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ECONOMIC AND ECOLOGICAL ANALYSIS OF VEHICLES USED IN RAILWAYS

Abstract

The dynamic development of transport recorded in recent decades is an essential factor in the economic development of the world, but on the other hand it is an important source of nuisances and environmental problems. The negative impact of transport can be felt both in the natural environment and in society. However, the dynamic development of this sector has enabled significant civilization development, with the effects vary depending on the level of advancement, the level of economic development, the use of various transport sectors, geographical location as well as environmental natural. Considering the significant development of transport and the increase in its popularity, an important element for the industry is the use of the most efficient and affordable vehicles. In addition, with modern transport threats, it is important to prevent them or minimize not only for environmental reasons, but also for financial reasons.

The article presents an economic analysis of the environmental and social burden of transporting goods by means of various means of transport. Economic analyzes of rail and road-rail vehicles were also taken into account. They focused on such aspects as: purchase, exploitation and comparative indicators.

Keywords: rail-road vehicle, semi-trailer, rail transport, environmental protection, economy of transport

JEL: R49, Q530

Introduction

Europe is facing a major economic challenge in the coming years. The European Union has committed itself to taking a leading role in the fight against climate change. Among the main climate initiatives of the EU is the European Commission's White Paper on Transport, which aims to reduce CO_2 emissions by 60 percent by 2050. In this context, it is important to understand the impact of switching to low-emission vehicles also in rail transport. The rolling stock which includes: passenger and freight locomotives, and shunting, passenger freight wagons, electric multiple units and rail-road vehicles are classified vehicles as vehicles with a long service life. The average lifetime of rolling stock currently reaches 32 years for locomotives and 35 years for wagons, which is the result of major repairs as well as vehicle upgrades. Long life of the rolling stock causes its use both in the physical dimension (aging, reduction of efficiency and reliability, increase in operating costs) as well as in the economic dimension – loss of functionality, low travel comfort in the case of passenger rolling stock or lower efficiency compared to the new rolling stock. Loss of utilitarian properties of vehicles as a result of long-term exploitation, as well as technical progress in the production of new vehicles and increasing requirements for energy consumption and environmental protection, force carriers to carry out a specific fleet renewal policy, which is linked to a continuous analysis of the rolling stock age structure and technical condition. The main method of limiting the emission of exhaust gases, and thus the emission of harmful compounds is the reduction of fuel consumption by engines and the possibility of replacing vehicles with solutions with less negative impact on the natural environment. New technologies of rail vehicle drives developed in recent years have enabled the use of various methods of traction vehicle drive. In addition to conventional solutions using internal combustion engines and electric drives on electric traction tracks, newer solutions such as hydrostatic drive, hybrid drive systems, CNG (Compressed Natural Gas) supply, or hydrogen powered fuel cells are used more and more often.

New vehicles used in the railways

The emphasis on the development of new propulsion technologies is caused by the growing requirements related to ecological aspects, namely the reduction of toxic compounds emissions from means of transport and the increase in the efficiency of drive systems and vehicle economics, which is why more and more attention is focused on the use of two-way vehicles. The trend for all categories of vehicles powered by the combustion engine is the continuous reduction of emission limits, also for non-road vehicles, which include two-way vehicles with internal combustion engines.

Special vehicles moving along tracks are often truck designs (e.g. Iveco, Scania, Volvo, Mercedes-Benz – for conducting train and maneuvering works on railway sidings), but also Ursus, Crystal and Claas tractors are increasingly used. The latest examples of this solution are rail-road tractors designed for works related to rolling wagons along tracks (narrow and wide) equipped additionally with a creeper gear reducer and narrowed track width. The CLAAS model ARION 600 rail vehicle is the most versatile solution among tractor models. It offers the largest range of possibilities and additional applications.

Tractor equipped with IPS TABOR in appropriate systems, enables driving on railway tracks and connection with railway wagons, thanks to which it can perform works both as a locomotive and as a tractor for towing on the road.

