

ECO-INNOVATIVE SOLUTIONS IN THE OPERATION OF MUNICIPAL TRANSPORT COMPANY SP. Z O.O. IN ZIELONA GÓRA

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Purpose: The purpose of this article is to present implemented innovative investments and changes in management forms in Municipal Transport Company Sp. z o. o. in Zielona Góra (hereinafter: MZK). These changes contributed to improving the operation of the company and providing services at a global level from the point of view of low-emission public transport and the concept of sustainable development.

Design/methodology/approach: The presented innovations are implemented investments and management changes that operate in MZK in Zielona Góra and bring measurable economic, ecological and social benefits. The co-authors of the article are employees of MZK and students of the Faculty of Economics and Management of the University of Zielona Góra. The research methods used in the article are the analysis of the company documents and a review of the subject literature in the field of: eco-innovation, communication services, electromobility, management and ecology.

Findings: Based on the analysis of documents and implemented investments, ecological, economic and social benefits were identified that MZK in Zielona Góra can boast of. Currently, it is the most innovative public transport company in Poland in terms of sustainable development and electromobility.

Research limitations/implications: Analysis of the company's documents allows us to show the benefits that innovations bring to passengers, the company and the environment. They indicate directions for further changes in order to provide even better service quality and company management.

Practical implications: The described innovative investments and implemented organizational changes in MZK make it possible to provide other plants in the industry with an incentive to take specific actions towards sustainable development and, as a result, to achieve such good results and satisfied customers as the company in question has.

Originality/value: MZK in Zielona Góra is currently the most modern enterprise in Poland, whose fleet consists mainly of electric buses. Innovative solutions were initiated through the implementation of the project entitled: 'Integrated system of low-emission public transport in Zielona Góra' in 2014-2020.

Keywords: electric buses, improving the quality of transport services, optimization of the transport offer, electricity and energy infrastructure, low-emission transport, supporting software.

Category of the paper: research work, case study.

1. Introduction

Transport has always accompanied man. At first, goods were carried on the backs of porters, then on carts, and as progress progressed - by rail, cars, ships or planes. The development of cities also contributed to the development of transport, and it was no longer about moving goods only from city to city, but also moving people and goods within cities (transport within the so-called 'juggernaut' cities is particularly problematic). Although transport needs are secondary human needs, giving up transport, despite the large amount of pollution produced, is not taken into account. In Europe, actions are being taken to introduce sustainable transport and pro-ecological transport solutions. Many of them are intended to improve transport traffic, reduce CO₂ emissions, reduce noise and vibration, switch to zero-emission cars, and in cities (especially large ones) increase clean transport zones and move away from combustion cars in favour of public transport. Brzeziński and Rezwow (2007, pp. 7-25) list such activities limiting the impact of transport in the city, distinguishing: 'traffic zoning (limiting car traffic depending on the density of buildings and the availability of public transport), development of public transport and providing passengers with the possibility of connecting several transport subsystems during one trip (e.g. bus, tram, scooter)'. In addition, various types of initiatives are undertaken to promote public transport, bicycle transport and carsharing (car rental services for minutes) and carpooling (sharing places in cars, e.g. using the Blablacar application) (Szpilko, Godlewska, 2020, pp. 133-134).

In accordance with the European Union's climate policy regarding the reduction of greenhouse gas emissions, the European Green Deal, the UN Action Program for Sustainable Development until 2030, the Paris Agreement of 2015 and other declarations, it is assumed that the country will strive to achieve climate neutrality in 2050. These documents emphasize the need to limit global warming to 1.5°C above pre-industrial levels and to prevent massive loss of biodiversity. According to the ESPAS report 'Global Trends to 2030: Challenges and Choices for Europe' (ESPAS, 2019), a temperature increase of 1.5°C is the maximum that the Earth can withstand, bearing in mind that if temperatures continue to rise after 2030, humanity will face even more droughts, floods, extreme heat, as well as the poverty of hundreds of millions of people and the probable destruction of the population groups most exposed to these phenomena. Therefore, action at global, European, national, regional and local levels is very important. One of such activities is the development of electromobility, which has been recognized as an effective tool for decarbonizing the transport sector and achieving climate goals (*Polityka spójności...*, 2021).

