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Environmental Effects of Electromobility in a Sustainable Urban Public Transport

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Abstract: This article has taken up an issue concerning the influence of the implementation of electromobility assumptions on reduction of air pollution in cities in terms of sustainable urban transport systems. The essential nature of the subject is confirmed by the following figures: transport is responsible for almost 25% of greenhouse gas emissions in Europe and is the main cause of air pollution in cities, almost 90% of city dwellers in the EU are exposed to levels of air pollutants deemed harmful by the WHO, and approximately 95% of vehicles on European roads still use fossil fuels. Therefore, the implemented transport policy, both in the international and domestic aspect of particular countries, is facing the need to significantly reduce the negative influence of transport on people and the environment. Electromobility has become one of the concepts that makes it possible to achieve this goal. Its main objective is to reduce emissions of harmful substances into the environment by deploying electric vehicles (EVs). Research conducted by the authors showed that public transport, apart from the obvious effect of decreased number of private vehicles and decreased congestion, can contribute to reduced air pollutant emissions and become a significant driver for the implementation of electromobility in cities. However, the achievement of this goal depends on taking appropriate actions not only in the transport branch but also in other sectors of economy. The following research methods were applied in the article: literature analysis, documentary method, case study, and mathematical methods. The research area was the city of Szczecin, Poland.

Keywords: electromobility; electric vehicles; EVs; air pollution; transport; public transport; urban transport; sustainable transport; transport management; transportation systems

1. Introduction

Ambient air pollution is the leading environmental health risk factor globally, resulting in nearly 3.5 million premature deaths in 2017 from stroke, ischemic heart disease, chronic obstructive pulmonary disease, lung cancer, lower respiratory infections, and diabetes. The global transportation sector is a major source of this health burden [1]. The European Union and its Member States are taking a number of actions in order to reduce the negative impact of transport on health and the environment.

The European transport sector has achieved significant reductions in the emissions of certain major air pollutants—mainly due to the introduction of emissions standards, financial measures, alternative fuels, and transport avoidance measures [2]. However, emissions from the EU transport sector are not reducing enough to limit its environmental and climate impacts in Europe. Within the last three years, the emission of greenhouse gases from the transport sector has increased; it also remains a major source of emission of particulate matters, nitrogen dioxide, and noise [3].

The issue raised in this article is important and relevant for several reasons. First of all, it concerns the significant problem of air pollution. Air pollution is a health and environmental issue across all countries of the world. It is one of the leading risk factors for death. In 2017, it was responsible for an estimated five million deaths globally. That means it contributed to 9%—nearly one-in-10—deaths. It is also one of the main contributors to global disease burden [4].

Second, it refers to the real problem of the excessive increase in the number of cars in Europe, which is a significant challenge for the authorities at all administration levels. According to the data presented by the European Automobile Manufacturers' Association (ACEA) from the year 2018, the EU counts 511 cars per 1000 inhabitants, and the European Union (EU) passenger car fleet grew by 5.7% over the last five years—the number of vehicles on the road went from 243 to 257 million [5].

Third, the conducted research concerns the means of transport, which constitute a significant part of the transport system of cities and regions. Buses are the most widely used form of public transport in the EU, serving cities and suburban and rural areas. The following data confirm the importance of the role of this mean of transport in the transport systems [6]:

- There are 745,000 buses in operation throughout the EU;
- In the EU, 55.7% of all public transport journeys (or 32.1 billion passenger journeys per year) are made by urban and suburban buses.

Buses are an important link in the multimodal mobility chain. They also constitute a tool for implementation of a sustainable transport policy, and therefore they can and should be a tool for electromobility. The following data confirm the importance of buses in this respect [6]:

- With one bus capable of replacing 30 cars on the road, buses help ease traffic congestion;
- Buses and coaches have the lowest carbon footprint per passenger of any form of motorized transport.

Furthermore, urban buses are specifically identified as a prioritized space for electrification, as these vehicles have predictable routes, allowing for smaller batteries and planned charging infrastructure [7].

The importance of the issue raised herein is also confirmed by data related to use of alternative energy sources in transport. Alternatively powered passenger cars make up only 3.4% of the total EU car fleet [8]. The global population is increasingly concentrating in cities [9]; a similar situation applies to EU countries, including Poland. The increasing number of city dwellers affects the higher number of road vehicles and an increase in the air pollution. Research shows that the generally high level of air pollution in cities constitutes a significant danger to their dwellers [10].

The main purpose of the article was to identify and analyze environmental effects resulting from the implementation of zero-emission buses in urban public transport on the example of the city of Szczecin. In the course of the study, the assumptions were made regarding the type and number of implemented zero-emission vehicles, in accordance with the provisions adopted by the Polish parliament in Act of 11 January 2018 on Electromobility and Alternative Fuels (AEAF) [11]. The area of research was the city of Szczecin, Poland. The research was conducted according to the data as of the end of the year 2018, projected up to the year 2035.

The following research hypotheses were formed for the purpose of the study:

Hypothesis 1 (H1). *Deployment of zero-emission buses in urban public transport is an important tool for reducing air pollution in cities.*

Hypothesis 2 (H2). *Achieving full effects in the field of electromobility in Poland depends on the implementation of activities also in economic sectors, others than transport.*

Hypothesis 3 (H3). *Deployment of zero-emission buses in urban public transport is one of the factors of sustainable urban transport development.*

The rest of this paper is organized as follows. Section 2 includes a review of the literature on the aspects raised in the article. The problem of air pollution is discussed with particular emphasis on urban areas, and the issue of electromobility is introduced. Section 3 describes the research material and indicates the applied methods. It presents a diagram showing the course of research divided into individual stages. Section 4 includes information related to electromobility assumptions in the EU and Poland and legal conditions for the implementation of electromobility, with particular emphasis on requirements stipulated in AEAF. Section 5 was devoted to the characteristics of the research area—the city of Szczecin and the analysis of its transport system, including the analysis of the condition and structure of the bus fleet currently used in public transport in the city. The analysis covered aspects necessary for the calculations carried out in Section 6 and therefore relating to the emission standard. This part of the article also presents the amount of pollution generated by buses deployed in urban transport in Szczecin. Section 6 presents the case study of the city of Szczecin. It presents the research results on the volume of pollutant emissions generated by combustion buses as well as zero-emission buses, projected up to the year 2035, and taking into account the character of the energy management in Poland. For illustration, the results were presented in the form of charts, and the detailed data were presented in the form of the tables. Finally, Section 7 is devoted to the discussion of the produced results and conclusions.

2. Literature Review

Urban transport systems are developing very rapidly. This is due to a very high and still increasing percentage of people living in urban areas. Currently, 55% of the population lives in urban areas [12], and it is estimated that this value will increase and exceed 61% in the year 2030 and 70% in the year 2050 [13]. This results in growing transport needs, both in the area of freight transport (delivery of various types of goods and services) and passenger transport (commuting to work, home, school, health, culture, sport or recreation centers). The increased demand for transport in urban areas and the need to meet the growing requirements of customers in terms of availability, time, and comfort of travel have influence on the growing number of vehicles and intensification of road congestion and road accidents. It also generates vibrations and has the influence of the increased noise and air pollutant emissions—NO_x, CO, CO_2, PM_{10}, $PM_{2.5}$ [14–18]. In this case, it is also important that fossil fuels still play a dominant role in propelling vehicles, which effects the influence of transport on the emission of harmful greenhouse gases and climate change [19,20].

