RESEARCH IN ELECTRO AND INTERNAL COMBUSTION ENGINE MOTOR VEHICLE ENERGY COSTS

Dainis Berjoza, Inara Jurgena, Kaspars Vartukapteinis
Latvia University of Agriculture
dainis.berjoza@llu.lv, inara.jurgena@llu.lv, kaspars.vartukapteinis@llu.lv

Abstract. At the beginning of automobile development electromobiles successfully competed with internal combustion engine motor vehicles. But with the development of internal combustion engine constructions automobiles were widely used outside cities and electromobile mileage without charging turned out not to be competitive. The beginning of the 21st century can be considered as rebirth of wider application of electromobiles when hybrid automobiles were started to be used and also modern electromobiles and other electric vehicles were constructed. One of the most essential advantages of electric vehicles is low application costs. The most important part of the application costs is fuel costs for internal combustion engine vehicles or charging costs of electric vehicles. The article presents the methods of determination of electric bicycle, slow pace purchasing electromobile, slow pace electromobile and electromobile charging parameters and the analysis of the costs as well as a comparison with analogical internal combustion motor vehicles.

Keywords: electromobile, electric bicycle, slow pace electromobile, costs, charging.

Introduction

A new stage of electric transport development has started with the beginning of the 21st century. The first modern electric automobiles were hybrid automobiles the pioneer of which production being the Japanese auto producer *Toyota*. Also other producers started to develop electromobiles. Several modern technology constructions without internal combustion engines only with electro motors and accumulator batteries were elaborated. Charging of these automobiles is planned from domestic electric nets.

The cheapest charging of electric transport is in home conditions. For promotion of the development of electric transport in several charging places in Latvia charging is free. Nevertheless, such charging is oriented to either a short charging period, for instance, 0.5 h, or for electric transport for charging of which a large amount of electric energy is not necessary, for instance, electric bicycles.

Calculating the consumption of electric energy for electric vehicles per one kilometer mileage the trends can be different from the internal combustion motor vehicles. For instance, in cities electric transport can consume less energy for one kilometer mileage than in traffic outside cities. Besides, sometimes the mileage of the same transport vehicles is very different from the traffic regime, especially from the speed of traffic. The covered mileage with one complete charging can differ even two times.

The longest mileage with one complete charging of electric vehicles can be achieved at the speed 50 – 70 % of the maximal. It is positive that for this reason using electric vehicles we should remember the fact that we need to get to the charging place. Due to this more considerate movement regime will be chosen that will ensure saving of the surrounding environment even more.

From the ecological point of view surely it is essential from what energy source the electric energy is obtained. There are calculations that in Latvia up to 70 % of electric energy is “green”, obtained from renewable resources but other electric energy is obtained in thermoelectrostations working in the process of cogeneration [1]. Due to this, charging electric transport in Latvia, this transport is one of the most ecological in the EU. For this reason introduction of electric transport in Latvia is very essential from the point of view of environment protection.

Materials and methods

1. Analysis of electroenergy tariffs

Depending upon the country where the electromobile is applied the charging costs can be different; it depends on the electroenergy tariffs in the definite country. Besides, the electroenergy tariffs even in the EU countries can differ to a greater extent than the prices of internal combustion motor fuel. In Latvia the basic electroenergy tariff is 0.1074 $LVL \cdot kWh^{-1}$ or 0.1528 $EUR \cdot kWh^{-1}$. This tariff occupies the 12. place among the European Union countries and is higher than in the neighbouring countries. In Estonia it is 0.1141 EUR·kWh^{-1} and in Lithuania – 0.1309 EUR·kWh^{-1}.

If electric transport is intensively applied, especially in case if it is high power, at least with 2 – 3 kW motor, it can be envisaged that the tariff will be exhausted already after 3 – 4 months as for charging of electric transport 5 – 20 kWh of electroenergy will be used per day. These costs depend on the intensity of electric vehicle application. Due to this, using electromobiles in Latvia it would be better to transfer to T3 tariff that envisages subscription cost for this tariff 41.66 EUR per year and the costs for the amount of the protection apparatus current is 1.68 LVL·A^{-1} per year. The T3 tariff provides for 0.0993 EUR·kWh^{-1} electroenergy start tariff on week days from 23.00 to 7.00, but the basic tariff 0.1193 EUR·kWh^{-1}, but during day time from 7.00 to 23.00 the tariff correspondingly is 0.1220 EUR·kWh^{-1}, but the basic tariff 0.1572 EUR·kWh^{-1} [2]. More precise calculation and the possible efficiency of choosing the tariff for different groups of motor vehicles will be analysed below.

