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The potential for military use of public transport vehicles

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Abstract. Political instability and armed conflicts require that the Polish state protect the civilian population, including through large-scale evacuation. Public transport fleets may support evacuation. However, the growing share of zero-emission busses introduces constraints related to charging and hydrogen refueling infrastructure. The main research problem is whether increasing adoption of zeroemission buses affects the flexibility of public transport fleets in evacuation scenarios and how this risk evolves over time. The research niche of this article is the impact of zero-emission propulsion on the feasibility of using public transport vehicles for evacuation. The study is based on a literature review and desk research (analysis of legal regulations, market trends and statistical data for selected Polish cities), complemented by a comparative case study of selected urban bus operators. Two related hypotheses are tested: H1 – propulsion source is related to flexibility of the public transport system in evacuation; H2 – the importance of this relationship increases as the share of zeroemission vehicles grows. The results indicate that dependence on electricity/hydrogen supply and specialised infrastructure may reduce fleet flexibility during prolonged crises with disrupted energy supply. The article concludes with recommendations (e.g., maintaining a minimum reserve of conventionalfuel vehicles, diversifying energy sources, and considering mobile charging/refuelling solutions) to strengthen evacuation readiness.
Keywords: public transport, people evacuation, zero-emission vehicles, electric bus, hydrogen bus

Introduction

The topics of alternative energy sources and zero-emission vehicles are frequently discussed in the literature. The journal "Military Logistics Systems" also features several articles on this subject. This is one of the most important trends in the transport industry, strongly affecting all types of vehicles, from passenger cars to trucks, buses, specialized vehicles, and other modes of transport (including aircraft and vessels).

The article is based on a literature review and desk research, including analysis of legal regulations and publicly available statistical data. The empirical illustration uses a comparative case study of selected urban bus operators. The research problem is whether increasing adoption of zeroemission buses affects the flexibility of public transport fleets in evacuation scenarios. Two related hypotheses are tested in this article:

H1: A relationship exists between the energy sources of vehicles used in public transport and the flexibility of the public transportation system in crisis situations.

H2: This issue will become more important as technological developments and the intensity of using zeroemission drives increase over time.

Later in the article, the author discusses zero emissions and their effect on the use of public transport vehicles in emergency situations. This problem is particularly relevant to urban centres, which have the highest needs in this area owing to their high population density. The evacuation of cities is discussed in the context of armed conflicts and natural disasters. Public transport vehicles are also commonly used for smaller incidents, such as evacuations after fires. However, what about war, floods, or other events that cause, for example, serious disruptions to the electricity supply?

Literature study

Population evacuation is usually discussed in the context of natural disasters and weather hazards such as earthquakes or floods. Many publications on these issues exist in the global literature (Yin et al., 2024; Daude et al., 2019; Yamada, 1996). Among these publications, some indicate the use of specific mathematical models to solve simulation tasks (Chu, Su, 2012) or describe specific examples (Renne, Mayorga, 2022). Technical developments have made it possible to simulate events and model both the development of crises and the methods of evacuating the population (Barnes et al., 2022; Katada et al., 2015). In recent years, machine learning models, the Internet of Things, and, more broadly, artificial intelligence have been used for prediction (Chen, Zhang, 2022; Sahil, Sood, 2022).

A separate group of publications deals with the topic of evacuation related to armed conflict (Borowska-Stefańska et al., 2023), also based on specific case studies (Borowska-Stefańska et al., 2025). The situation in Ukraine is geopolitically similar to that in Poland. The literature on the subject also includes publications devoted to evacuations from this area (Martinez et al., 2022; Walravens et al., 2022).

State of knowledge – the concept of decarbonizing public transport

Public transport is one of the pillars of proper city functioning and development. Mobility is a basic human need that grows with socio-economic development. In addition, public transport systems are also being developed. These systems have undergone intensive transformation in recent years, including vehicle propulsion and the use of alternative fuels. The desire to use fuels other than fossil fuels has become a catalyst for change in many transport systems. Decarbonization, which is the process of reducing or eliminating carbon dioxide emissions, is increasingly being discussed.