The indicated phenomena have the influence on decreased life quality in cities, exposure of city dwellers to a threat of health loss or even life, and also have a negative influence on the economy [21,22], cutting lives short, increasing medical costs, and reducing productivity through working days lost across the economy [23]. In order to stop this process, as indicated by J. M. Cansino, A. Sánchez-Braza and T. Sanz-Díaz, the H2020 strategy is the most ambitious EU package to date, and it seeks to fight against global warming. It includes a specific 20% target for increasing the share of the renewable energy source (RES), which is up to 20% for the final energy, and reducing GHG emissions up to 20% from the 1990 levels. The European Council extended this objective to 40% by 2030. Without setting an obligatory objective, the White Paper on Transport also established the aim of reducing 60% CO_2 emissions in transportation by 2050 [24].

In order to reduce the negative influence of urban transport on economy, environment as well as human health and life, various activities are being undertaken in the transport sector, both in terms of freight and passenger transport. They relate to various areas, including, i.a. development and promotion of public transport as a solution that attains a more efficient use of road networks and provides a more socially equitable and clean mobility than private vehicles [25], limiting development of private car transport, integration of various means and modes of transport, ensuring a rational division of transport tasks between individual modes of transport, development of new, environmentally friendly, techniques and technologies of transport and delivery, promotion of alternative forms of movement in urban areas, as well as changes in users' behaviors and habits.

With reference to the above and having made an analysis of the solutions described in literature regarding sustainable transport systems in urban areas it is worth indicating the following concepts: car-free zones, low emission zones (LOZs) [26,27], congestion charging [28], electric vehicles (EVs), hydrogen vehicles (HVs), hybrid electric vehicles (HEVs), zero-emission vehicles (ZEVs) [29,30], bike-sharing [31,32], car-sharing, carpooling, Park&Ride, Bike&Ride, Kiss&Ride [33–35], bus rapid transit (BRT), dedicated lanes for buses [36,37], priority for buses [38] and trams, free fare public transport (FFPT) [39], paid parking zones [40], promotion of walking and cycling [41,42], powered two-wheelers (PTWs) [43], electric powered two-wheelers (ePTWs) [44], electric freight vehicles (EFVs), light electric freight vehicles (LEFVs) [45–47], cargo cycles [48,49], loading/unloading bays [50–52], cargo consolidation centers (CCCs) [53], freight consolidation centers (FCCs) [54,55], urban consolidation centers (UCCs) [56], underground logistics system (ULS) [57,58], cargo hitching [59,60], cargo drones [61,62], light rail transit (LRT), light rail system (LRS) [63–65], and light freight railway (LFR) [66,67].

Electromobility in a broad sense is becoming an important solution for building sustainable transport systems in urban areas. Electromobility (e-mobility) occurs more and more often in EU transport policy and individual member states. It is considered to be one of the most important tools in the activities aimed at limiting the negative influence of transport on the environment [68]. Electromobility is becoming a significant alternative for traditional mobility systems, gaining in importance year by year in the whole EU [69,70], and electric vehicles (EVs) appear to be one of the most promising alternative fuel vehicles [71].

Electromobility and EVs may become a key factor of sustainable and environmentally-friendly mobility in the future [72], contributing to the reduction of air pollution and greenhouse gas emissions [73]. Lack of local emissions of air pollution by EVs is particularly important in urban areas because they are characterized by high population density and heavy traffic. It is therefore assumed that e-mobility may become the dominant technology applied in future mobility in urban agglomerations.

An application of electrical power as an alternative power source for vehicles allows for the development of the sustainable mobility concept. This concept aims at reducing the number of combustion engine vehicles, particularly in urban areas, and thus reducing their negative influence on the environment and human health [74].

However, the implementation of e-mobility assumptions has currently a number of obstacles and limitations. They include a limited range of vehicles available on the market and their high purchase price, poor preparation of the power grid, a limited network of vehicle charging stations, the limited distance range of EVs [75,76], and, according to the authors, the fact that the share of renewable energy sources (RES) in the overall balance of power production is too low.

A vital aspect of examining the efficiency of e-mobility turns out to be the appropriate manner of analyzing the impact that electric vehicles exert on the environment. Publications describe the approach based on the analysis of the entire fuel life cycle—the Well-to-Wheel method (WTW) [77].

The WTW method is composed by two distinct methods—Well-to-Tank (WTT) and Tank-to-Wheel (TTW) [78]. Publications also describe the TTW and WTW methods as Pump-to-Wheel (PTW) and Well-to-Pump (WTP) [79–81]. However, such a wide analysis from cradle to grave is hindered due to the necessity of including all the processes connected with extracting raw materials, producing fuel, and the supply chains. Therefore, the analyses are usually limited to the Tank-to-Wheel method (TTW), leaving out the Well-to-Wheel method (WTW).

Keeping the aforementioned in mind, it should be pointed out that EVs appear "clean" because they do not generate emissions when driving. Such a conclusion is most often the result of applying the TTW method [82], which limits the examination of the emission solely to the energy consumption of the vehicle.

It is significant that further development of e-mobility and its objectives will depend on the degree of preparation of the power generation market (electricity producers and distributors). We need to keep in mind that the projected dynamic growth of EVs' share in the transport market will contribute to a dynamic increase in the demand for electricity, which will result in the need to adapt the market to the new requirements of its users. The success of EVs in the future will also be determined by price and reliability of the battery, which may lower the costs of operation and prices of new vehicles.

The decision to purchase an electric vehicle may also depend on subsidies given to producers and consumers, which affect competitiveness of such vehicles [83].

3. Materials and Methods

The research was conducted in several stages.

Stage 1 consisted of the analysis of literature and the documents (strategies, plans, programs, and legal acts) developed at the national and European level in the field of electromobility. As a result, the assumptions and objectives of electromobility in Europe were determined, and the obligations of public transport organizers in cities resulting directly from AEAF provisions were identified.

Stage 2 analyzed the conditions of the transport system in the city of Szczecin from the perspective of the electromobility assumptions (carriers, rolling stock structure). Furthermore, the obligations of the city of Szczecin arising directly from AEAF were identified, and a schedule for the replacement of combustion vehicles with zero-emission buses was developed along with the quota required by AEAF.

Stage 3 covered an estimation of projected growth of pollution emissions (CO_2, NMHC/NMVOC, NO_x, SO_2, PM) generated by buses deployed in public transport in Szczecin. The calculations were made in two options: V0—partial replacement of the vehicle fleet with new buses with EURO 6 diesel engine—and V1—partial replacement of the fleet with zero-emission vehicles. As a result, the outcome was discussed, and the conclusions were made.

The diagram showing the implementation of individual stages of the research is illustrated in Figure 1.

