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ANALYSIS OF ELECTRIC VEHICLES EFFICIENCY AND THEIR INFLUENCE ON ENVIRONMENTAL POLLUTION

Mirosław Karczewski, Leszek Szczęch, Filip Polak, Szymon Brodowski

Military University of Technology
Faculty of Mechanical Engineering
Institute of Motor Vehicles and Transportation
Gen. Sylwestra Kaliskiego Street 2, 00-908 Warsaw, Poland
e-mail: miroslaw.karczewski@wat.edu.pl, leszek.szczech@wat.edu.pl
filip.polak@wat.edu.pl, szymon.brodowski@student.wat.edu.pl

Abstract

Electric vehicles are increasingly present on the roads of the whole world. They have the opinion of ecological vehicles, not polluting the environment. Society is more and more often persuaded to buy electric cars as an environmentally friendly solution but is this for sure? Electric cars need quite a lot of electricity accumulated in batteries to drive on a long range. During the charging process, this energy is obtained from the electricity network, to where it is supplied by power plant. Electricity production from renewable sources is a privilege for the rare. However, electric cars are charged from the electricity grid, which in large part energy comes from non-renewable fuels. The efficiency of energy production in power plants and the energy transmission and conversion chain causes that only part of the energy produced in this way goes to the vehicle's wheels. Although the power plants are equipped with more and more efficient exhaust gas cleaning systems, they do not clean them up to 100%. Sulphur, nitrogen, mercury and heavy metals remain in the exhaust. The article is an attempt to answer the question whether the total emission of toxic components associated with the use of an electric vehicle is not bigger than in a traditional internal combustion engine.

Keywords: *electric vehicle, exhaust gas toxic components, electro power plants, electricity production*

1. Introduction

Currently, more and more attention is paid to energy technologies environmentally friendly. The acquisition of electricity from renewable energy sources such as solar radiation, wind or water energy is an increasingly common challenge. One of the important factors affecting the natural environment is cars, used daily in mass quantities. According to data of the Central Statistical Office, in 2017 over 28 million cars were registered in Poland, including approx. 22 million passenger cars, of which about 13.5 million have passed technical tests and bought car insurance [6].

Society is more and more often persuaded to buy electric cars as an environmentally friendly solution. Electric cars need quite a lot of electricity accumulated in batteries to drive on a long range. During the charging process, this energy is obtained from the electricity network, to where it is supplied by power plant. The dominant share of electricity production from non-renewable sources is a problem. Nearly 85% of the energy market is coal-fired power plants powered by bituminous coal and lignite, and ca. 5% is covered by gas-turbine power plants operating on natural gas. Power plants produce exhaust gas in which toxic compounds, heavy metals, and particulate matters are contained. Their quantity and quality depends on the type of power plant, installed exhaust gas cleaning systems and on the level of electricity production. Another problem is the low efficiency of electricity transmission to consumers. Only 85-88% of the energy generated in the power plant is delivered to the vehicle charging point, where the battery is charged. In addition, even less energy goes to the vehicles' drive wheels. Transmission lines, charging stations, electric motors and electrical converters in the vehicle have their efficiency. The various stages of energy transformation cause an increase for compounds produced to the environment related to the distance travelled by the electric vehicle. It can therefore turn out that the use of an electric vehicle results in a greater total emission of chemicals than in a car with an internal combustion engine. Which means that electric cars cannot pass the emission standards (Euro 6).

2. Characteristics of selected cars with electric drive

Electric vehicles are driven by electricity stored in a traction battery or taken from a fuel cell that generates electricity from fuel carried in the vehicle and oxygen from the air or from the traction network close to the vehicle's driving path. The drive motors are DC or AC electric motors that can operate both in motor and generator mode (i.e. recovering energy during braking). Electric combustion engines at the beginning of the automotive industry were used as readily as combustion engines. The first vehicle to overcome the 100 km/h barrier was an electric vehicle. The large mass of batteries needed to store energy, their low durability and long charging time discouraged vehicle users until the end of the 20th century, the renaissance of electric cars.

Nowadays, the leaders producing electric cars are Hyundai with the Ioniq Electric, Nissan with Leaf and Tesla with the S model. It is believed that these types of vehicles are future-proof, due to their low cost of ownership and environmental friendliness. The article estimates the emission of toxic compounds associated with their use in order to assess the degree of impact of these electric vehicles on the natural environment.

Electric vehicles have many advantages and disadvantages. Basic advantages can include, for example:

– low cost of ownership,
– easy cooling of electric motor,
– lack of lubrication system of electric motor,
– basic construction, easy to control,
– low level of noise and vibration,
– lack of exhaust gas (on the road).