Considering that in Germany the costs of 1 kWh do not exceed 0.25 EUR·kWh^{-1}, but in Norway and Denmark approach 0.30 EUR·kWh^{-1}, the electromobile application costs increase in these countries.

The above analysed electroenergy costs are given charging at home. But, charging at charging places the electroenergy costs can be higher depending on what the owner of the charging place has determined. In Latvia on 16.02.2012 there are 9 charging places operating among which at six charging is free [3]. Free charging is meant for development of electrotransport application, but with the increase of the number of electric vehicles and with this also the increase of the demand for charging services it can be envisaged that it will be necessary to pay for charging.

The possibilities to charge electric vehicles at different charging places depending on the price of electric energy are summarized in Figure 1.

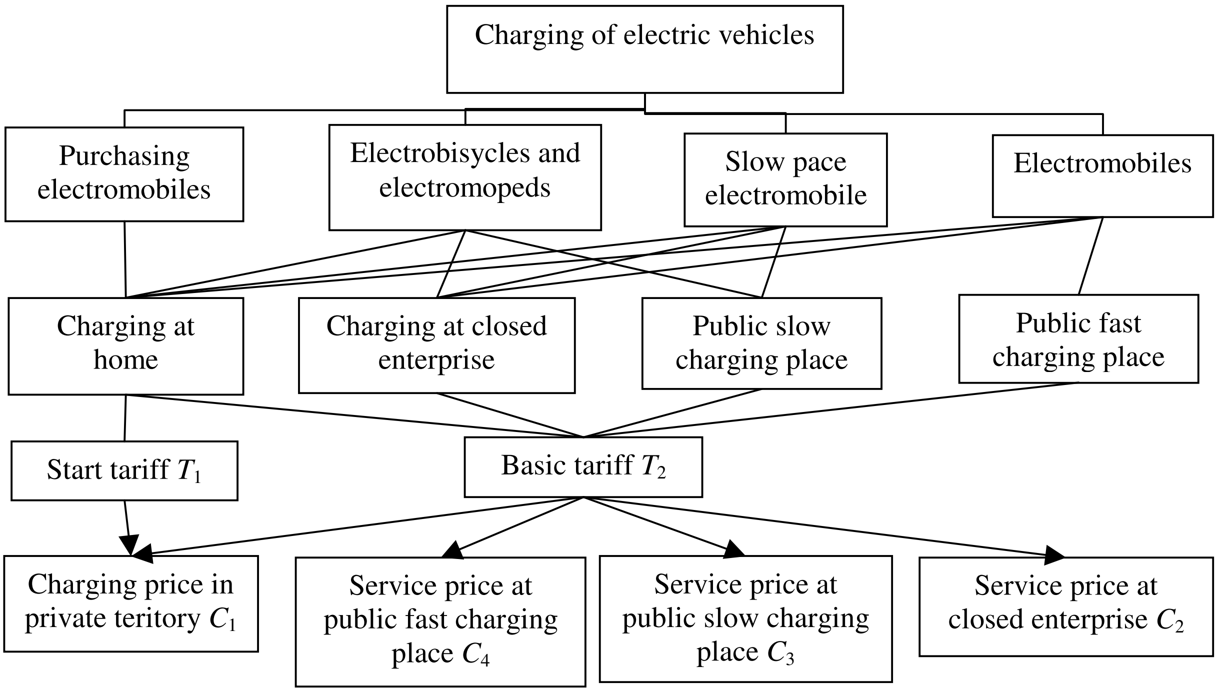

Fig. 1. **Formation of charging price**

Depending on the status of the charging place the charging price is formed. In any case the charging price will be higher that the electroenergy tariff, even at a private house. Usually in such cases it is assumed that the price C_1 (See Fig. 1) approaches the electroenergy tariff, nevertheless, in this price the costs of building of the charging place are included, especially in cases if the automobile is stored in open storing conditions and this charging place is to be built especially for an electromobile. In this case building of a simple charging place, including the electricity cable and charging box, does not exceed 40 – 60 EUR, including the work if installation is done by the owners themselves.