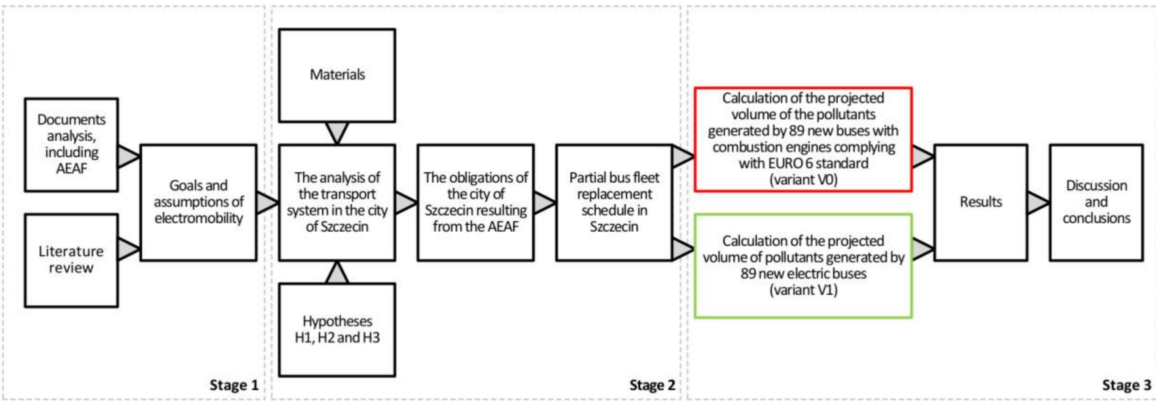

Figure 1. Stages of the research.

The city of Szczecin was a case study for the conducted research. The materials obtained from the following sources constituted the source data for the research:

- Szczecin City Hall;
- Roads and Public Transport Authority in Szczecin;
- Four public bus transport carriers providing transport in the area of Szczecin: SPAK, SPAD, SPPK, and PKS.

Furthermore, in order to calculate the share of zero-emission vehicles in the total bus fleet in Szczecin, it was necessary to take into account the requirements stipulated in AEAF.

The volume of pollutants emitted by combustion and zero-emission buses was calculated using the tool "Calculator of pollutant emissions and climate costs for public means of transport—Excel spreadsheet," developed and made available by the Center for EU Transport Projects (CEUTP) unified for all transport projects in Poland.

4. Electromobility in European and Domestic Documents

The EU policy puts a growing emphasis on the measures that aim at reducing climate change that is harmful to people and the environment. An important role in limiting these changes is played by the activities related to the implementation of an increasingly restrictive EU transport policy. The development of low-carbon and zero-emission transport is one of the priorities of EU environmental policy.

Transport remains very dependent on oil, with oil-derived fuels accounting for 95% of final energy consumption in transport. According to the European Environment Agency data, the transport sector is responsible for generating around 25% of EU greenhouse gas emissions, whilst the transport in cities and urban areas contributes to CO_2 emissions, which constitutes over 25% of the total value generated by transport in general. Furthermore, more than 40% of emissions of nitrogen oxides and almost 40% of primary $PM_{2.5}$ emissions come from road transport [84].

The main ecological problems in cities were identified in the Green Paper "Towards a new culture for urban mobility" from 2007 [85]. It was found that they result from the advantage of using diesel oil as the main fuel used in transport, which in turn results in CO_2 emissions and leads to air pollution and excessive noise. According to the Green Paper, transport is one of the most difficult sectors in terms of ability to control CO_2 emissions. Despite technological progress in the automotive field, an increase in traffic volume as well as driving manners and driving flow in urban areas (frequent starts and stops of vehicle) are a crucial and still growing source of CO_2 emissions that affect climate change. Consequently, climate change causes dramatic disruptions in the global ecosystem. This requires effective action to be undertaken in order to reduce these disruptions. In this aspect, it was stated that the EU should promote and co-finance the expansion, renovation, and modernization of clean urban public transport, i.e. trolleybuses, trams, underground and commuter rail, and other sustainable urban transport projects [85].

In accordance with the White Paper guidelines from 2011, transport must be sustainable in the light of the new challenges [86]. Unfortunately, the continuous dependence on oil derivatives and the dynamic growth of demand for transport services in urban and agglomeration areas have and may continue to have a negative influence on the economy and the environment. In relation to this problem, among 10 objectives adopted in the White Paper for the benefit of creation of a competitive and resource- efficient transport system, the first and foremost objective was to halve the number of cars with conventional drives in urban transport by 2030 and to get rid of cars in cities by 2050. Such provisions are particularly important as far as the transport policy at a national and regional level is concerned, the assumptions of which should comply with the guidelines accepted on the international stage.

The development of "A European Strategy for Low-Emission Mobility" [87] was a further elaboration of the courses of action adopted by the EU in the field of reducing the negative influence of transport on people and the environment. It lists the following key courses of action for the issues raised in this article: more efficient transport system, low-emission alternative energy sources for transport, and low-emission and zero-emission vehicles. As observed in the document, the success of the strategy will, to a large extent, depend on the actions taken by cities and local authorities, whereby it needs to be noted that cities are the leaders in switching into low-carbon mobility, even now [87].

On the basis of global statistics regarding the growth rate of electric vehicles and bearing in mind the EU requirements for improving air quality, Poland has prepared an Electromobility Development Program. It is the result of EU activities aimed at promoting electromobility and alternative fuels in the countries of the Community. As part of the Electromobility Development Program, a regulatory package was created that consists of the following strategic documents [88]:

- Electromobility Development Plan in Poland "Energy for the Future", a document adopted by Polish government on 16 March 2017 specifies the benefits related to promotion of use of electric cars in Poland and identifies the economic and industrial potential of the country;

- The national policy framework for the development of infrastructure for alternative fuels, a document adopted by Polish government on 29 March 2017 implements European regulations regarding, i.a. conditions of the infrastructure development for alternative fuels in 32 Polish agglomerations;
- Act of 11 January 2018 on electromobility and alternative fuels (AEAF), tasked to stimulate the growth of electromobility and promotion of other alternative fuels (i.a. LNG i CNG) in the transport system in Poland;
- Act of 6 June 2018 establishing a low-emission transport fund, tasked to finance the projects related to growth of electromobility as well as the transport based on alternative fuels.

With respect to the research problem undertaken in this article, it is important to note that the condition for the success of electromobility development is to create the grounds for the electromobility ecosystem, but also to coordinate activities in the field of electromobility industry development and stimulate the demand for electric vehicles. Furthermore, a model role of the administration is a key factor in implementation of this process [88]. Therefore, the activities carried out by central and local authorities in implementation of zero-emission vehicles in public transport are designed not only to have a direct influence on the improvement of environmental conditions but also to initiate actions and popularize involvement in a low- and zero-emission economy.

In relation to the research, the AEAF provisions are particularly significant in Poland. It is an important legislative part in the area of changes proposed by the EU on the market of car transport services, which is aimed at limiting the negative environmental effects of this mode of transport. It particularly refers to the public transport services provided by this mode of transport.

