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Analysis of Pollutants Emission into the Air at the Stage of an Electric Vehicle Operation

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ABSTRACT

The article discusses the research on CO_2 emissions at the stage of electric engine vehicle operation. The operation stage includes, among others use of the vehicle as well as maintenance and charging for the vehicle's propulsion. The origin of the electricity consumed during charging has an impact on the vehicle's emissions balance. The scope of considerations concerns coal as the main energy carrier in Poland. The obtained results can be a benchmark for comparing other primary energy sources used for electricity production. Based on the collected technical data of electric cars, the values of CO_2 emission factors from electricity production in thermal power plants and data on the state and structure of electricity production in Poland, an analysis of CO_2 emissions from electric vehicles in the operational stage was performed. The vehicle's electricity consumption of 0.14–0.16 kWh/km is accompanied by CO_2 emissions of 100.94–115.36 g/km. The calculated CO_2 exceeds the EU limit value from 01/01/2020 (95 g/km) for average CO_2 emissions from new passenger vehicles. The main message of the work is the statement that increasing the efficiency of the electricity generation process in commercial thermal power plants in Poland will translate into a reduction in the emission of electric cars consuming this energy for propulsion. The research shows that the change in the efficiency of energy transformations in a thermal power plant from 38% to 46% leads to a reduction in the emission of an electric vehicle by over 17%. The emission of CO_2 from a passenger car with a compression-ignition engine is discussed. The considerations include the stage of the use of the vehicle and the stage of production of diesel oil, which is consumed during the use of the vehicle.

Keywords: electric cars, efficiency of thermal power plants, emissions from vehicles, electricity from coal, vehicle operation stage.

INTRODUCTION

The increase in the share of electric vehicles in the total number of registered vehicles in Poland will undoubtedly reduce the emissions of harmful substances from the road transport sector. An important argument to confirm this thesis is the fact that electric vehicles do not emit substances into the air during their use.

A comprehensive environmental impact assessment for an electric vehicle should take into account not only the use stage, but also other stages of the vehicle's life cycle. There are three main stages of the vehicle's life cycle: the production stage, including the extraction of the necessary raw materials, the production of the necessary materials and their transport, the vehicle operation stage and the used vehicle management stage. The exploitation stage includes the use of the vehicle, maintenance and charging, as well as breaks in the use of the vehicle.

A particularly important issue in the assessment of the environmental risk of an electric vehicle at the stage of its operation is the emission of substances into the air from the production and distribution of electricity used to charge the vehicle's battery. The origin of the energy consumed during charging has an impact on the vehicle's emissions balance. The research problem in the work is the assessment of the amount of carbon dioxide emissions (CO_2) generated during the generation of electricity consumed by the vehicle for the purposes of its propulsion. The scope of considerations concerned coal as the main energy carrier in Poland. The main message of the work is that the construction of highly efficient coal-fired power units in Poland will translate into a reduction in the emission of electric cars consuming energy from the Polish power grid. The obtained results can be a benchmark for comparing the impact on the emission of other primary energy carriers.

RESEARCH METHOD AND ASSUMPTIONS

The method of data analysis grouped into three areas was used: technical data of motor vehicles, values of CO_2 emission factors from the production of electric emission in thermal power plants and data on the state and structure of electric emission production in Poland. The sources of data are technical vehicle documentation, scientific publications and statistical studies.

Based on the collected data, the amount of CO_2 emissions from the production and distribution to the electric emission power grid, which is used to charge the vehicle's electric battery, was determined. The scope of the considerations concerned electric energy production processes based on coal in Poland. The stage of coal acquisition (mining, processing into a finished product, fuel transport to a power plant) has been ignored in the considerations. The obtained results indicate that at the charging stage, electric vehicles are a source of emissions of substances into the air. The amount of emissions depends on the electricity generation technology.

In addition, on the basis of the collected data, a quantitative assessment of CO_2 emissions from a vehicle with a compression-ignition engine was performed. The considerations include the stage of the use of the vehicle and the stage of production of diesel oil, which is consumed during the use of the vehicle.

