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Prospects for the development of zero- and low-emission vehicles in urban distribution systems in terms of the situation on the fuel market

Perspektywy rozwoju pojazdów bezemisyjnych i niskoemisyjnych w systemach dystrybucji miejskiej w świetle aktualnej sytuacji na rynku paliw

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Abstract. Nowadays, problems related to sustainable transport and limiting the negative impact on transport are essential to the agenda of the European Union. At the same time, the increase in the popularity of zero- and low-emission vehicles may be influenced by the global situation on the fossil fuel market and rising oil prices. Due to their characteristics, the use of zero- and low-emission vehicles is justified, especially in cities, both in individual transport as well as in public transport and freight transport. The article focuses on analysing prospects for using zero- and low-emission vehicles in distribution systems (especially in cities). Therefore, the research goal of the paper is to answer the question: what are the expected trends in the level of use of zero-emission and low-emission vehicles in distribution systems? The research hypothesis assumes that the level of use of zero- and low-emission vehicles in distribution systems will increase in the coming years, considering the situation on the global fuel market. Research methods such as desk research (including the analysis of data from the fuel market) and a critical literature review were used to verify the hypothesis. The article examines the possibility of using delivery vehicles with different load capacity. The research shows that taking into account the current trends on the fuel market, in the next 5-10 years, the operating costs of zero-emission and low-emission vehicles will become lower than the operational costs of conventional vehicles, which will lead to an increase in their use in urban distribution systems.
Keywords: city distribution systems, propellants, zero-emission vehicles, low-emission vehicles, transport economics

Abstrakt. W obecnych czasach problemy związane ze zrównoważonym transportem oraz ograniczeniem negatywnego oddziaływania na transportu stanowią istotny element agendy Unii Europejskiej. Jednocześnie na zwiększenie popularności pojazdów bezemisyjnych i niskoemisyjnych może mieć wpływ globalna sytuacja na rynku paliw kopalnych i rosnące ceny ropy naftowej. Ze względu na swoje cechy charakterystyczne, wykorzystanie pojazdów bezemisyjnych i niskoemisyjnych jest zasadne zwłaszcza w miastach, zarówno w transporcie indywidualnym, jak również w komunikacji miejskiej i w transporcie towarowym. W artykule skupiono się na analizie perspektyw dla wykorzystania pojazdów bezemisyjnych i niskoemisyjnych w systemach dystrybucyjnych (zwłaszcza w miastach). W związku z tym celem badawczym artykułu jest odpowiedź na pytanie: Jakie są przewidywane trendy w zakresie poziomu wykorzystania pojazdów bezesmisyjnych i niskoemisyjnych w systemach dystrybucyjnych? Hipoteza badawcza zakłada, iż: Poziom wykorzystania pojazdów bezemisyjnych i niskoemisyjnych w systemach dystrybucyjnych będzie rósł w najbliższych latach biorąc pod uwagę sytuację na globalnym rynku paliw. Do weryfikacji hipotezy wykorzystano takie metody badawcze jak: desk research (w tym analiza danych z rynku paliw) oraz krytyczny przegląd literatury. W artykule zbadano możliwość wykorzystania pojazdów dostawczych o różnej ładowności. Z przeprowadzonych badań wynika, że biorąc pod uwagę aktualne trendy na rynku paliw, w perspektywie najbliższych 5-10 lat koszty eksploatacji pojazdów bezemisyjnych oraz niskoemisyjnych staną się niższe od kosztów eksploatacji pojazdów konwencjonalnych, co będzie prowadziło do zwiększenia poziomu ich wykorzystania w miejskich systemach dystrybucyjnych.
Słowa kluczowe: city distribution systems, propellants, zero-emission vehicles, low-emission vehicles, transport economics

Introduction

The problem of organizing transport and determining transport plans is widely described and reflected in many transportation modes. In urban areas, it comes down to the efficient use of means of transport, which must perform a series of operations to deliver cargo to their destination, taking into account traffic congestion and reducing the negative impact of transportation on the environment (Fisher, 1995; Nieuwenhuijsen, 2020). Emission-free electric vehicles (Light Commercial Vehicles) or hybrid vehicles are increasingly used to organise transport in urban areas (city logistics).

However, their share is still low compared to the total number of vehicles performing transport work in cities. The article shows the reasons for the lower interest in electric vehicles in cargo distribution systems, with an indication of the prospects for the development of the use of electric vehicles in urban areas in Poland and Europe and an analysis of the profitability of using electric vehicles in distribution systems, taking into account the dynamically changing prices of propellants in recent years. An analysis of the impact of changes in fuel prices on the profitability of using zero- or low-emission vehicles was carried out.

The aim of the publication is to examine the more widespread use of zero- or low-emission vehicles in the next 5-10 years. The authors adopted a research method based on a review of historical fuel prices and the calculation of the actual operating costs of vehicles used for transport in urban areas. The authors identified two primary research questions, i.e. whether the implementation of electric vehicles in the perspective of the next decade in the field of delivery vehicles will be profitable, and also, what will be the further dynamic growth of fuel prices? Taking into account the extensive analysis of statistical data, the estimated increase in fuel prices, and the pursuit of an energy-neutral European continent, a research hypothesis was formulated, indicating an increase in the profitability of the operation and an increase in the dynamics of the use of emission-free delivery vehicles already in the short term, i.e. within five years. The research hypothesis was verified based on a calculation example.

Urban distribution systems

Distribution systems in cities meet the needs of transporting loads, improve the competitiveness of the economy, ensure territorial cohesion, offer customers the right way of transporting by their expectations, improve the quality of life, improve the attractiveness of space, and above all, contribute to reducing the emission of air pollutants, noise, and vibrations (Lu et al., 2021).

To effectively reduce the negative impact of transport on the environment in urban areas, it is necessary to introduce zero- and low-emission vehicles, especially light electric delivery vehicles, to service the transport processes. Other solutions used in urban areas to reduce the negative impact of transport on the environment are separate entry zones for vehicles that do not meet specific emission standards, time-limited delivery zones, and limiting the weight and dimensions of vehicles that can deliver in selected areas. In addition, solutions are being implemented to reduce the volume of transport work by launching cargo consolidation centres (CCC) within the logistics systems of cities.

