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Influence of the road profile in different geographical areas of the Czech Republic to the operational parameters of the electric vehicle

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Abstract. The aim of this paper is to compare the operating parameters of the full-electric vehicle VW e-up! operated in two significantly different geographic areas of the Czech Republic. The first tested area was the lowland area in the vicinity of municipality Mělník; the second area was a hilly area near the municipality of Ústí nad Labem with frequent and very sharp altitude changes. During measurement, the operating parameters of the battery (voltage, level) and electric motor (instantaneous voltage and current) were recorded. The results show a surprisingly small difference in vehicle tank range in both compared regions because the recuperation in the hilly area was used very often. It is possible to conclude that these electric vehicles can be used for everyday commuting under conditions of different geographical areas.

Key words: recuperation, real-world driving, altitude, vehicle range.

INTRODUCTION

For our global society, individual car transport is a key factor. Emissions, particularly emissions from road transport, have caused serious environmental pollution. With an emphasis on changing climate conditions, resource scarcity and population growth, vehicle manufacturers need to look for solutions that reduce the impact of individual car traffic on the environment. Road transport accounts for about one-fifth of total carbon dioxide emissions in the European Union. Furthermore, manufacturers are forced to comply with stricter emission standards (European Commission, 2010). The aim of the EU in the transport sector to reduce emissions by 60% until 2050. (European Commission, 2010).

A possible way to reduce emissions of internal combustion engine vehicles (ICEV) is to use biofuels. The disadvantage of biofuels is higher maintenance of the fuel system (especially removal of water from the system), lower engine performance and higher fuel consumption, based on the calorific values. In contrast, the advantage of using biofuels is the higher lubricity and very good biodegradability against diesel (Pexa & Mařík, 2014).

Another way to reduce car exhaust gases, is to replace ICEV with electric vehicles (EV). The worldwide trend is the ever increasing demand for EV (Mosquet et al., 2015). However, it is important to note that EVs do not produce any harmful emissions during operation, but the production of electricity itself and the other life cycle stages may have an impact on the environment (Li et al., 2016).

EV can contribute to sustainable road transport (Williams et al., 2012). However, the limited range represents a significant disadvantage of EV compared to ICEV. 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¸ Yuan et al., 2015).

For potential EV customers, the main parameter is a possible range. In order to get electric mobility, the main barrier is the range of EV (Franke et al., 2013). Range is affected by many factors. The first factor influencing the range is the construction of the vehicle and the other is the driver's impact on driving efficiency. In current EVs, the battery is the most expensive component. For this reason, it is advisable to focus on other vehicle design parameters, such as aerodynamic drag or a properly dimensioned electric motor. Driving style is critical for the EV range. Aggressive driving can significantly reduce range (Rimkus et al., 2012). It is also important in what conditions the EV works. A large altitude difference and extreme climatic conditions can significantly reduce the range of EV and therefore the use of EV in some areas seems to be ineffective.

The aim of this paper is to compare the operating parameters of the full-electric vehicle VW e-up! operated in two significantly different geographic areas of the Czech Republic and to show that even in such different locations, similar consumption can be achieved.

MATERIALS AND METHODS

The electric vehicle VW e-up! (Fig. 1) was used for this experiment. The e-up! is the electric version of Volkswagen up! city car. 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. Taking into account the vehicle properties and the 150 km range, the e-up! is ideal for city driving and for commuting purposes.

Figure 1. Volkswagen e-up!

Table 1. Technical parameters of VW e-up!

ENGINE	
Design	synchronous AC electric motor with permanent magnets
Power	60 kW
Torque	210 Nm at 0 rpm
Fuel system	electric plug-in
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
Manufacture year	2016
DRIVE PERFORMANCE	
Max. speed	130 km h^{-1}
Acceleration 0–100 km h^{-1}	12.4 s
Fuel consumption	11.7 kWh 100 km^{-1}
Tank range	150 km

The vehicle operating data (engine speed, load, vehicle speed, battery voltage and current, etc.) from the engine control unit were recorded via the OBD interface. Car diagnostic system VAG–COM was used for communication and record data from the OBD. The position and immediate speed and GPS coordinate were measured by Garmin GPS 18x USB with 1 Hz frequency.

