

The development of electromobility in the aspect of the energy infrastructure condition assessment

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Abstract. Electric vehicles are considered emission-free. However, having high-emission and a high degree of electricity demand coverage infrastructure, these vehicles should be considered as internal combustion cars. The purpose of the analysis carried out in this study is to present the state of energy infrastructure in Poland, to determine losses related to energy transmission and greenhouse gas emissions to the atmosphere in relation to unit consumption. Analyzing the data obtained, the emission of the electric vehicle was compared to that of a vehicle powered by diesel oil and fuel with the addition of a biocomponent.

1 Introduction

Restrictive regulations contribute to the creation of new legal principles in the field of energy, industry and means of transport as these are the main sources of harmful substances emission into the atmosphere. Actions decentralizing the energy sector, in which the client becomes a prosumer are being taken. When using renewable energy sources, the surplus of unused energy is sent to the network. With the current technological solutions, full energy accumulation is not possible and the continuous support of conventional power plants is required to ensure the continuity of electricity supply. In Poland, over 67% of electricity comes from commercial thermal power plants powered by lignite and hard coal. Contemporary electric vehicles use construction solutions that are nearly one hundred years old yet are now coupled with modern computer technologies. Many research institutions constantly conduct studies aimed at improving the operational parameters of the vehicles. However, it cannot be concluded that these types of vehicles are emission-free. This is due to the insufficient amount of clean energy produced. Therefore, in terms of the impact on the environment, electric vehicles should be considered just like any other vehicles with conventional combustion engines. Differences affecting the amount of substances emitted

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into the atmosphere result from the applied construction solutions, as well as external factors having a direct impact on the operation of the vehicle [1,10,15-18].

2 Analysis of the national energy infrastructure

The energy infrastructure in Poland consists of commercial power plants, which are divided into hydroelectric and thermal power plants powered by coal or gas. There are also auto producer power plants and the ones using renewable energy sources [1].

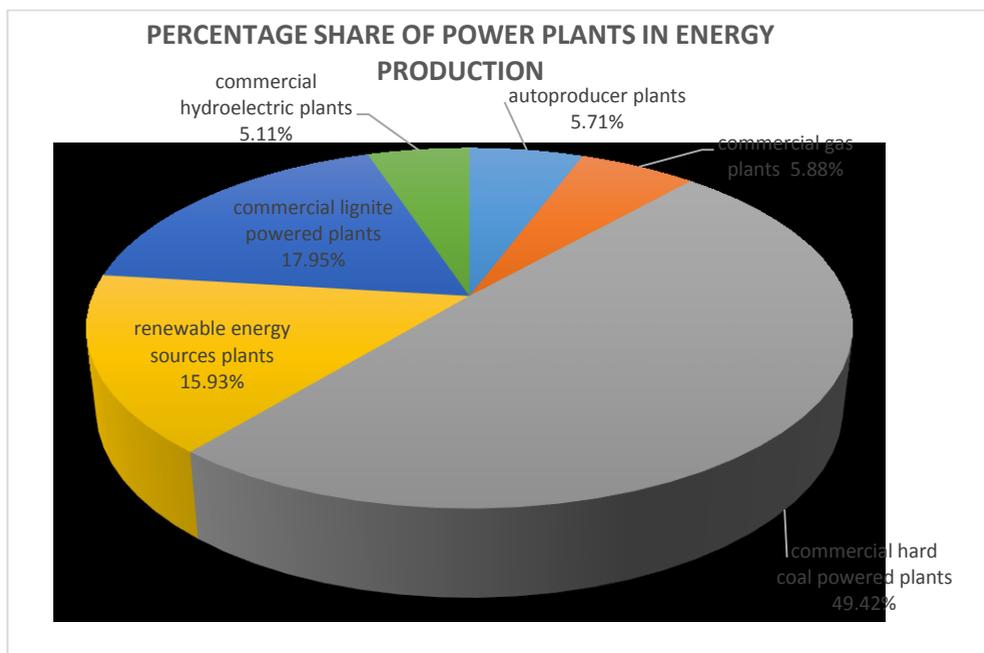


Fig. 1. Percentage share of power plants in energy production [1].