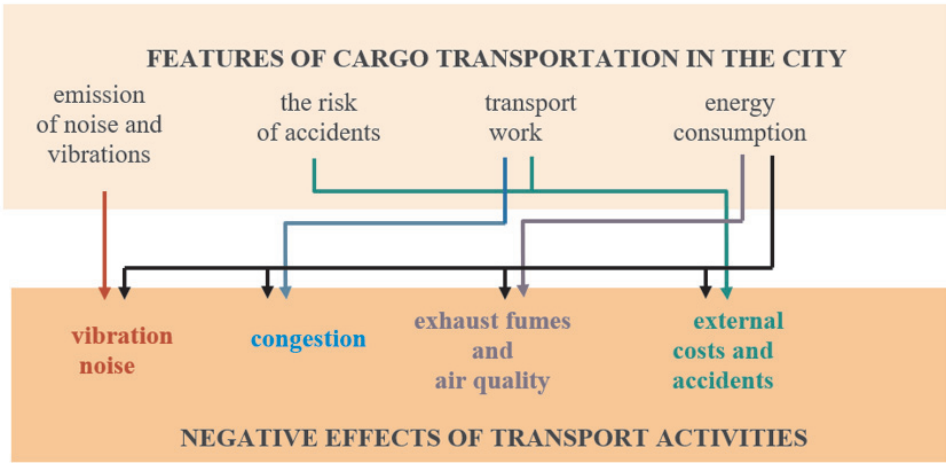

Fig. 1. The impact of cargo transport on the environment
Source: Own study based on [Wojewódzka-Król, 2021]

In small agglomerations, transports from cargo consolidation centres are used and carried out directly to end recipients. In the case of larger urban agglomerations, transshipment hubs are used (Fijałkowski, 2010). They may be used for reloading goods onto vehicles with a lower load capacity. The time and quality of delivery of transport services in urban areas require measures to improve the distribution process. It is assumed that cargo consolidation centres, as independent economic entities, provide logistic services and reloading, storage, and distribution of tangible goods. If the urban area is vast, the quality of transport services can be improved by establishing additional cargo consolidation centres and urban transshipment hubs.

The spatial structures of cities can be very diverse, directly impacting distribution planning, the selection of transport means, and the designation of service areas (Carotenuto, 2018). For proper cargo distribution, the sequence of servicing individual customers by appropriately selected means of transport is essential, and the need to minimize the total costs of transport services while meeting many constraints (Toth et al., 2002). Numerous analyses of cargo transport management and delivery configuration in urban areas were carried out, taking into account such factors as the reliability of logistics processes (Ozkan et al., 2019), indicators for assessing the quality of transport services (Ricci et al., 2000; Eboli et al., 2011), indicators of the safety of the implementation of transport processes (Taniguchi et al., 2014; Jacyna-Gołda eta al., 2019; Rudyk et al., 2019; Murawski et al., 2022), assigning means of transport to transport tasks (Sánchez-Silva, 2005; Bliemer et al., 2017), or supporting the process of locating distribution points (Szczepański et al., 2014; Das et al., 2020).

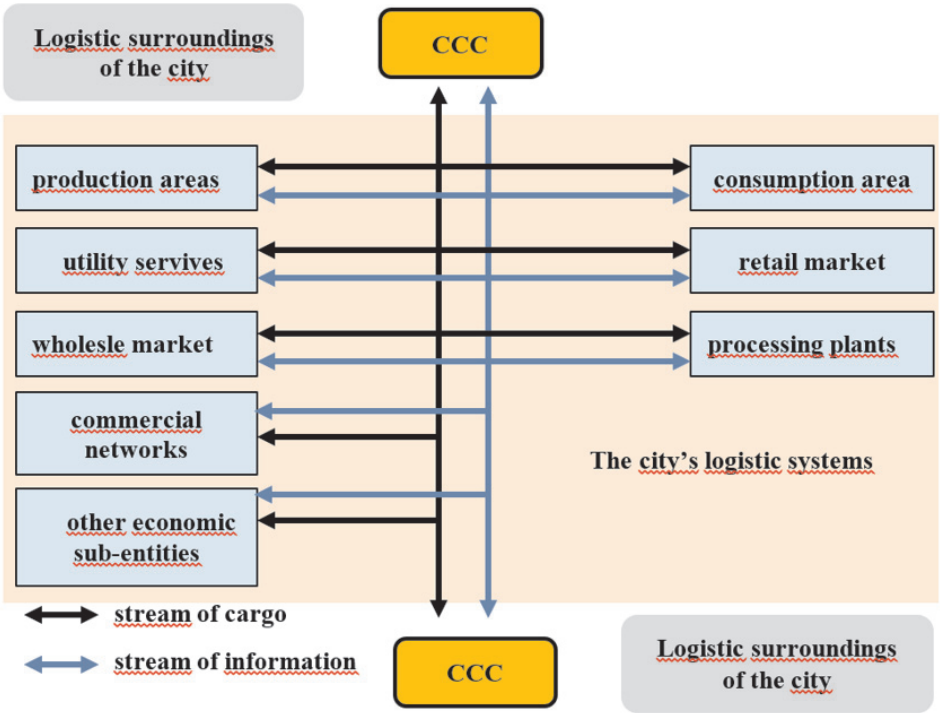

Fig. 2. Elements of the urban's logistics system
Source: Own study

The European market for environmentally friendly means of transport

Regarding means of transport intended for the provision of cargo transport services, in 2013-2019, over 14 million new vehicles for the transport of cargo were registered in Europe, of which nearly 88% were vehicles whose gross vehicle weight did not exceed 3,5 tons about 12,5 million vehicles. The most significant number of vehicles was registered in France (2,4 million), Germany (2,0 million), Great Britain (1,6 million), Turkey (1,2 million), Spain (1 million), and Italy (1 million), respectively. A list of registration of new vehicles for cargo transport in the years mentioned above shows the number of total vehicles in 2013-2019, which was above 800 thousand.

Commercial vehicles and trucks account for only 5% of Europe's total number of vehicles. It should be emphasized that delivery vehicles and trucks are responsible for nearly 28% of carbon dioxide emissions generated in the transport sector.