AEAF clarified the concept of "zero-emission bus." On the basis of the general definition of the term "bus," according to which it is "a motor vehicle designed to carry more than 9 people including the driver" [89], the term was limited only to vehicles that meet strictly specified technical parameters. Therefore, these are the only vehicles that use the following [11]:

- Electricity generated from hydrogen fuel cells; or
- An engine with a life cycle of which does not lead to greenhouse gas emissions or other substances covered by the greenhouse gas emissions management system.

According to AEAF, the scope of the "zero-emission bus" concept excludes vehicles with a diesel engine, which have constituted the majority in the fleets of public transport carriers so far, and vehicles that supplement their fleet more and more often—vehicles with CNG drive or hybrid vehicles.

AEAF imposed a number of new obligations on local government units (LGU). According to its provisions, LGU is required, among others, to: [11]:

- Ensure the share of electric vehicles in the government unit's own fleet in an amount equal to or greater than 30% of the total number of vehicles used by the government unit;
- Perform public tasks (excluding public transport) using electric or gas-powered vehicles, the number of which equals to or is greater than 30% of all the vehicles used for this purpose or commission another entity to perform public tasks (excluding public transport), the fleet of which constitutes electric or gas-powered vehicles in an amount equal to or greater than 30% of all the vehicles used for this purpose;
- Provide or commission to provide urban public transport to an entity whose share of zero-emission buses in the fleet of vehicles used in the local government unit area amounts to 30% or more.

AEAF assumed a gradual increase of zero-emission buses in the overall structure of the rolling stock used in public transport so as to obtain the respective shares [11]:

- 5% from 1 January 2021;
- 10% from 1 January 2023;
- 20% from 1 January 2025;
- 30% from 1 January 2028.

The importance of the problems related to environmental pollution was also observed in the legal acts at the regional level. The sustainable development plan for public transport, adopted for the West Pomeranian Voivodeship, indicates that it is necessary to aim at reducing the volume of gases and solid particles emitted by transport. Therefore, support of the solutions in the field of transport organization and technology is planned to reduce the production of pollution. Among others, the modernization process of the line infrastructure condition in accordance with ecological requirements as well as the activities aimed at adapting the rolling stock to standards meeting the environmental protection conditions are of crucial importance [90]. Thus, these provisions are in line with the guidelines adopted at national and European level.

5. Public Transport System of the City of Szczecin—the Condition Analysis From the Perspective of the Guidelines and Aims of Electromobility

The research, as part of this article, was conducted in the city of Szczecin, situated in the north-western part of Poland at the mouth of the Odra River (through the Szczecin Lagoon) debouching to the Baltic Sea and located on Dąbie Lake. Szczecin is the capital of the West Pomeranian Voivodeship and the largest urban center of the region. It is also the center of the Szczecin Metropolitan Area (SMA). The area of the city is 301 km^2, thus ranking third in the country. The population of Szczecin amounted to 403,274 people as of 30 June 2018 [91].

The public transport system in the city of Szczecin comprises two subsystems—bus and tram transport. The Roads and Public Transport Authority (Zarząd Dróg i Transportu Miejskiego, ZDiTM) is a public transport organizer on behalf of the city of Szczecin. As part of public transport in the city, transport services are provided on the basis of the agreements concluded between ZDiTM and the following five carriers:

- Szczecin Bus Company "Klonowica" Ltd. (Szczecińskie Przedsiębiorstwo Autobusowe "Klonowica" Sp. z o.o., SPAK)—within the scope of regular bus transport;
- Szczecin Bus Company "Dąbie" Ltd. (Szczecińskie Przedsiębiorstwo Autobusowe "Dąbie" Sp. z o.o., SPAD)—within the scope of regular bus transport;
- Szczecin-Police Comunication Company Ltd. (Szczecińsko-Polickie Przedsiębiorstwo Komunikacyjne Sp. z o.o., SPPK)—within the scope of regular bus transport;
- Automobile Communication Company in Szczecin Ltd. (Przedsiębiorstwo Komunikacji Samochodowej w Szczecinie Sp. z o.o., PKS)—within the scope of regular bus transport;
- Szczecin Trams Ltd. (Tramwaje Szczecińskie Sp. z o.o., TS)—within the scope of regular tram transport.

According to the data from 2018, the public transport in Szczecin provided passenger services with the help of the following lines [92]:

- 12 daytime normal tram lines;
- 57 daytime normal bus lines;
- 3 daytime normal bus lines— transport on demand;
- 6 daytime fast bus lines;
- 16 night bus lines.

With reference to the issue raised in this article, it is worth emphasizing that the current document, entitled "The Plan for Sustainable Development of Public Transport for the City of Szczecin for the Years 2014–2025" indicated that it is a tram with a supporting bus network that is and will remain the basic means of public transport in the city. Furthermore, it was pointed out that traffic priority in the city center would be given to tram communication, and the means of transport would be combined by integrated transfer nodes [93]. Such provisions show that the transport policy implemented by the city assumes that the transport system will be environmentally friendly, performing transfers with use of electric vehicles, which gives the opportunity to implement the principles of sustainable development and sustainable mobility.

It is also worth pointing out that the investment project entitled Szczecin Metropolitan Railway (SMR) was commenced in 2018 in SMA. SMR is to be the main axis of public transport in a sustainable transport system in SMA. SMR will operate on the existing rail network in the region, which will be renovated or rebuilt to a large extent.

According to the assumptions adopted in the project, regional and local bus transport as well as municipal bus and tram transport in the city of Szczecin alone will perform the function of passenger pick-up/drop-off for SMR. Rail means of transport operating on SMR lines will be electric vehicles. As far as the transport system of the city of Szczecin is concerned, it is important that 26 SMR stops (out of all 40 stops) will be located within the boundaries of Szczecin. Such a number of stops will create an opportunity for SMR to play not only the role of metropolitan railway but also the role of urban railway. This means that the transport system in the city will be extended, giving passengers the opportunity to also commute within the city by rail. The investment is scheduled to be completed in the year 2022 [94]. The authors of this article are the authors of SMR concept as well as the design team members preparing the Feasibility Study for SMR.

With respect to the problem raised in this article, the condition of the bus fleet used in urban public transport in Szczecin was analyzed. The total number of vehicles used by all four carriers in the year 2018 amounted to 296 buses: SPAD—104, SPAK—102, SPPK—58 and PKS—32 buses, respectively. The vehicles were diesel engines buses, powered by diesel fuel. The structure of the rolling stock according to the EURO pollution standard was presented in Table 1. According to the data in Table 1, the buses used in public transport in Szczecin belong to all emission standard groups, ranging from EURO 1 to EURO 6. What is particularly disturbing, the buses with the highest standard—EURO 6—constituted only slightly over 16% of the entire fleet, and buses from the three lowest groups (EURO 1, 2 and 3) constituted almost 33% of the total fleet.

Table 1. The structure of the bus rolling stock in the public transport in Szczecin according to the EURO emission standard (2018).

