Study of the ecological impact of production, operation and disposal of various types of cars

M. Los[1], K. Jaššo[1]

[1] Department of Electrical and Electronic Technology, Faculty of Electrical Engineering and Communication, Brno University of Technology, Czechia

E-mail: xlosma00@vut.cz, xjasso00@vut.cz

Abstract—The life cycle of a car includes three basic phases: production, operation and end-of-life. All these phases can potentially produce emissions that have a direct impact on the environment. However, different types of cars may produce different amounts of emissions during the life cycle phases, depending not only on the type of propulsion but also on local factors such as the emission factor of the energy mix. The results of the research showed that the potential environmental benefit of lower greenhouse gas (GHG) emissions of battery electric vehicles depends primarily on the emission factor of the energy mix. In countries such as Poland, where the majority of electricity produced is generated by burning coal and lignite, the life cycle environmental performance of battery cars will be higher than that of combustion cars. Conversely, in countries with a favorable energy mix, such as Sweden, the potential to reduce transport emissions by replacing the existing car fleet with electric cars is significant. Practical part of this papers aims to compare the environmental impact from the view of greenhouse gas emissions throughout the life cycle of conventional petrol, diesel, natural gas and electric cars in local conditions.

Keywords—Ecology, cars, emissions, life cycle, production, operation

1. INTRODUCTION

With the current pressure to minimize the environmental impact and greenhouse gas emissions of transport, alternative forms of vehicle propulsion, primarily battery electric cars, are being promoted. However, the carbon footprint of BEVs (battery electric vehicles) can vary considerably depending on the country in which they are operated, because although they do not produce emissions directly during operation, the emissions from electricity generation depend on the emission factor of the local energy mix.

The life cycle of a car consists of production, operation and end of life. It is then important to further divide the operational phase into primary and secondary emissions. As this is a cradle-to-grave analysis, the life cycle of the car and the resulting emissions are considered from the point of extraction of raw materials, their processing and conversion into parts, assembly, logistics, car operation and fuel production processes to the end of life and associated recycling.

4 types of propulsion are analyzed in this work: petrol, diesel, CNG (compressed natural gas) and BEV.

2. MODELLING OF REFERENCE CARS

For the purpose of assessing the cars that are currently in common use in Czechia, 4 reference cars were modelled, 1 for each type of drive mentioned above. The technical specifications of these cars are based on at least 4 representatives of popular C-segment vehicles, i.e., cars of the lower middle class with the intention to represent actual cars actually used in the present on Czech roads. The parameters of the modelled reference vehicles are given in Table I.

The next important parameter to be set is the mileage of the reference car. According to Kazda [1] the average car in Czechia travels 29 km daily and as reported by ACEA (European Automobile Manufacturers' Association) [2], the average car age in Czechia is currently around 15 years. After a

simple calculation with the use of the mentioned data, it emerges that average local car's mileage over its life hovers around the 160 000 km mark, which is a crucial piece of information for further calculations.

Table I: Reference car technical parameters

	Unit	Petrol	Diesel	CNG	BEV
Enigne displacement	l	1.5	2.0	1.5	-
Maximum power	kW	116	103	89	98
Curb weight	kg	1254	1378	1309	1522
Curb weight without battery	kg	-	-	-	1208
Battery weight	kg	-	-	-	314
Battery capacity	kWh	-	-	-	46
WLTP emissions	g CO_2/km	127	116	101.75	0
WLTP combined fuel consumption	l/100km	5.6	4.4	-	-
	m^3/100km	-	-	5.7	-
	kWh/100km	-	-	-	16

3. CALCULATION

The aim of this paper is to evaluate a car's lifecycle environmental impact from the greenhouse gas emissions point of view; therefore, the process of calculation shall lead to a final value of greenhouse gas emissions in tons of CO_2eq for each propulsion type reference vehicle. The base equation used for the calculation is (1), which is a sum of emission values coming from the individual phases of a lifecycle.