Main disadvantages are:

– range of the vehicle is low, it should be charged every 200-300 km,
– lack of charging stations,
– long time for recharging,
– high cost of buying an electric car,
– fast aging and diminish of battery capacity,
– high cost of battery replacing.

In the presented analyses of toxic compounds emissions, three models of electric cars were considered, to which further stages of work were devoted. These are Hyundai IONIQ ELECTRIC, Nissan LEAF, Tesla Model S.

Fig. 1. An electric car – Hyundai IONIQ [8]

Fig. 2 Nissan LEAF electric car [9]

Fig. 3 Tesla Model S electric car [11]

Hyundai IONIQ ELECTRIC is a sedan car, with front-wheel drive, five-person, five-door, compact class. Nissan LEAF is a hatchback car, with front-wheel drive, five-person, five-door, compact class and The Tesla Model S is a lift back passenger car with rear-wheel drive, five-person, five-door, premium class.

The electric cars presented above are different in terms of weight, engine power and battery capacity. Tesla stands out here in a special way, as it is part of the segment of luxury cars, but also costs almost twice as much as the other two.

Tab. 1. Basic data of Hyundai IONIQ electric car [8]

Electric motor	
Type	Synchronous with permanent magnets
Effective power (kW)	88
Torque (Nm)	295
Battery	
Type of battery	Lithium-ion polymeric
Capacity (kWh)	28
Power (kW)	98
Results	
Maximum speed (km/h)	165
Acceleration 0-100 km/h (s)	9.9 (sport mode) / 10.2 (normal mode)
Efficiency (kWh/100 km)	11.5
Range (km)	280
Charging	
DC charger 400 V (mode IV)	30 min (up to 80% of capacity)
AC charger 400 V (mode II)	4.5 h
AC charger 230 V (included – mode I)	12 h

Tab. 2. Basic data of Nissan LEAF electric car [10]

Electric motor	
Type	A/C
Effective power (kW)	120
Torque (Nm)	254
Battery	
Type of battery	Lithium-ion
Capacity (kWh)	24
Voltage (V)	360
Results	
Maximum speed (km/h)	144
Acceleration 0-100 km/h (s)	11.5
Energy consumption (Wh/km)	150
Range (km)	199
Charging	
Fast charging	30 min (up to 80%)
Standard charging	8 h
EVSE wire	12 h

Tab. 3. Basic data of Tesla Model S electric car [12]

Electric motor	
Type	Asynchronous motor
Effective power (kW)	386
Torque (Nm)	525
Battery	
Type of battery	Lithium-ion
Capacity (kWh)	70
Power (kW)	245
Results	
Maximum speed (km/h)	230
Acceleration 0-100 km/h (s)	5.4
Electricity consumption (kWh/100 km)	21
Range (km)	442
Charging	
Fast charging	30 min up to 80%
Standard charging	10 h

3. Energy consumption by electric cars

During testing and developing the energy balance of an electric car, factors such as energy consumption and efficiency of individual components should be taken into account, including, among others, electric drive - battery motors. It should also take into account all electronic devices (chargers, inverters) located in the electric energy conversion path from the power plant to the vehicle wheels, and take into account other elements of electrical equipment in the car such as displays, clocks, backlight diodes, but also the air-conditioning system or power steering system.

In the presented work, calculations of energy consumption by compared vehicles during the NEDC test were carried out (Fig. 4.).

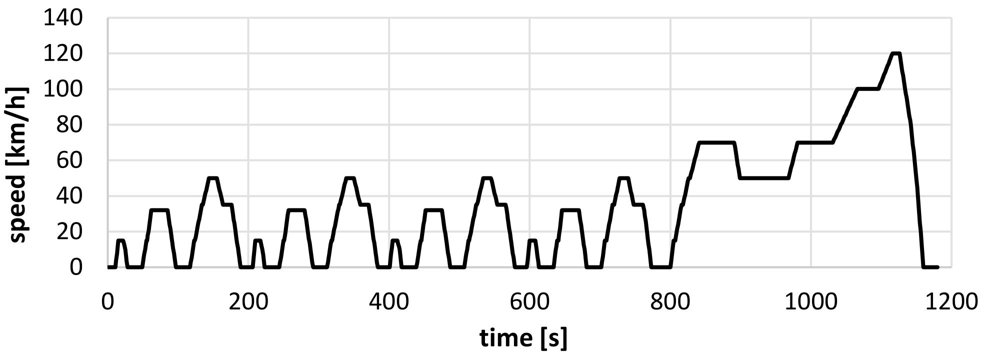

Fig. 4. NEDC test

The calculations used data of compared cars affecting the level of energy consumed by the vehicle – in accordance with the system of forces applied on the vehicle and the demand for rotational speed and engine torque (traction characteristic). The energy demand was calculated for a 100 km section (about 9 NEDC test lengths). The assumed conditions did not include energy recovery from braking. The energy that has been determined is the electric energy needed to accelerate the car and its driving at a constant speed, as well as to overcome the resistance, friction and inertia. The results are shaped in the following way [13]:

– Hyundai IONIQ ELECTRIC – 13.22 kWh/100 km,
– Nissan LEAF – 13.66 kWh/100 km,
– Tesla Model S – 17.12 kWh/100 km.