Euro Emissions Standards	Number of Buses [pcs.]	Share [%]
EURO 1	4	1.35
EURO 2	7	2.37
EURO 3	86	29.05
EURO 4	33	11.15
EURO 5	117	39.53
EURO 6	49	16.55
IN TOTAL	**296**	**100.00**

During the course of the research, the amount of pollution generated by the buses used in public transport in Szczecin was calculated. The summary of the results was presented in Table 2. The data show that the problem related to pollution generation by public transport is relevant for the city of Szczecin. In order to reduce the emission of harmful substances and increase the quality of life for the city dwellers, including the protection of their health, and following the AEAF provisions, the city must take measures to replace the bus fleet with vehicles that have a less negative influence on the environment and people. Section 6 presented the results of the conducted research taking into account two options for the city: partial replacement of the fleet with vehicles that currently comply with the highest emission standard EURO 6 (V0) or partial replacement of the fleet with electric vehicles and the environmental effects resulting therefrom (V1).

Table 2. The amount of pollutant emission generated by the buses used in public transport in Szczecin in 2018.

Carrier	Number of Vehicles [pcs.]	Transport Activity in 2018 [Vehicle Kilometers Travelled]	Amount of Pollutant Emission in 2018 [Tonnes]				
			NMHC/NMVOC	NO_x	PM	SO_2	CO_2
SPAK	**102**	6,305,344	16.58	93.56	1.316	0	8,631.24
SPAD	104	7,381,005	13.86	74.65	1.082	0	8,688.97
SPPK	58	2,275,568	3.15	16.43	0.268	0	2,331.96
PKS Szczecin	32	1,458,418	4.17	30.55	0.603	0	1,562.20
IN TOTAL	**296**	**17,420,335**	**37.76**	**215.19**	**3.269**	**0**	**21,214.37**

6. Study of the Effect of Replacement of Bus Fleet With Electric Vehicles on the Reduction of Air Pollutants in the City of Szczecin

The aim of the research conducted by the authors was to identify and analyze the environmental effects resulting from the deployment of zero-emission buses in urban public transport on the example of the city of Szczecin. The research took into account the AEAF requirements related to the necessity of gradual partial replacement of vehicles operated by the city with zero-emission- electric vehicles.

The research was conducted in the form of a comparative analysis, which assessed the effects of partial replacement (in accordance with AEAF) of the operated fleet powered by standard combustion engines with electric vehicles (investment option—V1). This was compared with the effects of replacement of vehicles with diesel buses that currently have the most restrictive standard—EURO 6 (replacement variant—V0).

On the basis of AEAF stipulations and analysis of the structure of rolling stock operating in Szczecin (data for 2018), the share of zero-emission vehicles required by AEAF in the overall bus fleet of the city of Szczecin was calculated, together with an indication of the purchase schedule.

Further to the above, the following was assumed for the city of Szczecin:

- a total of 89 vehicles will be the subject of the replacement (i.e. 30% x 296, where 296 means a number of the operated vehicles in Szczecin in 2018),
- deployment of new vehicles will be gradual: year 2021—15 buses, year 2023—15 buses, year 2025—30 buses and year 2028—29 buses, respectively (a total of 89 buses).

In order for the vehicles to be deployed from 1 January of a given year, they should be purchased each time until the end of the preceding further stage stipulated in AEAF.

The underlying assumptions were presented in Figure 2.

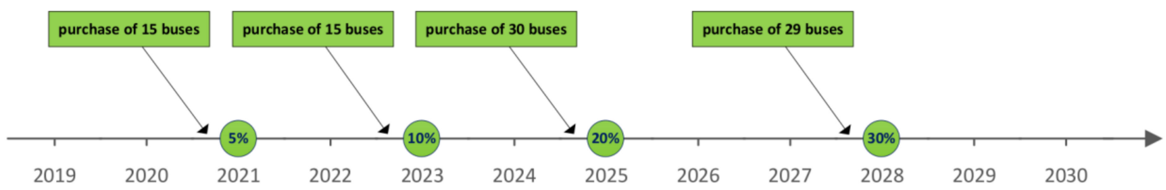

Figure 2. The purchase volume of electric buses in Szczecin in accordance with Act of 11 January 2018 on Electromobility and Alternative Fuels (AEAF).

During the course of the research, it was agreed that, under the AEAF requirement out of four companies providing bus transport services in the city of Szczecin, the subject of a replacement will be the vehicles of two companies (SPAK and SPAD) only. This assumption results, i.a., from the scope of transport work performed by the indicated companies as well as the course of individual bus lines. Zero-emission buses should be primarily used in the core area of the city center or other densely populated and built up housing estates. The other two carriers operate mainly in a suburban area or provide services on night bus lines and bus lines on demand.

It was also assumed that only two categories of vehicles would be purchased:

- MAXI buses—vehicles 10.5–13 m long;

- MEGA buses—vehicles 13 m long or longer.

The adopted assumptions related to the vehicle replacement schedule and the allocation of a specific number and type to a given carrier were presented in Table 3.

Table 3. Purchase schedule of electric buses in Szczecin in accordance with the AEAF.

Year	Requirements of the AEAF [%]	Requirements of the AEAF [pcs.]	Purchase Volume [pcs.]	SPAK		SPAD	
				MAXI Buses	MEGA Buses	MAXI Buses	MEGA Buses
2020			15	15			
2021	5%	15					
2022			15	5	10		
2023	10%	30					
2024			30	9	9	12	
2025	20%	60					
2026							
2027			29	6		13	10
2028	30%	89					

In order to determine the potential benefits of gradual partial replacement of the vehicles operated by the city with zero-emission electric vehicles, which was stipulated by AEAF, the assumptions for the research specified projected annual transport performance for new vehicles. It was assumed that this value will correspond to the average transport performance achieved per one vehicle in particular companies according to data for 2018. It amounted to

- 59,994 km a year—in SPAK;
- 69,491 km a year—in SPAD, respectively.

In order to calculate and compare the projected amount of pollutant emissions, it was also necessary to determine the fuel demand for the vehicles with combustion engines (variant V0) and electrical power for electric vehicles (variant V1). The values for fuel demand for the combustion engine vehicles were adopted according to the average data from the bus carriers in Szczecin for 2018; whilst declarations of the rolling stock manufacturers and experiences of Polish cities that have already deployed zero-emission rolling stock were used to estimate the value of electricity consumption (Warszawa, Kraków, Jaworzyna, Tarnów).

In light of the above,

- Power consumption for MAXI electric buses was estimated at the level of 125 kWh/100 km;
- Power consumption for MEGA electric buses was estimated at the level of 150 kWh/100 km;
- Fuel consumption for MAXI diesel buses was estimated at the level of 37.5 l/100 km;
- Fuel consumption for MEGA diesel buses was estimated at the level of 47.2 l/100 km.

The projected emissions of CO_2 as well as other harmful substances (NHMC/NMVOC, NO_x, PM and SO_2) were calculated with use of the "Calculator of pollutant emissions and climate costs for public transport—Excel spreadsheet" provided by CEUTP.

