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DOES ELECTRIC CAR PRODUCE EMISSIONS?

Summary. This article focuses on the comparison of the amount of emissions produced by vehicles with a combustion engine and electric cars. The comparison, which is based on the LCA factor results, indicates that an electric car produces more emissions than a vehicle with combustion engine. The implementation of electric cars will lead to an increase in the production of greenhouse gases.
Keywords: electric car, emissions, LCA, road transport

1. INTRODUCTION

The road transport is an inseparable part of life in society. It participates in goods, materials and finished products transportation from their original location to the place of usage. Only the fraction of a needed amount of workforce could get to work without the road transport. The road transport partakes in transportation of people not only to their work and back but also to get relaxed, to cinema, theatre or for a recreation. Modern society could not manage without it to meet its needs, which can lead to its ending. However, vehicles on the road instead of wished effect and transportation of goods and people can also cause a negative effect. It includes the use of land for infrastructure, production of heavily biodegradable solid

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and liquid waste, which imposes some burden on our environment. Nonetheless, the most significant undesirable product of vehicle activity is a production of greenhouse gases.

2. ROAD VEHICLE EMISSIONS

Road vehicles create power needed to overcome running resistances by combusting hydrocarbon fuels. During the combustion of fuels, exhaust gases are produced including:

- nitrogen - N_2
- oxygen - O_2
- water, water vapour - H_2O
- carbon monoxide - CO
- carbon dioxide - CO_2
- sulphur dioxide - SO_2
- hydrocarbons - HCs
- nitrogen oxides - NO_X

Nitrogen and oxygen. These are also found in clear air and have no harmful effects in contrast to other components of exhaust gases.

Water vapour. According to [3], is responsible for approximately two thirds of natural greenhouse effects. The reason for this is that water molecules capture the heat in the atmosphere, which is emitted by the Earth. Such captured heat is emitted again in all directions while heating the Earth's surface. The water vapour in the atmosphere is part of the water cycle in nature. Human activities do not increase the amount of water in the atmosphere.

Carbon monoxide. This is produced during the incomplete oxidation of carbon contained in the hydrocarbon chain of fuels. Carbon monoxide is highly toxic and odourless. It comes into contact with red blood cells in the lungs and binds with haemoglobin 240 times more effectively than oxygen. Since carbon monoxide binds with haemoglobin, there is a reduction in oxygen transmission by blood, which can damage tissue and cells, mainly of the brain and nervous system. The inhalation of carbon monoxide in small amounts causes fatigue, vertigo and even unconsciousness. While the half-life of a CO compound and haemoglobin in blood is between four and six hours, using pure oxygen can reduce the period from 70 to 35 minutes.

Carbon dioxide. This is considered to be the most harmful greenhouse gas, making up about 55% of total emissions. It is colourless, non-toxic gas, which is heavier than air. Thanks to photosynthesis in the plants, carbon dioxide is returned to the biosphere cyclically. Combustion of fossil fuels causes approximately 14.10^{10} tonnes of carbon dioxide to be emitted into the atmosphere yearly. Currently, the amount of carbon dioxide is increasing by 0.20% every year.

Sulphur dioxide. This is a colourless, foul-smelling and non-combustible gas, which can cause respiratory diseases. Sulphur dioxide can only be found in small amounts in exhaust gases if fuel containing sulphur is used.

Hydrocarbons. These result from the production of incomplete fuel combustion [6] and occur in their most diverse forms as non-combusted or partly combusted parts of fuel. Certain hydrocarbons irritate the sense organs, such as carcinogenic benzyl.