The price $C_2 \geq C_1$ as in private territories charging vehicles that do not belong to the enterprise will usually be of higher price than for the local users. In public charging places this price can be even higher and the correlation $C_3 \geq C_2$ will be valid. In relation to the high costs of building of fast charging places the depreciation costs of these places should be included in the service price. Due to this, based on the above analysis the correlation will be valid:

$$C_1 \leq C_2 \leq C_3 \leq C_4 = T_x E + I_A + I_O + I_N + \frac{I_{LP}}{t}, \tag{1}$$

where T_x – corresponding existing tariff – start or basic, LVL;
I_A – service costs, LVL;
I_O – servicing operator or system costs (system of settlements costs), LVL;
I_N – costs for taxes, LVL;
I_{LP} – charging place building costs, LVL;
t – charging places exploitation time or number of charging cycles till replacement of the charging place equipment;
E – amount of electric energy consumed for charging of electric vehicles, kWh.

Special cases are possible when the price can differ from the above analysis as it is determined also by the geographical position of the charging place, its exclusiveness, operator's salary (presence of automatic or manual registration system).

2. Methods of calculation of electric vehicle charging costs and internal combustion motor vehicle fuel costs

The costs necessary for charging of electric vehicles depend on the charging place. In Latvia charging is for payment only in three charging places, besides, mainly bicycles are charged. According to provisional research 0.05 $LVL \cdot h^{-1}$ are charged for charging of a bicycle.

The direct charging costs can be calculated according to the correlation:

$$I_u = T_N \times E + \frac{I_{LP}}{t}, \tag{2}$$

where T_N – charging tariff at the corresponding charging place.

If electric energy is not recorded in the charging place but payment is done for hours of charging, the following correlation is valid:

$$I'_u = C_h t_L, \tag{3}$$

where C_h – charging price, LVL·h;
t_L – time consumed for charging, h.

In case if the charging current does not exceed 16 A. It is not necessary to build a special charging place in home conditions; then using the existing garage power point $I_{LP} = 0$. Let us analyse the costs of electric energy or fuel per coverage of a definite distance. Electric vehicles consume $W \cdot km^{-1}$ electric energy, but for internal combustion motor vehicles the fuel consumption is $l \cdot km^{-1}$. The internal combustion motor vehicle fuel costs can be calculated according to the correlation:

$$I_d = C_d \times Q, \tag{4}$$

where C_d – price of the corresponding fuel, LVL;
Q – consumed amount of fuel, l.

Relating the obtained correlations 2 – 3 to the covered mileage a correlation for energy (electric or fuel) costs per km is obtained. As most often in practice values per 100 km mileage are used, calculations for electromobile 100 km mileage costs, if registration of electric energy is applied, are performed according to the correlations:

$$I_{lE} = \frac{I_u \times 100}{l} = \frac{100 T_N \times E}{l} + \frac{100 I_{LP}}{t \times l}, \tag{5}$$

where l – mileage with the corresponding amount of energy, km.

Calculations for electromobile 100 km mileage costs, if the payment is per hours, is performed according to the correlations:

$$I'_{lE} = \frac{I'_u \times 100}{l} = \frac{100 C_h t_L}{l} \tag{6}$$

Using internal combustion motor vehicles the following correlation is obtained:

$$I_{lA} = \frac{I_d \times 100}{l} = \frac{100 C_d \times Q}{l} \tag{7}$$

If it is necessary to determine the energy costs per 1 km, in the correlations 5 – 7 the coefficient 100 is not used.

Results and discussion

In order to state the energy consumption for charging of electric vehicles experimental investigations with different motor vehicles have been performed. In the experiments the electric vehicles are operated in the city or mixed movement regime until charging the battery by 90 – 95 %, determining the mileage with the GPS data logger. The experiments have been performed with five different electric bicycles. For driving the electric bicycles 180 W, 250 W and 500 W motors have been used. The average running speed 20 – 25 km·h^{-1} has been maintained depending upon the riding conditions. After the test the batteries are charged with the charging equipment provided for every electric vehicle. The charging equipment used in the tests switches off automatically ensuring the optimal battery charging time.