Following CEUTP, the projected pollutant emissions for diesel buses (variant V0) were calculated as follows:

- Burning a liter of diesel oil generated 2.68 kg of CO_2;
- In accordance with Regulation (EC) No 595/2009 [95] for the Euro 6 standard the emission factors of other harmful substances (NHMC/ NMVOC, NO_x, PM) amounted to: NHMC/ NMVOC—0.13 g/kWh, NO_x—0.4 g/kWh, PM—0.01 g/kWh, respectively;
- Diesel energy value amounted to 10 kWh/l.

In the case of electric buses (variant V1), the reference was made to the structure of electrical power production in Poland. In the case of this research the projected amount of pollutant emissions was calculated according to CEUTP, taking into account that

- CO_2 emission factor amounted to 846g/kWh;
- Emission factors of other harmful substances (NHMC/NMVOC, NO_x, PM, SO_2) amounted to: NHMC/NMVOC—0.01 g/kWh, NO_x—1.09 g/kWh, PM—0.03 g/kWh, SO_2—2.63 g/kWh, respectively.

This approach made it possible to calculate the emission of pollution which also considered the emission generated outside the vehicle, eliminating the aforementioned limitations of the TTW method.

The calculations were made in accordance with AEAF requirements relying in gradual increase of zero-emission buses in the total number of rolling stock. To assess the possible environmental effects of fleet replacement, the research was conducted in the form of a comparative analysis with a reference to purchase of electric vehicles (variant V1) as well as purchase of combustion engine vehicles complying with EURO 6 standard (variant V0), as an alternative.

The calculation results of the projected emission of CO_2, NHMC/ NMVOC, NO_x, PM and SO_2 were presented in Figures 3–7 in two options:

- Variant V1—(marked in green) concerned the emission of pollutants generated by zero-emission electric buses;
- Variant V0—(marked in red) concerned the emission of pollutants generated by combustion engine buses.

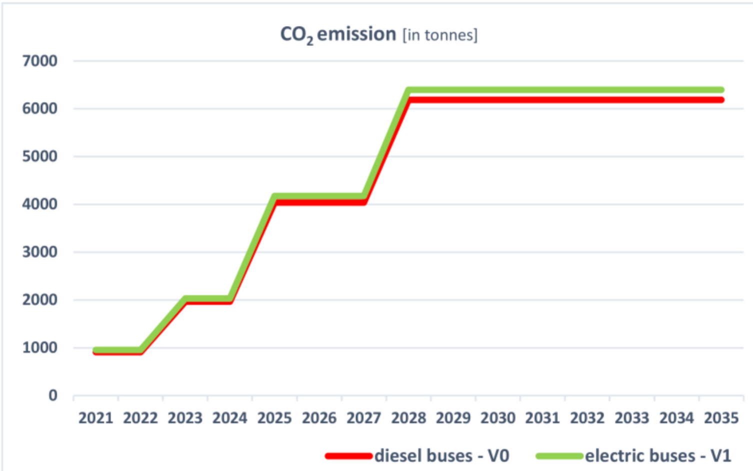

Figure 3. Projected amount of CO_2 emission resulting from purchase and maintenance of diesel (variant V0) and electric (variant V1) buses in Szczecin in the years 2021–2035.

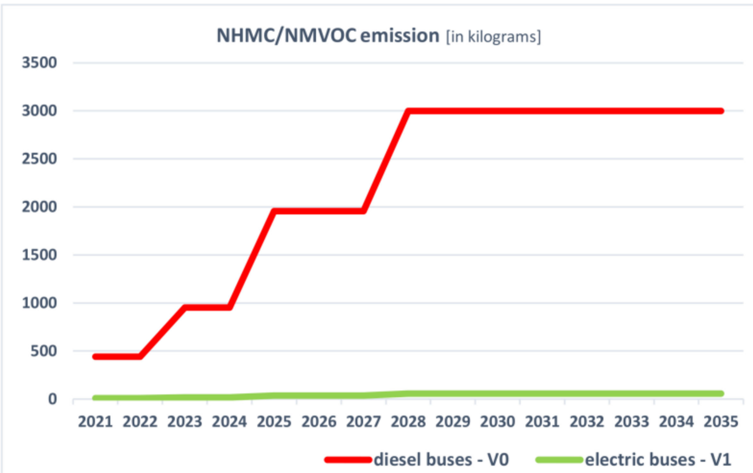

Figure 4. Projected amount of NHMC/NMVOC emission resulting from purchase and maintenance of diesel (variant V0) and electric (variant V1) buses in Szczecin in the years 2021–2035.

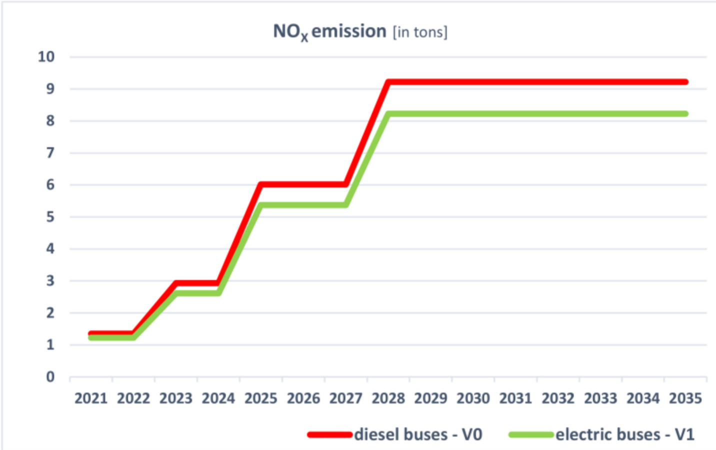

Figure 5. Projected amount of NO_x emission resulting from purchase and maintenance of diesel (variant V0) and electric (variant V1) buses in Szczecin in the years 2021–2035.

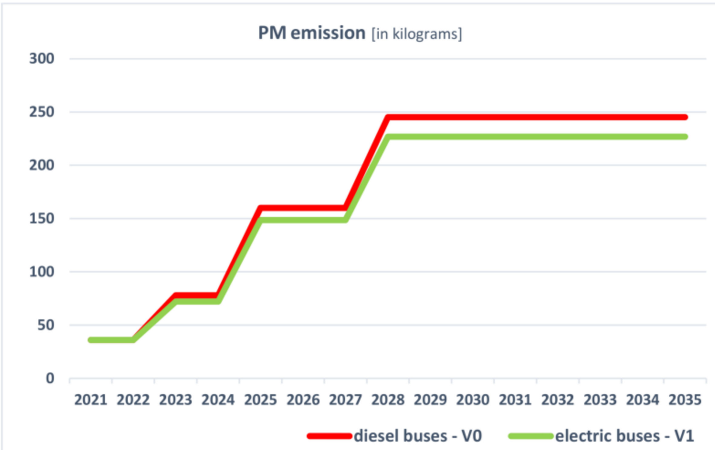

Figure 6. Projected amount of PM emission resulting from purchase and maintenance of diesel (variant V0) and electric (variant V1) buses in Szczecin in the years 2021–2035.