DETERMINATION OF CO_2 EMISSIONS DURING THE USE PHASE OF AN ELECTRIC VEHICLE

Electricity is a secondary energy carrier. It is obtained as a result of energy transformations from primary energy carriers, both renewable and non-renewable. In Poland, coal is the most frequently used energy carrier to produce electricity. The calorific value of coal and CO_2 emission factors for the coal combustion process in domestic power plants and combined heat and power plants are presented in Table 1. The value of CO_2 emission factors was expressed in kg/GJ and kg/MWh of heat produced from coal. The quoted values of emission factors are valid only for the calorific values of the fuel presented in Table 1.

Table 1. Calorific value and CO_2 emission factor from coal combustion process in Polish power plants and heat and power plants [KOBiZE 2020])

Fuel	Calorific value	CO_2 emission factor	
	[MJ/kg]	[kg/GJ]	[kg/MWh]
Coal	21.24	93.54	336.74
Lignite	9.47	105.95	381.42

The production of electricity from heat takes place with a certain efficiency. In 2019, the net efficiency of the technological process of electricity generation in commercial thermal power plants in Poland was on average 38.1% [GUS 2020]. Based on the knowledge of efficiency, the unit emission of CO_2 from the process of generating electricity can be calculated using the formula:

$$W_{e\_el} = \frac{W_e}{\eta} \tag{1}$$

where: W_{e_el} – CO_2 emission factor of the electricity production process in thermal power plants; W_e – CO_2 emission factor from the coal combustion process; η – net electricity generation efficiency.

The calculations according to the formula (1) show that the CO_2 emission factor is 883.83 kg per 1 MWh of electricity generated from hard coal and 1001.10 kg/MWh – from lignite. The above values were obtained using the data in Table 1 and the value η = 38.1%. Calculations for η = 46% show that the value of the CO_2 emission factor from the process of electricity production based on hard coal is 732.04 kg/MWh. It is over 20% lower than the value of the emission factor for η = 38.1%. The obtained results of the calculations justify the purposefulness of building new high-efficiency coal-fired power units. The higher the efficiency of such facilities, the lower the values of the CO_2 emission factor.

In Poland, in 2019, electricity production from hard coal accounted for 65.4% of the total electricity production from coal, and from

Table 2. Electricity production in Poland in 2019 (source: based on data from the Ministry of Climate and Environment [2021])

Description	Electricity production [GWh]
Conventional thermal power plants including:	138,028.7
Coal	78,872.7
Lignite	41,725.9
Natural gas	14,479.3
Other fuels	2,953.9
Installations of renewable energy sources	25,234.6
Pumped storage hydropower plants	706.5
Total	163,969.8

lignite – 34.6% (Table 2). Consequently, the average value of the CO_2 emission factor for the process of electricity production from coal in Poland is 924.4 kg/MWh.

In turn, the share of electricity production from coal in the total electricity production in Poland in 2019 was 73.55% (Table 2). Therefore, for each 1 MWh of electricity taken from the power grid in Poland, there is an emission of 680 kg of CO_2, which is caused by the process of producing electricity based on coal.

Losses in transmission and distribution of electricity in power grids in Poland in 2019 accounted for 5.6% of the total energy fed into the grid [PTPiREE 2020] (the loss ratio in the transmission network was 1.38% [Karwańska and Kałużny 2020]). Therefore, in order to be able to take 1 kWh of electricity from the power grid, it is necessary to produce approx. 1.06 kWh of energy. This means that for 1 kWh of electricity consumed from the grid, emissions of 721 g CO_2 are caused by the production of coal-based energy and the transmission and distribution of this energy.

According to the manufacturers, electric passenger cars currently have a range on a single charge from 130 km (Smart EQ Forfour) to 610 km (Tesla Model S Long Range). The energy stored in the batteries of these vehicles ranges from 17.6 kWh (Smart EQ Forfour) to 100 kWh (Tesla Model S Long Range) (Table 3).

