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The efficiency of electric cars for mitigating CO_2 emissions in Poland

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ABSTRACT

This paper concerns the estimation of indirect CO2 emissions associated with the use of electric engines in Poland. The indirect production of exhaust fumes emitted by electric cars is determined by two factors: the engine's power consumption and the volume of the emissions produced when generating power sold by distributors. The current structure of the Polish power system, which is the supplier of the prime mover for electric cars, uses mainly the conventional (high-emission) sources of energy. Thus, using electric cars becomes an indirect cause of the pollution in the atmosphere. Increasing the efficiency of the power production process along with limiting the emission level of the combustion process in conventional power plants is a fundamental and essential solution to reduce air pollution.

Keywords: electric cars, CO2 emission, electric power production, transport development strategy, Polish electric power system.

1. Introduction

The number of passenger cars registered in the European Union rose from 11.9 million in 2013 to 13.7 million in 2015 [ACEA 2016]. The majority of vehicles in the automotive industry are powered by the combustion of petroleum products, such as petrol, diesel fuel, LPG (Liquefied Petroleum Gas), and CNG (Compressed Natural Gas). The 20th century saw the development of alternative power supplies for mechanical vehicles, among them electric engines. According to the French Association for the Development of Electric Vehicles, in 2015 92 693 electric cars were sold, which meant a 61% increase in sales compared to the previous year [Avere France 2015, 2016]. Electric cars constituted 0.46% and 0.68% of all vehicles bought in 2014 and 2015. Statistics show that the electric vehicles market in the EU is still a small but dynamic sector of the automotive industry.

The main reason for the development of electric cars are GHG mitigation provisions included in the energy and climate package. It is estimated that around 10% of GHG emissions is caused by road transport [Ministry of Environment 2015]. One of the primary goals of the Polish Transport development strategy until 2020 (with an outlook to the year 2030) is implementing solutions which would minimize environmental pollution. This means not only improving the efficiency of road freights, but also an increased use of alternative fuels and renewable energy sources in transport. Recommended technologies include the use of hydrogen and fuel cells, natural gas engines, hybrid and electric vehicles. The development should be bolstered by the establishment of a charging and battery replacement station and hydrogen filling station system.

The aim of this paper is to estimate the indirect emissions related to the use of electric engines in Poland. The current structure of Polish electric power system relies mainly on conventional energy sources. Therefore, using electric cars leads to indirect emissions.

The study compares the environmental impact of electric and internal combustion cars. Particular attention has been paid to the following aspects: the unique nature of Polish power production and distribution system, energy consumption, and emission level in the examined cars. The article presents an original methodology of calculating indirect emissions in electric cars which takes into account the area where the energy is consumed.

2. Methodology

The aim of the analysis is to calculate the indirect emissions of gases to the atmosphere. The study covers the emissions of CO2, SO2, NOX and dust. It was based on the so-called Jevons paradox [Sorrell, 2009], which states that in certain conditions, a more efficient use of energy resources leads to an increase in their use and a negative impact on environmental conditions, instead of limiting resource use and improving the state of the environment. The paradox may occur with the use of electric cars if the electric power is obtained from conventional sources.

Determining the value of indirect emissions related to electric cars requires the use of information on energy consumption in electric cars, as well as the emission level for fuels and primary energy sources used to produce electric energy in various regions of Poland. Indirect emission was calculated according to the following formula:

$$\textit{indirect emission} = WE \times ZE$$

where:

WE – GHG emission created in the process of producing electric energy sold by distributors

ZE – average energy consumption in electric cars

To compare the effectiveness of substituting internal combustion vehicles with electric cars, indirect emissions values were juxtaposed with those of conventional cars. Vehicles with similar technical features were used for this purpose. Moreover, the assessment took into account carbon emission standards for new passenger cars [Ordinance no. 443/2009 of 23 April 2009] as well as emission standards for light passenger and commercial vehicles (Euro 6) [Regulation (WE) No. 715/2007 of the European Parliament and of the Council].

3. Data

3.1. Emission related to electric power production in Poland

Most of the electric power produced in Poland is generated in thermal and cogeneration power plants. They burn lignite, hard coal, natural gas, biogas or biomass [Wasiak 2010, pp. 12-13]. During the combustion process, they emit pollutants, such as carbon dioxide (CO2), sulphur dioxide (SO2), nitrogen oxide (NOX) and dust. Apart from the conventional sources, power production in Poland also uses water, wind and solar power.