The development and promotion of the idea of introducing electromobility in the European Union were a consequence of the provisions of documents such as: from 2019 - Directive (EU) 2019/1161 of the European Parliament and of the Council of 20 June 2019 amending Directive 2009/33/EC on the promotion of clean and energy-efficient road transport vehicles, from 2010 – ‘Europe 2020 strategy: Strategy for smart, sustainable and inclusive growth’ (COM/2010/2020 final), from 2011 – ‘WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system’ (COM/2011/0144 final). The White Paper calls for a 60% reduction in greenhouse gas emissions from transport by 2050 compared to 1990 levels. Directive (EU) 2019/1161 aimed to stimulate the market for low- and zero-emission and energy-efficient motor vehicles, thus accelerating the transition EU for low-emission transport.

The principles of operation and development of electromobility in Poland are regulated by the Act on Electromobility and Alternative Fuels of 2018 (consolidated text: Journal of Laws of 2023, items 875, 1394, art. 60), which is based on the Transport Development Strategy until 2020 of 2013 (*Transport Development...*, 2013) amended in 2019 as the Sustainable Transport Development Strategy until 2030 (*Sustainable Transport Development...*, 2019) and Electromobility Development Plan in Poland ‘Energy for the future’ (https://climate-laws.org/documents/electromobility-development-plan-in-poland_8db6?id=electromobility-development-plan_14da). The goal of the Electromobility Development Plan in Poland is to increase the number of electric vehicle users to 1 million by 2025 (PSPA, 2021).

Pursuant to the Act on Electromobility and Alternative Fuels of 2018 (consolidated text: Journal of Laws of 2023, items 875, 1394, Article 60), electric car charging infrastructure must be established in Polish cities with over 100,000 inhabitants. The number of charging stations depends on the population and the density of the car fleet per 1000 inhabitants and ranges between 60 (in 12 smaller cities with over 100,000 inhabitants) and 1000 charging points (in Warsaw).

Many local government units have already invested in new public transport fleet, most often modern electric buses. According to the counter kept by the Polish Chamber of Electromobility Development (in pol. PIRE) and the Transinfo.pl portal, at the end of February 2022, a total of 651 fully electric buses were registered in Poland, increased by 13 units by the end of the first quarter of 2022. Following vehicles, charging infrastructure for buses has also been intensively developed in recent years. The largest investments were implemented in Warsaw and cities such as Kraków, Poznań, Zielona Góra and Lublin (*Elektromobilność w Polsce...*, 2021, pp. 9-10). The leader in the production of electric vehicle charging infrastructure is Ekoenergetyka-Polska from Zielona Góra. Ekoenergetyka-Polska has a significant share in the bus fast charging station market. Devices designed and manufactured by the Polish company operate in most European capitals, e.g. Berlin, Paris or Warsaw. They are also developing intensively on the market of fast charging stations for passenger cars

and trucks, an example of which is the receipt of an order for several hundred ultra-fast charging stations for the Ioney network (*Elektromobilność w Polsce...*, 2021, p. 10).

Every 3 years, a local government unit is obliged to prepare an analysis of the costs and benefits related to the use, in the provision of public transport services, of zero-emission buses and other means of transport that use only engines whose operating cycle does not result in the emission of greenhouse gases or other substances. covered by the greenhouse gas emissions management system referred to in the Act of July 17, 2009 on the greenhouse gas and other substances emissions management system (Journal of Laws of 2022, item 673).

