ECONOMIC EFFECT OF ELECTRIC VEHICLES

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Abstract. Due to the decrease in fossil energy resources in the world and the increase in their consumption, new sources of energy are searched for. One of such kinds of energy is electricity. A methodology for assessing the economic effect of electric vehicles was developed. The methodology was approbated by computing economic effects for various types of electric vehicles. The electric vehicles were compared with analogous internal combustion engine vehicles. The expenses on charging a battery of electric vehicles are three times lower than the expenses on fuel for internal combustion engine vehicles. The expenses depend on the type of vehicles and exploitation conditions.

Keywords: electric vehicles, internal combustion engine vehicles, economic effect, cost, fuel consumption.

Introduction

More than 800 million automobiles are presently exploited in the world. On average, 55-75 million automobiles are produced in the world every year. Mostly fossil fuels are used in automobiles. The main kinds of liquid fuels produced from non-renewable resources and used in vehicles are diesel fuel and petrol. Liquefied petroleum gas (LPG) and compressed natural gas (CNG) are also used. Renewable energy sources, for instance, biofuel are used as well. In several countries in the world, for example, in Brazil, pure bioethanol or flex fuel E85 – a mixture of bioethanol and petrol in a ratio of 85:15 – is used. Biofuel and rapeseed oil are also used, but their use in vehicles that are not specially adapted for them is problematic, especially in winters when surrounding environment temperatures are below -5 ºC.

One of the kinds of energy that is little used in vehicles is electricity. Electricity is extensively used in public transport in cities – trams and trolleybuses. Yet, due to the heavy weight and the relatively low energy capacity of batteries, electric vehicles with batteries are not popular. Such vehicles are mostly used in the USA. In most cases, vehicles are individually converted, replacing their internal combustion engine with an electric engine. Automobile manufacturers have designed several models of electric vehicles, however, so far they are not widely available in the market. The sale prices of such automobiles produced by the large auto manufacturers are high, which will limit purchases of such kind of vehicles and their fast spread.

Let us compute the economic effect for various electric vehicles compared with analogous internal combustion engine vehicles.

Materials and methods

Distribution of motor vehicles by type of fuel in Latvia

Automobiles using various types of fuels are exploited in Latvia. Of liquid types of fuels, petrol and diesel fuel are used. The largest consumer of diesel fuel is lorries. Cars use both petrol and diesel fuel. Automobiles running on liquefied natural gas are also used – mostly cars with Otto engines. Due to the closure of all compressed natural gas stations in Latvia in the spring of 2010, the use of such automobiles is limited, and such vehicles can be fuelled up only by means of individual low capacity gas equipment installed for private needs. Such equipment can fill an automobile up with compressed gas within 8-10 hours. The amount of gas filled up within this period is enough for driving as far as 250-300 km, however, 1-2 automobiles can be fuelled up at such a filling station simultaneously. The price of such equipment is high, therefore, they have not become popular. The distribution of motor vehicles by type of fuel as of 1 January 2011 is summarised in Table 1 [1-3].

None of the types of fuel is produced in Latvia. Since electricity is produced in Latvia, the exploitation of vehicles would not be related to using energy resources of other countries.

Table 1

Distribution of motor vehicles by type of fuel in Latvia

Kind of vehicle	Total	Petrol engine vehicles	Diesel engine vehicles	Liquefied and compressed gas engine vehicles	Electri-city
Cars	636664	402136	210075	24453	-
Lorries	71575	7063	62771	1741	-
Motorbikes and quadrocycles	18325	18320	-	-	5
Mopeds	19486	19486	-	-	-
Buses	5377	194	5143	40	-
Trolleybuses	346	-	-	-	346
Trams	315	-	-	-	315
Total	752088	447199	277989	26234	666
As percentage	**100 %**	**59.46 %**	**36.96 %**	**3.49 %**	**0.09 %**

Consumption of various types of fuel in Latvia

The total number of automobiles and their distribution by the type of fuel is only one indicator showing the consumption of fossil energy resources in a region. Yet, it has to be taken into consideration that lorries and cars consume different amounts of fuel, besides, this difference could be even five times; therefore, it is of great importance to analyse the amount of fuel consumed. The amount of fuel consumed can be estimated by two methods: according to the data of the Central Statistical Bureau of Latvia or according to the average annual fuel consumption and kilometrage of automobiles. The data of the Central Statistical Bureau usually do not specify the fuel consumption for motor transport; therefore, the computation method that is based on several assumptions will be more precise.