Taking into account the initiatives taken at the European level to reduce CO_2 emissions also in the transport sector, from 2025 total delivery vehicle fleet, truck manufacturers have committed to reducing carbon dioxide emissions in newly produced vehicles by 15%, and from 2030 by another 30%. As many as 96% of European light commercial vehicles registered in 2013-2019 were powered by diesel engines. Gasoline engines powered just over 2,4% of vehicles, and only around 1.6% of vehicles belonged to zero- or low-emission vehicles, i.e., powered by hybrid, gas (LNG, CNG, LPG), or electric engines. In 2013-2019, there was an increase in registered electric and hybrid vehicles, i.e., those using conventional propulsion (petrol, diesel) with electric drive. There was a marked decline in the number of registered diesel vehicles in 2018 and 2019, by 8% in 2018 and 15% in 2019, respectively. However, the overall share of light commercial vehicles registered with diesel engines is still very high.

Taking into account the ambitious plans to reduce emissions of pollutants in EU countries, indicated earlier, especially in areas related to transport with the use of delivery vehicles in urban areas, the increase in the number of light, zero- or low--emission delivery vehicles, especially with electric drive, will significantly progress in the coming years. The current policy of the European Union regarding eliminating vehicles powered by internal combustion engines after 2035 will also contribute to this.

It is worth noting that in 2022, legal regulations were adopted at the EU level, establishing a ban on the sale of diesel vehicles after 2035. From 2035, new vehicles that will be registered should be zero- or low-emission vehicles will not be possible to market emission vehicles. The above will certainly positively impact the improvement of residents' living conditions in cities. It will significantly change the vehicles used to distribute loads in urbanized areas.

It can be assumed that after 2022, the share of zero- and low-emission vehicles in the total number of light commercial vehicles in the EU will exceed 2%. The barriers to the widespread use of light electric vehicles in urban distribution systems are primarily the high costs of purchasing vehicles and the limited operating range of vehicles, as well as the lack of universal subsidies for the purchase of vehicles. Nevertheless, the implemented legal regulations regarding privileging this type of vehicle in access to city centres certainly influenced the more common use of electric vehicles to distribute loads as part of deliveries made according to last-mile rules.

For vehicles with a gross vehicle weight exceeding 3,5 t, transporting cargo in urban areas and outside urban areas, registered in 2013-2019, it can be stated that diesel engines powered 99% of these vehicles. Nearly 0,5% by gasoline-powered engines. The remaining 0,5% of vehicles were low-emission vehicles, i.e., powered by hybrid, gas (LNG, CNG, PLG) engines, or zero-emission electric engines. The above indicates that in this group of means of transport, there is a lower share of vehicles with zero- and low-emission drives, primarily electric and hybrid vehicles, than in the case of light commercial vehicles. In the years 2013-2019, among heavy commercial vehicles, there was an increase in the number of registered electric

and hybrid vehicles, i.e., those using conventional propulsion (gasoline, diesel) with electric drive, but the number of such vehicles is still minimal compared to the dominant type of vehicles with propulsion in the form of diesel engines.

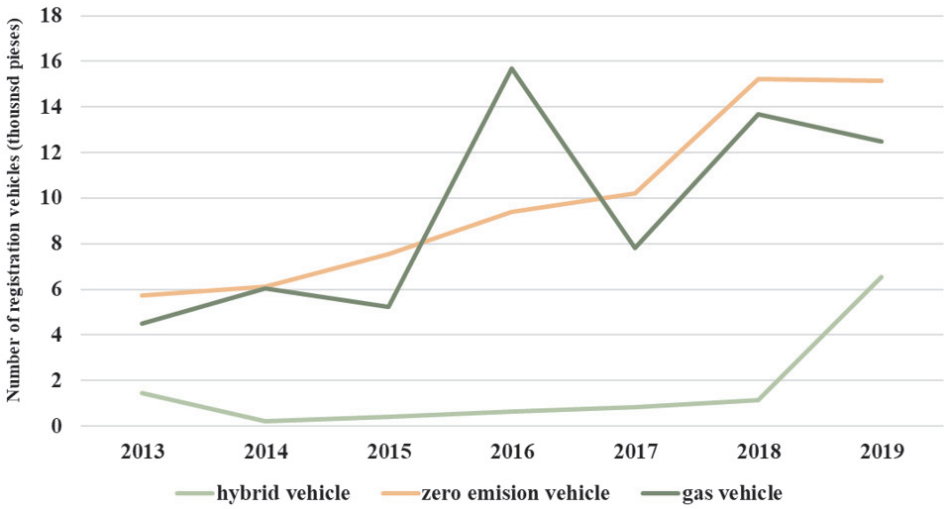

Fig. 3. Registrations of zero and low-emission vehicles with GVW < 3,5 t in the European Union in 2013-2019

Source: Own study based on [Eurostat]

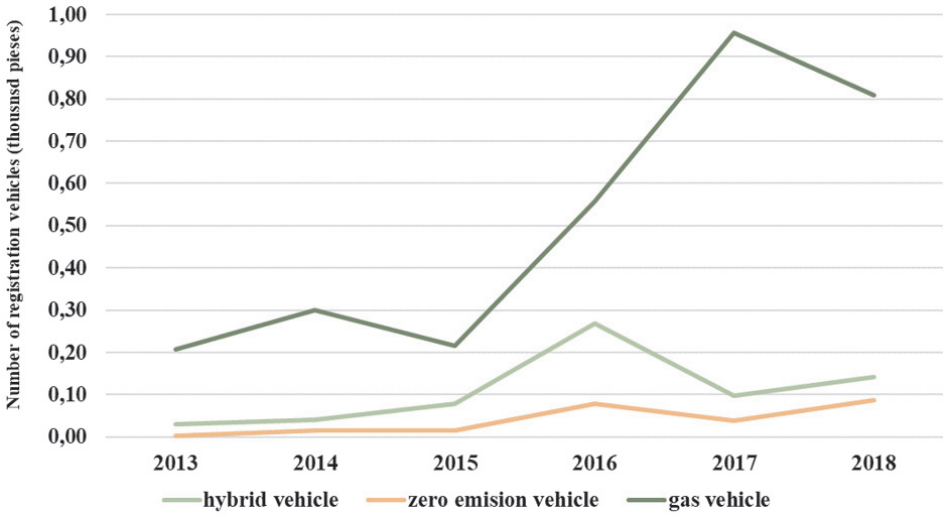

Fig. 4. Registrations of zero- and low-emission vehicles with GVW > 3,5 t in the European Union in 2013-2019

Source: Own study based on [Eurostat]

The above is mainly due to the characteristics of the transport work performed. Loads transported by this type of transport means are outweighed over longer distances, requiring vehicles with an appropriate power source. In addition, vehicles with higher load capacities with electric motors are characterized by much higher purchase prices of new vehicles than similar vehicles with conventional drive. The differences in prices can be almost twofold. Considering the high purchase prices of vehicles with higher load capacity and restrictions on the range of work, vehicles with diesel engines dominate this group of vehicles. Nevertheless, the EU's legal conditions will determine the implementation of new technological solutions in areas such as new materials and charging systems, thanks to which the use of this type of electric vehicle will be more profitable in the coming years.

