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Analysis of operation parameters of electric and gasoline vehicle in real driving

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Abstract. The reduction of transport-generated energy consumption and consequent emission production are currently a problem of global interest. Electric vehicles (EVs) are considered as one promising technological solution for limiting transport-generated energy consumption and emission production, but theirs operating parameters are strongly influenced by immediately operating conditions and it is often very problematic to prove or disprove benefits of EVs in real operation.

The aim of this paper is to present comparison of operating parameters of the full-electric vehicle VW e-UP! with identical vehicle Skoda Citigo with gasoline engine in real driving. Both vehicles were tested together in several different areas of the Czech Republic. The experiment was focused on analysis of energy (fuel) consumption and production of exhaust gases (CO, CO_2, NO_X). VAG-COM diagnostics system was used for sensing engine operating parameters, GPS coordinate were measured by Garmin GPS-18x, vehicle Skoda Citigo was equipped by the PEMS analyzer VMK for RDE emission sensing (CO, CO_2, HC, NO_X). The results bring a real comparison between the electric vehicle and the vehicle with gasoline engine in terms of fuel consumption and emissions production.

Key words: real driving emissions, vehicle range, fuel consumption, recuperation.

INTRODUCTION

Transport, especially individual car transport, is one of the main factors of air pollution and greenhouse gas emissions in urban areas. This trend has provoked European regulations to place a great emphasis on the decarbonisation of the transport sector (Directive 98/69/EC 1998), resulting in an increased production of pure electric, hybrid, and plug-in hybrid electric vehicles. Electric vehicles (EVs) are considered as environmentally friendly, but they always depend on the power source of electricity for charging. The promotion of EVs make sense only if it is ensured that a major share of electricity they use is generated from renewable sources, because the final goal is not just to increase the number of EVs but to reduce emissions (Ajanovic & Haas, 2016). Some results indicate EVs may prove to be dirtier than conventional vehicle with combustion engine in certain areas of usage (Manjunath & Gross, 2017).

EV can contribute to sustainable road transport (Huang et al., 2019). However, the limited range represents a significant disadvantage of EV compared to vehicle powered by internal combustion engine (ICEV - internal combustion engine vehicle). This disadvantage can discourage potential customers (Egbue & Long, 2012; Dimitropoulos et al., 2013) or lead them to purchase high-range EV, which are not cost-effective and even the most sustainable solution due to the environmental impact (McManus, 2012; Neubauer et al., 2012).

There are many factors that influence the potential environmental benefits of EVs (Li et al., 2017). Therefore it is necessary to verify the operating parameters of the electric vehicle in real operation (under real traffic conditions) and to compare the achieved results with the identical conventional vehicle. The aim of this paper is to compare the operating parameters (energy or fuel consumption, indirect and direct production of harmful exhaust gases) of the full-electric vehicle VW e-up! and the vehicle with gasoline engine together operated in two significantly different geographic areas of the Czech Republic. The results follow previous research, which was focused primarily on the operating parameters of the electric vehicle (Marcev & Kotek, 2018).

MATERIALS AND METHODS

The electric vehicle VW e-up! and Skoda CitiGo (Fig. 1) were used for this experiment. The e-up! is the electric version of Volkswagen up! city car identical to the Skoda CitiGo. It is powered by a 60 kW electric motor which is powered by a 18.7 kWh lithium-ion battery pack integrated in the floor. Detailed technical parameters are shown in Table 1.

Figure 1. Volkswagen e-up! and Skoda CitiGo.

Second vehicle Skoda Citigo is a small car from Škoda Auto producer equipped by small-volume 3 cylinder petrol engine. Other technical parameters are summarized in Table 1.

Table 1. Technical parameters of VW e-up! and Skoda CitiGo

	VW E-Up!	Skoda CitiGo
ENGINE		
Design	synchronous AC electric motor with permanent magnets	3 cylinder, spark ignition, atmospheric
Power	60 kW	55 kW at 5,000 rpm
Torque	210 Nm at 0 rpm	95 Nm at 3,000–4,300 rpm
Fuel system	electric plug-in	Multi-point gasoline injection
BATTERY		
Type	li-ion 323 V	
Capacity	18.7 kWh	
Number of cells	17 modules, 12 cells per module	
Weight	230 kg	
CAR BODY		
Service weight	1,185 kg	929 kg
Manufacture year	2016	2016
DRIVE PERFORMANCE		
Max. speed	130 km h^{-1}	160 km h^{-1}
Acceleration 0–100 km h^{-1}	12.4 s	13.2 s
Fuel consumption	11.7 kWh 100 km^{-1}	4.7 L 100 km^{-1}
Tank range	150 km	750 km

The vehicle operating data of both vehicles from the engine control unit were recorded via the OBD interface. Car diagnostic system VAG–COM was used for communication and record operating data from the OBD (engine speed, vehicle speed, voltage and current of the electric motor and battery, battery charge status).