In computing the amount of fuel consumed, it is assumed that a car consumes on average 8 l of petrol per 100 km, diesel fuel – 6 $l\cdot(100\ km)^{-1}$, and liquefied gas – 10 $l\cdot(100\ km)^{-1}$. It is assumed that the average annual kilometrage of a car is 20000 km. For lorries and buses, the average consumption of fuel is 32 $l\cdot(100\ km)^{-1}$ (buses with petrol engines – 40 $l\cdot(100\ km)^{-1}$) and the average annual kilometrage is 100000 km (lorries with petrol engines – 20000 km). For motorbikes and quadrocycles, the average consumption of fuel is 5 $l\cdot(100\ km)^{-1}$ (2.5 $l\cdot(100\ km)^{-1}$ for mopeds) and the average annual kilometrage is 10000 km (5000 km for mopeds). The computation includes only automobiles that have passed their technical checkup. The annual amount of fuel consumed for a particular type of motor vehicles is computed according to formula:

$$Q_g = \frac{L_g Q_{100km}}{100}, \tag{1}$$

where L_g – annual kilometrage of a vehicle, $km\cdot year^{-1}$;
Q_{100km} – consumption of fuel of a vehicle per 100 kilometres of travel, $l\cdot km^{-1}$.

The expenses on fuel are computed according to formula:

$$I_D = \frac{C_{D-1l} \times L \times Q_{100km}}{100}, \tag{2}$$

where $C_{D\text{-}1l}$ – expenses on purchasing 1 litre of fuel, LVL;
L – total kilometrage of vehicles during the period of exploitation, km.

The data of Table 1 were used for the computation. The computation result is presented in Table 2.

According to Table 2, one can conclude that almost 2.2 thousand millions LVL are spent on fossil fuels a year. By introducing electric vehicles, these costs could be reduced, and fossil energy resources could be replaced with renewable energy sources owing to using, for instance, solar, wind, or hydro energies in generating electricity.

Table 2

Average amount of fuel consumed by various types of motor vehicles a year

Type of motor vehicles	Petrol consumption, m^3	Petrol expenses, thsnd. LVL	Diesel fuel consumption, m^3	Diesel fuel expenses, thsnd. LVL	Liquefied gas consumption, m^3	Liquefied gas expenses, thsnd. LVL	Fuel expenses in total, thsnd. LVL
Cars	521168.3	469051.4	204192.9	183773.6	39613.9	17826.2	670651.3
Lorries	34716.1	31244.5	1542660.1	1388394.1	8022.5	3610.1	1423248.7
Motorbikes, quadrocycles and mopeds	7116.5	6404.9	-	-	-	-	6404.9
Buses	3069.1	2762.2	130179.6	117161.7	506.2	227.8	120151.6
Total	-	509462.9	-	1689329.4	-	21664.2	2220456.4

Algorithm for computing the economic effect

An algorithm was developed to determine the economic effect. This algorithm can be used for any types of motor vehicles. The main types of vehicles with electric drive are cars, motorbikes and quadrocycles, as well as various low-speed four-wheel and two-wheel electric vehicles, for instance, low-speed tourist bicycles and mopeds.

Only the costs that can change depending on whether these vehicles have an internal combustion engine or electric drive were taken into account in the computation. The total expense on exploiting vehicles from the moment of their purchase is computed according to formula:

$$I = I_{ieg} + I_{TA} + I_{TR} + I_D + I_C, \tag{3}$$

where I_{ieg} – purchase cost of vehicles, LVL;
I_{TA} – maintenance cost of vehicles, LVL;
I_{TR} – repair cost of vehicles, LVL;
I_D – fuel cost of vehicles, LVL;
I_C – cost of vehicles participating in traffic that includes technical checkup cost, taxes, and other payments, LVL.

Instead of the fuel cost for electric vehicles, the cost of electricity used for charging an electric vehicle has to be included in the computation. Due to the specifics of exploiting electric vehicles, which is based on limited availability of the related infrastructure in Latvia, electric vehicles are mostly intended to be exploited in urban areas, for instance, to go to work. In this case, a daily distance of travel will not usually exceed 50-60 km. Therefore, it is preferable to use relative indicators, for instance, per 100 km of travel for an economic comparison of electric vehicles and internal combustion engine vehicles. The costs per 100 kilometres of driving are computed according to formula:

$$I_{100km} = \left(I_{ieg} + I_{TA} + I_{TR} + I_D + I_C\right)\frac{100}{L}, \tag{4}$$

where L – total travel distance of vehicles during their exploitation, km.

The purchase costs are computed according to formula:

$$I_{ieg} = I_{sp} + I_{reg}, \tag{5}$$

where I_{sp} – vehicle purchase cost, LVL;
I_{reg} – vehicle registration cost, LVL.

The maintenance costs are computed according to formula:

$$I_{TA} = I_{TA-RD} + I_{TA-J}\ , \tag{6}$$

where $I_{TA\text{-}RD}$ – cost of spare parts used in maintenance of vehicles, LVL;
$I_{TA\text{-}J}$ – labour cost for maintenance of vehicles, LVL.