Nitrogen oxides NO_X. According to [13], the combustion of hydrocarbon fuels at high temperature and pressure, and with enough oxygen, can mainly produce nitrogen oxide (NO) and nitrogen dioxide (NO_2). Their proportion in exhaust fuels is 10-20% for diesel engines and 2% for petrol engines. They also react with haemoglobin and modify iron from Fe^{2+} to Fe^{3+}, as well as create a modification of haemoglobin, known as methaemoglobin, which is stable and does not transmit oxygen. They react to nitric acid and nitrous acid at a high level of concentration with moisture content in the lungs, which can cause acute respiratory diseases. Nitrogen oxides can:

- expedite heart disease
- induce cyanosis (blue or purple coloration of the skin or mucous membranes due to having low oxygen saturation and the growth in reduced haemoglobin above 50 g/l)
- widen the blood vessels resulting in blood pressure reduction
- cause pneumonia and pulmonary oedema
- cause the fading of plant leaves, such that they become smaller or even die
- catalyse the oxidation of sulphur dioxide (SO_2) into the more harmful sulphur trioxide (SO_3)

Nitrous oxide (N_2O) is colourless gas with a slightly sweet odour and taste. It depletes the ozone layer and causes a greenhouse effect that is almost 310 times more effective than CO_2. The lifetime of nitrous oxide in the atmosphere is estimated at 150 years. It is toxic for humans and can have a caustic effect on the mucous membrane as a consequence of inhalation. In small amounts, it can cause a state of intoxication and, in greater amounts, it acts as a narcotic. Furthermore, it causes a deterioration in psychomotor performance and the ability to remember.

Nitric oxide is produced at temperatures higher than 1,300°C (at the end of expansion, a temperature of 1,000-1,800°C can be detected inside a cylinder). When in contact with free oxygen, it reacts to nitrogen dioxide, while it creates nitric acid when combined with water. It also reacts with metals and organic materials, as well as produces weak acids and participates in the formation of photochemical smog. Nitric oxide plays a significant biological role because it ensures communication between cells.

Nitrogen dioxide is produced through the oxidation of nitrous oxide in fire and free air. It is more toxic and more active than nitrous oxide, as well as malodorous and an irritant when inhaled. It can also cause an asthmatic attack among asthma sufferers. Meanwhile, ultraviolet radiation causes a chemical reaction of ground-level ozone production.

Particulate matters. The EU has set the limit of their occurrence at 50 mg/m^3 as a 24-hour average for a concentration of microelements smaller than 10 µm or PM10 (1 µm = 10^{-6} m). While elements with 10+ µm can be absorbed by the nose and membranes, elements smaller than 2 µm can penetrate deep inside the lungs and have a harmful effect on lung cells. According to the WHO, emissions of particulate matter throughout the EU are responsible for 25 million incidences of respiratory diseases and 32,000 premature deaths every year. A 10 mg/m^3 increase in particulate matter concentration in the air can lead to a 1% increase in the mortality rate. Another 30 mg/m^3 increase can result in a 12% increase of asthmatic attacks. The risk of lung cancer in people living in cities is higher than in people living in clearer areas.

3. ELECTRIC CARS AND ENERGY

There is a general stereotype that an electric car does not produce any emissions. Indeed, as the above-mentioned information indicates, road vehicles present a threat to the environment and the health of citizens. According to [1], politicians in Germany and the EU have been pressured to ban the approval of internal combustion engines after 2030, with only electric cars to be approved after this year. Petrol and diesel engines will simply disappear from our roads. Is such a requirement realistic? If we consider that some vehicles, mainly lorries and buses, need to overcome a few hundred metres daily, we will come up against a need for energy supplements. While this could be solved by mandatory breaks for drivers, it would be near to the limit value. Another question concerns the accumulator weight for such a drive. Let us focus on a vehicle combination with a laden weight of 40 tons. According to driving tests conducted by [14], a vehicle can reach an average road speed of 82 km/h^{-1} on a motorway during the driving time, excluding breaks. As such, a 4.5-hour drive equates to 369 km of distance travelled. What energy supply would accumulators have to have? Let us assume that the average consumption of a vehicle combination is 23 l per 100 km of driving, which is in line with the test results in [14]. The specific fuel mass is 0.84 kg/dm^3 and its calorific value is 41 840 kJ/kg, while the energy contained in the consumed fuel is 2,982.807 MJ. The combustion engine of a vehicle can only use 45% of the energy, since that is its maximum efficiency level. Another 10% of transmitted energy is lost in the gears. Thus, the vehicle will use 1208.037 MJ of energy to overcome the running resistances [10]. If we wanted the vehicle to be powered by an electric motor instead of combustion engine, the accumulators must have offer such a capacity and also provide a reserve.