The main design features of this type of motor vehicle enable:

– access to the tracks on any level crossing;
– easy insertion of the vehicle on the track;
– straight downhill from the track to the road;
– operation on tracks of various width (1524 mm; 1435 mm);
– easy adjustment from normal to wide track;
– access by local roads to the destination place.

The model of the CLAAS ARION 620 rail-road tractor competes with the European rail-road vehicles, whose purchase price is almost three times higher in relation to the rail-road tractor made in the Rail Vehicles Institute TABOR belonging to the Łukasiewicz Research Center (Figure 1). Tractors of this type can be used on normal or wide tracks by using a changeable rail chassis. The time of moving the spacing of the guide rolls from the normal track to the wide one and vice versa is about 1 minute for four guide rollers.

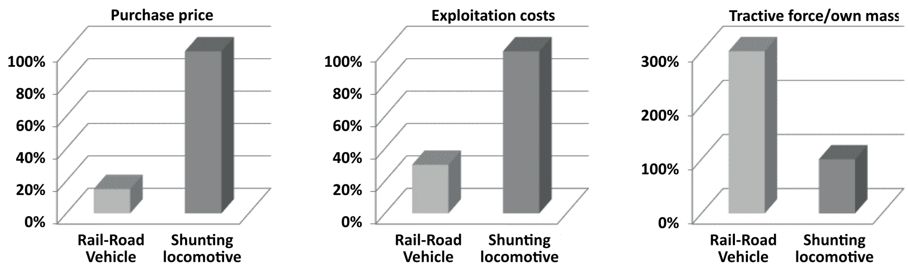

Figure 1. Economic comparison of a rail-road vehicle and a shunting locomotive
Source: (own elaboration)

In addition, this type of tractor may conduct maneuvering work with freight wagons, passenger cars, locomotives and traction units. The introduction of the tractor into the track by an efficient operator is within 1–2 minutes and in special cases it is also possible outside the flat terrain, where the level of the ground is not located at the level of track rail heads.

The document entitling to drive this type of vehicles within the railway siding is the driver's right to drive the vehicle referred to in Annex 7 to the Ordinance of the Minister of Infrastructure and Development issued by the employer 30 December 2014 Dz. U. from 2015 item 46.

The use of rail-road vehicles is justified both in terms of economy and ecology, by achieving a significant reduction in CO_2 emissions per tonne-kilometer, not only in relation to diesel locomotives, but also in comparison with road or air transport.

Pursuant to the provisions concerning the reduction of CO_2 emissions by 2050, rail transport is to be the least emission one, especially due to the possibility of using Stage IIIB emission standards (Bryk, Łukaszewski, Medwid, 2016; Daszkiewicz, Andrzejewski, 2017) of this type of motor vehicles for various maneuvering tasks.

Economic analysis for various types of transport

The most important areas of formation of logistic costs in business units include: – transportation of cargo – understood broadly and covering preparatory activities of transport means, proper transport, that is, movement of goods or persons, return to the base, stoppages related to transport law or loading/unloading conditions – manipulation of the load – it occurs between the stages of the logistics process throughout the entire supply chain; includes both loading/unloading operations as well as cargo handling in storage places and marking, conversion, packaging, storage of cargo – it also includes costs of adjusting the storage area to a given type of cargo and all activities related to the functioning of the warehouse and securing the cargo against the effects of extraordinary events – ordering process – including all purchase costs borne by the company in the process of ordering the goods, starting from the costs resulting from preparatory activities (for example searching for a supplier), through the costs of changing documentation, participation in fairs and the like (Martino et al., 2009). However, the basic service carried out on the logistics services market is the transport service. It results from the need to move goods from one place to another in order to meet a specific need. The intense increase in the exchange of goods, including international trade, the progressive specialization of work contribute to the significant development of transport services. This is related to the fact that transport plays a very important role in the national economy, enabling efficient and effective functioning of all its departments. Each transport of materials can be carried out using various means of transport. The analysis of the cost of transporting a load for a load transported with only one means of transport is presented below, an example of a rail freight transport scheme is shown in Figure 2.