The driving and charging tests are performed similarly with the slow pace electric automobile *Melex 963 DS* and electromobile *Fiat Fiorino Elettrico HC-S* offered for the experiments by the stock company *Latvenergo*.

The experiments determining the consumption of internal combustion engine fuel are performed with electric moped *YY50QT* and internal combustion engine automobile *Renault Clio* with 1.2 l Otto motor. The moped is operated similarly as the electric bicycles maintaining the possible higher speed 50±5 km·h^{-1}. For the automobile *Renault Clio* the fuel consumption tests are performed on the roller stand *Mustang 1750* doing the *IM 240* driving cycle. The automobile *Renault Clio* has been chosen for the tests due to the reason that its internal combustion engine will be replaced by electric motor and in further research comparative energy consumption data will be necessary. As there is not an automobile *Fiat Fiorino* with internal combustion engine at disposal of the research group, the data on fuel consumption of this automobile are taken from the technical data on the amount of fuel consumed in the European driving mixed cycle [4].

During charging for registration of the consumed electric energy the electric energy meters *ES-T9162* are used. The experiments are repeated five times. The parameters for electric vehicles stated in the experiments:

- electric vehicle mileage, km;
- electric energy consumed during charging, kWh;
- maximal charging capacity, W;
- charging time, h.

The parameters for internal combustion vehicles stated in the experiments:

- volume of consumed fuel, ml;
- mileage;
- output parameters – fuel consumption, l·100 km^{-1}.

The average values for different vehicle groups obtained in the experiments are summarised in Table 1. The table summarises the data from the experiments with electric vehicles as well as simultaneously performed experiments with internal combustion engine vehicles.

Table 1

Experimental data of charging

No.	Electric vehicle kind, brand	Mileage with full charging, km	Electric energy for charging, kWh	Consumed electric energy, Wh·km^{-1}	Consumed energy, Wh·100 km^{-1} or l·100 km^{-1}	Costs, EUR·km^{-1}	Costs, EUR·100km^{-1}	Maximal charging power, W	Charging time, h
1.	ER61	42.05	0.99	23.45	2344.94	0.0036	0.36	115.3	7.5
2.	Le Velec	18.86	0.38	20.28	2028.10	0.0031	0.31	90.5	7.5
3.	Easy Bike	15.50	0.36	23.23	2322.58	0.0035	0.35	85.0	8.0
4.	EMR750	24.78	0.53	21.47	2146.89	0.0033	0.33	63.8	7.4
5.	Giant	27.32	0.61	22.25	2225.48	0.0034	0.34	96.4	7.0
6.	MELEX 963DS	33.93	7.59	223.56	22356.48	0.0342	3.42	1855.8	7.8
7.	Fiat Fiorino Elettrico HC-S	96.18	20.55	213.68	21368.38	0.0327	3.27	2908.6	9.0
8.	Internal combustion moped YY50QT	–	–	–	2.57	0.0365	3.65	–	–
9.	Renault Clio 1.2 l	–	–	–	6.41	0.0910	9.10	–	–
10.	Fiat Fiorino Combi 1.4 l	–	–	–	6.90	0.0981	9.81	–	–

For transparency of the data graphical comparison of electric vehicle mileage, km and consumption of electric energy, Wh·km^{-1} has been presented in Fig. 2.

