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Investigation of Prospects for Electric Vehicle Development in Lithuania

***Abstract**. The aim of this work is to analyze the factors limiting the development of electric vehicles, to present ways to reduce the impact of these factors, and review electric vehicle development opportunities in Lithuania. The accomplished research indicates that the distance driven on a single charge remains the main factor limiting the popularity of electric cars. In this work the battery development trends and their potential are outlined and discussed, key factors that determine the distance that electric cars can travel on a single charge are distinguished, approximate energy consumption by vehicle type is presented, and factors that determine the energy consumption of electric car when traveling at a constant speed and also when driving under realistic conditions (i.e. at a variable speed and using a variety of auxiliary systems) are analyzed. The most limiting factor is the development of the infrastructure. Several variants of electric vehicle charging stations and their application possibilities regarding the consumer type were presented. Envisioned geographical layout of the charging stations in the territory of Lithuania is introduced. Concepts of electric vehicle development in Lithuania are outlined and analyzed.*

***Streszczenie.** W artykule analizowano czynniki ograniczające rozwój samochodów elektrycznych oraz czynniki mogące ten rozwój przyśpieszyć na przykładzie Litwy. Głównym ograniczeniem jest wciąż dystans jaki może samochód elektryczny pokonać między ładowaniami stąd tak ważny jest postęp w dziedzinie baterii i rozwój infrastruktury obsługującej samochody elektryczne. **Analiza czynników stymulujących postęp w użyciu samochodów elektrycznych na przykładzie Litwy**.*

Keywords: Electric, vehicle, charging, station, battery.
Słowa kluczowe: samochody elektryczne, bacteria, ładowanie.

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Introduction

At the present time it is difficult to say, who created the first transport vehicle driven by electricity, although all the initial efforts in creation of electrical motors were intended to find the alternative fuel source, which could replace noisy and smoke-emitting locomotives [1].

Many innovations and interest in motor vehicles increased greatly in the late 1890s and early 1900s. In 1897 the first commercial application was established as a fleet of New York City taxis [2].

After enjoying success at the beginning of the 20 century, the electric car began to lose its position in the automotive market.

The industry of electric cars began recovering only in 1960's, when concerns about the air pollution problems became strong, and due to an oil crisis which followed immediately after that.

Significance of Electric Car Batteries

As also in those times, the main factor which limited the success of electric cars and lead to competitive defeat remains the distance driven by such vehicle on a single charge (Fig. 1).

A modern gasoline or diesel powered car can travel 1000 km and more, and, as we can see from data presented in Fig. 1, electric cars today can go only about 160 km on one charge, i.e. 6 times less. Therefore, the urban transportation means currently are the only electric cars, where the distances a relatively small. In order to drive larger distances with electric car, it is necessary to increase the battery capacity and reduce the factors that affect the battery power consumption.

The main factors, that determine the distance which can be travelled by electric car on a single charge, are:

- The battery type, capacity;
- Weight of electric vehicle;
- Aerodynamics;
- Meteorological conditions;
- Traffic conditions;
- Type of motor [4];
- Tires.

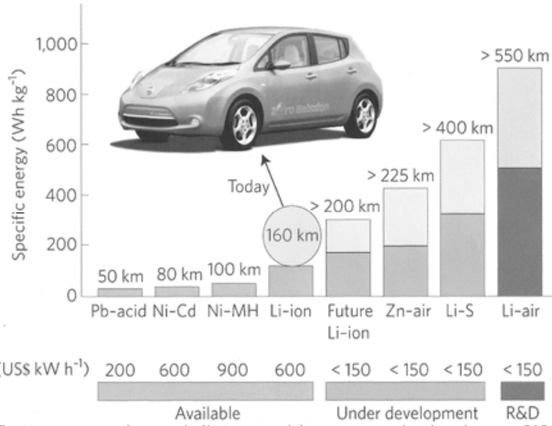

Fig.1. Battery capacity and distance driven on a single charge [3]

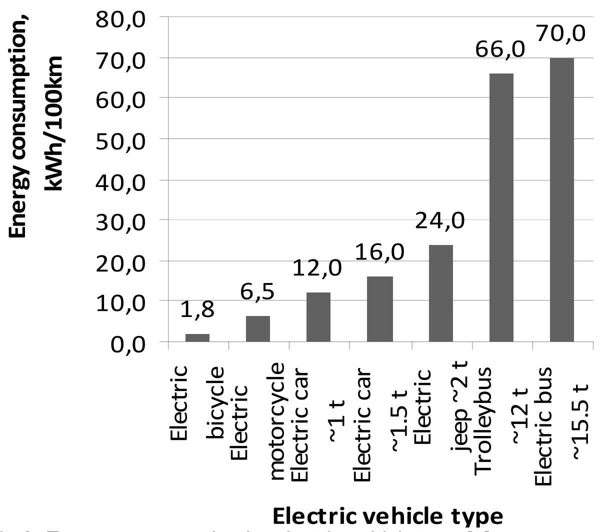

Fig.2. Energy consumption by electric vehicle type [5]

Fig. 2 shows the approximate energy consumption according to type of electric vehicle.