The presented analysis is based on the cost-effectiveness analysis basing on the idea of comparing alternative projects with a unique joint effect, which may vary in size. This method is aimed at selecting a project that, for a given product size, minimizes the updated net value of costs or, optionally, maximizes the product size for a given cost. AEK results are useful for projects whose benefits are very difficult or even impossible to estimate, while costs can be predicted with more probability. This methodology is often used in the economic analysis of programs in the field of health care, research, education and environmental protection. The basis for the assessment in economic terms in the integrated approach is the individual approach to environmental goods. On this basis, it is estimated directly or indirectly (in the case of public goods for which there is no market) willingness to pay (WTP) in case of additional benefit or willingness to accept (WTA) – in the case of financial compensation for deprivation of such an advantage (Martino et al., 2009). These are concepts related to consumer choice models. The estimation techniques generally used are based on demand curves (for disclosed and declared preferences that can be considered complementary rather than alternative) or on different approaches such as defensive expenses, dose-effect functions and – damage costs that apply for estimating external costs related to climate change (Martino et al., 2009).

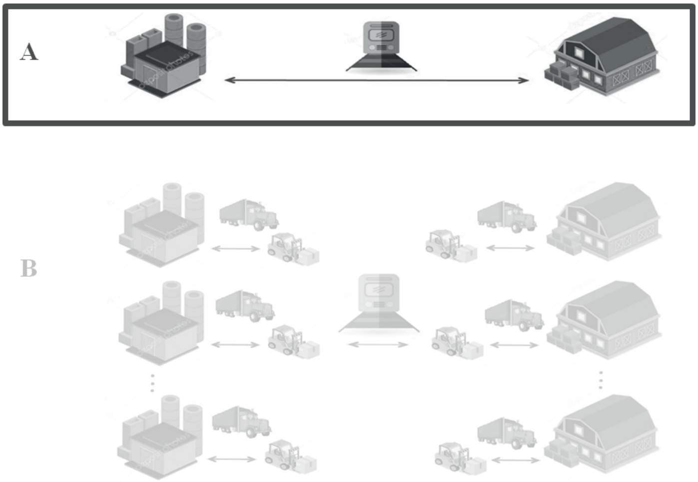

Figure 2. The structure of transport of cargo in transport: A – transport of cargo by rail, B – transport of cargo using several means of transport
Source: (own elaboration)

A transport accident by definition is an event in land, sea or air traffic in which at least one vehicle participates and which results in damage to property or damage to persons involved in it. In the cost statement resulting from the occurrence of such an event related to 1000 tonne-kilometer (Figure 3), there is a significant difference between road transport and rail transport as well as rail-road vehicles. Whereas the last two types of transport are at the same level of 0.2 EUR/1000 tonne-kilometer, the average costs of accidents in road transport are 51 times higher and amount to 10.2 EUR/1000 tonne-kilometer (Engelhardt, 2016). Such a big difference is caused by the mass of goods that a given vehicle can carry. Although road transport is the most popular on the market, is not characterized by high transport capacity comparing to rail transport. Rail-road vehicles combine some of these features. The transportability of such a vehicle is significant compared to road transport. In addition, such vehicles are usually produced on the basis of road vehicles, the accessibility of which to spare parts is quite easy.

The sound of excessive intensity in a given place and time is perceived as onerous and harmful, colloquially known as noise may have financial consequences. Long-acting on the human body has a negative impact on his health. For this reason, an important aspect is its maximum limitation. In the case of road transport, costs due to noise levels are the highest among the types of vehicles presented. This value is estimated at 1.8 EUR/1000 tonne-kilometer Railway transport is characterized by a lower cost factor related to tonne-kilometer and amounts to 1 EUR.

The lowest cost/tonne-kilometer ratio is marked by road-rail vehicles – 0.3 EUR/1000 tonne-kilometer (Engelhardt, 2016). This is due to the considerable transport capacity of such a vehicle and the lower noise generated. Hence, the costs caused by the noise level are the lowest for rail-road vehicles (Figure 4).