National and European perspectives on the development of environmentally friendly means of transport

Promoting more sustainable transport, especially in urban areas, is now a priority, confirmed, among other things, by appropriate legal regulations in CO2 emission reduction (European Commission, 2014, 2019). Electric vehicles can support reducing the negative impact of transport on the environment, but there are still significant barriers to the broader use of electric vehicles. However, it should be pointed out that electric vehicles are emission-free in the place of urban operation. The emission of pollutants in producing electricity, among others in Poland, is still significant. Based on PSE data, nearly 80% of electricity in Poland comes from burning coal (Polish Power Grids, 2021). Electric vehicles will be more environmentally friendly if the electricity produced comes from renewable energy sources. The obstacles are technical and economic. Technical barriers attempted to overcome are vehicle weight, which affects operational range, battery life and capacity, and the ability to repair the vehicle quickly. Most of these barriers are analyzed by manufacturers of vehicles and charging systems and resolved on an ongoing basis. Economic barriers are alleviated by introducing systems encouraging the use of electric vehicles, e.g., at the operational, tax, and financial levels, i.e., electric vehicles have easier access to selected urban zones, have unlimited travel around the city, and have numerous discounts or exemptions from local fees (Galati et al., 2021). The location of the appropriate charging infrastructure also influences the more widespread use of electric vehicles. Its inadequate positioning may interfere with the proper organization of shipment plans (Jaller et al., 2020; Jordán et al., 2022) and cause ineffectiveness from the point of view of the provision of transport services. Many initiatives are taken to increase the use of electric vehicles to transport goods under the so-called last mile. When analyzing the number of new vehicles registered in 2013-2019, it can be assumed that their number in scenario II compared to the scenario I (baseline) may double, and scenario III may triple.

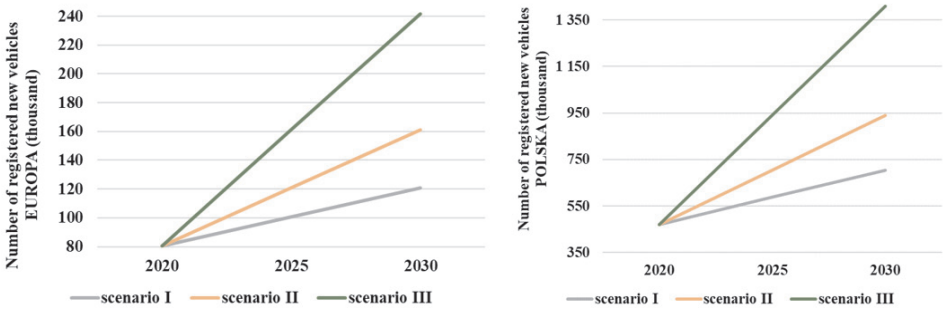

Fig. 5. Number of light zero- and low-emission commercial vehicles, scenarios 2020-2030, Europe and Poland

Source: Own study

For the mentioned scenarios to be achievable, research is carried out on, among others, the fi of the use of new materials for the construction of electric vehicles, which will contribute to reducing their weight and improving the operational range. After 2035, the statistics on implementing zero- and low-emission vehicles will improve. Still, with the current unstable situation in the energy market, it is difficult to predict how the development of zero- and low-emission vehicles among delivery vehicles will progress in the next decade. When analyzing the domestic market, it should be stated that the scenarios for developing electric and hybrid vehicles look more pessimistic based on the above assumptions. The number of low-emission vehicles was about 500 from 2013-2019.

The statistics and scenarios for the development of electromobility presented above indicate a growing interest in using electric vehicles to organize cargo transport. Interest is observed among the companies that provide cargo transportation. However, the anticipated purchase prices of delivery vehicles do not encourage the modernization of the fleet. Considering the adopted restrictions on the sale of combustion vehicles after 2035, the increase in the number of zero- and low-emission vehicles will show much greater dynamics. Still, from today's perspective, it is difficult to predict the pace of implementation of new technologies in the next decade.

Research projects are carried out to verify the profitability of transport by delivery vehicles that demonstrate the actual operating conditions and costs of using electric vehicles. These tests were performed as part of the EKOLOG project made by the Polish Alternative Fuels Association (Kania et al., 2021). Research has shown that through the use of electric propulsion, the potential savings on the annual purchase of fuel for propulsion can reach about 50% of the purchase costs of diesel fuel. In terms of noise and pollution emissions, using electric vehicles reduce noise emissions by about 20 dB and emissions by about 400 g CO_2 per kilometre. It was also found that over 70% of respondents considered the significant nuisance of delivery vehicles and trucks in urban areas in terms of emissions. Nearly 70% of respondents believe

that companies operating in cities should be inclined to change their fleet to more environmentally friendly ones. For this purpose, they should count on support in the scope of subsidies for this transport purchase. The electrification of the vehicles carrying out transport in urban areas will undoubtedly affect the image of transport companies. About half of the respondents claimed that combustion vehicles should not be allowed to enter the central zones of cities until 2030. Comparative analyses regarding vehicle operating costs, which may also affect the preferences for purchasing vehicles. In addition, the development of low-emission vehicles may be influenced by the methods of estimating energy expenditure in enterprises providing transport services in cities (Izdebski et al., 2021). Possible scenarios for reducing emissions of means of transport after the implementation of zero- or low-emission vehicles (Jacyna et al., 2021) can also encourage the widespread of electric vehicles.