Plants powered by hard coal and lignite are considered high-emission power plants. It is estimated that 67.37% of this energy is produced by 16 power plants managed by 4 different operators. Newly built power plants are characterized by high efficiency, amounting to 49.7%. However, the average efficiency of all power units is about 41.08%. Mutual correlation between the gross production efficiency and the emission of dust and greenhouse gases to the atmosphere can be observed [2].

Table 1. Technical parameters summary of two power plants [2].

Energy group	Plant	Power unit capacity [MW]	Gross production efficiency [%]	Dust emission [kg/MWh]	SO2 emission [kg/MWh]	Nox emission [kg/MWh]	CO2 emission [kg/MWh]
Zepak S.A.	Adamow	120	32.90	0.52	4.15	2.23	1217.4
Tauron S.A.	Siersza	120	34.00	0.17	2.8	2.22	1000

When analyzing power plants with the same power unit capacity, but with the difference in efficiency amounting to 1.10%, a significant reduction of harmful substances can be observed. The emission of dust is reduced by 67.30%, sulfur dioxide by 32.53% and carbon dioxide by 17.85%. Adamow power plant, which accounts for 2% of coal powered plants

capacity in Poland, was not able to comply with the EU IED directive regarding the emission of harmful substances. Thereby, according to 48-hour reports, these concentrations were 151 times higher than the acceptable values [3].

Renewable energy sources constitute a very unstable energy sector in Poland. In 2014, the installed capacity was estimated at 15.3% of which the real production value was 6%, which is only 39.21% of the declared capacity. Due to the intermittent character of work caused by changing weather conditions, it is necessary to use large reserves in order to ensure continuity in energy supply to consumers. During the periods of inefficiency caused by significant cloud cover and lack of wind, it is necessary to use the full availability of energy resources from other branches [5].

Apart from low efficiency in power generation, there are also losses associated with distribution and transmission.

Table 2. Average values of energy losses in the network [6].

ΔE% losses				
Year	400kv and 220 kv	110kv	Medium voltage networks	Low voltage networks
2002	1.89	4.21	4.38	11.94
2004	2.20	2.21	4.29	10.97
2006	2.15	2.75	3.89	8.88
2008	1.92	1.47	3.72	7.78
2010	1.87	1.85	3.47	7.32
2012	1.69	1.7	3.09	6.30
2014	1.64	1.44	3.03	5.74
2015	1.77	1.55	2.99	5.37

The losses in networks result from the conversion of electricity into heat. This phenomenon is described by the Joule-Lenz law, which says that the thermal power density of a current in a conductor is equal to the product of its specific conductivity and the square of the electric field strength. The origin of these losses can be classified as no-load and load losses. Based on substitute diagrams, the no-load losses are expressed by the resistance in the transverse branches defined as the square of the voltage at a given location. The load losses are expressed by the resistance in the longitudinal branches, and their value is proportional to the square of the current flowing in a given branch [7].

It is also important to present how differentiated the unit costs of generated and sold energy for individual sectors of the energy industry are. The difference in price may be more than three times greater for producing the same amount of energy [5].

Table 3. Average costs of generating and selling energy [5].