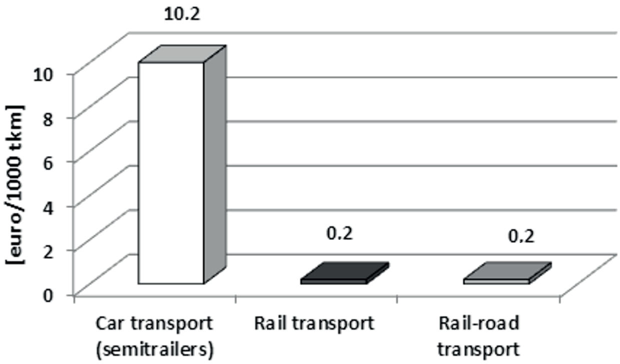

Figure 3. Average costs resulting from accidents with respect to 1000 tkm for car transport (semitrailers), rail transport and rail-road transport
Source: (own elaboration)

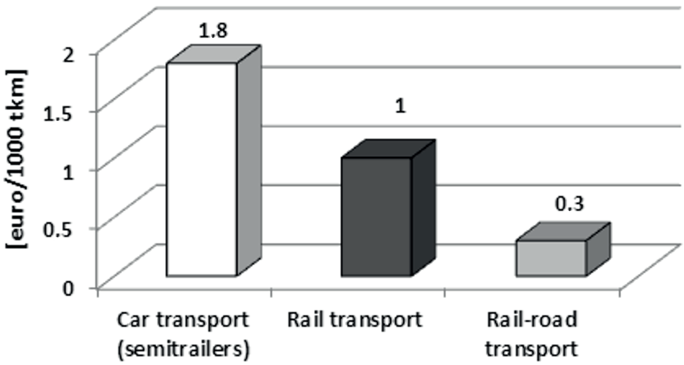

Figure 4. Average costs resulting from noise level in relation to 1000 tkm for car transport (semitrailers), rail transport and rail-road transport
Source: (own elaboration)

Air pollution is the cause of global environmental threats. It is estimated that around 14% of total air pollution comes from transport. The associated costs related to 1000 tonne-kilometer (Figure 5) are the largest in the case of road transport – 6.7 EUR/1000 tonne-kilometer (Engelhardt, 2016). This coefficient for rail transport is equal to 1.1, and for rail-road vehicles 0.2. This means that the costs of using the aforementioned form of transport are 5.5 times smaller than rail vehicles and 33.5 times lower than in road transport. This condition is caused by the high popularity of internal combustion engines. In the case of transporting goods with car transport, the utilization rate is almost 100%. In addition, the transport capacity of motor vehicles is much smaller than other types of vehicles, therefore in this case this factor has reached such a high value. Railway engines also use combustion engines but also emission-free electric motors. Hence, this coefficient due to the use of such propulsion systems and the possibility of transporting a large quantity of goods is 6 times lower than in road transport. In the case of rail-road vehicles, such a low value of the coefficient is due to lower emission values due to the use of much smaller engines than in rail vehicles and high transport capacity.

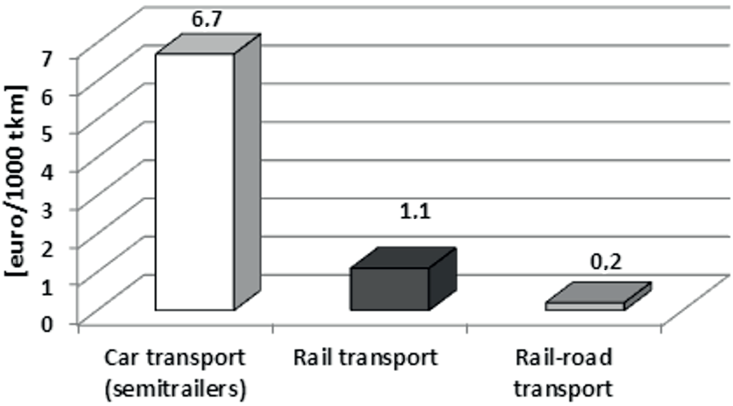

Figure 5. Average costs resulting from air pollution with respect to 1000 tkm for car transport (semitrailers), rail transport and rail-road transport
Source: (own elaboration)