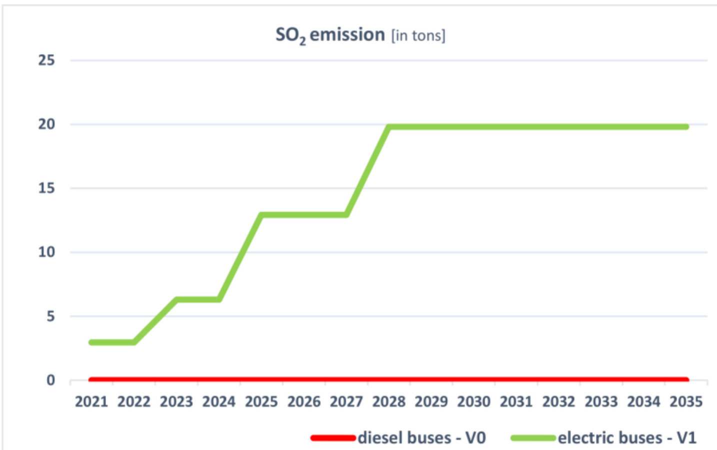

Figure 7. Projected amount of SO_2 emission resulting from purchase and maintenance of diesel (variant V0) and electric (variant V1) buses in Szczecin in the years 2021–2035.

The calculations presented in Figures 3–7 were made taking into account the gradual purchase of subsequent vehicles (to be purchased in 2021, 2023, 2025, and 2028) and hence the increased transport performance in subsequent years and they apply to new vehicles.

The analysis of the results is as follows:

- Projected CO_2 emission—annual emission was estimated at approximately 6187 tons for variant V0 and approximately 6391 tons for variant V1 starting from year 2028 (purchase of the last part of the buses in accordance with the AEAF requirements).

  Purchase and maintenance of electric buses (variant V1) can lead to an increase of overall CO_2 emission by over 200 tons per year, in comparison to purchase and maintenance of vehicles in accordance with variant V0. This situation results from the structure of electrical power production in Poland.
- Projected NHMC/ NMVOC emission—annual emission was estimated at approximately 2999 tons for variant V0 and approximately 57 tons for variant V1, starting from year 2028.

  Purchase and maintenance of electric buses (variant V1) can lead to a significant decrease by more than 50 times in the annual NHMC/ NMVOC emission, in comparison to purchase and maintenance of vehicles in accordance with variant V0.
- Projected NO_x emission—annual emission was estimated at approximately 9.2 tons for variant V0 and approximately 8.2 tons for variant V1, starting from year 2028.

  The purchase and maintenance of electric buses (variant V1) may result in a decrease in overall NO_x emission by approximately one ton per year, in comparison to purchase and maintenance of vehicles in accordance with variant V0.
- Projected PM emission—annual emission was estimated at approximately 245 kilograms for variant V0 and approximately 227 kilograms for variant V1, starting from year 2028.

  Purchase and maintenance of electric buses (variant V1) may result in a decrease in overall PM emission by approximately 18 kilograms per year, in comparison to purchase and operation of vehicles in accordance with variant V0.
- Projected SO_2 emission—annual emissions were estimated at 227 kilograms for the purchase and maintenance of electric vehicles (variant V1), starting from year 2028. SO_2 emission does not occur with combustion engine vehicles.

These findings, in particular a significant amount of emission of harmful substances observed during the maintenance of electric buses (V1), are directly related to the structure of electrical power production in Poland. In 2018, almost 80% of electrical power produced in Poland came from the coal power plants, and only less than 13% came from renewable energy sources (RES) [96]; the details were presented in Figure 8. Having drawn the conclusions, this fact requires consideration of harmful emissions generated in the process of burning coal in the power plants and thus affects the volume of emissions on a national scale.

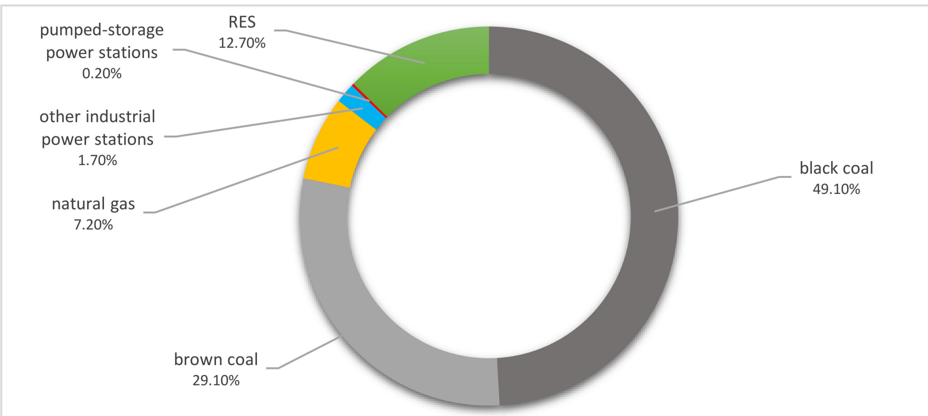

Figure 8. Structure of electrical power production in Poland in 2018 [96].

It needs to be emphasized that the amounts of pollutants estimated during the comparative analysis regarding the grounds for the introduction of variants V0 and V1 will be observed in different locations. In the case of maintenance of combustion engine vehicles (V0), the projected emission of pollutants will directly concern the place where the vehicles will be used—namely, the city of Szczecin. Projected emission of pollutants resulting from the maintenance of electric buses (V1) will have a different location. Taking into account the abovementioned structure of electrical power production in Poland, it can be pointed out that in the case of variant V1, the emission of pollutants will not directly concern the place where the vehicles will be used—the city of Szczecin. It will concern the places where the electrical power necessary to set the vehicles in motion is produced—areas where the power plants are located. In this case, it comes down to a phenomenon that can be described as the process of "geographical shift of emissions." The aforementioned phenomenon was illustrated in Figure 9.

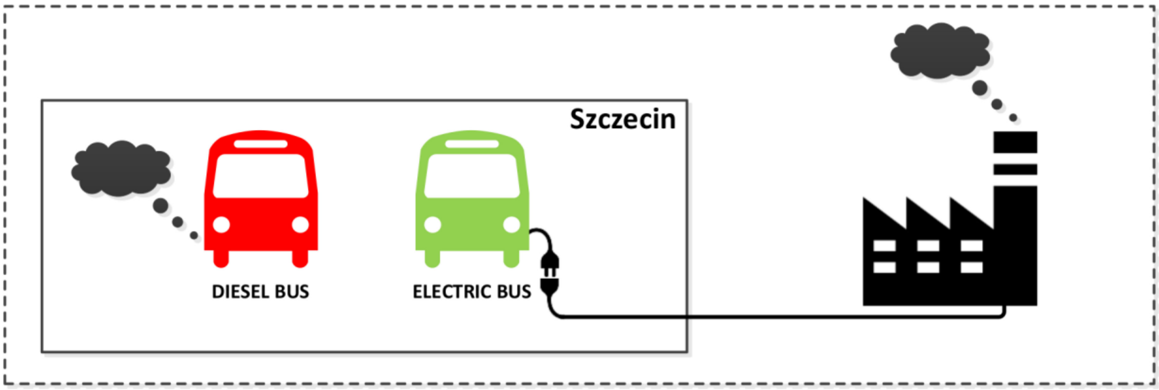

Figure 9. Geographical shift of pollutant emission during maintenance of electrical buses in Szczecin.