The owner and operator of the high-voltage transmission system in Poland is the state-owned Polskie Sieci Elektroenergetyczne SA (PSE Operator SA), while medium and low voltage distribution grids in Poland are owned and operated by 5 electric power distributors: Enea Operator Sp. z o.o., Tauron Dystrybucja SA, PGE Dystrybucja SA, Energa-Operator SA, RWE Stoen Operator Sp. z o.o.

All operators of distribution grids in Poland rely mainly on the sale of power coming from conventional sources (Table 1). This type of power constitutes between 67% (Energa-Operator SA) and 93% (Tauron Dystrybucja SA) of the sales. Renewable sources used for generating electrical energy consist primarily of biomass supplemented with water, wind and solar power.

Fuel structure is not the only determinant of the emission level of power production. The final emission values are affected by the age and efficiency of installations or environmental technologies. These factors cause Energa-Operator SA to emit relatively the largest volume of carbon dioxide and nitrogen oxide (915.63 g and 1.3 g respectively), despite the fact that it uses the largest number of RES to produce electric energy. The lowest volume of carbon dioxide and nitrogen oxide emitted when generating 1 kilowatt hour is produced by PGE Dystrybucja SA (694.99 g and 0.94 g respectively).

Table 1: Descriptive statistics of WIG20 returns in the period from 2.01.2004 to 31.10.2016

Specification	Enea Operator Sp. z o.o.	Tauron Dystrybucja SA	PGE Dystrybucja SA	Energa-Operator SA	RWE Stoen Operator Sp. z o.o.
Number of users [in thousands]	2 205	5 300	5 200	2 900	964
Service area [km^2]	58 192	57 940	122 433	75 000	510
Fuel structure	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**
Renewable energy sources	20.48	6.54	13.6	33.23	15.37
biomass	7.75	4.67	6.76	5.64	5.07
water power	2.81	0.36	2.06	4.52	1.3
wind power	9.92	1.44	4.7	23.01	9
biogas	-	0.06	-	-	-
solar power	-	0.01	0.08	0.05	-
Hard coal	42.18	83.61	47.71	31.68	47.14
Lignite	32.04	7.83	31.49	29.59	34.18
Natural gas	2.81	0.79	7.18	2.22	3.22
Other	2.49	1.21	0.02	3.28	0.09
Emission level	**[g/kWh]**	**[g/kWh]**	**[g/kWh]**	**[g/kWh]**	**[g/kWh]**
CO_2	731.6	847.27	694.99	915.63	824.87
SO_2	1.5	1.3	1.4	1.75	3.68
NO_X	1.1	0.99	0.94	1.3	1.12
Dust	0.1	0.069	0.069	0.095	0.08

Source: based on: cire.pl, Enea 2016, Tauron 2016, PGE 2016, Energa 2016, RWE 2016.

3.2. Technical parameters of electric cars

The environmental analysis of electric cars used data from catalogues published by the manufacturers of five electric cars which were best-sellers in Europe from January 2014 to July 2016. The selected models are: Renault Zoe, Nissan LEAF, Tesla S P90D, Volkswagen e-Golf and BMW i3 (Table 2). According to manufacturers' specifications, the energy intensity of electric cars varies between 0.24 kWh/km (Tesla S P90D) and 0.127 kWh/km (Volkswagen e-Golf).

3.3 Distinctive features of internal combustion-powered cars

Each of the selected electric cars was juxtaposed with the one equipped with a combustion engine and exhibiting similar parameters (Table 3). The elements taken into consideration were primarily the size and mass of the vehicle, as well as parameters important for the user: maximum power and maximum torque, maximum speed and acceleration. When it comes to the environmental factors, carbon dioxide emission levels quoted on each manufacturer's website were taken into account. This led to the selection of the following pairs: Renault Zoe and Renault Megane IV (1.5 Energy dCi 90 Hp); Nissan LEAF and Nissan Pulsar Visia 1.5 dCi; Tesla S P90D and Porsche Panamera Turbo; Volkswagen e-Golf and Volkswagen Golf VII Trendline 1.6 TDI; BMW i3 and BMW 1 series 120i .