The above values are related to the energy transferred from the vehicle's wheels to the road. Because in electric cars, the number of elements in the energy conversion chain is quite large, the appropriate efficiency (Tab. 4) necessary to calculate the energy generated by the power plant has been adopted to ensure that individual vehicles can drive over the 100 km section.

Tab. 4. Efficiency of car charging energy transfer chain [7, 13]

No.	Step of electric energy transfer	Efficiency [%]
1.	Electric grid – energy transfer	88
2.	Car battery charger	90
3.	Battery	95
4.	Electric motor controller –inverter	90
5.	Electric motor	90
6.	Transmission	93

The total efficiency of the energy conversion system for electric cars in the power plant-to-vehicle's wheel transformation system was estimated at 57%. The efficiency of a coal-fired power plant is approx. 40%. The efficiency of the entire energy conversion chain from obtaining fuel (coal, gas) to an electric car is at 20%.

The amount of energy generated in the power plant needed to enable individual vehicles to drive the distance of 100 km in the NEDC test was:

1. Hyundai IONIQ ELECTRIC – 24.12 kWh/100 km;
2. Nissan LEAF – 23.32 kWh/100 km;
3. Tesla Model S – 30.21 kWh/100 km.

4. Production of energy and toxic compounds by power plants

Energy for car charging points is supplied by utility power plants, which in Poland are mostly based on the combustion of lignite or bituminous coal. A coal-fired power plant is a thermal and steam power plant. In the combustion processes, fumes are emitted into the atmosphere by the flue gas treatment system; and create pollution associated with the consumption of the appropriate amount of energy through a connected receiver.

The fumes affect not only the atmospheric air, but also the soil and water. Current standards (Emission Standards, BAT Conclusions) are increasingly limiting the amount of toxic components and dust in the flue gas coming from the power plant. Unfortunately, even modern exhaust gas cleaning systems do not allow 100% reduction of toxic compounds emission in exhaust gases from energy sources. Tab. 5 presents types of pollutants that may come from the combustion of individual types of coal prepared on the basis of [1, 2]. Regarding [1], the emission levels of individual components were adopted in relation to combustion processes in the energy production and transformation sector. There is an assumption of electrical energy production from non-renewable sources at 149.4 TWh [5].

Tab. 5. Levels of emissions of chemical compounds related to the combustion process in the energy production and transformation sector, and emission rates for electricity in 2016 kg / year

No.	Exhaust gas component	Level of emission kg/year [1]	Emission coefficient kg/MWh (calculated)	Emission coefficient kg/MWh [2]
1.	Carbon monoxide (CO)	49773800.0	0.333	0.26
2.	Carbon dioxide (CO2)	–	–	806.00
3.	Nitrogen oxides (NOx/NO_2)	179478000.0	1.201	0.85
4.	Sulphur oxides (SOx/SO_2)	261170100.0	1.748	0.84
5.	Chrome (Cr)	6353.3	0.000043	–
6.	Copper (Cu)	18156.3	0.000122	–
7.	Mercury (Hg)	5184.0	0.000035	–
8.	Nickel (Ni)	34727.9	0.000232	–
9.	Zinc (Zn)	86405.6	0.000578	–
10.	Particulate matters PM	27146400.0	0.182	0.054
11.	Arsenic (As)	5106.9	0.000034	–

Tab. 6. Calculated emission values of exhaust components for electric cars

No.	Exhaust gas component	Emission in g/km			Emission in comparison to Euro 6 [%]			Euro 6
		Nissan	Hyundai	Tesla	Nissan	Hyundai	Tesla	g/km
1.	Carbon monoxide (CO)	0.0714	0.0692	0.0895	7.15	6.92	8.96	1
2.	Carbon dioxide (CO_2)	194.2	188.0	243.4	149.4	144.6	187.3	130*
3.	Nitrogen oxides (NO_x/NO_2)	0.247	0.239	0.310	412.0	398.7	516.3	0.06
4.	Sulphur oxides (SO_x/SO_2)	0.421	0.408	0.528				
5.	Chrome (Cr)	1.02E-05	9.92E-06	1.28E-05				
6.	Copper (Cu)	2.93E-05	2.83E-05	3.67E-05				
7.	Mercury (Hg)	8.36E-06	8.09E-06	1.05E-05				
8.	Nickel (Ni)	5.6E-05	5.42E-05	7.02E-05				
9.	Zync (Zn)	0.000139	0.000135	0.000175				
10.	Particulate matters PM	0.0438	0.0424	0.0549	875.8	847.6	1097.7	0.005
11.	Arsenic (As)	8.24E-06	7.97E-06	1.03E-05				