The use of electromobility as a local power supply will lead, as shown by the results of numerous studies and pilot solutions, to a significant improvement in energy efficiency and reduction of CO₂ emissions in the road transport sector, which will significantly contribute to the protection of the natural environment (Styczynski et al., 2012; Gąsiorek-Kowalewicz et al., 2023, pp. 71-92). The Electromobility Development Plan in Poland 'Energy for the Future' from 2014 highlights the growing use and dissemination of electric vehicles powered by renewable energy while ensuring their use for new network services, which will significantly reduce emissions of greenhouse gases, particulate matter and environmental noise, especially noise street in urban agglomerations (*Electromobility Development Plan in Poland*, 2014). An important aspect of the transition to electric transport is the fact that battery-electric vehicles emit virtually no pollutants into the atmosphere at the point of use. The noise level of BEVs is also much lower than that of combustion vehicles. All pollutants are created where electricity is produced, and the amount of pollutants depends on the way they are produced (Zarębska et al., 2019, pp. 1-11; Adamczyk et al., 2023).

The presents article shows investments and changes implemented in the MZK company in Zielona Góra, which contributed to the company's success in the form of meeting the principles of sustainable development as well as measurable financial and social benefits. Eco-innovative solutions were initiated through the implementation of the project entitled: 'Integrated system of low-emission public transport in Zielona Góra'. This project was implemented with the support of EU funds and the city of Zielona Góra and allowed, first of all, to withdraw some combustion buses from traffic, purchase the first low-emission buses in Zielona Góra and improve the quality of transport services provided.

2. Materials and methods

The article uses qualitative and quantitative analysis. The subject of the article is existing data on the operation of electric buses in the city of Zielona Góra (legal acts, available documentation of previous activities), innovations introduced in the public transport sector and the opinions of people participating in surveys conducted among city residents and users of

electric urban transport. The following research questions arise from the scope of the study defined in this way:

- To what extent does MZK in Zielona Góra implement the tasks assigned to it in the Electromobility Act?
- Do electric buses play an important role in the public transport system in public awareness?
- What have been the greatest successes during the implementation of eco-innovations in public transport so far?
- Do the inhabitants of Zielona Góra perceive the development of electric public transport as a way to improve the quality of transport services and the condition of the environment?
- Are the eco-innovations used in the case of MZK applicable in other regions of Poland?

The present research consisted of two parts. The first part of involved analysing the literature on the subject and strategic documents of the European Union. A systematic review of the literature on the subject and a critical analysis of the content of selected publications allowed us to identify the problem of air pollution caused by transport congestion and the need to invest in pro-ecological solutions in public transport and transport in general. Additional support in identifying the problem and solving it on a microregional scale was provided by the professional experience of the research co-authors (as experts and employees of MZK).

The second part of the article describes the pro-ecological investments carried out in MZK Sp. z o. o. in Zielona Góra, which is closely related to the EU countries' pursuit of an integrated low-emission public transport system under the Infrastructure and Environment Operational Program 2014-2020 (in pol. POIiŚ). The completed project called 'Integrated system of low-emission public transport in Zielona Góra' amounted to PLN 257 million (POIiŚ - PLN 167 million, city of Zielona Góra - PLN 38.5 million, PKP PLK S.A. - PLN 3.5 million). This program is an instrument for implementing the concept of sustainable development in terms of three pillars: economic, ecological and social. The main objective of the investments carried out in Zielona Góra was: elimination of harmful emissions from public transport, including reducing CO₂ emissions, reducing noise and vibrations related to road transport, reducing bus operating costs and improving the safety and quality of services provided, as well as making it easier for passengers to use public transport. Additionally, research by MZK in terms of analysis of the number of passengers transported (2023) and the assessment of the new rolling stock by passengers (2019) confirm the correctness of the investment.

The article formulates two hypotheses:

Hypothesis 1: MZK investments are consistent with the idea of sustainable development of the region and the pursuit of climate neutrality.

Hypothesis 2: Eco-innovative investments in public transport improve the quality of services provided, which translates into overall passenger satisfaction.