Assuming the reserve to be 20%, the accumulator must then have a capacity of 1,449.644 MJ, which equates to 402.7 kWh. According to [20], the energy density in a lithium-ion battery is a mass of 200 Wh/kg. Batteries thus would have a mass of 2013 kg. The load capacity of a vehicle would be reduced by this mass. There would also be an increase in so-called death weight, which needs to be accelerating and decelerating when starting, as well as the energy needed for overcoming the grade and rolling resistance [17]. Motorway driving means saving increased energy consumption for overcoming the grade by driving downhill. However, such energy is converted into heat in the brakes while driving on ordinary roads [2]. Since the overall vehicle mass is limited to 40 tons in most countries, the load capacity of the cargo carried would be then reduced from around 24 to 22 tons. This means that only 91.67% of goods can be transported by a vehicle combination of the same total mass, which would have an impact on the economy and inevitably on energy consumption, due to greater amount of driving needed to perform the same transport capacity.

A similar situation can be found with regard to private vehicles. With an average consumption of 6 l of petrol per 100 km, the batteries would have a mass of 325 kg for a required range of 400 km. This would mean an increase in the vehicle's total mass by that value, if it did not want to lose its performance characteristics. The consequences and the increase in energy consumption are the same as for lorries.

4. EMISSIONS PRODUCTION

Road transport is considered to be one of the main producers of greenhouse gases [11]. Table 1 provides a comparison of actual emissions of these gases according to particular sectors.

Table 1. Emissions of greenhouse gases according to sectors [14]

Sector	Percentage (%)	Sector	Percentage (%)
Industry	**29.1**	**Transport**	**14.5**
Non-ferrous materials	6.2	Road	10.6
Iron and steel	4.8	Air	1.5
Chemistry and petrochemistry	4.3	Rail	0.5
Non-ferrous metals	1.4	Other	1.9
Food and tobacco	1.0	**Energies (other)**	**14.5**
Paper, pulp and print	0.9	Energy utilized in the energy sector for its own needs	8.1
Other industries	10.5		
Agriculture and Forestry	**20.2**	Coal mining	2.7
Livestock and manure	6.5	Crude oil and natural gas production, refining and processing	3.7
Energy utilized in agriculture	0.8	**Waste dump areas and waste water**	**3.4**
		Waste dump	1.6
Combustion of agricultural waste	0.1	Waste water and other	1.8
Agricultural soil	5.2		
Forestry and other uses of soil	7.7		
Buildings	**18.3**		
Residential	11.2		
Commercial and public services	7.0		

Table 1 shows that road transport is not the most significant culprit as certain sectors clearly deserve much more blame. Are road vehicle emissions compared with other producers of greenhouse gases really so harmful? Let us compare the emissions of greenhouse gases in the production of electricity. The most appropriate way to calculate these is using LCA emissions factors. Table 2 provides an overview of LCA emissions factors for electricity consumption.

Table 2. National and European emissions factors for electricity consumption [14]

State	**Standard emission factor (t CO2/MWhe)**	**LCA emission factor (t CO2-eq/MWhe)**
Austria	0.209	0.310
Belgium	0.285	0.402
Germany	0.624	0.706
Denmark	0.461	0.760
Spain	0.440	0.639
Finland	0.216	0.418
France	0.056	0.146
UK	0.543	0.658

Greece	1.149	1.167
Ireland	0.732	0.870
Italy	0.483	0.708
Netherlands	0.435	0.716
Portugal	0.369	0.750
Sweden	0.023	0.079
Bulgaria	0.819	0.906
Cyprus	0.874	1.019
Czech Republic	0.950	0.802
Estonia	0.908	1.593
Hungary	0.566	0.678
Lithuania	0.153	0.174
Latvia	0.109	0.563
Poland	1.191	1.185
Romania	0.701	1.084
Slovenia	0.557	0.602
Slovakia	0.252	0.353
EU-27	**0.460**	**0.578**

