of urban space previously occupied by infrastructure for individual motorization, the improvement of the synchronization and comprehensiveness of the urban transport system, and action to reduce congestion in highly urbanized centers.

This optimal effect seems to be achievable when combined with efforts to increase the renewable energy in the energy mix. The involvement of energy companies in the creation of bases and charging stations for public transport, both in terms of CSR image and as a route to a new distribution area, remains an open issue.

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