Therefore, it can be indicated that, in the case when electrical power is predominantly produced from fossil fuels (black coal, brown coal), electric buses can be considered as zero-emission vehicles, bearing in mind the zero-emission concept they primarily refer to the place where they are used.

Having considered the results of the tests presented in Figures 3–7,

- The projected emission resulting from the implementation of variant V0 will concern linear emission in the city area;
- The projected emission resulting from the implementation of variant V1 will concern the "geographical shift of emission."

It can be concluded that replacement of combustion engine vehicles with electric ones (in accordance with the AEAF requirements) is justified for the given location, where the vehicles are planned to be used. Therefore, deployment and maintenance of such vehicles (instead of combustion engine vehicles) in urban areas help to decrease a linear emission of dangerous substances for the environment as well as the health and life of people. This fact supports our H1 hypothesis, assuming that "the deployment of zero-emission buses in urban public transport is an important tool for reducing air pollution in cities." The indicated reduction is particularly important in the cities, because it is the cities that are mainly facing the real threat arising from air pollution.

The effects of introducing electric buses on a national scale can be analyzed in a different way. The current energy mix in Poland (Figure 8) significantly limits the range of achievable electromobility effects. Therefore, further development of electromobility should be related with complementary activities in other sectors of the economy, e.g. increasing the share of renewable energy sources (RES) in the overall production. This supports our H2 hypothesis, which assumes that "achieving full effects in the field of electromobility in Poland depends on the implementation of activities also in economic sectors, others than transport."

7. Discussion and Conclusions

Contemporary transport can be considered as

- An economic development generator;
- A factor ensuring territorial and social bonds;
- A tool allowing for commercial exchange.

Therefore, it is difficult to imagine a contemporary, well-developed local or supraregional economy without a developed transport infrastructure and a network of passenger and freight connections. On the other hand, transport has a negative influence on natural environment and human health. Air pollution has an influence on global warming, noise, or demand for ground. As a result, the transport sector is constantly looking for new solutions that will be able to reduce its negative influence on the environment.

Electromobility is one of the solutions aimed at reducing transport-related nuisance. It assumes reduction of pollution by deploying zero-emission vehicles. Such a solution can significantly improve the quality of human life, especially in highly urbanized areas where the demand for people and cargo transport- related services is particularly high.

The research conducted by the authors was aimed at identifying and analyzing the environmental effects resulting from the deployment of zero-emission buses in urban public transport. The research was performed on the example of the city of Szczecin, in two options: variant V1—purchase of electric buses in accordance with the AEAF recommendations—and variant V0—purchase of diesel buses complying with the EURO 6 pollution standard. The calculations and analyses showed that certain conditions (influence of exogenous factors) may result in a situation, in which use of electric buses may influence the emission of harmful substances (including CO_2 and SO_2) on a national scale. This situation is directly related to the structure of electrical power production in a given economy, i.e., Poland in our case. Electrical power production based predominantly on fossil fuels may impede the achievement of the assumed effects of electromobility to the full extent, limiting them primarily to geographical shift of the pollution from urban areas to other areas. Geographical shift is obviously desired by cities, as it directly influences the reduction of pollution in their area. However, it does not solve air pollution problems from a global perspective. Most sources of outdoor air pollution are well beyond the control and demands concerted action by local, regional, and national level policy makers working in sectors like transport, energy, waste management, urban planning, and agriculture [97].

Having analyzed the research conducted in the city of Szczecin, the importance of the decisions made and the actions undertaken to pursue the sustainable urban transport system needs to be emphasized. Taking into account the fact that an electric motor does not emit any pollution in the place where it is operational, it needs to be noted that the current urban transport system in Szczecin complies to a large extent with the requirements related to the environment protection, stipulated at the European and national levels. The city has an operational tram line, based on electric vehicles, which is still being developed, a city bike network, systems of electric scooters and mopeds are being implemented, and SMR is to be launched in the year 2022, which will also use electric vehicles. Therefore, the last subsystem in the public transport in the city of Szczecin, which requires specified actions to adjust the system to meet the environmental requirements is the bus transport.

As far as electromobility assumptions are concerned the analysis of the rolling stock condition showed its unfavorable structure. Seeking to create a fully sustainable public transport system, the city must decide on the replacement of the bus fleet. Therefore, depending on the type of transport to be deployed (diesel buses or electric buses) the system will remain unchanged (item 1 in Figure 10) or will be heading towards its sustainability (item 2 in Figure 10). Therefore, supporting our H3 hypothesis, it needs to be stated that "the deployment of zero-emission buses in urban public transport is one of the factors of sustainable urban transport development."

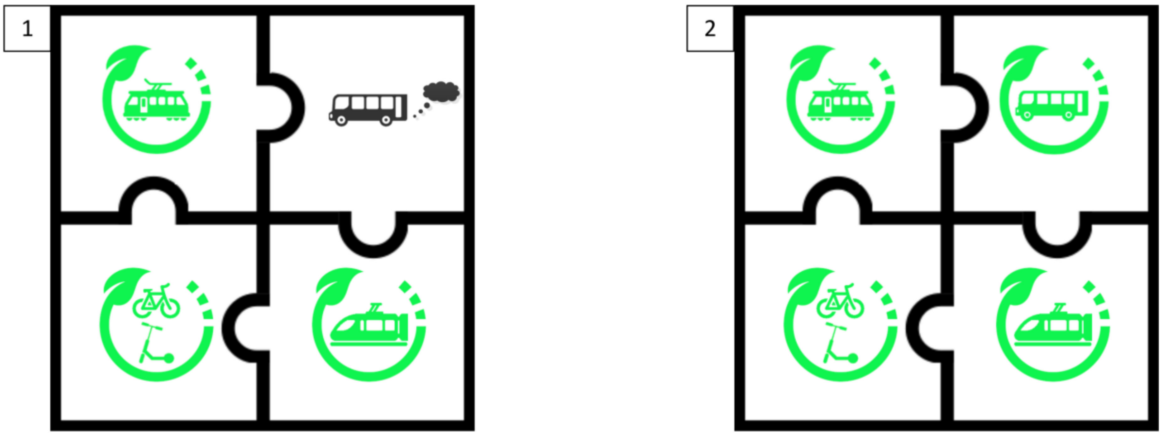

Figure 10. (**1**) A mixed urban public transport in Szczecin: (**2**) A sustainable urban public transport in Szczecin.

The problem of emission of harmful substances and thus environmental pollution relates to most cities in Poland. It can be concluded that the decisions concerning replacement of the bus fleet with electric vehicles made by particular cities will reduce pollution in urban areas but increase the geographical shift of pollution. It is therefore necessary to conduct simultaneous activities in search of and use of alternative energy sources.

Electric drives are more efficient, and if sustainable and renewable energy sources and electricity production methods are used, operating an electric vehicle can be completely emission-free and climate-neutral [68]. Such an approach will allow for the implementation of electromobility goals not only on the local scale but on the national and global scale as well.

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