EV Simulation Tests in Various Road Conditions

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Abstract Electric vehicles are gaining popularity all the time. As a result, they have become the subject of much research. The purpose of this work is to analyze the energy consumption of the vehicle depending on the specificity of the designated routes. For this purpose, three routes with different types of traffic have been designated. Then, the research test vehicle, together with the necessary equipment, made runs on the indicated roads. This made it possible to record the basic parameters related to the movement, such as: instantaneous velocity, acceleration, travel time and route length. Based on the collected data, simulation tests were carried out in the AVL Cruise program. The obtained results show the parameters related to energy consumption on each route. The amount of input and output energy from the battery, energy consumption per 1 km of the route and the course of changes in the battery current or changes in the battery charge status were determined. The conducted research allowed to obtain specific conclusions and propose further research directions.

Keywords electric vehicle, energy consumption, type of road, state of charge

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1. Introduction

Electric vehicles are becoming more and more popular in Poland. This is based on the data provided by the E-Mobility Index launched by the Polish Association of Automotive Industry and the Polish Alternative Fuels Association. In January 2022, there were 39,328 electric passenger vehicles registered in Poland. In January 2023, this number amounted to 67,097 vehicles [1].

In recent years, the purchase of electric vehicles has been strongly supported by government policy in many countries in the form of subsidies and other benefits [2, 3, 4]. These activities significantly contributed to increasing the willingness to buy vehicles with this type of drive by consumers. However, this is not the only factor analyzed in connection with the purchase of vehicles. Other conditions are also being analyzed, e.g. range, impact on the environment, energy efficiency or availability of charging infrastructure [5, 6, 7].

The energy efficiency and energy consumption of an electric vehicle is an extremely important aspect that is subject to various studies [8, 9]. The paper [10] presents a set of the most important factors influencing the energy consumption of an electric vehicle. The following should be mentioned as main factors: ambient conditions (air temperature, wind speed) [11,12], route specifics (road gradient, traffic conditions, road type) [13, 14,15], driving style of the driver [13] and vehicle characteristics (vehicle weight, use of air conditioning) [12,16].

The authors in [17] showed how electricity consumption changes depending on the efficiency of the engine and its power. The impact of these factors on the sensitivity of energy consumption can range from 10 to 21%. In [18], the authors decided to investigate how the energy consumption of a vehicle changes concerning varying loads and battery charges. For this, they used a simulation program based on the standardized NEDC (New European Driving Cycle) test, the WLTP (Worldwide Harmonized Vehicle Test Procedure) and the highway cycle. The results showed that a maximum vehicle load increases energy consumption by 7% compared to a load of 50 kg. Furthermore, driving at 40 °C increases energy consumption by 2% compared to driving at 20 °C.

The purpose of this article is to present the changes of vehicle energy consumption depending on the type of route. For this purpose, road tests were carried out with a test vehicle with the aim of recording basic data related to performance parameters. Then, simulation test were carried out, the results of which are described in Section 3.

2. Methodology

2.1. Vehicle and test equipment

The research vehicle used to carry out the measurements was a Ford Transit. It is part of the equipment of the Department of Automotive Engineering and Transport at the Kielce University of Technology. The necessary measuring equipment was installed in the vehicle.

Basic data, i.e. instantaneous velocity, acceleration or relative altitude, were recorded using a Kistler® brand device. The equipment consisted of a Kistler® GPS CDA system, a TAA KCD15911 linear acceleration sensor and a KIDAQ

5501A data acquisition station. The test equipment used for the measurements is shown in Figure 1.

Figure 1. Vehicle and test equipment

2.1. Tested routes

Three routes were mapped for the measurements in Kielce (Poland). Each route was 10 km long. The drive was a loop, where the test car driving along the designated route in one direction, then returned the same way.

Route 1 is the road leading to the exit road from the city (towards Warsaw) and runs in the opposite direction to the city centre. Route 2 is the route toward Lodz, which is characterized by heavy truck traffic. Route 3 is a road leading through selected streets in the city center. The most important information about journeys are shown in Table 1.

Table 1. Trip data

Parameter	Number of routes		
	1	2	3
Travel time, s	1115	1225	1827
Average velocity, km/h	31.1	27.3	19.0
Number of stops	6	9	23

The course of the designated routes is shown in Figure 2. For each of them, a velocity profile was obtained based on measuring devices.