Prospects for the development of fuel prices

Propellants used to power means of transport can be divided into those obtained as a result of refining crude oil (mainly liquid fuels such as gasoline, diesel oil, or LPG gas) and electricity, which in Polish conditions is principally obtained as a result of burning fossil fuels, such as coal or natural gas, and to a lesser extent from renewable energy sources (wind turbines, photovoltaic, panels, and others). The policy of sustainable transport development, consistently implemented in the EU countries, directs the means of transport towards their supply by the so-called alternative energy sources, which are assumed to be ecology. At the same time a minimal negative impact on the natural environment. The fast-paced technological development in this area already allows electricity or hydrogen cells to be used effectively. While passenger cars powered by electric energy, fully or hybrid, have been produced since 1997 (hybrid Toyota Prius), those powered by hydrogen cells are just entering production. In the hydrogen technology, the Toyota concern again turned out to be a precursor, offering 2021 the Mirai model in its showrooms, in which the production of electricity takes place on board the car and is the result of a chemical reaction of hydrogen with oxygen.

Apart from the ecological aspects, the prospect of exhaustion of fossil fuel sources and their constantly growing prices drive producers of means of transport towards the development of alternative power supply technologies and renewable energy sources. Unfortunately, at present, alternative technologies are not developed enough (the problem of storing electricity in large quantities that would allow it to travel long distances) to allow for a quick departure from fossil fuels. Therefore, despite the continuous development of alternative energy sources, fossil fuels still dominate vehicle power sources. In Poland, over 80% of electricity is produced from

fossil fuels. The beginnings of their use to power motor vehicles date back to 1885 when Carl Benz built a three-wheeled car with a single-cylinder, four-stroke Gottlieb Daimler gasoline engine (WiktorowskaJasik, 2016). At that time, crude oil was obtained from liquid fuels valued per barrel. This price has fluctuated continuously over the last 100 years (see Figure 9). The first significant increase officially occurred in 1920 and was related to the automotive industry's rapid development industry. Another marked increase in the price of crude oil was recorded in 1980 as a result of the Iranian Islamic Revolution and the subsequent Iraqi-Iranian war. Another significant increase in the price of crude oil in 2008 was caused by a substantial increase in demand for this commodity in connection with the global economic growth recorded in the years 2004-2005. This price almost doubled in 2009 as a result of the worldwide crisis.

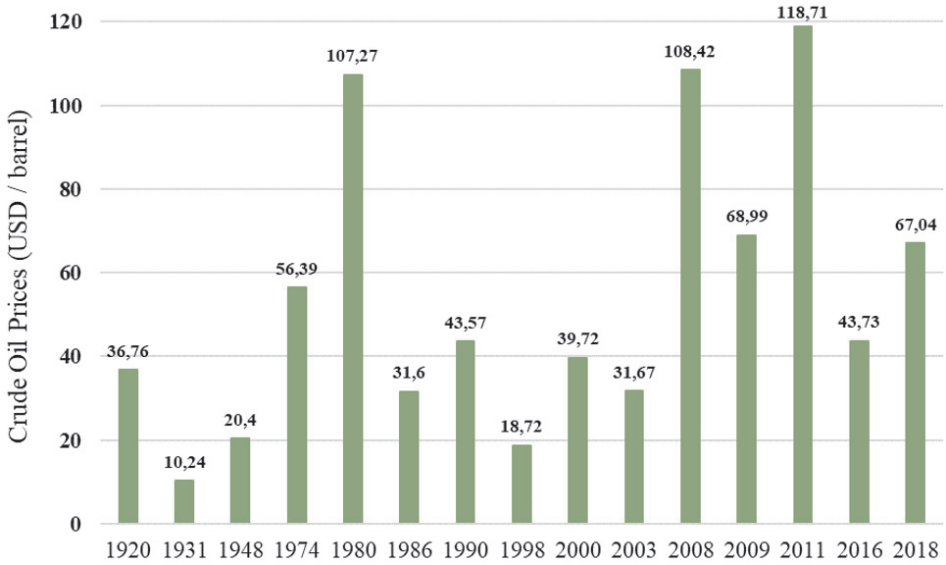

Fig. 6. Crude oil prices in 1920-2018, USD / barrel
Source: Own study based on [BP, 2021]

The above analysis shows how political turmoil, OPEC decisions, changes in supply and demand as well as random events, such as natural disasters, shape the fuel market in the world and may, in a short time, affect the price of crude oil and, consequently, the price of fuel at a gas station. The latter, in turn, is influenced not only by the price of crude oil but also by the costs of its refining, producer and sellers' margin, distribution costs, and the state's fiscal policy. The share of individual expenses is shown in Figure 7.

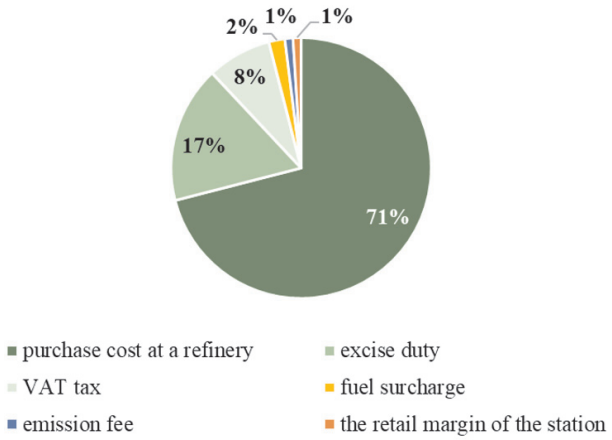

Fig. 7. Percentage share of components of the retail price of unleaded gasoline
Source: Own study

Over the past 20 years, fuel prices in Poland have also changed. Figure 8 shows the changes for the years 2004-2022. In addition to gasoline and diesel prices, gas prices were also compiled, which in Poland in 2021 powered approx. 13.9% of passenger cars.

Analyzing the above charts, it can be concluded that over the last 20 years, the price of fuel for road transport has maintained an upward trend. Their decline in 2008 was caused by the economic crisis and the lower fuel demand. The renewed rise in prices in 2011-2014 was strongly correlated with the high price of crude oil resulting from the political turmoil in the Middle East. Based on previous years, it could be assumed that fuel prices will continue to grow gradually and that they will be strongly correlated with the price of crude oil. Unfortunately, in 2022, fuel prices at gas stations broke away from crude oil prices. This is due to a significant reduction in crude oil import from Russia and the growing US dollar price of the Polish zloty.