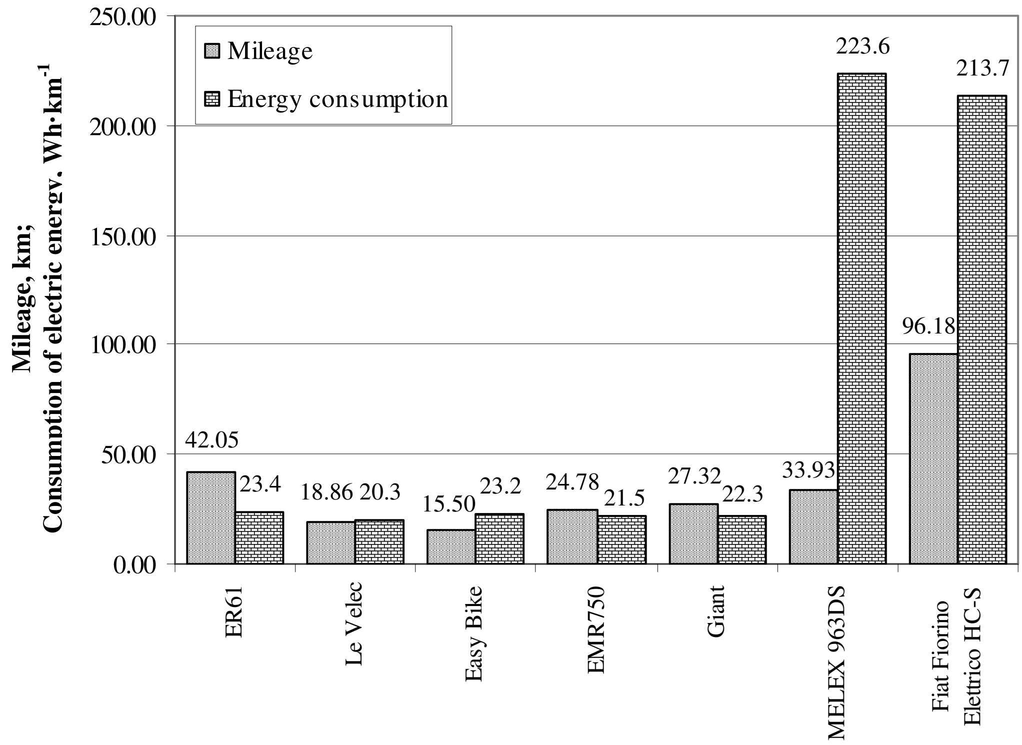

Fig. 2. **Mileage of electric vehicles and consumption of electric energy**

According to the data in Fig. 2 the largest mileage is for the electric bicycle *ER61* – 42.05 km. Still, this mileage is not corresponding to the given in the technical specification and differs by 30 %. The mileage of other electric bicycles is in the range from 18 to 27 km and in total it corresponds to the bicycle specification data.

The electric energy consumption data differ essentially. The lowest electric energy consumption - 20.3 $W \cdot km^{-1}$ is for the electric bicycle *Le Velec*. This is the only electric bicycle for which the electric motor is activated afterwards when it is treadled. Due to this the movement cannot be started and the inertial mass cannot be overcome only by means of electric motor and the consumption of energy in the acceleration regime is minimal. This electric bicycle conception ensures the cheapest motorised movement possibility.

The largest energy consumption, 23.4 $W \cdot km^{-1}$, is for the most powerful of the experimental electric bicycles (500 W motor) *ER61*.

The largest energy consumption, 223.6 $W \cdot km^{-1}$, is for the automobile *Meleks 963 DS*. It could be explained by accumulator batteries the remaining resource of which could be about 40 % that does not ensure the average exploitation mileage – 50 km. For increasing the mileage it is necessary to operate the electric vehicle in the speed that does not exceed in the average 70 – 80 % of the maxim al movement speed.

According to the amount of energy consumed during charging and the mileage the energy costs are calculated for 100 km mileage (See Fig.3). The lowest costs are for electric bicycles and they are in the range from 0.31 to 0.36 EUR per 100 km. The highest costs of electric vehicles are for electromobiles, but they in the experimental regimes do not exceed 3.50 EUR per 100 km. It is interesting that the internal combustion moped energy costs 3.65 EUR per 100 km are higher that the costs for the electromobiles *Meleks* and *Fiat Fiorino*.

The energy costs of the internal combustion motor automobile *Fiat Fiorino Combi* are exactly three times higher than the costs of the analogous prototype *Fiat Fiorino Ellectrico* – 9.81 EUR per 100 km.

This research has been performed based on the fuel and energy prices in Latvia in February, 2012. In other countries these costs and their relation can be different due to other energo resource prices.