The position and immediate speed and GPS coordinate were measured by Garmin GPS 18x USB with 1 Hz frequency.

A mobile PEMS on-board emission analyser VMK was used to measure emissions of Skoda CitiGo. The analyser uses non-dispersive infrared (NDIR) method to detect CO and CO_2 emissions and electrochemical cell to O_2 and NO_X emissions. Data was recorded with 1 Hz frequency on memory card. The technical data of analyser are summarized in Table 2.

Table 2. Technical parameters of mobile emission analyser

Measured values	Measurement range	Resolution	Accuracy
CO	0...10 % Vol.	0.001 % Vol.	0…0.67%: 0.02% absolute, 0.67%…10%: 3% of measured value
CO_2	0...16 % Vol.	0.01 % Vol.	0…10%: 0.3% absolute, 10…16%: 3% m.v.
HC	0...20,000 ppm	1 ppm	10 ppm or 5% m.v.
NO_X	0...5,000 ppm	1 ppm	0…1,000 ppm: 25 ppm, 1,000…4,000 ppm: 4% m.v.
O_2	0...22 % Vol.	0.1 % Vol.	0…3%: 0.1%, 3…21%: 3%

The measurement was carried out on the two significantly different geographic areas of the Czech Republic (see Fig. 2). In both areas, extensive questionnaire surveys were conducted to identify the most frequent transport destinations of the population. In both locations there is a well-available fast-charging station within a distance of 20 km.

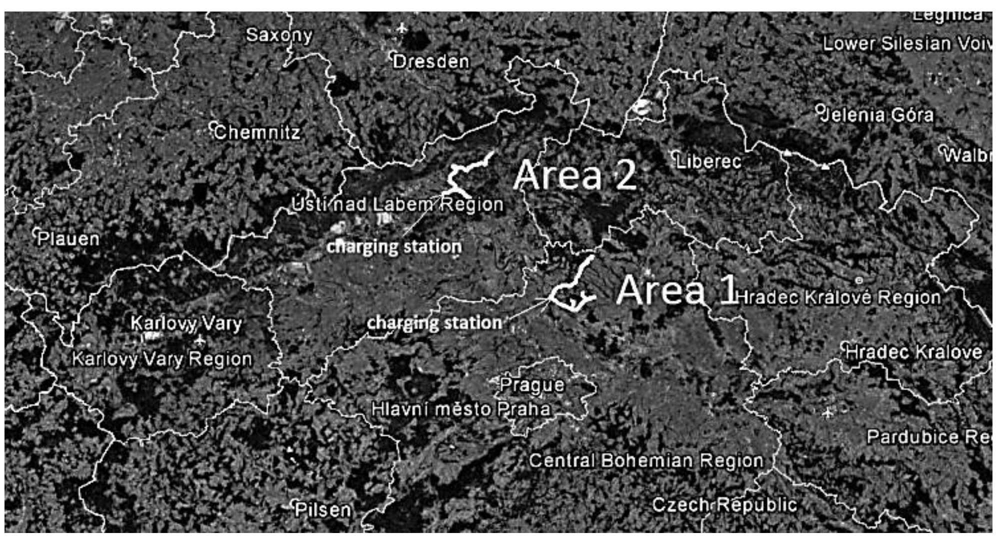

Figure 2. The map of tested areas with charging stations.

The first tested area was the lowland area in the vicinity of municipality Mělník which seems to be ideal for the use of an electric vehicle due to the appropriate terrain's properties. The first area is shown on the Fig. 3.

Figure 3. The map of area 1 – Mělník.

The second area (Fig. 4) was a hilly area near the municipality of Ústí nad Labem with frequent and very sharp altitude changes, which seems to be a very problematic altitude profile for an electric vehicle use because of on the first look this profile require much more power to overcome driving resistances, especially the gradient resistance.

