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ELECTRIC ROAD TRANSPORT IN POLAND – AN ANALYSIS OF EXTERNAL COSTS

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ABSTRACT: The paper assumes the possibility of having road transport based entirely on vehicles propelled by electric motors. Taking into consideration the numbers of the particular vehicles and their technical parameters, the theoretical energy requirement for this sector of transport was determined. The objective assumed in the paper was to assess the difference in external costs related to the operation of combustion and electric vehicles accomplishing all of the current tasks of the road transport in the conditions of the Polish transport and energy system.

KEY WORDS: road transport, electric vehicles, external costs

 JEL: Q51, Q53

Introduction

Road transport has a significant share of air pollution resulting from emission nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), particles with a diameter of 2.5 µm ($PM_{2.5}$), particles with a diameter of up to 10 µm (PM_{10}) and carbon dioxide (CO_2) both in Poland and in the EU (table 1). The largest share of emission is connected with NO_x – 30,4% for Poland and 39,4% for the EU. In the case of NMVOC emission, road transport in Poland has twice bigger share than in the EU (19,3% compare to 10,6%). Share of emissions of other compounds ranges from 9.0% to 13.4% and these values are comparable to Poland and the EU.

Table 1. Road transport share in total NO_x, NMVOC, $PM_{2,5}$, PM_{10} and CO_2 emissions in Poland and in the EU in 2014 [%]

	NO_x	NMVOC	$PM_{2,5}$	PM_{10}	CO_2
Poland	30,4	19,3	13,4	9,0	12,3
EU	39,4	10,6	13,1	11,5	11,5

Source: Eurostat database (Environment and energy, Air emission inventories).

Considering that, it is no surprise that actions are taken, aimed at reducing the emissions of pollutants in this sector of economy. Since the early 1990s, more and more restrictive fuel emission standards have been successively introduced, and since 2015, standards of CO_2 emissions have also been in force. Even though these measures bring effects in the form or decreasing emissions of NO_x, $PM_{2.5}$, PM_{10}, NMVOC, and also CO_2 in recent years (Preisner, Trela, 2013), in the EU, the European Commission more and more emphatically stresses the necessity of an evolution of the combustion road transport towards electromobility arguing at the same time that the negative impact of this type of drive on the environment is negligible. It is just electromobility that is supposed to ultimately reduce the emissions of pollutants and thereby reduce external costs related to the operation of means of road transport. Thus, the purpose of the paper is to assess the external costs associated with operation of road vehicles in the Polish conditions, with the assumption that all vehicles are powered electrically; and to draw conclusions as to the direction and magnitude of changes, based on a comparison with corresponding costs for the currently operated fleet of vehicles.

Technical aspects of electric drives of road vehicles

Current for powering electric motors in the currently manufactured cars comes from batteries that have to be first charged with mains current, or from reactions in fuel cells that require refuelling with hydrogen. The choice of the manner of acquiring electric power for the drive depends on the type of vehicle and related technical and financial considerations.

Passenger cars

When creating electric vehicles, manufacturers concentrated first of all on the category of passenger cars. In this category, there are available both battery-driven vehicles and ones utilising fuel cells. With regard to the size of the offer (the only mass-produced vehicle powered with fuel cells is Toyota Mirai, not offered in Poland), the purchase price of a fuel-cell-powered vehicle, which is more than twice as high as for a battery-driven vehicle, as well as its operating costs (the cost of hydrogen is approx. PLN 50/100 km), it was assumed that the analysis would concern a model of a battery-driven vehicle. Vokswagen e-Golf was chosen as the most representative model because a corresponding combustion-engine driven vehicle has invariably been one of the best-selling models in Europe and in the world.

Key technical specifications concerning this model:

- Horsepower: 100 kW
- Max speed: 150 km/h
- Range: 300 km
- Energy consumption: 12,7 kWh/100 km
- Charging time (socket/charger/ specialised charging station up to 80% battery capacity): 17 h/5 h 20 min./45 min.