Table 3 shows that the currently available models of electric cars can travel 6.1–7.4 km using 1 kWh of electricity stored in the traction battery. Thus, the vehicle consumes electricity at the level of 0.14–0.16 kWh/km. Using the results of previous calculations, it can be concluded that the electric energy consumption of 0.14–0.16 kWh/km by the vehicle is accompanied by the emission of CO_2 at the level of 100.94–115.36 g/km. For comparison, the limit applicable in the EU from 01/01/2020 for average emissions of CO_2 from new passenger vehicles is 95 g/km [Regulation of the European Parliament 2019/631]. The calculated CO_2 emissions lower than the average CO_2 emission for combustion-powered vehicles traveling on Polish roads, dominated by used cars imported from abroad (the average age of imported cars in the period January-March 2021 is 12 years [Samar Automotive Market Research Institute 2021]).

Figure 1 shows the results of the study of the impact of the efficiency of electricity generation from coal on the emission of CO_2 caused by energy production for the drive of electric vehicles. The results were obtained assuming the share of hard coal (65.4%) and lignite (34.6%) in coal-based electricity generation present in Poland. The research took into account three different levels of the share of coal in the total electricity production: 74% (current state in Poland), 80% and 85%. The influence of different proportions of the shares of hard coal and lignite in the production of electricity from coal on the CO_2 emission factor generated at the stage of operation of electric cars is shown in Figure 2. The charts (Fig. 2) were prepared assuming that the share of electricity production from coal in the total electricity production is 74% (current state in Poland). Moreover, the results presented in Figures 1 and 2 were obtained assuming the unit electricity consumption of an electric car of 0.16 kWh/km.

Based on the analysis of the results (Fig. 1), it can be concluded that the change in the efficiency of energy transformations in a power plant from 38% to 46% has a positive effect in

Table 3. Technical parameters of selected electric passenger cars (source: based on car manufacturers' data)

Vehicle	Range [km]	Battery capacity [kWh]
Smart EQ Forfour	130	17.6
Kia e-Niro (39.2 kWh)	289	39.2
Kia e-Niro (64 kWh)	455	64
Tesla Model 3 Standard Range	530	75
Tesla Model S Long Range	610	100

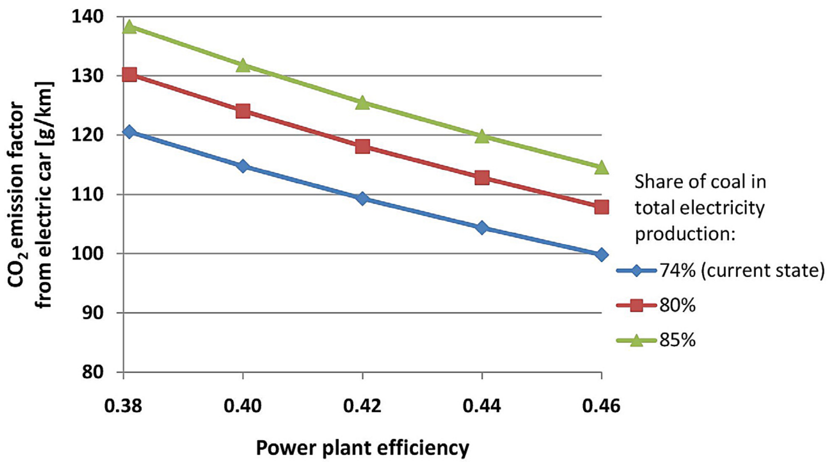

Figure 1. Effect of power plant efficiency and the share of coal in electricity production on the amount of carbon dioxide emissions from an electric car at the operating stage

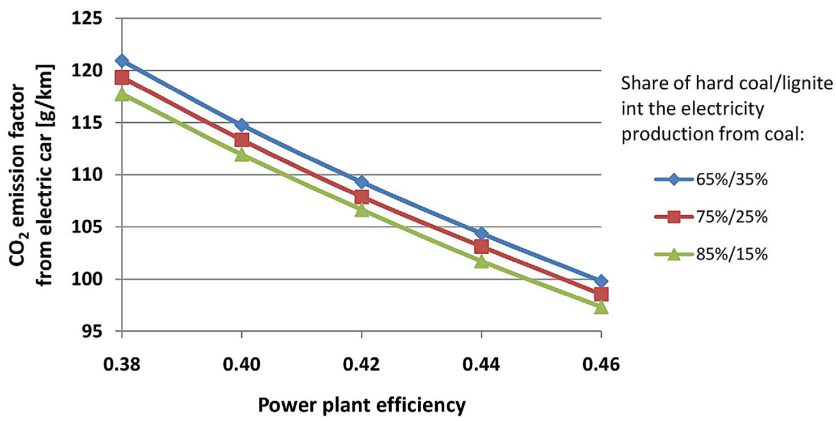

Figure 2. The impact of power plant efficiency and the proportion of hard coal and lignite shares in electricity production on the amount of carbon dioxide emissions from an electric car at the stage of vehicle use