3. Pro-ecological investments carried out in MZK in 2014-2020

The most important pro-ecological investments implemented by the City of Zielona Góra in the area of public transport include replacement of the bus fleet, reconstruction of the electrical and energy infrastructure, reconstruction of bus loops, construction of a transfer centre and purchase of specialized supporting software. The basic goals of the implemented projects were: eliminating harmful emissions from public transport, reducing CO₂ emissions, reducing noise, reducing bus operating costs and, finally, improving safety and facilitating the use of public transport (MZK, 2023).

As part of the first tender for the purchase of electric buses in 2017, Ursus Bus S.A. was selected as the contractor and delivered 43 of the 47 ordered electric buses. They have batteries with a capacity of 90 kWh, which allows them to travel approximately 50 kilometres in SORT-2 conditions. In addition to air conditioning, they are equipped with a hybrid (electric and combustion) heating system. Depending on the battery charge level and ambient temperature, the heating device is powered by fuel oil or electricity. At the same time, a tender was concluded for the supply of 17 large-capacity, articulated diesel buses meeting the EURO6 exhaust emission standard. Mercedes-Benz buses were delivered by Evobus Polska Sp. z o.o.

Further electric buses, purchased in 2022, were delivered by Solaris Bus & Coach sp. z o.o. (8 12-meter buses) and Evobus Polska Sp. z o. o. (4 electric articulated buses). The buses have batteries with a higher capacity than those purchased 5 years earlier - 100 kWh and 258 kWh, respectively. The range of these vehicles is approximately 100 km on a single charge. In addition, the vehicles are equipped with a heat pump, which consumes less energy than a traditional air conditioning unit.

All electric buses are charged in two ways. The first is fast loop charging using a pantograph mounted on the vehicle (Figure 1). These chargers have a power of 200-400 kW and allow you to fully charge the bus in about 20 minutes.



Figure 1. Buses charging at the transfer centre.

Source: MZK Zielona Góra materials.

The second method is plug-in charging using a cable (Figure 2). There are 25 two-station chargers with a power of 80 kW at the MZK depot. This charging process is necessary to maintain the properties of the batteries by balancing them - i.e. equalizing the state of charge of individual cells in the battery.



Figure 2. Slow charging charger.

Source: MZK Zielona Góra materials.

The depot, which has also been completely rebuilt for the needs of electric buses, is powered by electricity produced by Elektrociepłownia Zielona Góra S.A. located directly next to the depot. Heat and Power Plant Zielona Góra S.A. is a professional energy company conducting business activities in the field of combined heat and electricity production based on domestic natural gas (Zarębska et al., 2019, pp. 1-11). The parking lot is roofed, and the bus

shelter structure (Figure 3) is prepared for placing photovoltaic cells on the roof. The construction of a photovoltaic farm is currently underway. It is estimated that it will cover 65.5% of the annual total energy consumption. Additionally, rainwater is collected in tanks and used to wash buses in a closed circuit. The described investments confirm hypothesis 1. The rebuilt maintenance hall uses lifts instead of channels to repair buses.



Figure 3. A shelter at the parking lot.

Source: MZK Zielona Góra materials.

Specialized software is used to manage the fleet of electric buses and monitor the charge level of traction batteries. It allows you to manage the power of chargers (including increasing or limiting power), monitoring their condition, remote diagnostics and reviewing data on completed charging sessions. For fleet management, a map (Figure 4) is extremely useful, which, in addition to the actual location of the vehicle, also presents information on battery charge and deviation from the timetable. The dispatcher in the MZK traffic supervision centre is able to constantly monitor and eliminate threats to the timetable by sending a reserve bus or increasing the charging power.