For decades, cities have been building transportation systems based on various solutions. These include urban systems based on rail vehicles, which are not covered in this study because they usually operate on a closed track network. The same applies to trolleybuses, which, owing to technical limitations, have been restricted by the traction network for years (this limitation has been partially eliminated). The discussion focuses on buses, among which at least seven different types of propulsion (drives) can be distinguished depending on the type of fuel used. The classification of these vehicles is shown in Figure 1 below.

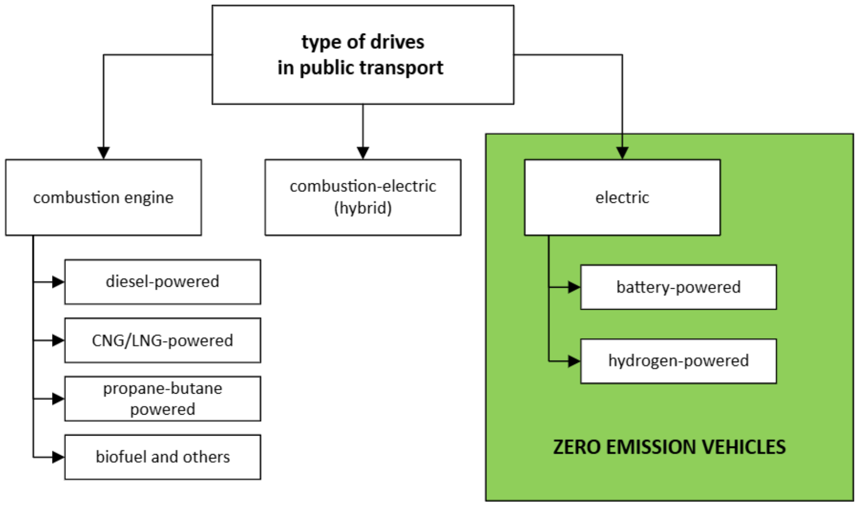

Fig. 1. Drives in public transport vehicles
Source: Own study

The primary document defining the key elements of the policy for implementing alternative fuel vehicles (including zero-emission vehicles) in public transport is the "Act on Electromobility and Alternative Fuels" (Act, 2024). The Act specifies, among other things, the rules for creating infrastructure for alternative fuels. According to the Act, a zero-emission bus is one that "uses electricity for propulsion, including energy generated from hydrogen in a fuel cell installed in it, or exclusively an engine whose operating cycle does not lead to greenhouse gas emissions (...)" (Act, 2024, p. 2). This means that, according to the provisions of the Act, zero-emission vehicles cannot burn various types of fuel, such as diesel, CNG, propane-butane gas, or hydrogen. The Act also introduced the concept of a public charging station operator. This is "an entity responsible for the construction, management, operational safety, operation, maintenance, and repair of a public charging station" (Act, 2024, p. 3).

The Act includes provisions concerning the level of zero-emission vehicles in the fleets of various public entities, both central and local governments, as expected by the legislator. The relevant provisions are contained in Articles 34 and 35 of the Act (2024). Simultaneously, following the latest amendment, pursuant to Article 36 of the Act (2024), from January 1, 2026, municipalities with a population exceeding 100,000 (and entities commissioned or entrusted with transport services) are required to purchase only zero-emission buses (for the purposes of transport in that municipality). This does not apply to situations where buses are used to provide transport services beyond the administrative boundaries of a city with a population exceeding 100,000 (or where the organizer is a municipality with a population exceeding 100,000 and transport services are provided to a neighbouring municipality with a population not exceeding 100,000) (Act, 2024, pp. 36-37).

It should be noted that increasing the share of zero-emission buses in the fleet has been pursued for many years. In the first text of the Act (2018), there was a provision on the need to ensure the share of zero-emission buses in the fleet at the level of 5% (from January 1, 2021), 10% (from January 1, 2023), and 20% (from January 1, 2025). The provisions of the Act have been amended several times, specifying the obligations regarding zero-emission buses in relation to time (and their validity in subsequent years), local government units (municipalities with up to 50,000 inhabitants or over 100,000 inhabitants), and percentage indicators (regarding the number of zero-emission buses in the fleet).