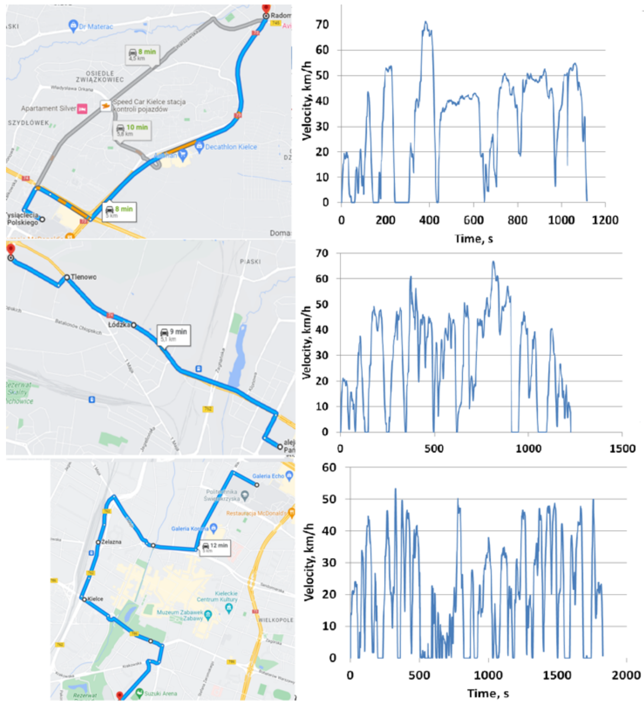

Figure 2. Course of a router along with obtained velocity profiles

Based on the graphs presented in Figure 2, it can be seen that the routes have different velocity profiles. Despite the identical length of the routes, different travel times were obtained in the tests. The journey carried out on the dual carriageway, towards the exit road (route 1) was characterized by smoother traffic. This allowed for a quick drive with a small number of brakes and stops. The route in the city centre required the driver to brake and stop much more often due to traffic conditions and infrastructure (traffic lights, pedestrian crossings). The velocity profile for route 2 is an intermediate route, considering the number of stops and frequency of braking

3. Simulation result

The obtained velocity profiles recorded in real-world conditions were applied to the AVL Cruise simulation program. This program provides the possibility of generating trip data for vehicles with different types of propulsion. It is possible to use a vehicle model that is available in the system or to create your model. In addition, it allows to obtain of detailed data on the energy consumption of the trip, emissions, fuel consumption or power. AVL Cruise has standardized cycles in its interface, it is possible to upload your data related to velocity and time. The program was able to obtain detailed data related to the energy consumption of the vehicle on each route.

The results obtained from the AVL Cruise simulation program were analyzed and presented in graphs. Figure 3 shows the change in SOC (State of Charge) and the course of the battery current. It can be seen that at times when the charging current suddenly increases, the SOC increases slightly. The same is true when the current decreases rapidly. The state of charge of the battery then decreases. The final SOC value, despite an identical initial value, for the analyzed routes ranges from 93.0 to 93.5%. It can be seen that the way of discharging the batteries is similar on the tested routes. However, the current flow into and out of the battery is completely different for each route. This is due to the number of brakes and accelerations recorded along the route.

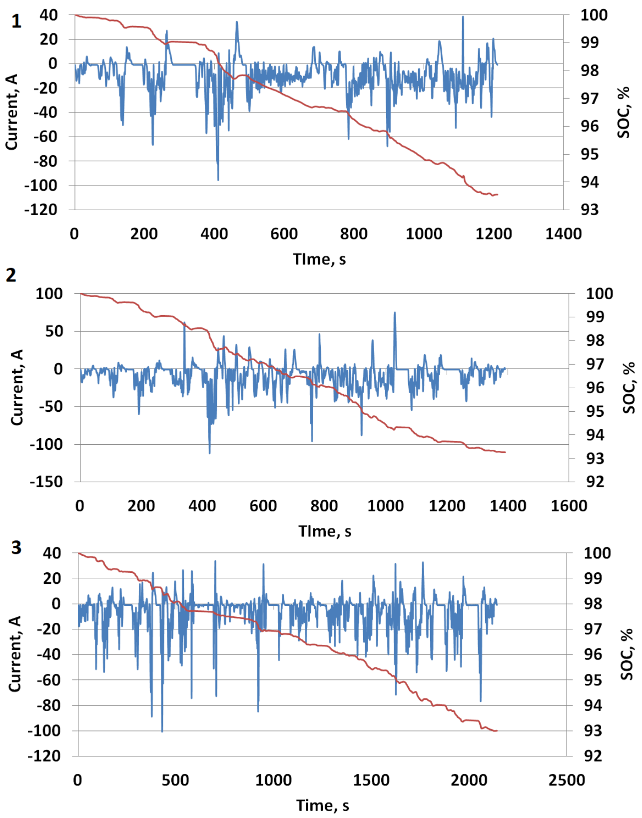

Figure 3. The course of the SOC value and the current in the battery on each of the tested routes

The energy consumption of the routes is shown in Figure 4. It shows the amount of energy consumed and the amount of energy recovered. It can be seen that the most energy from the battery was used on route 3. This was the route with the most varied traffic characteristic. The vehicle used the least energy on route number 1. This was the smoothest route and the trip was made at the highest average velocity. In the case of recovered energy, the trend is the same. The difference between the lowest and highest value of total energy consumed is 13%.