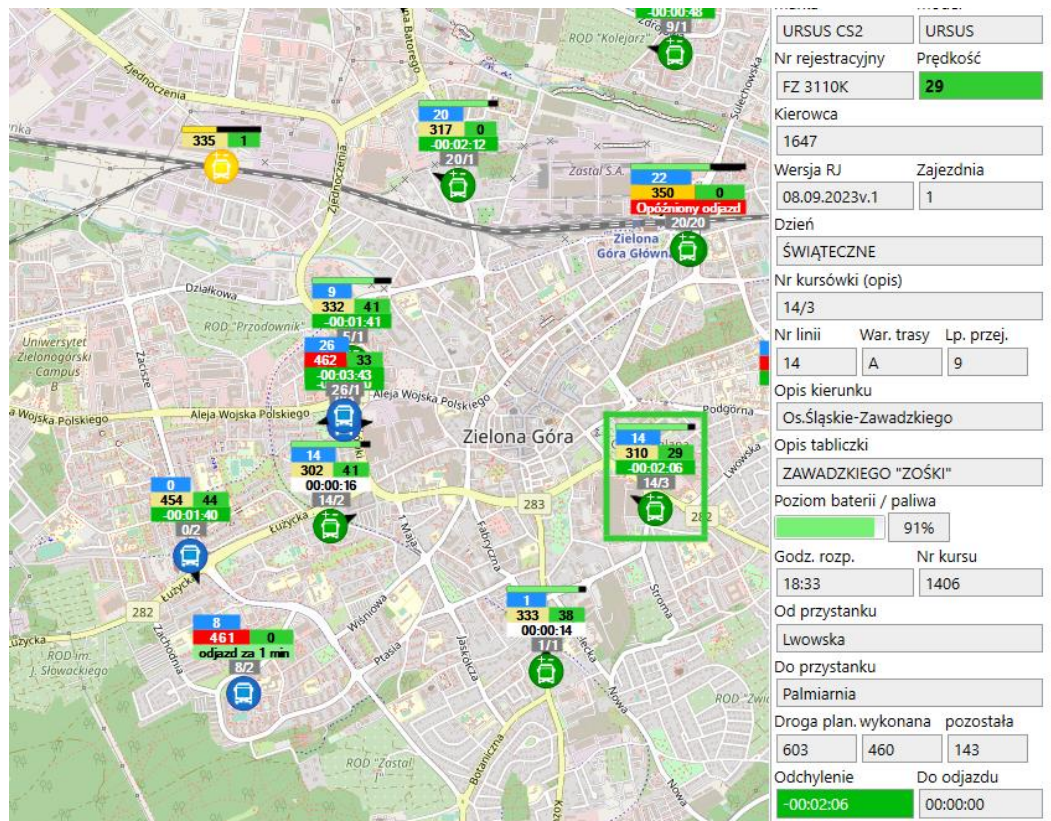


Figure 4. Map in the MZK Traffic Monitoring Centre.

Source: MZK Zielona Góra materials.

Planning timetables is a multi-stage process. The basic assumptions include full coordination of departures on individual communication routes, common timing intervals, adaptation of the type of rolling stock to the number of passengers using them and the greatest possible share of electric buses in the transport work. Regulations regarding drivers' working hours should also be taken into account. The chargers are located on 11 loops. The timetable and routes of bus lines are designed in such a way that the driver's breaks in work take place primarily on loops equipped with chargers and are thus used to recharge the traction batteries. Varying inter-stop travel times depending on the time of day allows you to reduce routes that are delayed compared to the timetable to a minimum and plan actual charging breaks. Drivers are obliged to use every break, even a few minutes, to recharge their batteries.

The route of most lines runs through the Transfer Centre, which is the heart of public transport in Zielona Góra. In addition to transfers between buses of different lines, there is a convenient transfer to regional and long-distance trains. The facility consists of four two-station stop platforms, is fully roofed and connected to the platforms of the Zielona Góra Główna railway station, and passengers have two air-conditioned waiting rooms, toilets and a customer service point at their disposal. The transfer centre serves approximately 16,000 passengers every day.