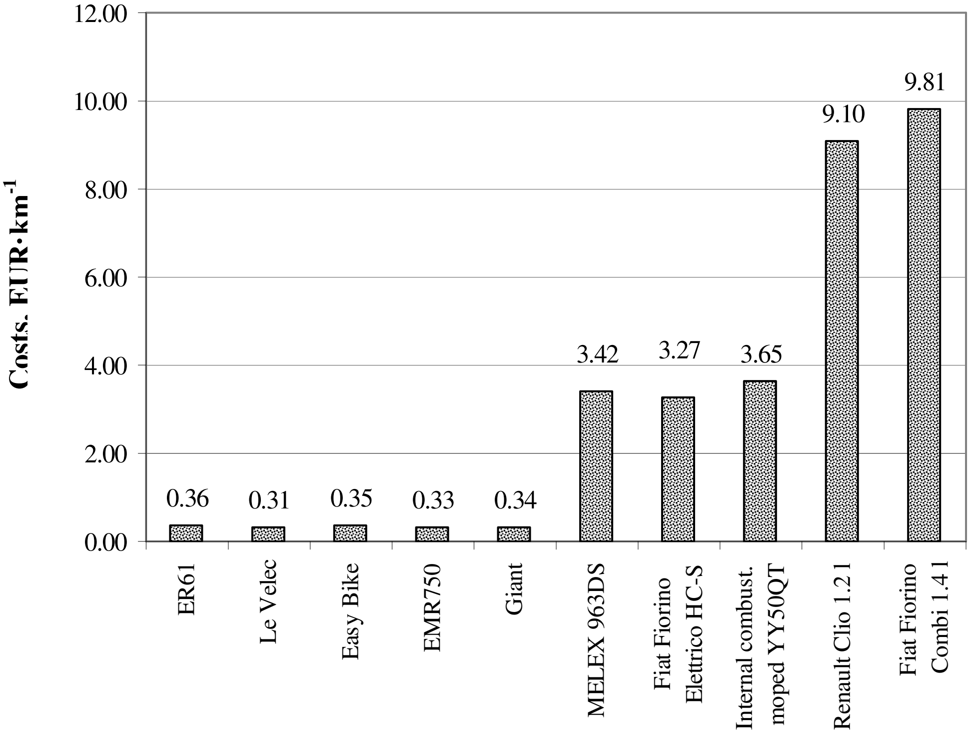

Fig. 3. **Motor vehicle energy costs**

Conclusions

1. The electric vehicle electric energy costs depend on the kind of the charging place and the price for electric energy at it. The cheapest charging is at home conditions.
2. From the point of view of energy costs the cheapest are electric bicycles without exceeding 0.36 EUR per 100 km.
3. Using bicycles with electric motor activisation at definite speed of pedalling the lowest energy costs can be obtained for 100 km mileage – 0.31 EUR, that can be explained by overcoming of inertia resistance starting movement using the power of muscles and relieving the electric motor.
4. The costs of the internal combustion motor automobile *Fiat Fiorino Combi* are three times higher than of the analogous internal combustion motor automobile *Fiat Fiorino Ellectrico* – 9.81 EUR per 100 km.
5. The energy costs depend on the tariffs in the country and fuel prices and they can essentially differ from the research results in Latvia.

Acknowledgements

Funding support for this research is provided by the ERAF Project 'Usage of Electric Energy in Motor Vehicles of Physical Persons' (No. 2010/0305/2DP/2.1.1.1.0/10/APIA/VIAA/130). Research was carried out in co-operation with the public limited company *Latvenergo AS*.

References

1. Energijas ražošana (In Latvian). [online] [15.02.2012.] Available at: http://www.latvenergo.lv/portal/page/portal/Latvian/latvenergo/main_page/energijas_razosana/ENERGIJAS_RAZOSANA
2. Latvenergo elektorenerģfijas tarifi (In Latvian). [online] [15.02.2012.] Available at: http://www.latvenergo.lv/portal/page/portal/Latvian/latvenergo/main_page/pakalpojumi_priv/tarifi_privatpersonam
3. Elektroautomobiļu un divriteņu transportlīdzekļu publisko uzlādes punktu karte (In Latvian). [online] [15.02.2012.] Available at: http://www.latvenergo.lv/portal/page/portal/Latvian/latvenergo/main_page/korp_atbildi/UZLADES_PUNKTU_KARTE
4. Fiat Fiorino Combi Car emission information. [online] [15.02.2012.] Available at: http://www.car-emissions.com/cars/view/28633