The vehicle recovered the most energy on the route where braking was frequent. The least energy was recovered on route number 1 where there was little braking. The highest value of total energy delivered to the battery is 42% higher than the lowest value.

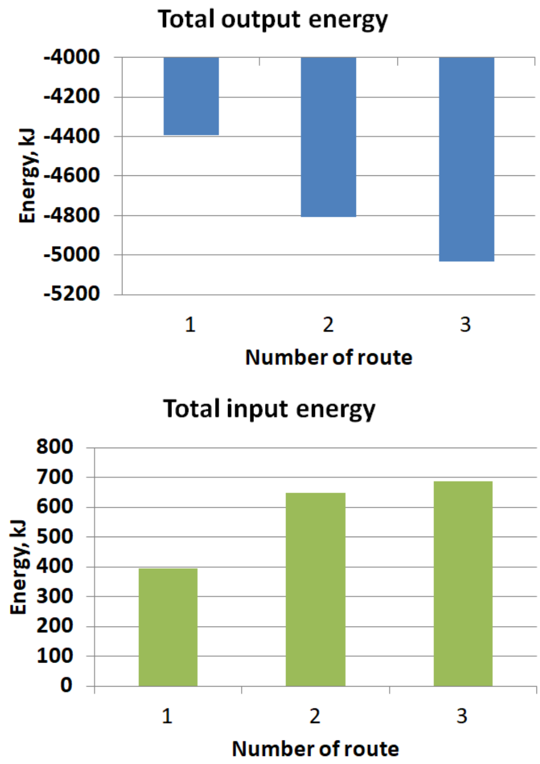

Figure 4. Total output energy and total input energy on the tested routes

In addition to the total energy consumption and the state of charge of the battery, another parameter that determines the energy consumption of a vehicle is the consumption per kilometer of the route. This parameter is shown in Figure 5. It can be seen that the highest energy consumption is on route 4, while the lowest is on route 1. The highest consumption on route 3 is 7% higher than the lowest on route number 1.

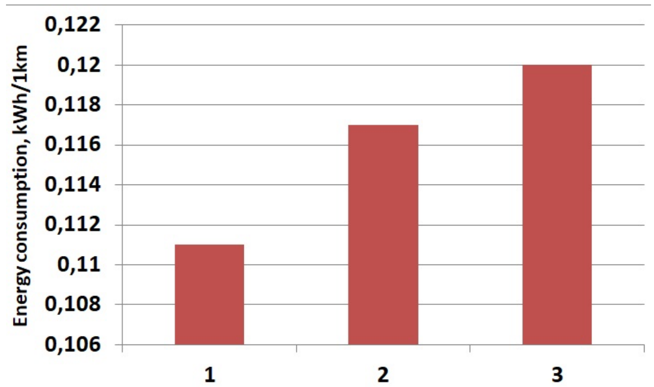

Figure 5. Energy consumption on the tested routes

4. Conclusions

The energy consumption of an electric vehicle is a topic that is still being discussed by many researchers. Energy consumption depends on many factors. This paper shows how energy consumption changes depending on the specificity of traffic on different types of roads in the city.

The research shows that routes with more complex traffic conditions require the electric vehicle to use more energy.

Driving on a road in the city center, where traffic is hindered by a large number of vehicles and infrastructure (traffic lights, intersections, roundabouts, pedestrian crossings), is much more energy-intensive. This is also due to the travel time, which is increased by the factors mentioned above.

It is worth noting the amount of energy input to the battery. It is significantly higher on the route where the vehicle has carried out frequent braking manoeuvres. This is also confirmed by the current in the battery. Significant jumps or drops in its value cause the SOC value to fluctuate. As the electric vehicle has the possibility of recovering energy during braking, an assessment was also made of the total energy per kilometer. The maximum relative change in energy consumption does not exceed 8 %.

After analyzing the collected data, it is worth taking the direction of further research. In a further stage of the work, it is planned to extend the number of analyzed routes, taking into account the specific nature of their terrain and the different road conditions. In order to fully assess the energy consumption of the various drive systems, measurements will be made for the various analyzed sections of the route, taking into account the greater length of the route, in different weather conditions and at different times of the day.

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