Electric buses have travelled over 13 million kilometres since the beginning of their operation. These are vehicles equipped with a large number of sensors and electronic equipment, but they are no more reliable than vehicles with traditional combustion engines. On Saturdays and Sundays, only electric buses run on the streets of Zielona Góra.

4. Own research and plans for the future

MZK Sp. z o. o. in Zielona Góra, in order to check the effectiveness of improving the quality of transport services provided by implementing electric buses, commissioned a travel satisfaction survey from an external company. The study was conducted at public transport stops and vehicles on a representative sample of passengers aged 16-75 (n = 1022), with an estimated gender and age structure corresponding to the entire population of Zielona Góra residents. According to the research design, at least 700 interviews were carried out in electric vehicles, and at least 300 - in combustion vehicles. The areas where interviews were conducted were evenly distributed throughout the entire area of operation of Zielona Góra public transport. The data were collected using the direct questionnaire interview (PAPI - Paper & Pen Personal interview) method. The research questionnaire consisted of 10 questions: 9 - closed and 1 - open, in which it was possible to provide the interviewers with their own comments regarding the newly introduced electric buses in MZK.

To summarize this study, it should be stated that: 89% of respondents were satisfied with the introduction of electric buses, these buses received an overall rating of 4.51 - on a rating scale from 2 to 5 (total transport - 4.3). In addition, the advantages of electric buses were emphasized, such as: quietness of the electric drive (39%), environmental friendliness (38%), and impact on air quality in the city (80%). Almost 89% of respondents believed that it is still necessary to invest in electric buses and replace the rolling stock with modern ones.

The next study concerned the analysis of the number of passengers transported (from March 2023). A comparative analysis of 2023 to 2013 showed an increase in the number of passengers transported by 25%. Passenger satisfaction confirmed in surveys and growing indicators in analyses of the number of passengers transported confirm that the direction of changes being introduced is correct and should be developed. The research confirms hypothesis 1. Therefore, further rolling stock replacement projects are currently being implemented. This year 2023, the following will join the Zielona Góra MZK fleet: 5 10-meter buses of the Pileta brand, 6 12-meter buses of the Solaris brand and 3 minibuses of the Karsan brand. After the buses are delivered, some of the oldest diesel buses from 2011 will be withdrawn.

When the efficiency of bus traction batteries does not allow their further use in vehicles, it is planned to use them in the form of energy storage facilities at bus depots and terminals. They will be charged from photovoltaic cells during the day and will allow the buses to be charged at night.

High quality transport services is not only about comfortable and ecological rolling stock. An equally important aspect is an attractive transport offer. The constantly changing transport needs of passengers must be compared with the financial capabilities of the city as the organizer and the availability of drivers and rolling stock. Electric bus fleet, which is expensive to purchase, should be used as efficiently as possible while taking into account the need to charge traction batteries. Specialized supporting software is used to develop timetables. When designing timetables, it checks the correctness of combining routes into tasks, takes into account the maximum distances between charging and allows for mutual coordination of departures of individual lines. The timetable is modified on an ongoing basis - most often in the case of road investments and road closures, but also based on line load analyses.

The future may belong to a different type of drives. Electric buses may be replaced by hydrogen drives over time. Some of the buses operated by MZK is adapted to change the drive in the future. The dynamic development of Zielona Góra means that more buses will be needed on the streets, and new lines and buses will run on new streets and housing estates. Employees of new workplaces in industrial zones will use public transport as a real alternative to passenger cars, to the benefit of the environment and the health of residents.

5. Discussion

The development of electromobility in Poland is one of the key elements of the current economic policy. A special and fastest growing area of electromobility is the public transport market (Kühne, 2010; Ajanovic, Reinhard, 2016; Tucki et al., 2019). It is still important to search for the most perfect solution and obtain the best, lasting effect in public transport (Klucininkas, 2012). According to the Polish Investment and Trade Agency, Bergman Engineering (Electromobility in Poland..., 2021), investments in the electromobility sector are located mainly in the southern and western part of the country, in the following provinces: Dolny Śląsk (12 projects), Śląsk (5 investments).