Light commercial vehicles

Light commercial vehicles, i.e. those with a maximum Gross Vehicle Weight (GVW) not exceeding 3.5 tonnes, are manufactured in the electric versions exclusively as battery vehicles. The most popular model in this category is Renault Kangoo Z.E., and it was this model that was included in the analysis. At the same time, is should be remarked that mass-produced light commercial vehicles with a higher capacity are not available at present. According to the manufacturers' announcements, Renault Master Z.E. and Volkswagen e-Crafter are to be launched in the marked by the end of 2017. It was decided that the representative mode in this group would be Renault Master Z.E due to the more credible data that are available from experience in the operation of electric commercial vehicles.

Key technical specifications concerning models Renault Kangoo Z.E./ Master Z.E.:

- Horsepower: 44/57 kW
- Max speed: 130/115 km/h
- Range: 270/200 km
- Energy consumption: 12,2/16,5 kWh/100 km
- Charging time (charger): 6/6 h
- Load capacity: 650/1000 kg.

Heavy goods vehicles

In the case of heavy goods vehicles, the limited range of electric vehicles makes their practical application only marginal. The currently manufactured structures are only capable of accomplishing distribution tasks in city centres where mileages are not high, and a range of 200 km or even 100 km can be sufficient. A representative of vehicles with payloads up to 5 tonnes can be Fuso eCanter, quite popular in this category. In the case of vehicles with payloads above 5 tonnes and below 15 tonnes, the analysis includes Mercedes-Benz Urban eTruck currently being launched in the market. And in the case of the heaviest vehicles and road tractors, the Nikola One project was considered to be a representative vehicle. The first vehicles of this model are to be manufactured in 2017, and the series production is to be launched in 2019. While the two previously mentioned vehicles are powered by batteries, the Nikola One is to have fuel cell as it is only such solution that currently enables reaching a range that would be satisfactory to owners of the fleets operating on long distances.

Key technical specifications concerning models Fuso eCanter/MB Urban eTruck/Nikola One:

- Horsepower: 185/500/735 kW
- Power source: li-ion battery/li-ion battery/fuel cells
- Range: 100/200/1800 km
- Energy consumption: 70/106/- kWh/100 km
- Hydrogen consumption: -/-/4,6 kg/100 km
- Charging time (charger): 7/2*/- h
- Hydrogen refueling time: -/-/15 min
- Load capacity: 4630/12800/26000 kg

  *specialised charging station

City buses and coaches

City buses in the electric version are manufactured by both the largest automotive companies and by smaller firms, including some Polish ones, e.g. Solaris, Solbus or Ursus, and both in the battery versions and those utilising fuel cells. Due to the availability of fuel, the purchase cost and the operating costs of the bus, the battery-driven Solaris Urbino 12 electric was chosen for the analysis. A similar model in the combustion version is the definite best-seller among the Polish makes and is a popular model in the European market of city buses.

In the case of coaches, there are no mass-produced electric vehicles and likewise, there is no credible information available concerning any possible preparatory arrangements for launching such a vehicle in the market in the nearest future. This is undoubtedly due to the necessity of ensuring a long driving range for vehicles of this type. The only solution that enables accomplishment of this requirement seems to be the application of fuel-cell based drive. Therefore, the closest vehicle in terms of design that does exist and whose technical data are publicly available is the City Smile Fuel Cell Electric Bus. For the purpose of performing the analysis, this vehicle will be taken as being representative for intercity buses and coaches with the assumption that hydrogen consumption in intercity buses and coaches will be 50% of the value of fuel consumption for the city bus.

Key technical specifications concerning models SU12 electric/City Smile FCE Bus:

- Horsepower: 250/n/a kW
- Power source: li-ion battery/ fuel cells
- Range: 150/450* km
- Energy consumption: 170/- kWh/100 km
- Hydrogen consumption: -/3,5 kg/100 km
- Charging time: depends on battery capacity and refueling technical aspects
- Hydrogen refueling time: -/10 min

* In the case of intercity and coaches, the range can be easily extended by the use of other hydrogen tanks

Motorcycles and mopeds

Motorcycles and mopeds that come in electric versions are battery-powered. Several such structures have already been created and are manufactured by both renowned manufacturers of combustion motorcycles and firms that only want to be present in the segment of electric vehicles. For the analysis, a scooter offered by the manufacturer Romet, model Ev1, and a motorcycle from the firm Zero Motorcycles, model Zero S ZF 13, were selected.