Specification	Technical production cost per unit [PLN/MWh]			Energy sold cost per unit [PLN/MWh]		
	Lignite power plants	139.7	134.6	134.9	154.3	160.8
Hard coal power plants	212.5	199.3	183.9	250.8	227.5	205.3
Gas thermal power plants	303.1	372.2	261	324.1	405.9	286.9
Hydroelectric power plants	186.2	153	170.5	232	181.1	227.7
Wind power plants	208	222.1	227.8	361.1	365	367.4
Biomass power plants and thermal power plants	446.1	405.6	361.6	463.7	451.1	412.7

3 The analysis of the means of transport emission

The act on electro mobility is aimed at popularizing electric means of transport. An electric vehicle, unlike a combustion vehicle, does not have a strictly defined “exhaust emission” and its actual values depend on the energy system in a given country [8]. On the basis of the above analysis, taking into account the condition of the energy infrastructure in Poland, it can be assumed that the coefficient of the energy origin from high-emission sources is $\alpha = 0.75$. Therefore, it is possible to estimate the amount of harmful substances emitted into the atmosphere, taking into account the losses at the distribution stage and the share of high-emission sources in the energy system.

Table 4. The emission of greenhouse gases generated during the production of 1 kWh of energy.

	SO_2 emission [kg/MWh]	NO_x emission [kg/MWh]	CO_2 emission [kg/MWh]
1kWh of energy with the $\Delta E\%$ losses taken into account and the coefficient α for the 400kv and 220kv networks	0.00100347	0.000733139	0.722908866
1kWh of energy with the $\Delta E\%$ losses taken into account and the coefficient α for the 110kv network	0.001005993	0.000734983	0.724726936
1kWh of energy with the $\Delta E\%$ losses taken into account and the coefficient α for medium voltage networks	0.001020372	0.000745488	0.735085499
1kWh of energy with the $\Delta E\%$ losses taken into account and the coefficient α for low voltage networks	0.001064001	0.000777364	0.766515934

Having approximate data on emissions and losses, it is possible to estimate the amount of greenhouse gases emitted by electric vehicles and compare them to conventional vehicles powered by diesel oil and fuel enriched with biocomponents.

On the basis of the summary of the most popular electric vehicles available in Poland and their technical parameters, it is possible to determine the emission of individual substances into the atmosphere, which is emitted due to the vehicle being supplied with electricity [9].

Table 5. Selected operation parameters of the specified means of transport.

	BMW i3	Nissan Leaf	Renault Zoe	Jaguar I-Pace	Audi E-Tron
Power [KM]	184	218	136	400	503
Torque [Nm]	270	340	245	696	973
Battery capacity [kWh]	42	62	52	90	95
Energy consumption [kWh/100 km]	16.5	18.7	13.6	19.1	28.4

Energy consumption in electric vehicles, which is directly related to the emission of carbon dioxide, sulfur dioxide and nitrogen compounds, is influenced by, among others:

- power and number of propulsion engines,
- the weight of the vehicle
- weather conditions,
- C_x , aerodynamic drag coefficient,
- type of tires used.

Table 6. Selected operation parameters of the specified means of transport.

Greenhouse gas emissions for 400kv and 220kv networks					
Parameter	BMW i3	Nissan Leaf	Renault Zoe	Jaguar I-pace	Audi E-Tron
SO2 emission [kg/100km]	0.016557	0.018764882	0.013647187	0.01916627	0.02849854
NOX emission [kg/100km]	0.012097	0.013709706	0.009970696	0.014002962	0.02082116
CO2 emission [kg/100km]	11.928	13.5183958	9.831560584	13.80755935	20.5306118
Greenhouse gas emissions for 110kv networks					
Parameter	BMW i3	Nissan Leaf	Renault Zoe	Jaguar I-pace	Audi E-Tron
SO2 emission [kg/100km]	0.016599	0.018812074	0.013681508	0.019214471	0.02857021
NOX emission [kg/100km]	0.012127	0.013744186	0.009995771	0.014038179	0.02087352
CO2 emission [kg/100km]	11.95799	13.55239371	9.856286332	13.84228448	20.582245
Greenhouse gas emissions for medium voltage networks					
Parameter	BMW i3	Nissan Leaf	Renault Zoe	Jaguar I-pace	Audi E-Tron
SO2 emission [kg/100km]	0.016836	0.019080956	0.013877059	0.019489105	0.02897856
NOX emission [kg/100km]	0.012301	0.013940632	0.010138641	0.014238827	0.02117187
CO2 emission [kg/100km]	12.12891	13.74609884	9.99716279	14.04013304	20.8764282
Greenhouse gas emissions for low voltage networks					
Parameter	BMW i3	Nissan Leaf	Renault Zoe	Jaguar I-pace	Audi E-Tron
SO2 emission [kg/100km]	0.017556	0.019896811	0.014470408	0.020322411	0.03021762
NOX emission [kg/100km]	0.012826	0.014536699	0.010572145	0.014847644	0.02207713
CO2 emission [kg/100km]	12.64751	14.33384797	10.4246167	14.64045434	21.7690525