Decarbonization of public transport primarily means the use of vehicles that do not emit carbon dioxide, usually electric ones. This poses many new challenges, such as vehicle range given the existing limitations of battery systems and the construction of a network of chargers (including the use of different types of chargers, not only wired but also pantograph chargers) with the appropriate technical parameters. Another challenge is the organization of the entire network of chargers to provide access to electricity (not only in bus depots but also in densely urbanized areas). The spatial distribution of electric vehicle charging infrastructure is a broader problem that affects not only cities but also the entire country. The main problem with this network is the spatial unevenness of the charger distribution. Half of them is located in 15 cities (Pawlos, Zadorożny, 2024).

Zero-emission vehicles are based on electric buses, in which electricity is stored in batteries but is obtained from an external source. A separate group of vehicles are those that generate their own electricity but use external fuel sources. This is the case for hydrogen-powered buses, which represent a new niche in the public transport market. Currently, there are few vehicles of this type in operation; therefore, the infrastructure for charging them is also modest. Currently, there are seven hydrogen refuelling stations in Poland. According to data from H2.live (2025), these are the ORLEN facilities in Katowice and Poznań, as well as NESO stations (operator: PAK-PCE STACJE H2 Sp. z o.o.) in Gdańsk, Gdynia, Warsaw, Lublin, and Rybnik. All of the stations indicated are dual-function – they allow refuelling at both 350 bar (e.g., passenger cars) and 700 bar (buses). The spatial distribution of the stations on the map of Poland is shown in Figure 2. This clearly shows how much of a barrier the unavailability of alternative locations can be. Such a possibility is available only for public transport vehicles in the Tri-City.

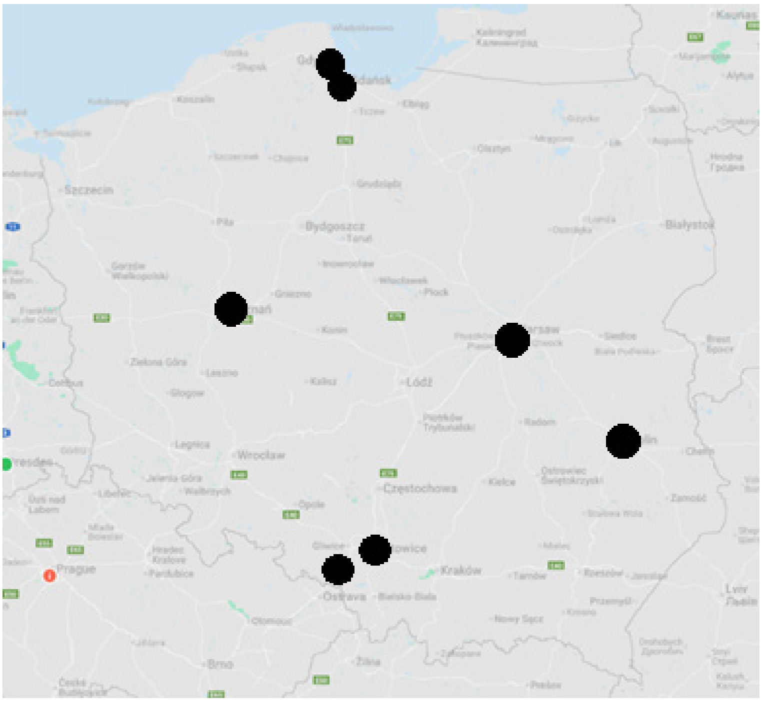

Fig. 2. Hydrogen refuelling stations in Poland
Source: H2.live [Accessed: 05 August 2025]

The potential for using public transport vehicles in a crisis situation

Crisis management is one of the tasks of public administration, which is all the more difficult because it requires taking into account, among other things, spatial diversity and the unpredictability of individual behaviour (Biłozor et al., 2013). Evacuation of the population is one of the most important elements of crisis management, reflecting the need for security rooted in human nature and supported by the state (Czerechowski, 2015). Today, there is increasing discussion about the need for local communities to support military tasks. According to some researchers, it is possible to go even further, viewing this cooperation as a source of economic development (Orłowska, 2023).