The repair costs are computed according to formula:

$$I_{TR} = I_{TR-RD} + I_{TR-J}\ , \tag{7}$$

where I_{RD} – cost of spare parts used in repair of vehicles, LVL;
$I_{TR\text{-}J}$ – labour cost for repair of vehicles, LVL.

All types of vehicles do not incur the cost of taking part in traffic, for instance, electric bicycles and electric mopeds are not required to pass technical checkups. The owners of vehicles incurring such cost have to pay it once a year. Therefore, this cost is related to the duration of vehicle exploitation:

$$I_C = T \times C_C\ , \tag{8}$$

where T – total duration of vehicle exploitation, years;
C_C – costs of technical checkups, road tax, and other annual payments.

By integrating Formulas 2 and 5-8 in Formula 4, the cost per 100 km is obtained as follows:

$$I_{100km} = \frac{\left(I_{sp} + I_{re\dot{g}} + I_{TA-RD} + I_{TA-J} + I_{TR-RD} + I_{TR-J} + T \times C_C\right)100 + C_{D-1l} \times L \times Q_{100km}}{L} \tag{9}$$

Results and discussion

Economic effect for various types of vehicles

The economic effect will be computed for 9 compact class cars that might have a 1.2-1.4 l Otto engine or a 1.4-1.5 l diesel engine, for instance, Renault Clio:

- new standard automobile with an internal combustion Otto engine (*N-Otto*);
- new standard automobile with an internal combustion diesel engine (*N-Diz*);
- new standard automobile with an internal combustion compressed gas engine (*N-LPG*);
- 5 year old standard automobile with an internal combustion Otto engine (*5Y-Otto*);
- 5 year old standard automobile with an internal combustion diesel engine (*5Y-Diz*);
- 5 year old standard automobile with an internal combustion compressed gas engine (*5Y-LPG*);
- 5 year old standard automobile converted to an electric automobile individually (*5Y-ConvInd*);
- new serial electric automobile (*N-Electro*);
- 5 year old automobile converted to an electric automobile industrially (*5Y-Electro*).

The computation was done by applying Formula 9 and using Latvian statistical and other informative materials [4; 5]. An Excel table was used, in which not only the relative data (cost per 100 km of driving), but also the total costs were summarised and computed. The computation result is shown in Table 3.

Several assumptions were made for the computation in Table 3, the result of which will be analysed. If an automobile is converted by oneself, it is not purchased and its internal combustion engine is replaced with an electric engine. Instead of lithium-ion batteries, another type of batteries (cost less than 3000 LVL) are installed both on an automobile converted by oneself and on a 5 year old automobile converted to an electric automobile at a factory. Batteries are replaced after 100000 km of driving. It is assumed that batteries are rented from their producer for a new electric automobile. Such an activity will not be possible in Latvia in the nearest years, as it requires large government subsidies. In case of the automobile converted by oneself, its conversion registration cost, too, is included in the registration cost [6]. The labour cost for maintenance and repair is assumed to be 15 $LVL \cdot h^{-1}$. Repairs do not include automobile body repairs. The cost of replacement of batteries for electric automobiles (except a new electric automobile) are included in the cost of repairs, but the cost of engine repair significantly decreases owing to the simple design of electric engine and a small number of its units. It is assumed that the cost of technical checkups for an electric automobile is the same as for an analogous Otto engine automobile. It is also assumed that the road tax for an electric automobile is paid only for its mass, but not for its engine capacity. An accumulated distance of travel over the lifetime of a vehicle for a new electric automobile is assumed to be 300000 km, but for a used automobile – 150000 km. The cost of electricity consumed per 100 km of travel for a new automobile is assumed to be 1.40 LVL and 1.50 LVL for used automobiles owing to the effectiveness of batteries.

Table 3

Main automobile costs per 100 km of driving

Type of motor vehicles	Purchase cost, LVL	Purchase cost, LVL·(100 km)$^{-1}$	Registration cost LVL·(100 km)$^{-1}$	TA+TR cost LVL·(100 km)$^{-1}$	Technical checkup and taxes LVL·(100 km)$^{-1}$	Fuel (electricity) cost, LVL·(100 km)$^{-1}$	Daily distance of driving, km	Total cost, LVL·(100 km)$^{-1}$
N-Otto	8300	2.77	0.01	0.42	0.18	6.84	82.2	10.22
N-Diz	9600	3.20	0.01	0.53	0.19	4.77	82.2	8.70
N-LPG	8800	2.93	0.01	0.43	0.19	3.60	82.2	7.16
5Y-Otto	3000	2.00	0.02	0.61	0.18	6.84	82.2	9.65
5Y-Diz	4500	3.00	0.02	0.72	0.19	4.77	82.2	8.70
5Y-LPG	3500	2.33	0.02	0.62	0.19	3.60	82.2	6.76
5Y-ConvInd	5000	3.33	0.11	3.13	0.32	1.50	27.4	8.39
N-Electro	20000	6.67	0.01	0.15	0.32	1.40	27.4	8.55
5Y-Electro	7000	4.67	0.02	3.15	0.32	1.50	27.4	9.66

To demonstratively show a comparison of costs, the relative costs, measured in LVL·(100 km)$^{-1}$, were computed (see Table 3). The relative costs are summarised and shown in Fig. 1.