In addition to liquid fuels, the prices of electricity used to power electric road vehicles are also constantly increasing. The figure below shows a diagram of changes in the retail electricity price in the years 2004-2022 in Poland. This graph clearly shows that the price of electricity has doubled over the course of almost two decades. Because electricity in Poland comes mainly from coal, the supply has not been disturbed so far. Therefore there are no price fluctuations for electricity as in the case of liquid fuels.

Unfortunately, the prices of liquid fuels and electricity may change significantly in the long run. At the moment, unpredictable political decisions have the most significant impact on the price of fuel or electricity. It should be expected that with the deepening crisis in Ukraine and the related difficulties in obtaining crude oil and other fossil fuels from Russia, the prices of raw materials such as crude oil,

natural gas, LPG, and coal will continue to rise. Problems with obtaining them force individual countries to diversify supplies of these raw materials at a higher price than those from the East.

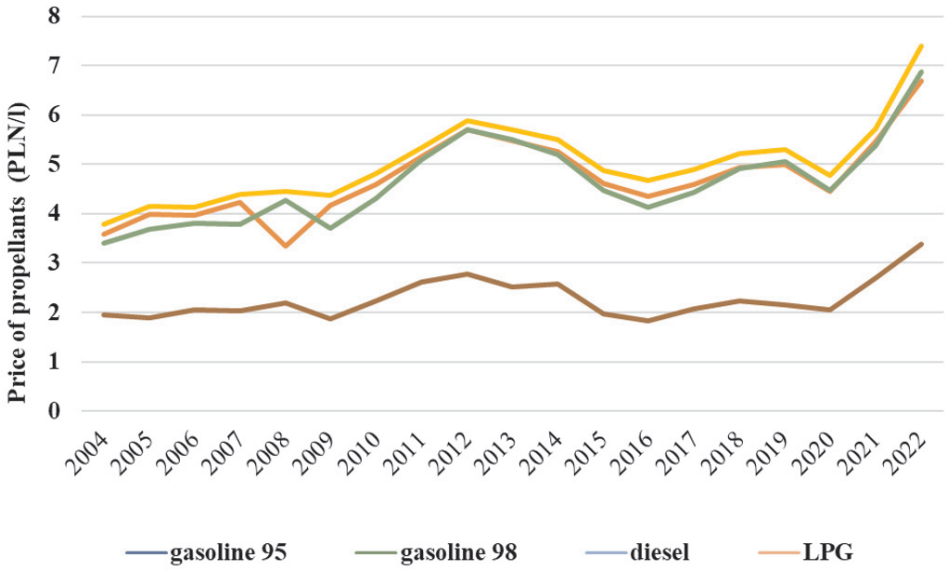

Fig. 8. Retail prices of propellants in 2004-2022, PLN / l
Source: Own study based on [Central Statistical Office]

Fig. 9. Average annual retail electricity prices for household consumers, 2004 - 2022, PLN / kWh
Source: Own study based on [Central Statistical Office, 2021]

The problem of the organization of transport in urban areas in the context of operating costs

The distribution of cargo in urban areas links production and consumption. For the efficient cargo transport in the classical approach, it is necessary to determine the input data, i.e., the number of means of transport at the disposal, types of means of transportation, number of serviced customers, load capacity of means of transportation, the volume of deliveries to customers, costs of direct transport between shipping points and customers, costs of using the means of transport and other external expenses related to the implementation of transport. Ultimately, each transportation plan begins at the starting point and then, after meeting the transport needs of a specific group of customers, ends at the starting point. Factors that contribute to the greater complexity of the problem in this model are cargo consolidation centres and urban transshipment hubs, vehicle characteristics, limited delivery times, delivery times to customers, a large number of recipients in a small area, recipient time expectations and service priorities, various types of vehicles serving a given urban area, spatial structure of cities, limited accessibility to individual city zones, financial consequences of service inconsistent with customer expectations. The main goals of determining the transport plan in urban areas are, therefore: minimizing the overall transport costs depending on the distance travelled by vehicles, types of vehicles used, fixed costs of vehicle use, as well as reducing the number of vehicles and drivers required to service customers, choosing the right roads, delivery time and load capacity of vehicles, adherence to reported delivery times and minimizing the cost of penalties resulting from delayed deliveries.

Transportation plans in urban distribution systems are ordered routes followed by individual vehicles to meet the transportation needs reported by customers in urban areas. During the development and implementation of these transports, the limitations resulting from the specificity of transport organization in the city must be met. More and more often, transport plans for selected means of transportation, serving distribution systems in cities, are determined using specialized computer tools. Computer-aided planning and design achieve the city logistics goal of managing cargo flows to be disruptive and cost-effective. As mentioned earlier, the effectiveness of the transport services depends on the type of transport means used and other transport-related activities. Transport processes carried out the means of transport are part of value chains, the remaining links of which are production, packaging, confectioning, internal logistics, marketing, recycling, and information flow. There are various concepts of value chains, but their common feature is an attempt to map a specific scope of activities necessary to deliver the cargo to the final recipient. Value chain analysis has become more common due to the fragmentation of production, and the components required for a comprehensive analysis of the value chain, mapping its links, assessment, and quality of the flow of cargo, and

information flow allow us to identify all activities necessary to meet the emerging transport needs of end customers. The value chain indirectly influences the value of the service provided or the price of the offered product for sale. The quality of the transport service can therefore be defined as the degree to which the service or product meets the needs of transport users, the process being a function of the technical, operational, and economic characteristics related to the road means of transport, time, and subject of transportation.