Table 2. Specification of selected electric cars

Feature	Renault Zoe	Nissan LEAF	Tesla S P90D	Volkswagen e-Golf	BMW i3
Engine					
Max. power	65 kW/88 hp	80 kW/109hp	515 kW/691 hp	85 kW/115 hp	125 kW/170 hp
Max. torque	220 Nm from 250 to 2500 rev/min	254 Nm from 0 to 3008 rev/min	967 Nm from 100 to 3900 rev/min	270 Nm	250 Nm
Max. rotational speed of engine	11300 rev/min	10500 rev/min	16000 rev/min	12000 rev/min	-
Battery					
Capacity	22 kWh	24 kWh	90 kWh	24,2 kWh	18,8 kWh
Other parameters					
Vehicle mass	1468 kg	1474 / 1548 kg	2328 kg	1538 kg	1,195/1,270 kg
Power consumption	0.146 kWh/km	0.15 kWh/km	0.24 kWh/km	0.127 kWh/km	0.129 kWh/km
Max. speed	135 km/h	144 km/h	249 km/h	140 km/h	150 km/h
Acceleration: 0-100 km/h	13.5 s	11.5 s	3.3 s	10.4 s	7.2 s
Zasięg (NEDC)	210 km	199 km	509 km	190 km	190 km

Source: own work based on: renault.com, nissan.pl, zeperfs.com, volkswagen.pl, bmw.pl.

Table 3. Specification of internal-combustion powered cars

Feature	Renault Megane IV (1.5 Energy dCi 90 Hp)	Nissan Pulsar Visia 1.5 dCi	Porsche Panamera Turbo	Volkswagen Golf VII Trendline 1.6 TDI	BMW 1 series 120i
Engine					
Capacity [cm^3]	1461	1461	3996	1598	1598
Max. power [rev/min]	66 kW/90 KM	81 kW/110 KM	404 kW/550 KM	81 kW/110 KM	130 kW/177 KM
Max. torque	220 Nm with 1750 rev/min	260 Nm with 1750-2500 rev/min	770 Nm with 1960 - 4500 rev/min	250 Nm with 1500-3000 rev/min	250 Nm with 1500-4500 rev/min
Parameters					
Mass [kg]	1205	1270-1352	1995	1265	1375
Max. speed [km/h]	175	190	306	179	210
Acceleration:0-100 km/h [s]	13.4	11.5	3.6-3.7	11.9	8.5
Fuel consumption and emissions					
urban cycle [l/100 km]	4.2	4.1	12.8 - 12.9	4.5	6.2-6.7
extra-urban cycle [l/100 km]	3.4	3.3	7.2 - 7.3	3.5	4.3-4.7
combined cycle [l/100 km]	3.7	3.6	9.3 - 9.4	3.8	5.0-5.4
Carbon emission [g/km]	95	94	212 - 214	99	116-126
Fuel type	diesel	diesel	petrol	diesel	petrol

Source: own work based on: renault.pl, nissan.pl, porsche.pl, volkswagen.pl, bmw.pl.

4. Results and discussion

Electric cars manufacturers promote them as thoroughly environmentally friendly vehicles, whose use does not affect GHG emission. Nevertheless, the unique nature of Polish electric power system makes it necessary to consider indirect emission linked to the demand for electric energy which accompanies the growing popularity of new technologies in transport.

According to the estimations (Table 4), indirect carbon emission resulting from electric car use in 2015 reached 88.26 – 219.75 g/km, depending on the car model and power distributor. The indirect emission indicator for SO2 equalled 0.165-0.884 g/km, indirect emission of NOX amounted to 0.12-0.312 g/km, and indirect emission of dust ranged between 0.0088-0.0228 g/km.

For carbon emission, it is possible to compare the indirect emission values with the results of traditional internal combustion cars. A comparison of emission values (Table 5) shows that most of the analysed cars emit less CO2 than their electric counterparts, or else their emission values are similar and depend on the power distributor that supplies the power required to charge the vehicle.

Table 4. Volume of the indirect emissions of GH and dust for selected electric car models in Poland in 2015 [g/km]