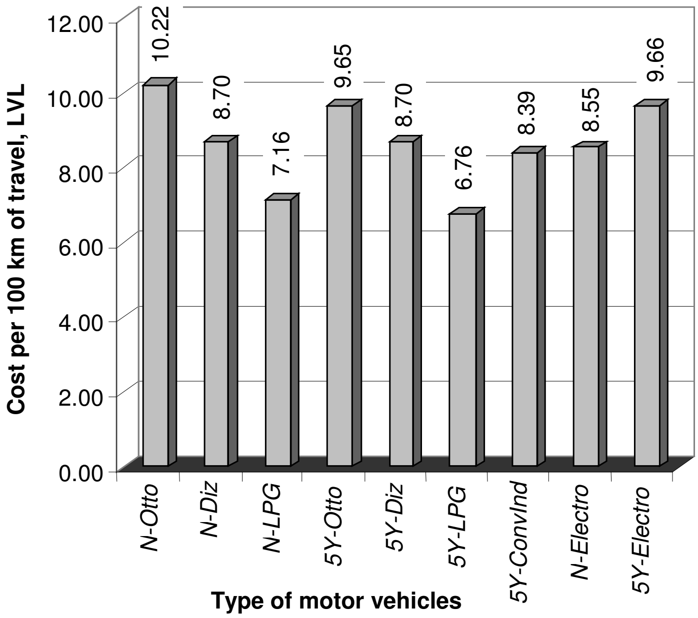

Fig. 1. **Total relative costs for various types of motor vehicles, LVL·(100 km)$^{-1}$**

Owing to the relatively low price of liquefied gas, the most efficient is an automobile of such type, besides, the lowest cost or 6.76 LVL is obtained for such used automobile. Among electric automobiles, the highest efficiency or the lowest cost is obtained for an automobile converted by oneself. In general, the cost of replacement of batteries increases the costs for all electric automobiles.

If lithium-ion batteries are replaced after 100000 km of driving for a new automobile, its efficiency is very low and reaches 20.50 LVL·(100 km)$^{-1}$, which is twice as much as for internal combustion engine automobiles. The cost of a used electric automobile is relatively high due to its shortage in the automobile market, and the prices of 5 year old automobiles usually range within 7000-8000 LVL [6].

The analysis shows that automobiles converted by oneself are the most prospective among the analysed electric motor vehicles. The owner of such an automobile can individually select the specific parameters for power, travel, and batteries that are directly related to the use of automobiles. For instance, if a daily travel by such an automobile is 30-40 km, one can choose cheaper and lower capacity batteries designed for a travel of only 50 km. In this case, no special infrastructure is required, as batteries can be charged at home.

Conclusions

1. By introducing electric motor vehicles in Latvia, fossil energy resources can be saved, and electricity can be domestically produced without consuming oil products.
2. The largest consumer of fossil fuels in Latvia is lorries, more than 1.4 thousand millions LVL are spent on fuel annually for the fleet of lorries, however, the introduction of electric motor vehicles in lorry transport is problematic due to the present technologies.
3. The algorithm for computing the economic effect includes all automobile exploitation costs per 100 km of travel. The algorithm was approbated by using the data on compact class automobiles and recognised as functional in comparing costs of various types of motor vehicles in an independent way.
4. Of automobiles using fossil fuels, the lowest cost or 6.76 LVL·(100 km)$^{-1}$ was obtained for a 5 year old automobile running on compressed gas owing to its low purchase and fuel costs.
5. Among electric motor vehicles, the highest efficiency or 8.39 LVL·(100 km)$^{-1}$ was obtained for a 5 year old automobile that is converted to electric power. Purchasing a used electric automobile is relatively expensive due to its high price exceeding 7000 LVL.
6. An economic effect of 8.55 LVL for a new electric automobile is possible only in case if its batteries are rented and there is no need to replace them during repair, however, such a service will not be available in Latvia over the next years due to a need for large government subsidies.
7. Electric automobiles in cities and urban areas can compete with fossil energy automobiles, especially in cases when they are designed to ensure certain parameters of exploitation.

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