Detailed rules for the defence of the population are set out in the "Act on Population Protection and Civil Defence" (Act, 2024b). Among the numerous tasks related to population protection and civil defence, the following are highlighted: planning and preparing conditions for the evacuation of the population, and the evacuation of the population, property, and movable cultural goods. The mayor (or city president) is responsible for preparing the contribution to the provincial evacuation plan for the municipality (Act, 2024b, pp. 2-5). As specified in the Act (Articles 38-39), these include the number of people to be evacuated in a given area, an indication of the land, water, and air transport infrastructure to be used during the evacuation, and an indication of the forces and means of transport necessary to carry out the evacuation in a given area (Act, 2024b, p. 20).

Public transport may play another important role, in accordance with Article 95 of the Act (2024b) "Underground structures located within the administrative boundaries of cities used for transport purposes, including road and rail transport, in particular underground train, tram and railway facilities, shall be designed and constructed in such a way as to ensure that they meet the technical and technical conditions of use for protective structures" (p. 33). Just as public transport vehicles can assist in evacuation, so too can selected elements of infrastructure can take on the function of hiding places.

Detailed rules for conducting population evacuations are found in the implementing documents. Currently, these include the Regulation of the Council of Ministers of May 30, 2025, on the evacuation of the population and protection of property. In accordance with the provisions of the above-mentioned regulation, the selected administrative authorities (commune head, mayor or city president, county administrator or provincial governor) are responsible for determining the means of transport at their disposal, based, among other things, on data obtained from other competent authorities. This authority is also responsible for the disposal of these means of transport in the area where the threat has occurred (Regulation, 2025, p. 2).

Own research – diversification of drives in public transport

The growing number of vehicles powered by alternative fuels raises the question of what if these vehicles need to be used for evacuating people. In practice, their usefulness and suitability for evacuation depend primarily on ensuring continuous access to the appropriate fuel.

According to data from the PIRE Association (2024), by the end of 2023, 1,073 electric buses were registered in Poland, mostly Solaris vehicles (with a number of 648). To obtain the full picture, these data should be compared with the total number of vehicles of this type on Polish roads. According to data from the Central Statistical Office (GUS, 2024a), as of December 31, 2023, there were 132,400 buses registered in Poland, 60.1% of which had more than 45 seats. Therefore, assuming that these vehicles constitute the core of the public transport fleet, at the end of 2023, electric buses accounted for approximately 1.4% of all buses (with more than 45 seats). At the same time, it should be noted that a large proportion of vehicles in the country are heavily used – over 30 years old (31.9%) or 16-30 years old (40.2%). Buses operating in domestic and international traffic (through companies employing more than nine people and excluding public transport) accounted for approximately 12,500 units.

More detailed data from the Central Statistical Office (GUS) shed a slightly different light on these issues. Public transport companies used (all data as of the end of 2023) 12,466 buses, of which 2,688 were alternative-fuel vehicles. Interestingly, the latter have a significantly higher share of vehicles in traffic (of the total) (92% compared to 80% for all vehicles), although at the same time they cover shorter distances per day (an average of 160 km compared to 192 km) (GUS, 2024b).

In the common understanding, alternative drives are not only electric vehicles but also those powered by natural gas (LNG, CNG) or other fuels. Therefore, this concept is broader than that of zero-emission vehicles, which is limited to electric buses (including those powered by hydrogen). Analysing the above data, it can be assumed that in cities (where public transport operates), buses with alternative drives account for approximately 20% of vehicles (2,688 out of 12,466). Simultaneously, electric buses account for an average of approx. 8.6% of vehicles (1,073 of 12,466). Considering the continuous renewal of fleets and the intensive acquisition of zero-emission vehicles by urban transport operators, it can be assumed that this indicator will increase in the future. This was confirmed by data from the following year. In 2024, 433 buses with alternative drives were registered in Poland, of which 384 were city buses. Of these, 200 were electric buses powered by batteries (195 urban and five intercity), and 31 were buses powered by electric motors and hydrogen fuel cells (Samochody Specjalne, 2025). Thus, (considering further deliveries in 2025), it can be assumed that electric buses (including hydrogen-powered ones) account for several percent of the entire fleet of public transport companies.