Would it be appropriate to claim that electric cars offer a solution for reducing greenhouse gases produced by road transport? The answer can be seen in the comparison of LCA emissions factors in respect of electricity production in Table 2 with LCA emissions factors in respect of MWh in fuel combustion, as stated in Table 3. Assuming that a combustion engine will consume the same energy as an electric car for overcoming the running resistances, it will be enough to compare the LCA factors for the production of emissions. It is evident from Tables 2 and 3 that a vehicle powered by electricity can produce more greenhouse gases per kWh consumed than a vehicle with a combustion engine. Only France with 0.146, Sweden with 0.079 and Lithuania with 0.174 can offer a better LCA factor (t CO_2-eq/MWhe) for electricity production than the EU-27 average of 0.578. The conclusion is clear: the implementation of electric cars will not reduce greenhouse gas emissions; on the contrary, they will increase! We have also drawn attention in the above to increasing the energy efficiency of electric cars, since the overall vehicle mass will rise in line with the accumulator’s mass, which will be reflected in the increase in the resistance of rolling, inertia and grade. Increasing energy efficiency will lead to more mass, as well as grade returns (with certain efficiency) into the reservoir due to recovery. There will be no increase in rolling resistance due to recovery. Such losses were not taken into consideration in the above.

Table 3. Emission factors for fuel combustion [14]

Type of fuel	Standard emission factor (t CO_2/MWhfuel)	LCA emission factor (t CO_2-eq/MWhfuel)
Natural gas	0.202	0.237
Residual fuel oil, municipal waste (excluding biomass)	0.330	0.330
Petrol fuel	0.249	0.299
Gas oil, diesel oil	0.267	0.305

Natural gas liquid	0.231	
Vegetable oil	0	0.182
Biodiesel	0	0.156
Bioethanol	0	0.206
Anthracite	0.354	0.393
Other bituminous coal	0.341	0.380
Subbituminous coal	0.346	0.385
Lignite	0.364	0.375

So far, we have only carried a direct comparison of greenhouse gas emissions. However, the electric car also includes losses from energy conversion. If we charge a battery from an electricity network, the energy will be stored in the battery from which it will be gradually released for consumption by the electric motor. In addition, a loss of energy due to the battery's efficiency will be necessary. According to [4], the lithium-ion battery has 80-90% efficiency. Energy transmission in an electric motor from the electrical to mechanical functions can achieve an efficiency of almost 90% [19]. In the charging network, the electricity is distributed in the form of alternative voltage. To be able to supply energy in the battery, it needs to be rectified, which is carried out with certain efficiency. According to [5], their appliance, Subrak NTX 4053.XXXX.B (19" SUBRACK ZU), achieves 87-91% efficiency for a current rectification. Providing that mechanical losses in transmissions will be the same, the creation of emissions as a result of electricity production needs to be increased by losses due to energy conversion efficiency in an electric car.

$$\eta_{\text{total}} = \eta_{\text{rectifier efficiency}} \cdot \eta_{\text{battery efficiency}} \cdot \eta_{\text{electric motor efficiency}}$$

If the efficiency of some appliances has a certain range, the average value is added to the calculation.

$$\eta_c = 0.89 \text{ x } 0.85 \text{ x } 0.9 = 0.681$$

Thus, only 68.1 kWh from 100 kWh of energy delivered to the point will be used for powering the vehicle. This proportion needs to be used for increasing greenhouse gas emissions in electricity production for powering an electric car. These then, with 1 kWh of electricity consumption per drive, based on the EU-27 average, will produce, according to the LCA cycle, not 0.578 kg of greenhouse gases, but almost 0.849 kg (0.578/0.681). To compare, using diesel oil results in 0.305 kg of greenhouse gases and using petrol results in 0.299 kg. There are also other harmful substances in addition to greenhouse gases in energy production, namely, particulate matters, nitrogen oxides, sulphur dioxide and carbon monoxide. A comparison of the amount of emissions related to the unit of electricity produced under Slovak conditions and diesel engine emissions is provided in Tables 4, 5 and 6.