$$E = E_{prod} + E_{op} + E_{EOL} \tag{1}$$

The greenhouse gas emissions emitted during the phase of production were then calculated according to (2), where E_{prod} stands for the amount of greenhouse gas emissions created during the process of vehicle manufacturing in tons of CO_2eq, m_{curb} is the curb weight of the vehicle and e_{prod} is the emission factor of the production per kilogram of the vehicle's weight in kg CO_2eq/kg. The same value 5 kg CO_2eq/kg of m_{curb} was used for the petrol, diesel and CNG car manufacturing as well as for manufacturing of the BEV glider. Both Hawkins et al. [3], who determined this value in terms of cradle-to-gate emissions by compiling an inventory of generic automotive components (about 140 subcomponents) and inferring their emissions intensity, and Schuller and Stuart [4], who reported an emission factor of 6 kg CO_2eq/kg for 2017 and assumed 5 kg CO_2eq/kg for 2030, lean towards this value.

$$E_{prod} = m_{curb} \times e_{prod} \tag{2}$$

The calculation of BEV production emissions requires a slightly different approach, since the production of the car battery has a significant impact on the final amount of greenhouse gas emissions of production. Equation (3) is used to calculate the BEV emissions separately for the vehicle's glider and the battery based on its capacity C_{bat} and emission factor of battery production resulting from analysis of 50 battery production studies [5].

$$E_{prod} = \left(m_{glid} \times e_{prod}\right) + \left(C_{bat} \times e_{bat}\right) \tag{3}$$

The phase of operation in this paper is concerned primarily with the well-to-wheel emissions, which represent the fuel cycle from its extraction and treatment, to logistics and its combustion or use in the

target vehicle. Emissions from the maintenance were not considered, because parts like tires are equal to all the reference vehicles and would make no difference. Other maintenance processes would only add an insignificant amount of emissions to the final result. The total well-to-wheel emissions were calculated as a sum of Well-to-Tank and Tank-to-Wheel emissions, as is shown in equation (4).

$$E_{op} = E_{WTT} + E_{TTW} \tag{4}$$

While calculating well-to-tank emissions (5), local pathways of fuel were considered and their emissions factors were taken from the JEC (EU Joint Research Centre, EUCAR, Concawe) Well-to-Tank report v5 [6]. The emission factor e_{WTT} is then multiplied by the fuel consumption of the reference cars over their operation phase mileage V. As for the BEV, the emission factor of fuel production represents the emission factor of the local energy mix which, according to European Environment Agency [7], is 436,6 g CO_2eq/kWh.

$$E_{WTT} = e_{WTT} \times V \tag{5}$$

Tank-to-Wheel emissions are then calculated as a sum of emission factors representing WLTP (Worldwide harmonized light-duty vehicles test procedure) CO_2 emissions in addition with CO_2 equivalent of N_2O and CH_4 calculated as fractions of their emission limits according to EURO 6 standard multiplied by their global warming potential and then multiplying the sum by the reference car life mileage d (6). For the case of BEV, its Tank-to-Wheel emissions result in naught, since the BEV produces no tailpipe emissions during the operation.

$$E_{TTW} = (e_{WLTP} + e_{N_2O} + e_{CH_4}) \times d \tag{6}$$

The emissions produced in the end-of-life phase of the vehicles have not yet been calculated at the time of writing this paper and are the subject of further work.

4. RESULTS AND CONCLUSION

As of the current progress, the results of greenhouse gas intensity of the selected reference vehicles are visible in Fig. 1.