Distributor \ Model	Nissan LEAF	Renault Zoe	Tesla S P90D	Volkswagen e-Golf	BMW i3
CO_2 emission					
Enea Operator Sp. z o.o.	109.74	106.81	175.58	92.91	94.38
Tauron Dystrybucja SA	127.09	123.70	203.34	107.60	109.30
PGE Dystrybucja SA	104.25	101.47	166.80	88.26	89.65
Energa-Operator SA	137.34	133.68	219.75	116.28	118.12
RWE Stoen Operator Sp. z o.o.	123.73	120.43	197.97	104.76	106.41
SO_2 emission					
Enea Operator Sp. z o.o.	0.225	0.219	0.360	0.191	0.194
Tauron Dystrybucja SA	0.195	0.190	0.312	0.165	0.167
PGE Dystrybucja SA	0.211	0.205	0.337	0.178	0.181
Energa-Operator SA	0.263	0.256	0.420	0.223	0.226
RWE Stoen Operator Sp. z o.o.	0.553	0.538	0.884	0.468	0.475
NO_x emission					
Enea Operator Sp. z o.o.	0.165	0.161	0.264	0.140	0.142
Tauron Dystrybucja SA	0.148	0.144	0.237	0.125	0.127
PGE Dystrybucja SA	0.142	0.138	0.227	0.120	0.122
Energa-Operator SA	0.195	0.190	0.312	0.165	0.167
RWE Stoen Operator Sp. z o.o.	0.168	0.163	0.268	0.142	0.144
Dust emission					
Enea Operator Sp. z o.o.	0.0150	0.0146	0.0240	0.0127	0.0129
Tauron Dystrybucja SA	0.0104	0.0101	0.0166	0.0088	0.0089
PGE Dystrybucja SA	0.0104	0.0101	0.0166	0.0088	0.0089
Energa-Operator SA	0.0143	0.0139	0.0228	0.0121	0.0123
RWE Stoen Operator Sp. z o.o.	0.0120	0.0117	0.0192	0.0102	0.0103

Source: own work.

Considering the structure of power production in Poland and indirect GHG emission, it cannot be clearly determined which type of engine, the internal combustion or the electric one, is more environmentally friendly in Polish conditions. The study implies that in most cases (15 in 25), it was the electric car that emitted more carbon that its internal combustion counterpart. It could be noted the environmental attractiveness of the internal combustion engine decreased more when its power grew significantly compared to a significant increase in the power of the electric engine.

Table 5. Comparison of CO2 emission in electric and internal combustion-powered cars

Electric cars	Indirect CO2 emission in g/km	Direct CO2 emission in g/km	Internal combustion cars
Renault Zoe	107-134	95	Renault Megane
Tesla S P90D	167-220	212-214	Porsche Panamera Turbo
Nissan LEAF	104-137	94	Nissan Pulsar
Volkswagen e-Golf	93-116	99	Volkswagen Golf
BMW i3	90-118	116-126	BMW 1 series

Source: own work.

Furthermore, carbon emission standards for internal combustion passenger cars (135 g/km) [Regulation of the European Parliament and of the Council no. 443/2009] are also met by most electric cars when it comes to indirect emission (Table 6). Cars with a high maximum power and large engine/battery capacity are an exception to this rule. These belong to the luxury cars category.

In case of Euro 6 emission standards, in force since September 2014, the upper limit of nitrogen oxide (NOX) emission is 0.06 g/km for internal combustion cars, and 0.08 g/km for Diesel engine cars. If Euro 6 limits applied also to electric cars, neither of these limits would be met and the cars would not be approved for the Polish market.

Table 6. Indirect CO2 emission in electric cars in Poland

Electric cars	Indirect CO2 emission in g/km
Renault Zoe	0.138-0.190
Tesla S P90D	0.227-0.312
Nissan LEAF	0.142-0.195
Volkswagen e-Golf	0.120-0.165
BMW i3	0.122-0.167

Source: own work.

5. Conclusion

The indirect production of exhaust fumes emitted by electric cars is determined by two factors: the engine's power consumption and the volume of the emissions produced when generating power sold by distributors. A decrease in power consumption could be achieved through improving the efficiency of the electric engine. This condition is difficult to meet because the efficiency of a modern electric engine is very high and exceeds 90%. It is worth noting the efficiency of an internal combustion engine does not exceed 40%.

Methods of limiting exhaust fumes emissions into the atmosphere include improving the quality of fuels used for electric power production, coal cleaning, implementing modern effective combustion technologies and introducing emission reduction technologies [Michalak 2014]. Increasing the efficiency of the power generation process along with limiting the emission level of the combustion process in conventional power plants is a fundamental and essential solution to reduce air pollution.

An effective method of limiting emission is changing the structure of energy mix in Poland. An improvement in the current air quality depends on the increased share of traditional low-carbon technologies and renewable sources in electric energy production.

An improvement in air quality can be achieved via respecting and implementing regulations based on previously approved government strategies. Two key areas include the development and implementation of alternative technologies in vehicle engines and increasing the efficiency of solar power production via the creation of high-efficiency power generation. The expansion of the electric car market depends on, among other factors, the development of infrastructure, especially modernisation of the transmission and distribution system.

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