Key technical specifications concerning models Romet EV1/Zero S ZF 13:
- Horsepower: 3/45 kW
- Max. speed: 45/158 km/h
- Range: 65/200 km
- Energy consumption: 2,5/6 kWh/100 km
- Charging time (socket): 7/9 h

Energy demand calculation

In order for the calculation of electric energy demand for the entire transport system to be possible, it is necessary to make some assumptions with regard to the activity of the individual means of road transport. Due to the lack of data concerning the consumption of electric energy by vehicles depending on the road infrastructure (city, outside city, motorway), the average annual mileage was taken as the only parameter that characterises this activity. It was assumed that the number of vehicles in each category would correspond to the number of combustion vehicles, which would enable accomplishment of the same transport tasks. The following division of means of transport into categories was adopted:
- passenger cars
- light commercial vehicles with a payload of up to 999 kg
- light commercial vehicles with a payload above 999 kg
- heavy commercial vehicles with a payload of up to 4,999 kg
- heavy commercial vehicles with a payload above 4,999 kg and below 14,999 kg
- heavy goods vehicles o with a payload above 14,999 kg and road tractors
- city buses
- intercity buses and coaches
- motorcycles
- mopeds.

Using the above data, the amount of energy needed to ensure the functioning of such designed theoretical transport fleet was calculated, which is presented in table 2.

In the calculations, it was assumed that the number of 5m passenger cars visible in the database of the Central Register of Vehicles and Drivers (CEPiK) is actually not reliable which is indicated by analyses comparing data from insurance companies with the data comprised in the CEPiK.

It was assumed that hydrogen is produced by electrolysis, and it is required to provide 46 kWh of electricity in order to produce 1 kg hydrogen.

Table 2. Representative vehicle, average electricity consumption [kWh/100 km], average hydrogen consumption [kg/100 km], average annual mileage [km], number of vehicles [pcs] in 2015 as well as the amount of electricity required to accomplish transport tasks [kWh] for each category of means of road transport

	representative vehicle	average electricity consumption [kWh/ 100 km]	average hydrogen consumption [kg/100 km]	average annual mileage [km]	number of vehicles [pcs]	amount of electricity required to accomplish transport tasks [TWh]
Passenger cars	Volkswagen e-Golf	12,7	-	11932	15723423	23,83
Light commercial vehicles with a payload of up to 999 kg	Renault Kangoo Z.E.	12,2	-	25960	1649530	5,22
Light commercial vehicles with a payload above 999 kg	Renault Master Z.E.	16,5	-	25960	798234	3,42
Heavy commercial vehicles with a payload of up to 4,999 kg	Fuso eCanter	70	-	34840	295179	7,20
Heavy commercial vehicles with a payload above 4,999 kg and below 14,999 kg	Mercedes-Benz Urban eTruck	106	-	34840	318162	11,75
Heavy goods vehicles o with a payload above 14,999 kg and road tractors	Nikola One	-	4,6	81830	367777	63,68
City buses	Solaris Urbino 12 electric	170	-	66050	11795	1,32
Intercity buses and coaches	City Smile Fuel Cell Electric Bus	-	3,5	73840	98049	11,66
Motorcycles	Zero S ZF 13	6	-	1717	1272333	0,13
Mopeds	Romet EV1	2,5	-	1474	1259187	0,05
					total	128,26

Average mileages were calculated as a weighted average of the average mileages presented for the individual types of vehicles based on: Trela, Sustainable..., 2016 and Trela, Proposal..., 2016.
Source: authors' own work.

Calculation of external costs

For the purpose of valuation of the environment, methods based on market prices (*physical linkage methods*) can be applied, e.g. the dose-effect method, the substitution, replacement, prevention, compensation, opportunity cost methods, as well as methods based on the functions of supply and demand (*behavioural linkage methods*), which include revealed preference methods, e.g. the travel cost method, the hedonic pricing method, and the stated preference methods, e.g. the contingent valuation method (Trela, Dubel, 2014). In the paper, the methodology applied is that of the *Handbook on estimation of external costs in the transport sector* bringing together a lot of research in which the above methods were applied. The external costs were calculated for the transport fleet currently, operating based on statistical data regarding pollution emissions from road transport, and for the theoretical transport fleet consisting exclusively of electric vehicles.