The table below shows the fleet of public bus operators (public) in the largest Polish cities, also divided into groups: zero-emission and combustion vehicles. Five large public transport operators serving urban areas (and, to a limited extent, neighbouring municipalities) were selected for this study. A summary of the bus fleets of these operators is presented in Table 1. Publicly available data and summaries presented by operators on their websites were used.

Table 1. Bus fleet of selected operators

Number of buses (and percentage of fleet)	**MZA Warszawa**		**MPK Kraków**		**MPK Łódź**		**MPK Wrocław**		**MPK Poznań**	
Combustion engines	1219	85%	453	70%	288	71%	328	96%	242	74%
Hybrid (diesel-electric)	4	0%	70	11%	91	23%	0	0%	1	0%
Electric	203	14%	121	19%	25	6%	13	4%	58	18%
Hydrogen	0	0%	3	0.5%	0	0%	0	0%	25	8%
Total number:	1426		681		404		341		326	
Date of data	n/a (access: 5.08.2025)		14.07.2025		29.05.2025		n/a (access: 5.08.2025)		5.05.2025	

Source: Own study based on (Warszawikia, 2025; MPK Kraków, 2025; MPK Łódź, 2025; MPK Wrocław, 2025; MPK Poznań, 2025)

The table shows that zero-emission buses fleet number is today between a few and over 20 percent of the fleets of the five largest municipal transport operators. Therefore, they constitute a significant, although not dominant, group of vehicles in terms of the processes performed.

Some cities in Poland have a significantly higher share of zero-emission fleets. An interesting example is the Municipal Transport Company (MZK) in Zielona Góra, Poland. This relatively small operator has a fleet of 89 buses, of which 69 (i.e., 77.5%) are electric buses (MZK Zielona Góra, 2025). At the Municipal Transport Company (PKM) in Jaworzno, electric buses account for 67.1% of the fleet (49 out of 73) (PKM Jaworzno, 2025).

With a few exceptions (such as Zielona Góra and Jaworzno), zero-emission buses are still in the minority, and their sudden shutdown in an emergency situation will not be critical in terms of the ability to evacuate residents. Over the years, the share of zero-emission vehicles will increase, for example, in line with the above-mentioned restrictions on the purchase of combustion engine vehicles or as a result of the continuous development of zero-emission vehicles.

Discussion – challenges associated with the operation of zero--emission vehicles

Zero-emission vehicles are relatively new, and companies are still learning how to operate such drives. Vehicles and infrastructure require appropriate knowledge, technical facilities and access to technology. One of the key risks is the potential disruption of fuel supply. These can occur during time of piece as well. An example of this is the sudden withdrawal of hydrogen-powered buses operated by MPK Poznań. On March 3, 2025, all vehicles of this type were withdrawn from service owing to contamination of the hydrogen system and the refuelling of 23 out of 25 vehicles with fuel of inadequate quality. The buses were sent for inspection and cleaning of the hydrogen system, and after approximately two weeks, all of them returned to service (MPK Poznań, 2025b).

Such a situation, through no fault of the operator, can occur to any fleet owner. In the case of zero-emission vehicles, especially hydrogen vehicles, there is often no alternative if the system is unavailable due to the limited number of refuelling points. Fuel unavailability can be caused not only by military action but also by technical factors, coincidences, or, for example, sabotage.

Currently, much attention is being paid to energy security and strengthening the European Union's defence capabilities. These issues remain unresolved challenges, and energy security is considered the foundation of mobility. On the one hand, there is talk of decarbonizing the transport sector, and on the other, developing infrastructure that ensures energy independence, including photovoltaics, which are more resistant to attacks due to their dispersion (PSNM, 2025). One of the basic directions of action is regional development, and contemporary researchers devote considerable attention to identifying the factors of regional development and measuring its impact (Orłowska, 2023).