The difference in “the emission” of harmful substances in relation to the network from which the energy is taken amounts to a maximum of 6%. This contributes to a slight fluctuation in greenhouse gas emissions by changing the voltage of the network that powers the vehicle.

On the basis of the above analysis, electric vehicles can be compared to conventional combustion vehicles powered by diesel fuel or a mixture of biocomponents with diesel fuel.

The study was conducted for a passenger car of up to 3.5 t of maximum permissible laden mass with a 1.6 HDI diesel engine [12]. As the basis for the analysis, all considerations have been narrowed down to one of the criteria, which is carbon dioxide emission. The average value of CO₂ emitted for a vehicle with a diesel engine is $114 \frac{\text{g}}{\text{km}}$ [11]. However, after the modification of the controller, which influenced the boost pressure of the turbocharger and the increase of the fuel dose enriched by volume by 10% of fatty acid methyl esters [12], the emission was reduced by 1.036% compared to the serial settings, which translated into the production of $109.867 \frac{\text{g}}{\text{km}}$ of carbon dioxide [13]. The Audi E-Tron vehicle with a CO₂ average emission at the level of $209.395 \frac{\text{g}}{\text{km}}$, assuming that the share of high-emission power plants $\alpha = 0.75$, showed the emission higher by 47.53% than the modified diesel engine, which additionally showed power and torque increase measured on the wheels with a dynamometer [12].

4 Summary

On the basis of the analysis carried out in the study, it can be concluded that the emission of harmful substances into the atmosphere produced by coal-fired power plants, which are the basis of the national power industry, covering up to 75% of the energy demand, has an average efficiency of 41.08%. The losses related to the transmission and distribution on networks of various voltage contribute to the greater amount of carbon dioxide emitted in order to produce 1 kWh of energy. In the case when the real efficiency of renewable energy sources is only 39.21%, it is necessary to use energy reserves from other energy sectors. This directly translates into air quality, as alarms are raised in many places about exceeded permissible values which is harmful to health [14].

Due to the insufficient infrastructure of low-emission energy sources, electric vehicles mostly use electricity generated in coal-fired power plants. Considering their emissivity like other motor vehicles is justified because electric vehicles are powered by the energy generated from coal. A passenger car equipped with a 1.6 HDI diesel unit powered by a mixture of diesel oil and fatty acid methyl esters, as well as a modified engine controller shows 47.53% lower CO₂ emission than the Audi E-Tron electric vehicle. Assuming that the vehicles will cover the distance of 20,000 km per year, the difference in the amount of carbon dioxide emitted will amount to 1,990.56 kg. The analysis shows that the interference in the diesel engine control unit and the change of power supply brings measurable benefits in the form of improvement of operating parameters and the reduction of CO₂ emission by over 1%. An electric vehicle gains an ecological advantage when it is charged directly from installations based on renewable energy sources. An example is a home photovoltaic installation, thanks to which the amount of energy loss is significantly reduced. Due to different weather conditions, the efficiency of the system changes, thus influencing the time of charging the vehicle.

At the same time, other operational criteria for means of transport [15-22] should be taken into account, which in the overall analysis and assessment of this issue are equally important.

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