The most common cause of transport tasks is e single-criteria optimization tasks that minimise transport activity costs (VRP). Regarding electric vehicles, the VRP issue can be described as ElectricVRP (EVRP). Its solution is to find a set of customer nodes whose transport needs must be met. The problem is to find the best transportation plan for an electric vehicle that minimizes the given cost function while meeting several restrictions and operating procedures for electric vehicles. There are many tools and methods for solving VRP tasks. In these types of tasks, the function of the criterion is usually to minimize the costs of transport or delivery. The costs of transport companies may have the nature of internal costs and environmental costs, which burden society with transport activities. The prime costs of the transport company are depreciation costs relating to the value of fixed assets, costs of consumption of propellants and energy, i.e., fuel, electricity, all administrative costs, costs of external services, e.g., for, warding and handling services, costs of employee salaries, social security, and contributions as a mark-up on remuneration, taxes, and fees for the conducted activity, as well as other costs by type. The specificity of road transport in urban areas allows for a cost analysis of fixed, variable, and additional costs. Fixed costs are as follows: employee salaries with overheads, depreciation costs, costs of property taxes and means of transport, costs of carrier's liability insurance, and costs of periodic inspections. Variable costs depend on the amount of transport work performed. These costs are energy or fuel costs, repairs, inspections, and services, replacement of operating fluids, tire wear, toll costs, and technical inspections. Additional costs are the costs of personnel training, permits for admission to transport, licenses, and registration costs for the transport task. Therefore, the total costs of the transport company's operation are the sum of all the ingredients mentioned above.

Prospects for the development of zero- and low-emission vehicles in urban distribution systems

Considering the increasing share of electric vehicles in the structure of light commercial vehicles, as well as more realistic scenarios of the widespread use of light electric delivery vehicles for cargo distribution in the city, the profitability of using zero- or low-emission vehicles to support transport processes in urban areas

was analyzed. Profitability was analyzed, taking into account various scenarios showing an increase in the prices of propellants. Profitability characteristics of using a given type of vehicle about changing fuel and electricity prices are presented below. Regarding fuel prices, a review of the above-mentioned statistical data was based. In the coming years, an increase in the prices of propellants was assumed at the levels observed in the last five years, i.e., in the period 2017-2022. The rise in gasoline, diesel oil, and gas prices from 2017 to 2022 amounted to nearly 50%. As regards electricity, the price increases were lower and amounted to over 20% in the last five years. Assuming the same growth dynamics in the subsequent five-year periods, a scenario of possible increases in the prices of propellants in 2027 and 2032 was developed. In 2007-2017, petrol prices increased by nearly 8%, diesel prices by almost 15%, and electricity prices by 30%. The smallest increase in prices was recorded for LPG. Nevertheless, the situation in the last five years had a significant impact on the rise in the price of propellants. Despite the end of restrictions resulting from the pandemic, no significant decrease in fuel prices has been observed. The prices of propellants forecast included the pandemic period, which turned out to be an exceptional situation. However, the situation in Ukraine is equally unique and challenging to predict. Considering the economic crisis caused by the pandemic and the armed conflict, complete data for 2007 - 2022 was used for the forecast.

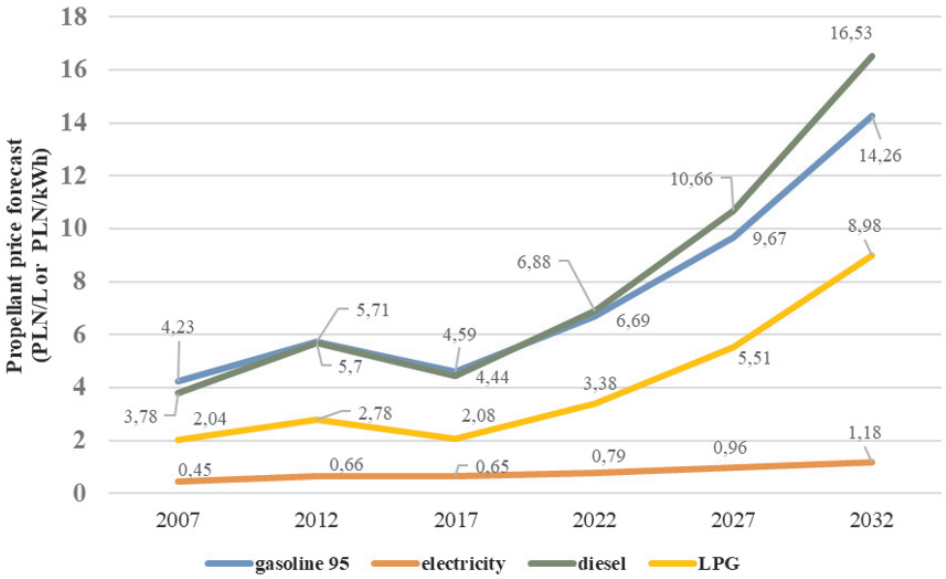

Fig. 10. Prices of propellants statistical data and forecast PLN / l, PLN / kWh
Source: Own study based on [Central Statistical Office, 2021]

The problem of profitability of the implementation of transport plans with the use of various types of new means of transport (first year of exploitation), which were equipped with different propulsion sources (vehicles with electric motors and, for comparison, vehicles with conventional engines, i.e., fuelled with diesel oil, gasoline, and gas) was analyzed. The subject of the analysis was transports performed in the urban area, taking into account the following assumptions:

- the analysis of the impact of propellant prices was carried out over 5-year periods;
- a comparative analysis of operating costs in individual 5-year periods was performed for new vehicles (1 year);
- the issue of the impact of the costs of replacing electric vehicle batteries on the total operating costs was not analyzed;
- cost components that do not affect the actual costs of vehicle operation were omitted due to their occurrence, regardless of the analyzed vehicle type;
- performance of transport work within the range of electric vehicles;
- data on combustion and energy consumption were taken from the catalogues of vehicle manufacturers.

As part of this work, the authors, under the term of vehicle operating costs, understand the costs of repairs, service, technical inspections, insurance, depreciation, and used propellants. To estimate the above operating expenses, the prices of fuels indicated above in Fig. 10 were adopted.

Regarding vehicles with a capacity not exceeding 1 t, transporting in urban areas, with different prices of propellants resulting from historical data and the forecasts mentioned above, it can be concluded that the total operating costs were understood as costs of repairs, service, technical inspections, insurance, depreciation, and used propellants of electric vehicles in the first year of operation are higher than that of conventional vehicles. The above is mainly due to the high purchase cost of an electric vehicle.