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.

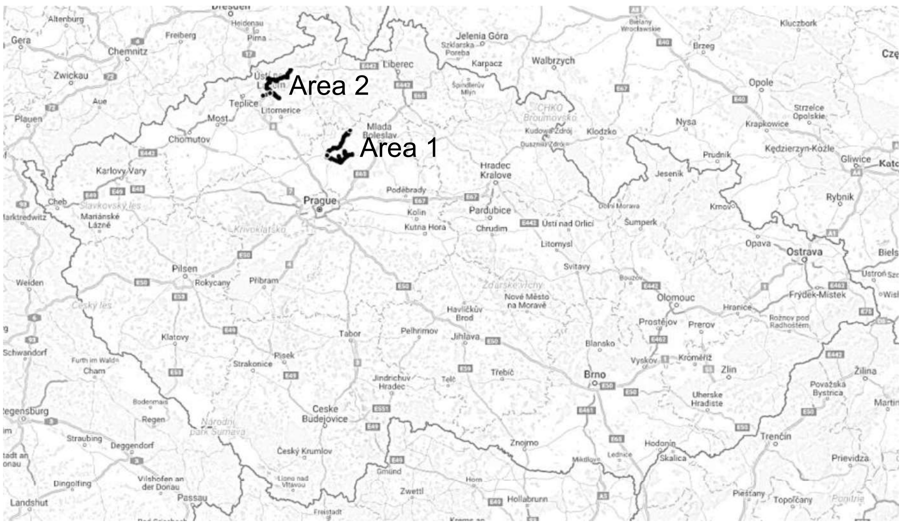

Figure 2. The map of tested areas with charging stations.

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.

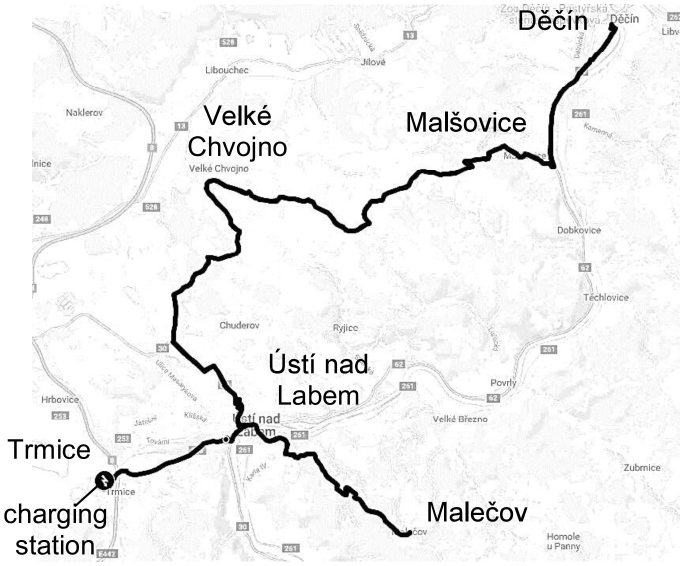

Figure 4. The map of area 2 – Ústí nad Labem.

The altitude road profile of both tested area is shown on Fig. 5. Table 2 provides summary of both areas with regard to time and track length spent with drive to uphill, downhill and along plane.