Table 4. The amount of emissions related to the unit of electricity produced under Slovak conditions [12]

Year		Electricity generation	Emissions				
			Dust	SO_2	NO_x	CO	CO_2
2015	kg	-	533,000	47,265	3,885,000	708,000	2,536,000
	Recalculated emissions	19,707 GWh	27 g/kWh	12.2 g/kWh	197 g/kWh	36 g/kWh	129 g/kWh

Table 4 does not take account of the LCA factor, which also includes emissions connected to electricity distribution. Table 5 presents the limits of emissions amounts for Euro VI emission class engines for heavy goods vehicles and buses, and those for M1 vehicles. Emissions of M1 vehicles are given per kilometre. To make the numbers comparable, we recalculated them in terms of their energy intensity for a typical private car with a consumption of 6l/100 km^{-1}, a gear efficiency of 92% and a combustion engine efficiency of 30%. To overcome the running resistances, it consumes 0.143 kWh of energy. This conversion will be also used in the recalculation of emissions by M1 vehicles.

Table 5. Emission limits for Euro VI emission class M1 vehicles [15]

		Emissions				
		Dust	SO_2	$HC+NO_x$	CO	CO_2
Spark-ignition engine	Limit (g/km)	0.005	-	0.10	1.0	-
	Recalculated emissions (g/kWh)	0.035	-	0.699	6.993	299
Compress ion ignition engine	Limit (g/km)	0.005	-	0.17	0.5	-
	Recalculated emissions (g/kWh)	0.035	-	1.189	3.497	305

Table 5 provides information about the amount of emissions directly recalculated into kWH.

Table 6. Emission limits for Euro VI emission class heavy goods vehicles and buses [15]

	Emissions				
	Dust	HC	NO_x	CO	CO_2
Limit (g/kWh)	0.01	0.13	0.4	1.5	305

5. ENVIRONMENTAL BURDEN OF OTHER TYPES OF TRANSPORT

Table 1 shows that rail transport produces only 0.5% of greenhouse gases. This percentage takes into consideration the fact that the largest proportion of such transport performance is produced on the basis of electric traction, such that there is no production of any emissions. However, it should be noted that certain greenhouse gas emissions are also produced in energy production, which should be added to the energy consumption calculation. Table 2 presents the amount of greenhouse gas production in specific states and the EU-27 average. It can be seen, therefore, that rail transport also produces a corresponding amount of emissions per kWh of energy consumed. According to [1612], the railways in Slovakia consume, per 1 hrtkm, 20.95 Wh in one-way traction, or 22.53 hrtkm in an alternating system. Hrtkm is calculated from the gross mass of a train set without a locomotive. According to [21], čtkm/hrtkm index of conversion was 50.67 in 2003. By using this index, we can calculate that, for transport, on a 1 ton per 1 km basis, Slovak railways consume an average of 42.905 Wh (Table 2 presents the equivalent amount of greenhouse gases). This means that 24.799 g of greenhouse gases are produced for average EU-27 amounts per tkm. To compare, a vehicle combination of 40 tons has an average consumption of 23 l of fuel per 100 km in order to transport 24 tons of goods. It thus produces 93.559 g of greenhouse gases per 1 tkm. As such, rail transport is not significantly more environmentally friendly than road transport, as Table 1 indicates.

6. CONCLUSION

When considering the environmental burden of particular types of vehicle power, the fact that electricity production can also produce greenhouse gases is overlooked. These gases need to be added into the relevant calculations. As we mentioned above, the mass production of electric cars may bring about a local reduction in the production of harmful gases, but it is not the case from a global point of view.

Utilizing electric cars is often connected with argument that they will use a so-called night tariff, which provides for cheaper operation. If we use the night tariff, we need to take into consideration the deterioration in greenhouse gas production, given that, nowadays, the proportion of thermoelectric power plants is on the increase. The reason for this is that their production of power is hard to regulate, while sources producing electricity from renewable sources are disconnected from the network (hydroelectric plants, pumped storage power plants etc.).

Utilizing electric cars would benefit countries that have a large proportion of such power plants (Sweden, Iceland etc.).