The prices of electric vehicles will undoubtedly change in the coming years; this aspect has yet to be analyzed. With the continued increase in fuel prices, already in 2027, the operating costs of the new electric vehicle will turn out to be lower in the first year of operation than the operational costs of vehicles powered by conventional propellants. This perspective means favourable conditions will arise for the more widespread use of zero- or low-emission vehicles for cargo distribution in urban areas.

For delivery vehicles with a capacity exceeding 1 t, transporting in urban areas, assuming different prices of propellants resulting from historical data and the forecasts mentioned above, it can be concluded that the total operating costs of electric vehicles are even higher than conventional vehicles in the first year of operation (compared to vehicles with a capacity of up to 1 t). Moreover, the balance point of the total operating costs in the first year of vehicle use is delayed by about five years due to the significantly higher purchase prices of new electric vans than conventionally driven vehicles.

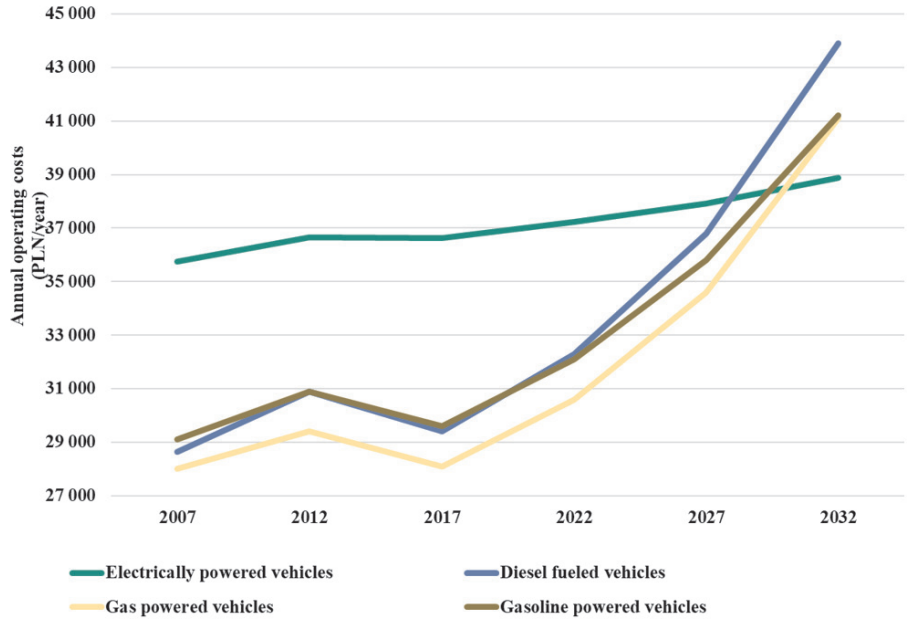

Fig. 11. Operating costs of new vehicles powered by various propellants, load capacity up to 1 t
Source: Own study

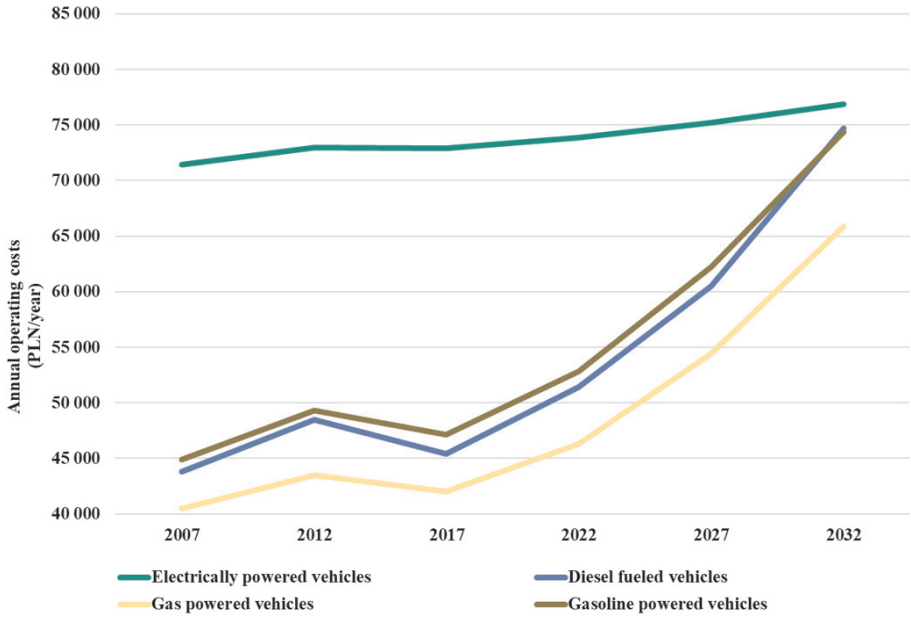

Fig. 12. Operating costs of new vehicles powered by various propellants, load capacity above 1 t
Source: Own study

The equilibrium point of TCO is more distant for vehicles with a load capacity above 1t, but potential savings from using electric vehicles can be observed. Considering the adopted legal solutions in the EU regarding the ban on the sale of combustion vehicles after 2035, transformation in the field of electric vehicle types is inevitable.

The above simulations indicate the increasing profitability of using zero- or low-emission vehicles due to the progressing wave of growth of propellants and energy. When analyzing the costs of operating a vehicle in individual years of its use, the profitability of using electric vehicles is higher in the case of vehicles with a lower load capacity. However, this condition is very much influenced by the cost of fuels and electricity.

Conclusions

In the coming years, transport services in urban areas will be performed by zero- and low-emission rolling stock, especially in light delivery vehicles. The prices of these types of vehicles are comparable to conventional vehicles; the total cost of operating UAVs may be lower over the lifetime with external subsidies and discounts. Simulations of the operating costs of various types of vehicles, presented in Fig. 11 and Fig. 12, indicate that in the coming years, it is possible to more widely implement zero- or low-emission vehicles for deliveries in urban areas. The above is also in line with legal reports on limiting or eliminating the introduction of internal combustion vehicles to the market after 2035. The situation is different in the case of vehicles transporting goods with a carrying capacity of over 1 tonne. Still, in the coming years, the scale of implementation of zero- and low-emission vehicles for transport in urban areas will continue. The next decade will be a breakthrough in the technological transformation planned for 2035 among commercial and passenger vehicles in the EU.

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