Greenhouse gases responsible for the greenhouse effect, i.e. the phenomenon of increasing the temperature of the planet, are the main emission problem in internal combustion engines. Water vapor and carbon dioxide as the main components of combustion are directly related to the amount of fuel consumed. The more fuel burned, the more greenhouse gases. Costs related to this phenomenon related to 1000 tonne-kilometer are shown in Figure 6. The highest costs for car transport – 1.7 EUR. In the case of rail transport, this value is EUR 0.2 and for rail-road vehicles it is EUR 0.1 (Andrzejczak, Selech, 2017). In this case, the factors that affect it are the amount of fuel burned and the size of the engines. Car vehicles with the lowest capacity therefore have the highest cost coefficient. Rail vehicles with the highest transport capacity at the same time consume a lot of fuel due to the use of huge traction motors. On the other hand, rail-road vehicles with a large transport capacity and engines of similar size as motor vehicles or smaller have the lowest cost factor due to greenhouse gas emissions.

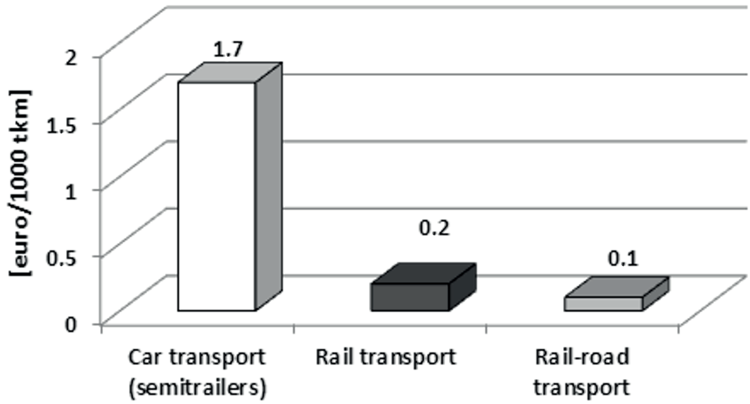

Figure 6. Average costs resulting from greenhouse gas emissions in relation to 1000 tkm for car transport (semitrailers), rail transport and rail-road transport
Source: (own elaboration)

In the case of the infrastructure cost factor related to 1000 tonne-kilometer (Figure 7), the lowest value is provided by road transport – 2.45 EUR. The value for railway and rail-road vehicles is 2.9 euro due to the same way of moving (Andrzejczak, Selech, 2017). The costs of road infrastructure are much smaller than in the case of railway infrastructure. The reason is a great complexity and the amount of necessary elements that make up the railway infrastructure.

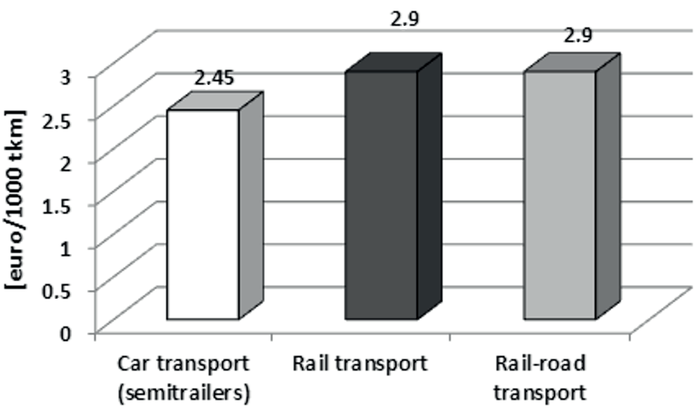

Figure 7. Average infrastructure costs in relation to 1000 tkm for car transport (semitrailers), rail transport and rail-road transport
Source: (own elaboration)

The costs resulting from congestion (Figure 8), i.e. the phenomenon of increased transport traffic from the transport capacity used by them, are the largest for road vehicles – 0.388 EUR/1000 tonne-kilometer (Engelhardt, 2016). This is the result of the popularity of using this type of transport and the need to share road infrastructure with other users. In addition, the efficiency of travelling a given road distance depends on many temporary factors that cannot be predicted. In the case of railways, the predictability of travel is much higher due to top-down planned rolling trips.