In the research conducted by Guzik et al. (2021) indicated groups of electromobility innovators in urban transport in Polish cities whose experience was based on trams and trolleybuses. Innovative cities pursued quite an intensive policy of investing in electricity or hybrid fleets (the average share was approximately 20% and was expected to double in the next 2 years). Zielona Góra was the first city to initiate the evolution of second-generation electromobility in public transport in Polish cities (Domański et al., 2016; Taczanowski et al.,

2018). Zielona Góra and Jaworzno are cities that, without previous experience, sought to quickly and completely replace their rolling stock with low-emission vehicles. In Poland in 2022, according to BGK (2023) research conducted on a group of local governments subject to the provisions of the Electromobility Act and several dozen local governments that, although not covered by the Act, have been involved in initiatives aimed at modernizing their public transport in the past (have participated in the Green Transport program). The percentage of all zero-emission buses was 6.6% in the fleets of all local governments covered by the study. The public transport fleet in Zielona Góra consists of 76% electric buses.

The role of the government and local authorities plays an important role in the process of developing electromobility in urban transport. The most important determinants of the development of low-emission public transport in Zielona Góra included, among others: the possibility of obtaining funds from the Cohesion Fund, the Green Transport Program or the Electromobility Act (appropriate energy policy, including striving for a high share of renewable energy sources in the energy mix) and fiscal policy (regulation of EU funds, system of subsidies and incentives for the purchase of low-emission vehicles).

The process of popularizing electromobility in public transport can be treated as the diffusion of technological innovation. Previous work (Taczanowski et al., 2018) identified a positive relationship between the location of the bus manufacturer and purchasing decisions regarding public transport rolling stock. A factor favouring the implementation of electromobility on a national scale was the presence of manufacturers of electric vehicles, chargers and other equipment necessary for the use of this type of vehicles. For example, the Ekoenergetyka-Polska company has been operating in Zielona Góra since 2009, which is an important factor in the development of electromobility in the city. The company is a designer and manufacturer of high-power charging stations for cars, delivery vans, buses and trucks.

Electromobility and its implementation, especially in public transport, is a promising and developing area of research. Further research may be focused on the development, optimization and stabilization of technology in electric urban transport, as well as the methods and determinants of its implementation, especially at the voivodeship and national level. The presented example of the city of Zielona Góra may be an example of good practice for cities where the development of electromobility in public transport is not so dynamic and advanced.

Reliable, up-to-date data on the implemented innovative solutions in urban transport will allow for the identification of barriers to the implementation of this concept and will provide guidance on effective solutions, benefits for public transport organizers, passengers, local communities, as well as guidelines and expected legal and financial instruments catalysing low-emission transport initiatives, especially in small towns.

6. Summary

Municipal Transport Company (MZK) Sp. z o.o. in Zielona Góra is currently the most modern public transport company in Poland, whose fleet consists mainly of electric buses. This is possible thanks to completed investments, but also to planned ones. Innovative solutions as part of the implementation of the project entitled: ‘Integrated system of low-emission public transport in Zielona Góra’ (2014-2020) are the beginning of activities towards the implementation of sustainable development tasks. The research described in the article proves that pro-ecological investments bring measurable effects not only economically (in the form of effective use of rolling stock), but also ecologically (reduced CO₂ emissions) and socially (passenger satisfaction). Passenger satisfaction with the quality of services provided, an increase in the number of passengers transported by 25% compared to 2013 to 2023, water and energy savings are just a few of the measurable benefits.

MZK plans to continue to develop as a modern company. An example is an investment related to the installation of photovoltaic panels on bus roofs or the use of software supporting timetable planning. The authors of the publication intend to continue monitoring MZK and city investments in the implementation of climate neutrality goals.

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