the form of reducing the emissivity of an electric vehicle by over 17%. The increase in the share of hard coal in the production of electricity from coal reduces the emissivity of the electric vehicle only to a small extent. For example, a change in the share of hard coal from 65% to 85% leads to a reduction in the emissivity of an electric vehicle by approx. 2.6%.

THE AMOUNT OF CO_2 EMISSIONS FROM PASSENGER CARS WITH A COMPRESSION-IGNITION ENGINE

The scope of the considerations was limited to one stage of the life cycle of a diesel car - the operational stage. Due to the fact that the analysis of the electric vehicle considered the same stage, it will be possible to compare both types of cars. The operational stage includes the use of the vehicle, maintenance and stoppage. The greatest impact on CO_2 is vehicle use ("from fuel tank to vehicle wheels" phase) and production of diesel fuel ("raw material extraction to vehicle fuel tank" phase) consumed in the operational phase.

The unfavorable environmental impact of the vehicle in the operational stage increases with the increase in diesel fuel consumption by the engine. The criteria for assessing the pressure of a vehicle on the environment are the amount of energy consumption [Marczak 2017] and emissions of CO_2 and other pollutants expressed in grams per kilometer.

The amount of CO_2 emissions generated during the combustion of diesel fuel is proportional to the average fuel consumption of the vehicle over a given distance. The level of fuel consumption is influenced, among others, by engine capacity and power, gearbox type, driving style and speed, road infrastructure type. The average fuel consumption for a given brand and model of a vehicle is the result of driving in all conditions. For example, for the new design vehicle Opel Astra with 1.5-liter engine, 90 kW/122 HP at 3,500 rpm, 9-speed automatic transmission, diesel consumption in the combined cycle according to the WLTP test (Worldwide Harmonized Light Duty Vehicle Test Procedure) is from 5.2 to 5.6 dm^3/100 km [Opel Automobile 2019]. The WLTP procedure is currently the applicable procedure for measuring fuel consumption and CO_2 emissions for light vehicles [Commission Regulation (EU) 2017/1151].

The CO_2 emission factor from the total and complete combustion of 1 kg and 1 dm^3 of diesel fuel can be determined from the relationship (2) and (3), respectively:

$$W'_{CO_2} = U_C \cdot W_{CO_2/C} \quad (2)$$

$$W''_{CO_2} = U_C \cdot W_{CO_2/C} \cdot \rho \quad (3)$$

where: W'_{CO_2} – CO_2 emission factor from the combustion of 1 kg of diesel; U_C – mass fraction of carboN in the engine fuel; $W_{CO_2/C}$ – CO_2 emission factor from total combustion of 1 kg of carbon ($W_{CO_2/C}$ = 44/12 kg CO_2/kg C); W''_{CO_2} – CO_2 emission factor caused by combustion 1 dm^3 of fuel; ρ – fuel density.

The amount of CO_2 emissions caused by combustion of a given amount (mass or volume) of fuel is represented by the following formulas:

$$E_{CO_2} = W'_{CO_2} \cdot Z'_p \quad (4)$$

$$E_{CO_2} = W''_{CO_2} \cdot Z''_p \quad (5)$$

where: Z'_p – the amount of fuel consumption (in mass units) over the distance travelled; Z''_p – the amount of fuel consumption (in units of volume) over the distance travelled; E_{CO_2} – the amount of CO_2 emissions as a result of fuel combustion in the amount of Z'_p or Z''_p.

The results of the calculations of CO_2 generated during the use phase of a car with a compression-ignition engine are presented in Table 4.

The diesel oil production stage consists of a series of sequential activities: crude oil extraction, raw material transport to refineries, fuel production process and transport of finished fuel to petrol stations. These operations can be performed in various ways. Therefore, the adopted assumptions will determine the results of the assessment of CO_2 emissions at the stage of diesel oil production.