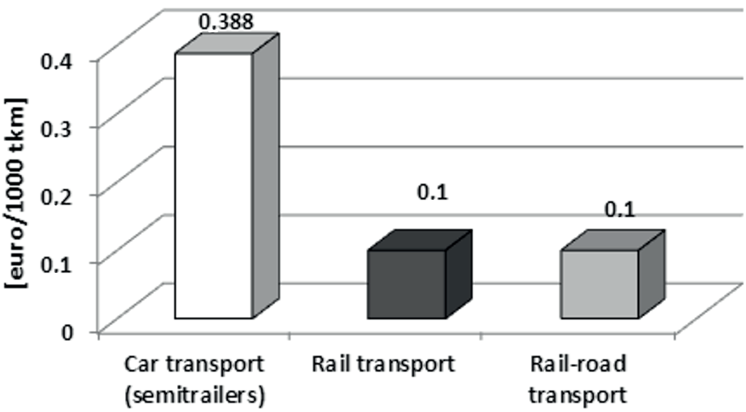

Figure 8. Average costs resulting from congestion with respect to 1000 tkm for car transport (semitrailers), rail transport and rail-road transport
Source: (own elaboration)

Figure 9 presents the total amount of environmental nuisance expressed in EUR/1000 tonne-kilometer for three types of transport. The highest cost of transporting goods for the environment is related to the transport of goods by road using semi-trailers, which causes the cost of environmental nuisance at the level of over EUR 23. The lowest costs are transported using two-way vehicles at a level of less than 4 EUR, due to a 10-times lower cost of buying rail-road vehicles than locomotives (Merkisz et al., 2016).

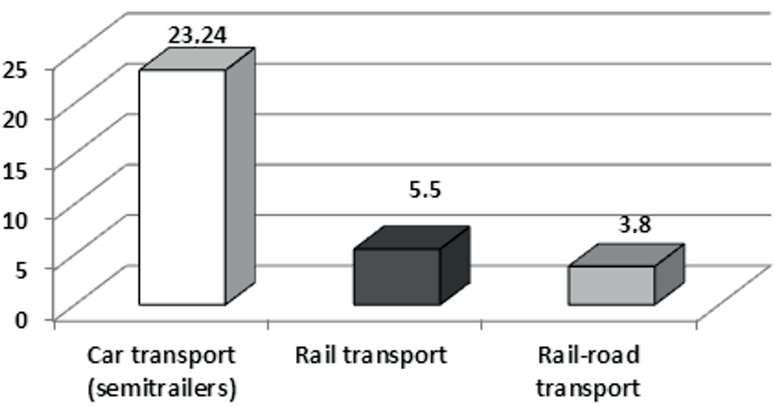

Figure 9. Total costs of environmental nuisance in relation to 1000 tkm for car transport (semitrailers), rail transport and rail-road transport
Source: (own elaboration)

Economic analysis of rail-road tractor

In the case of the purchase price of a given type of vehicle, the difference between a rail-road tractor and locomotives is very large. The cost of a two-way tractor with full equipment is around PLN 500,000. On the other hand, the cost that the customer must incur when purchasing a shunting locomotive is PLN 8 million and PLN 10 million in the case of an electric locomotive. This means that the company can purchase 16 or 20 rail-road tractors in turn for the price of a shunting locomotive (Figure 10).