*limit issued in 2015 [3, 4]

Table 6 shows the calculated emissions of individual exhaust components in relation to the energy generated in the Polish Power System needed to charge traction batteries of individual electric cars to a level that allows covering a distance of 100 km, according to the NEDC test in accordance with the methodology presented in Chapter 2. There is a visible emission increase of some components in relation to a vehicle powered by a classical internal combustion engine.

Based on the above we can state that the electric vehicle, despite many undoubted advantages in the case of electricity production from coal, has a very negative impact on our health. Despite significant progress in the field of pollution control on the so-called end of the pipe (i.e. on the chimneys of the power plant), thanks to the installation of dust electrostatic precipitators or desulphurisation and denitrification installations – coal-fired power plants still release huge amounts of substances harmful to man and the environment.

5. Conclusions

1) Electric cars are seen as ecological means of transport. However, if they are charged from non-renewable energy sources working on fossil fuels, this means the emission of toxic compounds by the power plant into the atmosphere.
2) Comparison of three electric cars indicates quite similar energy needs necessary to drive over a specific road section, while due to the low efficiency of the energy conversion chain between the power plant and the road, the amount of energy generated in the power plant must be almost twice as high, as the energy needed to overcome the resistance of the vehicles. The indications for the Tesla car are slightly larger due to the greater effort of the propulsion system (the vehicle is sport car).
3) The calculated emission values for individual electric cars indicate that while in the scope of carbon monoxide emission the Euro 6 standard is met, it is repeatedly exceeded in relation to the emission of nitrogen oxides and particulates (particulate matter). In the case of nitrogen oxides, the emission standard is exceeded about 5 times and in the case of particulate matter, up to 10 times.
4) The carbon dioxide emission limit introduced in 2015 for newly registered vehicles is exceeded by 50-90%, depending on the vehicle's performance.
5) The values of emission factors for heavy metals have been quoted to indicate the level associated with the operation of electric cars.

References

[1] *Krajowy bilans emisji SO_2, NO_X, CO, NH_3, NMLZO, pyłów, metali ciężkich i TZO za lata 2015-2016, raport syntetyczny*, KOBiZE, Warszawa, Styczeń 2018.

[2] *Wskaźniki emisyjności CO_2, SO_2, NO_x, CO i pyłu całkowitego dla energii elektrycznej*, KOBiZE, Warszawa, Grudzień 2017.

[3] https://kaizenfleet.pl/nowe-normy-co2-odmienia-branze-motoryzacyjna/ z dnia 10.07.2019.

[4] http://moto.pl/MotoPL/7,88389,23277145,unia-europejska-przycina-emisje-co2-pociagnie-to-za-soba-nizsze.html z dnia 10.07.2019.

[5] *Zestawienie danych ilościowych dotyczących funkcjonowania KSE w 2016 roku*, Raport 2016 KSE, Polskie Sieci Energetyczne, 2016.

[6] *Liczba pojazdów zarejestrowanych w Polsce wg danych CEPiK (8.08.2017)*, Prawo drogowe 10.07.2017.

[7] https://www.rp.pl/artykul/649811-Straty-w-przesyle-siegaja-w-kraju-12-proc-energii-rocznie. html, on the 25.06.2019.

[8] https://www.drivezero.com.au/cars/hyundai/hyundai-car-guides/hyundai-ioniq-guide/, 09.07.2019.

[9] https://commons.wikimedia.org/wiki/File:Nissan_Leaf_ZE1_Nissan_Global_Headquarters_Gallery_2017-08_1.jpg, 10.07.2019.

[10] https://www.auto-data.net/pl/nissan-leaf-ii-ze1-40-kwh-150hp-32049, 10.07.2019.
[11] https://www.motofakty.pl/artykul/tesla-model-s-po-liftingu.html, 10.07.2019.
[12] https://pl.wikipedia.org/wiki/Tesla_Model_S, 10.07.2019.
[13] Brodowski, S., *Analiza emisji związków toksycznych w aspekcie eksploatacji wybranego pojazdu z napędem elektrycznym*, Praca dyplomowa, WAT 2018.

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