1. As it can be seen from Fig. 2, the electric car weighting 1 t on average consumes 12 kWh of electrical energy per 100 km.

2. In addition to vehicle weight, there are a number of factors that determine the electric car energy consumption. At cruising speed, the most important factors are these: Aerodynamics, Drivetrain, Tires and Ancillary systems.

Aerodynamic energy losses, such as caused by air resistance, mainly occur when traveling at high speeds (> 80 km/h). When driving at low speeds, the drivetrain energy losses are the most prominent.

The energy losses of all the mentioned groups can have both fixed and variable (depending on the driving speed) components:

- *Aerodynamic energy losses* can be calculated using the following expression [6]:

$$F_D = \frac{1}{2}\rho V^2 A C_d \,, \tag{1}$$

where: ρ is the air density, V is the velocity of the car, A is its frontal area and C_d is the drag coefficient, depending on the shape of the vehicle.

- *Drivetrain energy losses* depend on the conversion process of electrical energy (battery) to mechanical energy (motor torque). Since there are such components available as: converter, electric motor, gearbox, etc., it is very complicated to assess these losses using single mathematical expression. Therefore, these losses are treated as a "black box" and they can be described using the following polynomial:

$$P_{Dr} = \alpha_{Dr} V^3 + \beta_{Dr} V^2 + \gamma_{Dr} V + C_{Dr} \tag{2}$$

Constant C_{Dr} represents the power usage of the complete drivetrain system when the car is not moving, which becomes 0.375 kW. Coefficients α_{Dr}, β_{Dr}, and γ_{Dr} become $4\cdot10^{-6}$, $5\cdot10^{-4}$ and 0.0293, respectively.

- *Losses caused by Tires* mainly depend on tire air flow resistance and the road surface grip. This, in turn, is determined by the tire shape, its hardness and internal air pressure. The power required to overcome the rolling resistance is a function of the normal force N (weight carried by the tire) and the coefficient of rolling resistance (C_{rr}), and is proportional to velocity V:

$$P_{Tire} = C_{rr} N V \tag{3}$$

- *Energy losses in Ancillary systems* consist of energy consumed in different electrical equipment: lighting devices, climate control system and other electronic vehicle control and comfort systems. These losses can be described using such dependence:

$$P_{Anc} = P_{Cl.Contr} + P_{Bat.Mngmnt} + P_{Lights} + P_{Audio} \,. \tag{4}$$

All the above-listed energy loss factors do not depend on the vehicle velocity, i.e. they are measured when driving at a constant speed. However, when driving under real world conditions acceleration and braking take place a lot; in this way the kinetic energy of a car is constantly varied, and this heavily influences the battery power consumption.

Kinetic energy in the vehicle is stored as linear and rotational kinetic energy, where linear kinetic energy is the movement of the total car in its direction and rotational energy is stored in the rotating parts of the vehicle (primarily the wheels). The equations for these are as follows [6]:

$$E_{kin.\,lin} = \frac{1}{2} m V^2 \,, \tag{5}$$

where: m is the total mass of the vehicle and V is the velocity. Rotational kinetic energy for any rotating object is of a similar form:

$$E_{kin.\,rot} = \frac{1}{2} I \omega^2 \,, \tag{6}$$

where: I the inertia of the rotating object (gears, wheels) and ω the radial velocity, which is proportional to V with one gear. Typically, rotational kinetic energy is only 5-10 % of the total kinetic energy stored in a car. Because it is easier to find the total mass of the car than the inertia of its wheels and interior rotating gears, it is assumed that the total $E_{kin.} = 1.05 \cdot E_{kin.\,lin}$ [6].

Apart from the above mentioned and described factors, there are other aspects that influence the battery energy consumption:

- Travel route – winding or hilly road, altitude and so on;
- Battery charge level – the battery is fully charged or discharged below the allowed minimum;
- Battery life – it influences the battery charge level, its general quality and the number of charge/discharge cycles;
- Temperature – the most economical battery operating temperature is +20 ... +40 °C. At much higher or much lower temperatures than the specified range, the battery power is reduced.

In the recent years the battery price per 1 kWh decreased several times due to the development of battery technologies, although it still represents a significant part of electric vehicle cost. Therefore, the battery is still one of the most important parts of the electric car and a special attention is dedicated to its development.