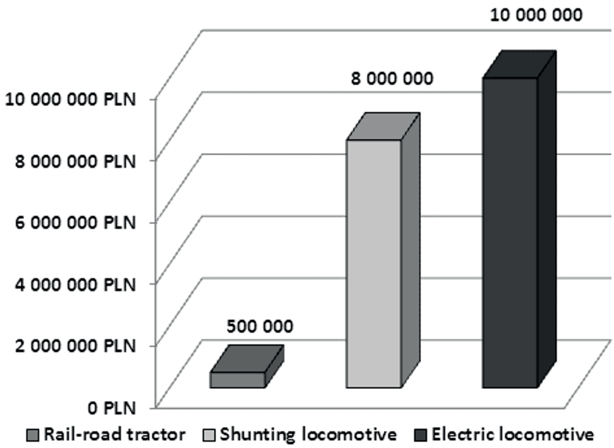

Figure 10. Purchase price for rail-road tractor, shunting locomotive and electric locomotive
Source: (own elaboration)

An important aspect during the service of a given vehicle are operating costs. In this comparison, a shunting locomotive with the highest operating costs was accepted as a 100% benchmark value. An electric locomotive has 30% lower maintenance costs compared to a shunting locomotive. On the other hand, the operating costs of a rail-road tractor due to the less complicated construction and dimensions are 70% smaller than the shunting locomotive (Figure 11). The cost of 10 million for the locomotive was adopted on the basis of recent offers submitted by domestic locomotive manufacturers for PKP Intercity, the lowest of which was PLN 12.6 million. The cost of repairing the main and complete modernization of the locomotive is less than half of the purchase amount of the new locomotive, however, the possibility of obtaining EU funds means that carriers are more and more often seeking subsidies and exchanging rolling stock with a new one.

Analyzing the tractive force to the mass, based on Figure 12, it can be clearly stated that the two-way tractor, despite the smallest own weight, can transport loads of 10 wagons. When considering a tractor, as a motor vehicle, which is to replace the work of a locomotive, it is important to know how many wagons a tractor can roll. The ideal solution would be to work with all, at least a dozen or so wagon trains, but for the tractor these values are not available. An essential parameter is to determine the maximum traction force. The tractive force is caused by the friction between the rail head and the vehicle tire, therefore, if you want to pull a set of 10 wagons, it is necessary to have the correct pressure of the tire against the track rails. Gross Vehicle Weight (GVW) is directly related to the construction so that the built-up vehicle can move on public roads (for other work).

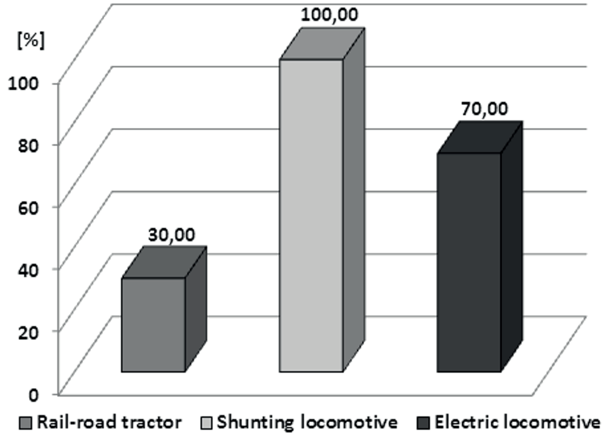

Figure 11. Exploitation costs for rail-road tractor, shunting locomotive and electric locomotive
Source: (own elaboration)

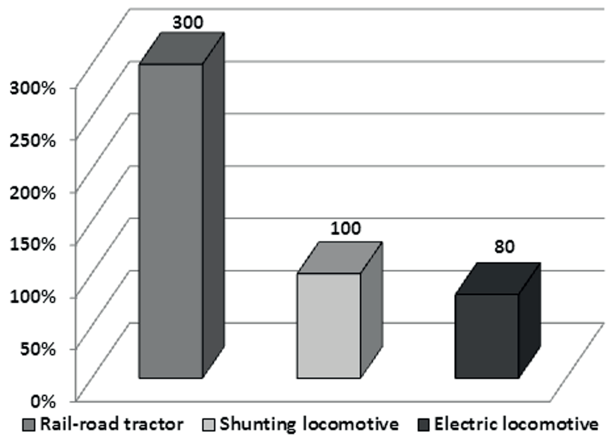

Figure 12. Tractive force/own mass ratio for rail-road tractor, shunting locomotive and electric locomotive
Source: (own elaboration)