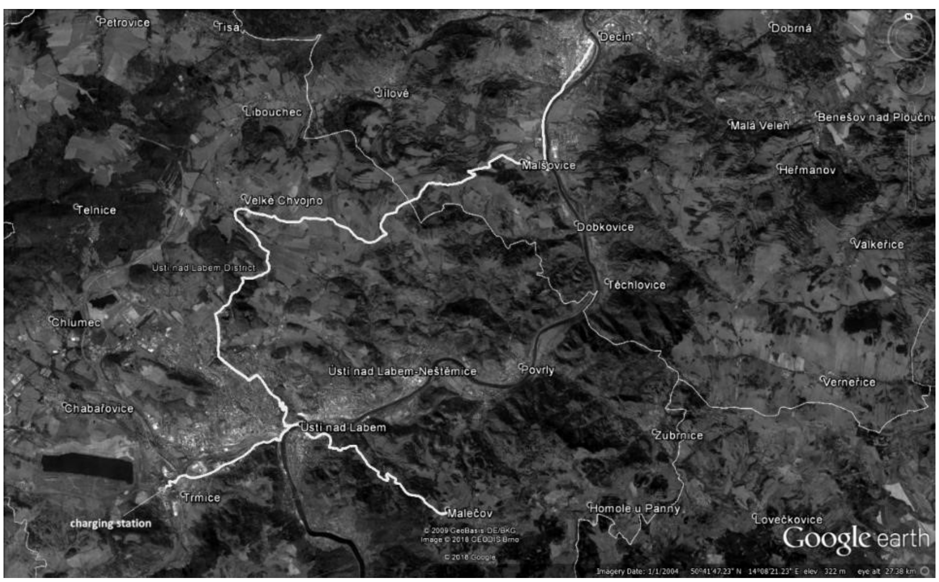

Figure 4. The map of area 2 – Ústí nad Labem.

The altitude road profile of both tested area is shown on Fig. 5. Table 3 provides brief description of both areas with regard to time and track length spent with drive to uphill, downhill and along plane.

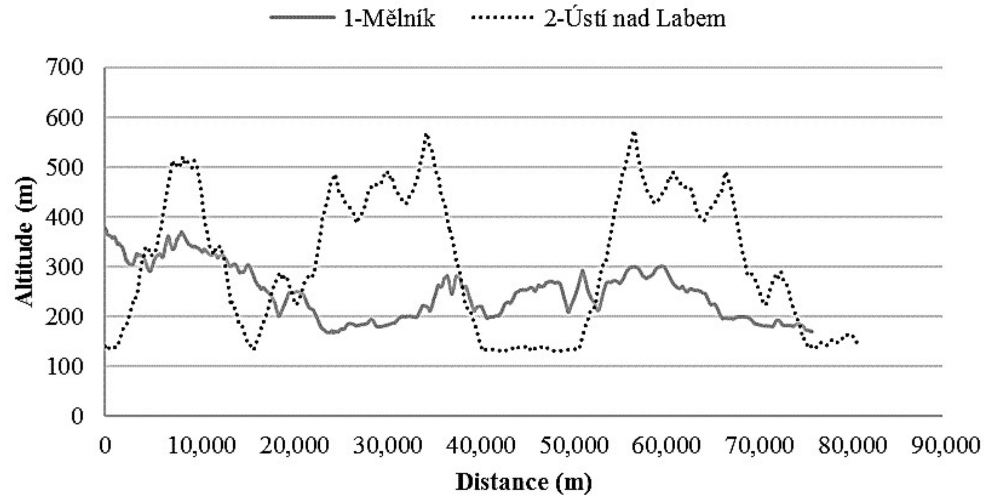

Figure 5. Altitude profile of tested areas.

The experimental drives were conducted during weekdays at the time of morning and afternoon rush hour on 19–21 September 2017. The road test uncertainty has been minimized by repetition of measurement. With respect to time-consuming of experiment, the measurement was repeated five times on each track. The method floating car data (FCD) were used in the experiment. It means that the driver kept calm driving style and the drive is influenced by the immediate traffic situation. Both vehicles drove just behind to ensure identical traffic conditions for the operation of both vehicles. During the experiment, the outdoor temperature was around 12 °C, windless, partly cloudy, dry roads. In the vehicle the internal temperature was set to 20 °C and no additional electrical appliances were switched on.

Table 3. Tracks characteristics

	1 – Mělník	2 – Ústí n.L.
total track length (km)	75.92	80.77
total travel time (s)	6,187 ± 167	7,239 ± 278
avg. speed (km h^{-1})	44 ± 2.3	40±3
abs. elevation difference (m)	210	442
PLANE		
track length (km)	10.92	6.58
ASCENT		
track length (km)	28.99	37.62
ascent (m)	0.796	1,953
avg. ascent (%)	2.75	5.19
DESCENT		
track length (km)	36.01	36.57
descent (m)	1,004	1,943
avg. descent (%)	2.79	5.31

For the purpose of comparing both cars in terms of emission production it is necessary to know the emission factors in the production of electricity. For the Czech Republic, emission factors for 2018 (see Table 4) are known according to the so-called energy mix taking into account the representation of different types of power plants (ČEZ, 2018).