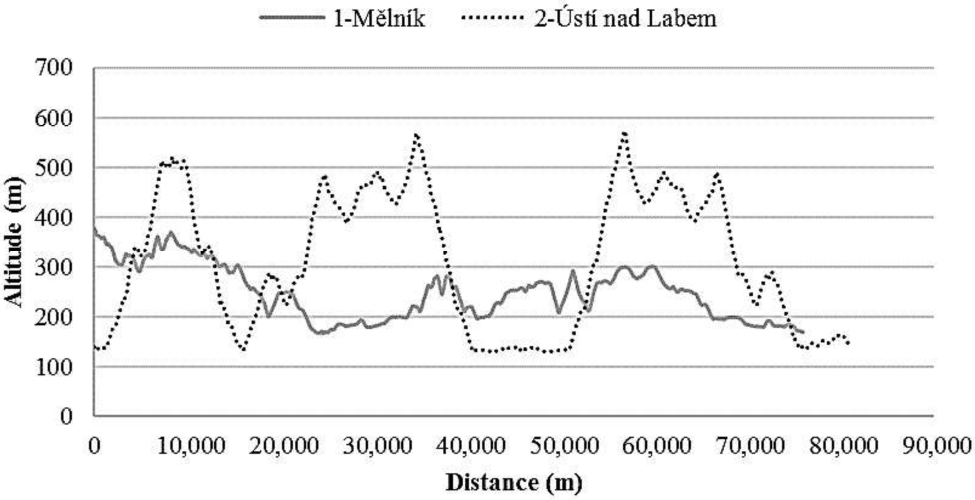

Figure 5. Altitude profile of tested areas.

Table 2. Tracks characteristics

	1 – Mělník	2 – Ústí n.L.
total track length (km)	75.92	80.77
total travel time (s)	6,187	7,239
avg. speed (km h^{-1})	44	40
abs. elevation difference (m)	210	442
PLANE		
time (s)	1,439	1,556
track length (km)	10.92	6.58
ASCENT		
time (s)	2,172	2,876
track length (km)	28.99	37.62
ascent (m)	0,796	1,953
avg. ascent (%)	2.75	5.19
DESCENT		
time (s)	2,576	2,807
track length (km)	36.01	36.57
descent (m)	1,004	1,943
avg. descent (%)	2.79	5.31

The experimental drives were conducted during weekdays at the time of morning and afternoon rush hour on 19–21 September 2017. 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. 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.

RESULTS AND DISCUSSION

The main monitored parameter of the EV was the instantaneous consumed or recuperated current. Figs 6 and 7 show a selection of typical instantaneous power values from part of the test area. As can be seen from Fig. 6, in the lowland region of Mělník, the instantaneous value of peak power values reached maximum around 20 kW. Each deceleration is accompanied by a decrease in the current up to the negative values that signal the recuperation process. Compared with the second monitored area (Fig. 7), it is clear that maximum power values reaches up to double values. This phenomenon is mainly due to the course of the track altitude profile. The similar values of electric power distribution can be seen in (Fiori et al., 2016) where the EV was operated in driving cycle with higher vehicle speed, but without the influence of the gradient. The impact of gradient on energy consumption increases almost linearly with increasing absolute gradient (Liu et al., 2017).