The issue of electromobility can also be viewed in a broader context by examining other groups of vehicles. In the case of city buses, which are usually operated in an infrastructure-stable environment, the organization of an appropriate charging or alternative fuel refuelling network requires investment but does not usually cause major problems. In the case of vehicles performing tasks related to the broadly understood rescue of people and property, these conditions are difficult and variable, and reliability is crucial. Simultaneously, an increasing number of publications emphasize the role of electric vehicles in the transport sector. They are consistent with the idea of sustainable development, and an increase in their number may contribute to improving the natural environment (Gądek-Hawlena, Bęben, 2023).

Given the limitations in infrastructure availability and the disadvantages of alternative vehicles (lack of access to fuel or charging networks, long charging times, etc.), such drives are not currently a viable alternative for emergency vehicles (such as fire trucks) or for military vehicles. Of course, there is a lot of work being done with these vehicles, such as the electric military vehicle concept (GM Defense LLC, 2025) or the first successful trials of electric fire trucks (Centralna Szkoła PSP, 2022). However, the scale of the use of these vehicles is many times smaller than that of alternative drives in buses.

Conclusions

Therefore, is the use of zero-emission vehicles an opportunity or a threat from the point of view of safety and the ability to carry out tasks such as evacuating buildings? To properly manage logistics potential (in all states of the country's functioning for military units and institutions), a comprehensive approach is necessary (Jałowiec, 2021). Therefore, the possibility of using public transport vehicles for military purposes should be viewed holistically.

Zero-emission vehicles can be viewed from two perspectives. On the one hand, political instability and the economy may lead to an increase in fossil fuel prices and even disruptions in the supply of these fuels. This argues in favour of using electric vehicles, especially when developing various ways of obtaining electricity, including environmentally friendly methods and those using installations independent of imported raw materials (fuels). However, in a crisis situation, disruptions in the supply of electricity are likely, which argues in favour of using vehicles powered by traditional fuel and diesel engines.

Simultaneously, there is a clear trend towards increasing the share of zero-emission vehicles in the fleets of urban operators, and such vehicles will also appear among regional carriers. Therefore, it is crucial to diversify energy sources and develop infrastructure in various areas. Technologies such as mobile charging stations (for electric vehicles) and refuelling stations (for hydrogen vehicles) are already available in the market. Mobile charging stations for electric buses have been tested in many cities (even during tests of this type of bus), and a mobile installation for refuelling buses with hydrogen has been tested in Wałbrzych, among others. On the other hand, the electric vehicle charging network is already extensive but is usually dedicated to passenger cars (rather than buses with large batteries and specialized equipment, such as pantograph chargers).

Based on the above discussion, recommendations can be made. It would be valuable to define (analogous to the minimum fleet of zero-emission vehicles) a minimum fleet of diesel-powered vehicles (to secure the needs of population evacuation) for the largest cities with potentially the highest evacuation needs. It is desirable to secure energy supplies for large fleets of zero-emission vehicles in the event of loss of access to the main power supply. Cooperation between the military and civilian sectors would also be valuable for the safe development of zero-emission mobility, such as the exchange of information and for example training. This would ensure that the potential of use of public transport vehicles will be maximized.

The analysis clearly indicates that there is a connection between the energy sources and the flexibility of the public transportation system in the case of evacuation (so H1 hypothesis can be positively verified). As zero-emission technology continues to develop and battery-powered vehicles become more popular, the second hypothesis (H2) is also being confirmed – this problem is becoming increasingly important. Both hypotheses were confirmed during the research process. Why are the analyses mentioned above innovative and important from the point of view of logistics and economic sciences? From a scientific perspective, the description of reality led to the creation of certain generalizations, which are the basis of two hypotheses. Confirmation of hypotheses based on numerical data and literature analysis indicates directions of changes and allows achieving the prognostic goal.

The analysis shows that the process of implementing innovations should be viewed from many perspectives. Not only in terms of the economic efficiency and efficiency of transport systems in their typical operation but also taking into account the impact on emergency situations or unforeseen events. Especially today, when there is a widespread discussion about the instability of the geopolitical environment, military crises, or natural disasters. The results obtained may also serve as an inspiration for other researchers who will tackle similar topics in the future.

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