When analyzing the capacity to weight ratio of different types of batteries (Fig. 1), it is obvious that the most recent batteries are not only smaller in comparison with their predecessors, but at the same time lighter and technologies used to produce them are less harmful to the environment.

The number of charge-discharge cycles is one of the main technical characteristics of the battery. The number of cycles of different types of batteries is shown in Fig. 3.

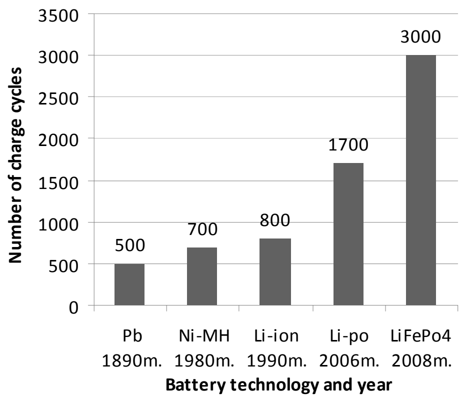

Fig.3. Approximate number of charge-discharge cycles of different types of batteries [5]

LiFePo4 batteries provide not less than 3000 charge-discharge cycles. If electric car is operated intensely enough and the batteries of this type are charged each day, their resource should be sufficient for more than 8 years.

Impact of Infrastructure on the Development of Electric Vehicles

Research shows that the majority of Lithuanian residents going to work each day by car travel less than 100 km per day. Therefore already today the electric vehicle could satisfy the transportation needs of a major population part. Considering the fact that the distances between the largest cities of Lithuania are relatively small, a properly developed network of charging stations would also allow to cover the intercity trips within the country.

The largest distance is between cities of Vilnius and Klaipėda – 312 km. Considering the distances covered by currently manufactured electric cars on a single charge, the distance between Vilnius and Klaipėda could be travelled using 1-2 intermediate recharges.

Unlike cars with internal combustion engines, the electric “gas stations”, i.e. charging stations could be installed in various locations. These could be private garages, public parking lots, the existing petrol stations.

The first electric car charging station conforming to European standards was installed in Lithuania in 2011, 22 April, in Kaunas, near the Kaunas district municipality building [7]. At the end of the year 2011 four charging stations were already installed in Lithuania: two in Vilnius and two in Kaunas.

Regarding the type of consumers, the electric car charging stations can be divided into several groups: intended for private use (installed in private garages, at home, etc.) and intended for public use. The need for each type of stations should be assessed separately. A large part of population in the cities of Lithuania lives in multi-apartment buildings. While the electric car recharge could be most comfortable to handle during the night, only a part of residents have private garages, making it likely that the need for the private stations would be less than the number of available electric cars. Meanwhile, the number of public charging stations does not directly depend on the number of electric vehicles. In order to promote the electric cars different countries or even separate cities are developing the charging station networks. Currently there are more than 13 thousand charging stations of different types installed across the entire Europe [8], and this number is constantly growing.

After collecting data and reviewing the future electric car development strategies in European countries, an assumption was made on the basis of obtained results about the development of electric car market in Lithuania [5]. In 2011 1,6 million cars were registered in Lithuania. It is forecasted, that around 1000 electric vehicles will be driven on the roads of Lithuania before year 2015, and in 2020 their number will reach approximately 35 thousand and they will form about 2 % of all cars registered in Lithuania.

Table 1. Numbers of electric cars and charging stations in lithuania in 2012–2020 [5]

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Electric cars	55	150	400	1.000	2.400	5.500	12.000	27.000	60.000
Home charging stations	14	38	100	275	600	1.375	3.000	6.750	15.000
Public charging stations	44	120	320	880	1.920	4.400	9.600	2.1600	48.000
Fast charging stations	1	2	2	4	4	7	14	32	72
Battery replace-ment stations	-	-	1	2	4	6	8	10	12

According to the opinion of Lithuanian Electric Vehicles Association (LEVA), by 2020 the number electric cars will increase up to 3,4 % of all registered vehicles. Based on optimistic projections, the number of electric cars should reach 60 thousand. In anticipation of such number of electric cars, nearly 48 thousand public charging stations should be built in Lithuania before 2020. Numbers of electric cars and charging stations are given in Table 1, the distribution of the number of electric cars by cities is shown in Fig. 4.