Considering the energy/fuel cost (Figure 13), the lowest unit cost is the electric locomotive. Unfortunately, in our country, 95% of electricity comes from the combustion of coal, so despite the lowest cost of electricity in the event of costs associated with the emission of toxic compounds, the values of these indicators will be quite different.

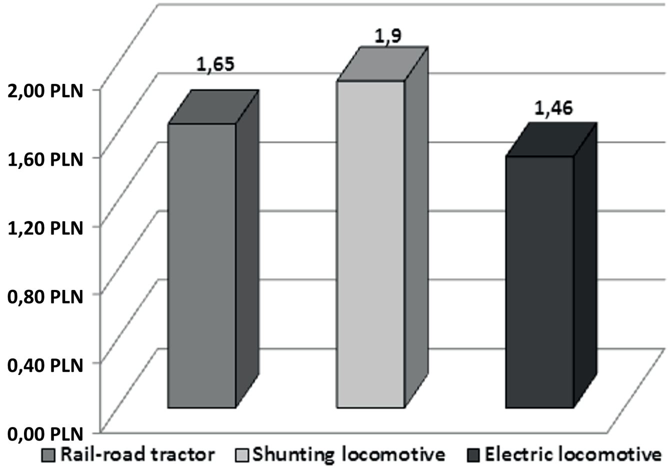

Figure 13. Energy cost/fuel ratio for rail-road tractor, shunting locomotive and electric locomotive
Source: (own elaboration based on: Martino et al. 2009; Merkisz et al., 2016)

Conclusions

The developing two-way vehicle industry and available data estimate that the number of two-way vehicles in Poland is several dozen. In addition to inspection and repair halls, they will also be used in warehouses with railway sidings. According to the data available in the Kompass catalog, there are 75 companies in Poland that support this type of warehouses, which requires maneuvering, and vehicles of this type will be used at Intermodal Terminals. According to the data of the Central Statistical Office "Intermodal transport in Poland in 2018", 24 terminals, of which 24 served rail-road shipments. According to the data of the Office of Rail Transport in 2019, on the basis of a license issued by the President of UTK, freight transport can implement 68, and passenger carriers – 17, which is another group of potential customers of two-way vehicles. According to the report of the Railway Market "Railway Rolling Stock in Poland 2017" there are currently 13 of them.

Taking into account the above initial analysis of the target market, assuming the national demand for 1 system for each of the above mentioned companies, we obtain a number of approximately 200 two-way vehicles. It is also necessary to consider the interest of foreign entities, especially from Europe, which creates additional export possibilities for the rail-road vehicle solution.

In the field of motor testing of rail vehicles, advanced cognitive work is carried out. They mainly concern determination of pollutant emission and fuel consumption during actual operation. Due to the specificity of railway vehicle operation and track infrastructure, this type of measurements have been significantly limited recently, mainly due to exceeding the dimensions of the railway gauge by the facility with the equipment installed, therefore it is very difficult for the evaluation of ecological indicators to refer to the total costs of environmental nuisance from transported goods by various means of transport. Progressing miniaturization covering all areas of life, including measuring equipment for research that once was impossible to perform, today become feasible. The conducted analysis allowed to indicate the results, which prove the fully justified use of rail-road vehicles during track work. The economic calculation carried out so far has shown that the costs of operating the tractor in relation to the shunting locomotive are about 60% lower. The analysis of toxic compounds emission presented in the article clearly shows that a rail-road tractor with a load emits 74.8% less toxic compounds during the same work than the diesel locomotive. It should be emphasized that at stops, during which the locomotive works all the time at idle, the tractor has an easy possibility of immobilizing the drive unit.

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