According to the literature data, the greenhouse gas emission factor expressed as CO_2 equivalent at the stage of diesel oil production is 0.57 kg/dm^3 [Schmied and Knorr 2012]. For the purposes of the calculations, it was assumed that the CO_2 emission factor would have the same value. The amount of CO_2 emissions at the stage "from the extraction of raw materials to the wheels of the vehicle" is 166.64–178.92 g/km (Table 5).

The obtained results indicate that the amount of CO_2 emissions in the use phase of a compression-ignition motor vehicle is more than 78% higher than the amount of CO_2 emissions associated with the production of diesel fuel for the purposes of drive of this vehicle.

Table 4. The amount of CO_2 emissions at the stage of use of a motor vehicle with a compression-ignition engine

Vehicle model	Fuel consumption Z''_p [dm^3/100 km]	Coal share U_C [% wt.]	Fuel density ρ [kg/dm^3]	Emission factor		Emissions E_{CO_2} [g/km]
				W'_{CO_2} [kg/kg]	W''_{CO_2} [kg/dm^3]	
Opel Astra 1.5D 90 kW/122 HP	5.2	85	0.845	3.117	2.633	137
	5.6					147

Table 5. The amount of CO_2 emissions at the stage of use of the motor vehicle and the production of diesel oil

Vehicle model	Fuel consumption Z''_p [dm^3/100 km]	Emission factor W''_{CO_2} [kg/dm^3]		Emissions E_{CO_2} [g/km]	
		vehicle use strategy	production of diesel fuel	vehicle use strategy	production of diesel fuel
Opel Astra 1.5D 90 kW/122 HP	5.2	2.633	0.570	137	29.64
	5.6			147	31.92

CONCLUSIONS

Electric drives in vehicles are one of the best technical solutions to protect the environment in transport. There is no doubt about such an assessment of electric vehicles at the point of use. Then the vehicles do not emit pollutants into the air. However, the environmental impact assessment of an electric vehicle cannot ignore the effects related to the production and distribution of electricity. The burden on the environment at the stage of charging the batteries in electric vehicles depends on the electricity generation technology.

Currently available models of electric cars can travel a distance from 6.1 to 7.4 km on one kilowatt-hour of electricity stored in a traction battery. For a distance of 1 km, the vehicle consumes electricity in the amount of 0.14–0.16 kWh. The research shows that in Poland, 721 g CO_2 is emitted per kilowatt hour of electricity taken from the power grid, caused by the production and distribution of electricity based on coal. Such a significant amount of CO_2 emissions results from the large share of electricity production from coal in the total electricity production in Poland - in 2019 this share was 73.55%. Vehicle electricity consumption of 0.14–0.16 kWh/km is accompanied by CO_2 emissions from carbon-based energy production of 100.94–115.36 g/km. This emission value was obtained taking into account the net efficiency of the technological process of electricity generation in commercial thermal power plants in Poland - it amounts to 38.1% on average. The calculations show that an increase in efficiency from 38.1% to 46% would contribute to the reduction of the emission of electric vehicles by over 17% with the vehicle energy consumption of 0.14–0.16 kWh/km.

The results of the tests of CO_2 emissions from the internal combustion engine vehicle show that the emission value is 166.64–178.92 g/km with a combined fuel consumption of 5.2 to 5.6 dm^3/100 km. The obtained amount of emissions is the sum of the emissions generated in the operational phase of the vehicle and emissions from the production of diesel oil. The emission level in the operational phase of the vehicle ranges from 137 to 147 g/km and is over 78% higher than the emissions associated with the production of diesel fuel for the purposes of propelling the vehicle.

The greatest possibilities of reducing the emission of an electric vehicle at the stage of vehicle operation in our country lie in the activities in the field of Polish energy. In the area of conventional energy, activities should focus on the construction of highly efficient, low-emission power units. In parallel, measures should be taken to increase the amount of energy produced from renewable energy sources. The challenge for the future is to create the possibility of completely resigning from fossil fuels in the energy sector in favor of the production of energy from renewable sources.

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