References

1. AutoBild. “Crazy proposal: classic motors are going to be completely removed”. 2016. Available at: http://autobild.cas.sk/clanok/212058/sialeny-navrh-klasicke-motory-idu-uplne-zrusit.
2. Caban Jacek, Andrzej Marczuk, Branislav Šarkan, Ján Vrábel. 2015. “Studies on the operational wear of glycol-based brake fluid”. *Przemysl Chemiczny*, Vol. 1 (10): 176-180. ISSN 0033-2496. DOI: 10.15199/62.2015.10.30.
3. Ec.europa. “Change - greenhouse gases”. 2016. Available at: http://ec.europa.eu/clima/sites/campaign/pdf/gases_sk.pdf.
4. Elektromobily. “Li - ion batérie”. 2016. Available at: http://elektromobil.vseznamu.cz/baterie-v-elektromobilech/li-ion-akumulatory.
5. Elteco. “Subrack”. 2016. Available at: http://www.elteco.sk/ elteco/slovenska/ntxsub.htm.

6. Figlus Tomasz, Jozef Gnap, Tomáš Skrúcaný, Branislav Šarkan, Jozef Stoklosa. 2016. "The use of denoising and analysis of the acoustic signal entropy in diagnosing engine valve clearance". *Entropy,* 18 (7): 253. ISSN 1099-4300. DOI: 10.3390/e18070253.
7. International Atomic Energy Agency. "Environment report". 2016. Available at: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/31/062/ 31062517.pdf.
8. Pundir B.P. 2011. *Engine Emissions.* Oxford: Alpha Science International Ltd. ISBN 978-1-84265-401-9.
9. Alternative Propulsion. Book LLC®, Reference Series 2010. www.booksllc.net.
10. Gnap Jozef, Tomáš Skrúcaný, Branislav Šarkan. 2016. "Influence of aerodynamic trailer devices on drag reduction measured in a wind tunnel". *Eksploatacja i Niezawodnosc - Maintenance and Reliability,* Vol. 18 (1): 151-154. ISSN 1507-2711. DOI: http://dx.doi.org/10.17531/ein.2016.1.20.
11. Gnap Jozef, Martin Kendra, Tomáš Skrúcaný, Branislav Šarkan. 2015. "Software simulation of an energy consumption and GHG production in transport". In *Tools of Transport Telematics,* edited by Jerzy Mikulski, 151-160. Switzerland: Springer International Publishing. ISBN 978-3-319-24577-5. DOI: 10.1007/978-3-319-24577-5_15.
12. Michalk Philip, Kristýna Prušková, Vladimír Rievaj, Ondrej Stopka, Branislav Šarkan, Vrábel Ján. 2016. "Measuring the resistance of tyres for a passenger vehicle against rolling and sliding on the loading area of a flatbed truck when providing transport services". *Communications: Scientific Letters of the University of Žilina,* Vol. 18 (2): 124-128. ISSN 1335-4205.
13. Slovak Power Plants. "Operational effect on the environment". 2016. Available at: https://www.seas.sk/vplyv-prevadzok-na-zivotne-prostredie.
14. Smidt Martin L. 2003. *Reduction of NO_2 by Hydrocarbons over H-form Zeolites*. PhD thesis. University of Twente: Twente University Press.
15. Soglasheniemerov.eu. "Technical annex for the completion of the standard form SEAP - emission factors". 2016. Available at: http://www.soglasheniemerov.eu/IMG/pdf/technical_annex_sk.pdf.
16. Vlaky.net. "News from the world of trains and railways". 2016. Available at: http://www.vlaky.net/zeleznice/spravy/001743.
17. Lenntech. "Carbon dioxide". 2016. Available at: http://www.lenntech.com/carbon-dioxide.htm.
18. The Official U.S. government source for fuel economy information. "All-Electric Vehicles". 2016. Available at: https://www.fueleconomy.gov/feg/evtech.shtml.
19. Battery University. "Is Lithium-ion the Ideal Battery?". 2016. Available at: http://batteryuniversity.com/learn/archive/is_lithium_ion_the_ideal_battery.
20. World of Transport. "Tightening of emission limits of road vehicles". 2016. Available at: http://www.svetdopravy.sk/sprisnovanie-emisnych-limitov-cestnych-motorovych-vozidiel/.
21. ZSSK Cargo. "Statistical Yearbook 2003". 2016. Available at: http://www.zscargo.sk/files/dokumenty/Statistika2003.pdf.

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