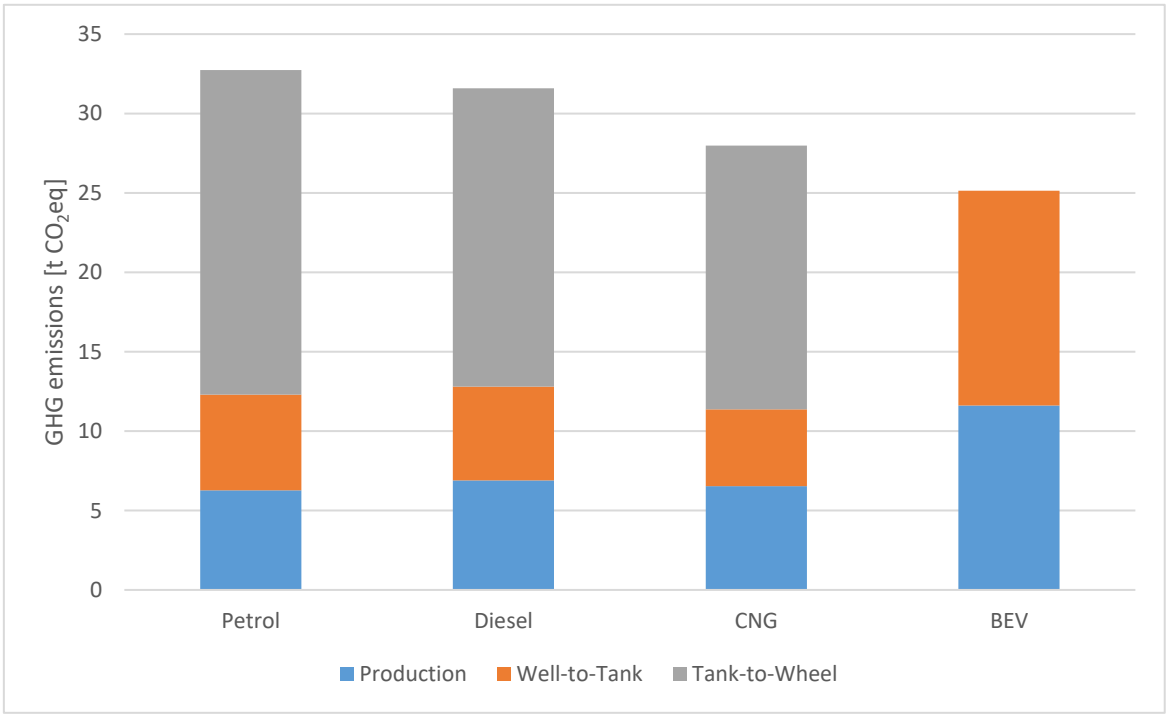

Figure 1: Calculation results

The results show that majority of GHG emissions produced by the petrol, diesel and CNG cars come from the Tank-to-Wheels process i.e., the fuel combustion. Emissions from the production of the fossil fuel vehicles are roughly the same, around 6,5 t CO_2eq, while production of the BEV is almost twice as GHG intensive. Regarding the energy mix emission factor in Czechia, it is still less emission-intensive, than the whole life cycle of the three considered fossil fuels.

In conclusion, the considered reference BEV emits the least greenhouse gas emissions during its lifecycle among all of the four compared propulsion type vehicles, although its emissions intensity is heavily dependent on the local energy mix, as it varies across the countries and the Well-to-Tank emissions are this vehicle's most notable greenhouse gas emissions source. It is highly probable, that BEVs operated in countries with more environmentally friendly energy sources, such as Sweden or Norway, would account for much lower amount of greenhouse gas emissions over their lifecycle.

It is important to note, that emissions from the end-of-life phase are to be added, although even despite the fact that the recycling process of BEV batteries is more emission intensive, it will, probably, not shift the results.

REFERENCES

[1] M. Sedlák, "U elektromobilu stačí měnit pneumatiky a kapalinu do ostřikovačů, říká expert", Obnovitelně, c2020.

[2] ACEA, "Vehicles in use Europe: January 2021," 2021.

[3] T. R. Hawkins, B. Singh, G. Majeau-Bettez, and A. H. Strømman, "Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles", Journal of Industrial Ecology, vol. 17, no. 1, pp. 53-64, Aug. 2012.

[4] A. Schuller and C. Stuart, ""From cradle to grave: e-mobility and the energy transition": Addendum for Italy, the United Kingdom, Spain and the European Union to "Le véhicule électrique dans la transition écologique en France"", August 2018.

[5] C. Aichberger and G. Jungmeier, "Environmental Life Cycle Impacts of Automotive Batteries Based on a Literature Review", Energies, vol. 13, no. 23, 2020.

[6] M. Prussi, M. Yugo, L. De Prada, M. Padella, R. Edwards, and L. Lonza, "JEC Well-to-Tank report v5: EUR 30269 EN", 2020.

[7] "Greenhouse gas emission intensity of electricity generation by country", Europena Environment Agency, 2021.

[8] J. Mikulka, D. Chalupa, J. Svoboda, M. Filipovič, M. Repko and M. Maxová, "Multimodal and Multiparametric Spatial Segmentation of Spine," 2020 19th International Conference on Mechatronics – Mechatronika (ME), 2020, pp. 1–5, doi 10.1109/ME49197.2020.9286666.

[9] P. Horowitz and W. Hill, *The Art of Electronics*. New York: Cambridge University Press, 2021.