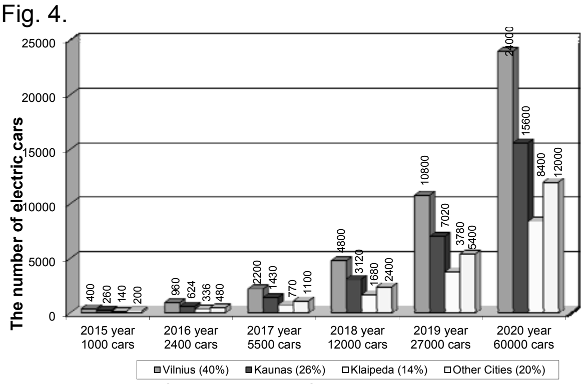

Fig.4. Distribution of the number of electric cars by cities in 2015–2020 [5]

According to the predicted number of population if 2020, the estimated distribution of the number of electric vehicles by cities is:

- Vilnius county – 24 thousand (40%),
- Kaunas county – 15,6 thousand (26%),
- Klaipėda county – 8,4 thousand (14%),
- Other cities – 12 thousand (20%).

Projected geographical locations of charging stations in the territory of Lithuania (major cities) are shown in Fig. 5.

It can be seen from Fig. 5, that after allocation of charging stations in the major cities of Lithuania, they will be almost evenly distributed throughout the entire territory of the country. In this way a convenient network of charging points will be created, allowing easy reach of charging station from any location in the territory of Lithuania. During further development if electric car infrastructure and expanding the network of charging stations, they should be installed in each city or larger town.

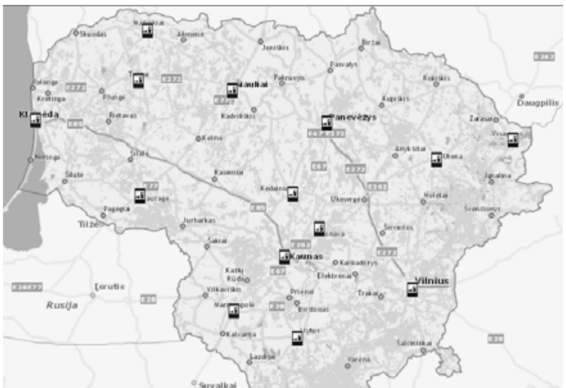

Fig.5. Projected geographical locations of charging stations in the territory of Lithuania

Concepts of Electric Car Development in Lithuania

The development of electric vehicles is currently dominated by several conceptions – improvement of hybrid cars, assembly of original electric cars, and conversion of conventional cars to electric. The number of original electric cars in a global market is quite large, and each year new manufacturers strive to offer the electric models in additional to conventional ones. However the expansion of these vehicles is different in different countries: their adoption is slowed by the fact that initially it is necessary to create a specific infrastructure (specialized service stations, battery replacement stations, etc.). Due to mentioned reasons most of electric cars are not available in Lithuania.

In this respect, another concept is more attractive – a conversion of conventional automobiles. Lithuanian State

Road Transport Inspectorate approved the technical specifications, and the first converted electric car 3E (former Honda HR-V) manufactured in Lithuania was registered on October 9, 2010, and, according to the data from Lithuanian Electric Vehicle Association, in the beginning of 2012 there were 25 electric vehicles already.

A concept of electric car conversion from conventional models is attractive for several reasons. First of all – this results in relatively small costs when expanding the business. This concept does not require a significant investment in service infrastructure, which can be developed in parallel with the increase of the number of electric cars. The second reason is the cost of time. Design and manufacture of conventional car transits many steps from concept and design to manufacturing and testing. Meanwhile, during conversion into electric car a normal car body is used, which has already passed the safety tests carried out by the manufacturer. Due to the shorter period of the whole process it is possible to exploit all the technical innovations available in the market: latest batteries, control electronics, etc.

Currently several Lithuanian companies are engaged in electric vehicle conversion. Fig. 6 shows the converted electric car Toyota Aygo EV, which was converted by UAB „Elinta".

Fig. 6. Electric car Toyota Aygo EV

Conversion works for this model were completed in May of 2011 and from that time its mileage already exceeded 20 thousand kilometers. This electric car can be charged using 230 V power network and can travel 160 km while fully loaded. The motor power is 66 kW, 0-100 km/h acceleration is 11,5 sec. [9].

Conclusions

Even though electric cars currently fall behind the conventional vehicles with internal combustion engines in respect of the distance covered on a single charge, a rapid development of semiconductor electronics and battery technologies already allow the creation of electric cars capable of competing with regular vehicles.

Research indicates that a major part of Lithuanian residents travel small distances by cars each day, and most part of them drive less than 100 km per day. Therefore electric cars can meet the needs of the most residents already today.

Several concepts dominate during the development of electric vehicles: improvement of hybrid cars, assembly of original electric cars, and conversion of conventional cars to electric. The conversion of conventional cars into electric vehicles is the most promising in Lithuania, since this concept requires relatively small costs and is accessible to medium-size companies. Currently, several such projects are already completed, and converted electric cars are successfully registered and constantly used.

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