The individual emission components were calculated according to the following formula:

$$emission\ \left(\frac{g}{km}\right) = energy\ consumption\ \left(\frac{kWh}{km}\right) \cdot emission\ factor\left(\frac{g}{kWh}\right) \quad (1)$$

RESULTS AND DISCUSSION

Table 5 summarizes the resulting operating parameter values of both tested vehicles. Both vehicles achieved a higher average consumption in location 2, where both had a similar increase in fuel consumption by approximately 10%. The geographically more demanding locality 2 was thus reflected by the same increase in consumption and there is no obvious benefit of any of the drive types. The same trend can be observed for CO_2 production, but in terms of the absolute value the EV achieved a 40% decrease in CO_2 production. This may be due both to the higher energy efficiency of electricity production but also to the fact that EVs can use of recuperation (Li et al., 2017).

Indirect exhaust emissions of EV are directly affected by the power source and the relevant emission factor reflecting the current energy mix for the area or country. The emission factors used - see Table 4 and the following calculation according to formula (1) are based on the energy mix of the Czech Republic for 2018. Similar emission factors for CO_2 are described (Jochen et al., 2015), when the Czech Republic ranks among the EU countries with a higher utilization of coal power plants, corresponding to a higher emission factor than the EU average (0.43 g kWh^{-1}). In the case of NO_X production, the same emission factor was also observed (Weiss et al., 2019) in Germany since 2010, when there was a similar share of coal-fired power plants as in the Czech Republic.

Table 4. Emission factors for electricity production in the Czech Republic (ČEZ, 2018)

NO_X	CO	CO_2
G kWh^{-1}	g kWh^{-1}	g kWh^{-1}
0.441	0.0698	581

Table 5. Resulting values of the operating parameters of the tested vehicles

Vehicle	Location	Consumption 100 km^{-1}	CO_2 g km^{-1}	CO mg km^{-1}	NO_X mg km^{-1}
Skoda CitiGo	1-Mělník	4.15 ± 0.15 L	100 ± 4	150 ± 10	9.54 ± 0.12
	2-Ústí	4.61 ± 0.22 L	108 ± 6	816 ± 84	24.11 ± 0.31
VW E-Up!	1-Mělník	10.23 ± 0.52 kWh	59.4 ± 2.1	7.15 ± 0.15	45.1 ± 2.3
	2-Ústí	11.28 ± 0.61 kWh	65.5 ± 2.4	7.87 ± 0.17	49.8 ± 2.9

In terms of CO emissions, there was a significant impact of locality 2 on CO production of the Skoda CitiGo, where there was approximately 5 times higher, while CO production of VW e-Up increased by only 10%. This may be caused, in particular, by the transition modes of the internal combustion engine where the stoichiometric fuel ratio cannot be maintained and thus the efficiency of the catalyst is considerably reduced. Therefore, the EV achieves negligible CO values compared to the classic vehicle.

The opposite situation is evident in the NO_X production, where from the point of view of the absolute value, the classic vehicle achieved the significantly better results (50%–80% decrease). However, the influence of the locality on the increase in NO_X emissions is significant again at the classic vehicle because of strong influence of transient operation modes of combustion engine.

CONCLUSIONS

The production of harmful emissions from EVs is strongly dependent on the source of electricity, that is, on the type of power plant and its primary source of energy. The advantages of electric vehicles are mainly the independence of emission production due to transient operation modes, which are often occur in real traffic condition where maximum emissions are achieved especially at the classical combustion engines. As the results show, ICEV has achieved 5 times higher CO emissions and 2.5 times higher NO emissions in more demanding terrain, while for EV only a slight increase up to 10 percent has occurred. Power production can be considered as stationary regimes where very good measures can be taken to eliminate harmful emissions. From the point of view of the absolute value of produced exhaust emission, the EV achieved 40% decrease in CO_2 production, 95% decrease in CO emission and up to 4 times increase in NO_X production.

Another advantage is that emissions can be produced outside human settlements, and emissions from electricity generation may not directly affect to people, but, of course, the impact of these emissions in the environment (eg acid rain) should be taken into account.

EV does not produce harmful emissions at the point of driving, but it should be noted that it produces indirect emissions depending on how the electrical energy is produced, and also it is necessary takes into account the whole lifecycle of an electric vehicle from production to disposal.

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