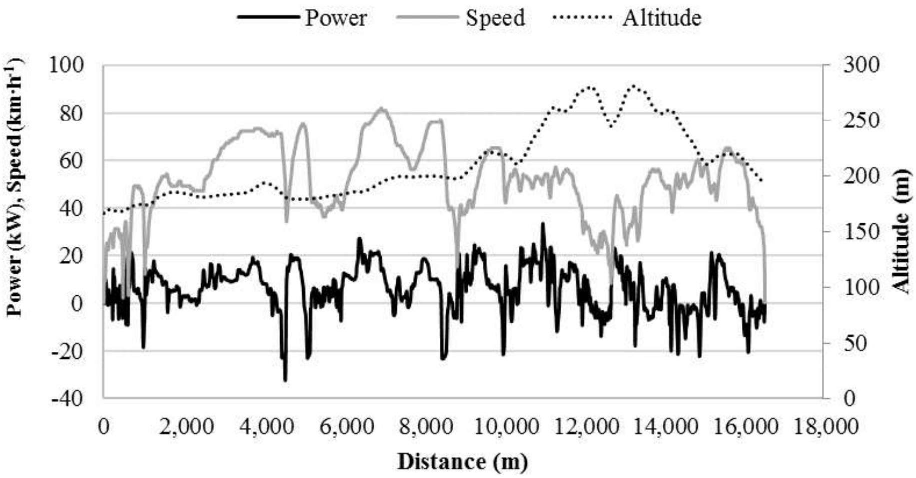

Figure 6. Example of typical instantaneous values of the electric power in the Mělník area.

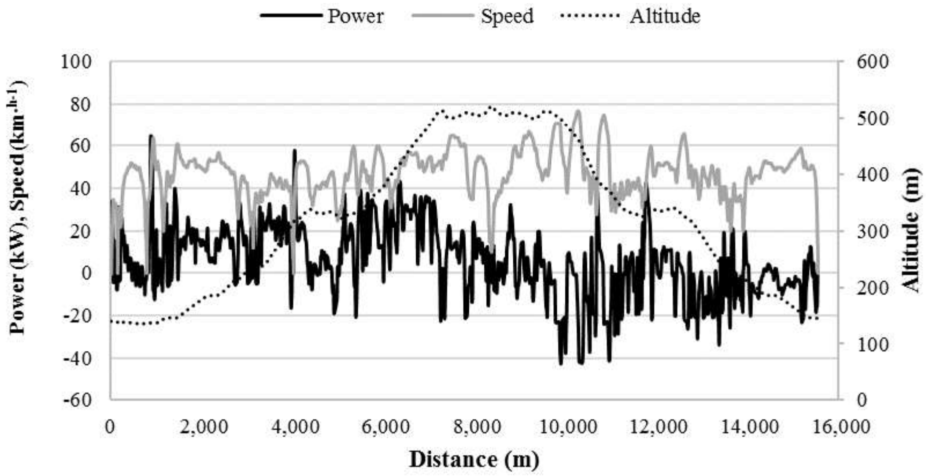

Figure 7. Example of typical instantaneous values of the electric power in the Ústí n.L. area.

Table 3 summarized total balance of EV current, power and consumption on both areas. It is obvious from the consumed battery level and avg. consumption that the hilly area around Ústí nad Labem can be expected to have higher electricity consumption, on the other hand, there is more often use of recuperation with higher avg. charging current thanks to which the average consumption increased by only 10%. The regenerative braking shows that EVs are more energy efficient than conventional fuel vehicles, especially in mountainous areas where conventional vehicles do not regenerate energy (Liu et al., 2017).

Table 3. Summary balance of current and power

	1 – Mělník	2 – Ústí n. L.
consumed battery level (% 100 km^{-1})	75.65	81.17
avg. consumption (kWh 100 km^{-1})	10.23	11.28
IDLING		
time (s)	608	979
CONSUMED		
time (s)	3,863	3,987
avg. current (A)	27.58	37.20
avg. power (kW)	10.33	13.90
RECUPERATED		
time (s)	1,717	2,274
avg. current (A)	18.36	26.16
avg. power (kW)	6.96	9.97

CONCLUSIONS

When choosing the appropriate route and riding style, energy consumption is not so fundamentally dependent on the location and altitude profile; in hilly area can be reached a similar consumption as in the lowland area. Of course, in the hilly area, it is necessary to expect a higher flow of electrical energy, which is necessary to overcome the driving resistances, especially the gradient resistance. On the other hand however on this area there is a potential to use recuperation abilities of EV. At the same time, it is necessary to take into account the battery state of charge, when at full charge there it is not possible to achieve maximum recuperation effect and hence the braking effect of the recuperation.

The experiment in form of real-world driving showed that small EV can be used for everyday commuting under conditions of different geographical areas especially when the each route not exceed the length of 70% real vehicle range.

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