Account was taken for the cost of pollution emissions, such as: non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NO_x), particulate matter ($PM_{2.5}$ and PM_{10}), carbon dioxide (CO_2) sulphur dioxide (SO_2). No account was taken for external costs of traffic accidents, congestion and noise. External costs of traffic accidents and congestion will be identical for electric and combustion vehicles. External costs of noise will be lower for electric vehicles but they will not equal zero as noise is emitted by the motor, rolling resistance and air resistance. Due to the lack of a methodology enabling determining the difference in those costs, they were not taken into account in the calculations.

It was assumed that producing 1 kWh of electricity in the Polish energy system involves emission of 0.95 Mg CO_2/MWh for hard coal and 1.07 Mg CO_2/MWh for lignite (Czopek, Trzaskuś-Żak, 2011). The other emission indicators were adopted based on the *EMEP/EEA emission inventory guidebook 2016*.

It was assumed that 50.62% of electricity required to power vehicles is produced from hard coal and 33.11% of electricity comes from lignite (Rynek..., 2015).

Values of the external costs presented in Table 3 are given in prices from 2015 at the exchange rate of the National Bank of Poland from 28.07.2017 at 4.2617 PLN/EUR based on *Handbook on estimation of external costs in the transport sector.*

The total of external costs resulting from emissions of pollutants is significantly lower for the current fleet of combustion vehicles than for the theoretical fleet of vehicles powered only with electric energy in the conditions of the Polish energy system. Emissions of $PM_{2.5}$, PM_{10}, NO_x and NMVOCs, and the related external costs are admittedly lower in the case of electric vehicles than combustion ones; however, the very big difference in emissions of CO_2 and above all SO_2 (sulphur content in fuels is negligible and generates very small external costs for combustion vehicles) is the reason that the aggregate costs are almost twice as high as in the case of electric vehicles.

Table 3. External costs of pollution emissions for the theoretical fleet of electric vehicles and for the currently operating vehicle fleet

Chemical compound	Volume of emissions [mg]	External cost [pln]	Total of external costs [pln]
	theoretical fleet of electric vehicles		
PM2,5	1284	64426741	25935284500
PM10	3007	76069512	
NOx	86610	1466183509	
NMVOC	448	1894972	
CO2	107117187	14836292741	
SO2	448490	9490417026	
	actual fleet of combustion vehicles		
PM2,5	9799	3317679896	13769874818
PM10	11681	254877990	
NOx	212613	3599254392	
NMVOC	72051	304931822	
CO2	45402660	6288506774	
SO2	239	4623944	

Source: authors' own work.

Conclusions

Replacing all road vehicles in Poland with electric vehicles would involve the necessity of providing an additional amount of 128 TWh of electricity annually by the Polish energy system. This would in turn result in the necessity of increasing electric energy production by approx. 80%, which would have to lead to very substantial changes in the energy system. Additionally, it should be noted that replacing all combustion vehicles with all-electric ones would not at all lead, with the present energy system, to any benefits in the scope of emissions. This is due to the very high emissions of CO_2 and SO_2 in the process of burning hard coal and lignite. However, a reduction of external costs would be possible in the case of introducing electric cars instead of combustion ones but it would be necessary to take into account the costs of noise emissions. The assumptions that electric vehicles do not emit any noise is incorrect but noise emissions in the case of an electric vehicle is without a doubt significantly lower than for a corresponding combustion vehicle. Thus, is seems essential to conduct research and create a methodology enabling credible calculations of external costs of noise emissions for electric vehicles, which would provide a basis for the ultimate determination which kind of drive is more environmentally friendly in the Polish transport and energy system.

Without such a tool, taking additionally into account analyses concerning the costs of purchasing and operating electric vehicles, it would be difficult to justify the sense of introducing vehicles with such a drive in Poland.

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