ECOLOGICAL EFFECT OF ELECTRIC VEHICLES

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Abstract. New solutions to the use of various alternative energies are searched for in the sector of transport owing to the fast increase in the consumption of energy resources. One of such alternative energies is electric energy used in electric vehicles. The use of electric vehicles is not only economically beneficial, but it also ensures fewer emissions as well as localises these emissions outside the exploitation site of these vehicles (outside cities). Electric vehicles produce less CO_2, CH, NO_x, and CO emissions, and in some conceptions the amount of emissions is even considered to be 0. The present paper analyses the potential effect of the increase in the proportion of electric vehicles on the ecology of Latvia.

Keywords: automobiles, electric vehicles, exhaust gases, toxic components, and calculation algorithm.

Introduction

The overall ecological situation in Latvia, compared with other European countries, is not very problematic. Yet, it is often related not to the introduction of the newest technologies protecting the environment, but to the poorly developed industry. One of the fields affecting the ecology is transport. Transport mainly consumes imported energy resources.

It is presently stipulated in Latvian legislation that conventional fuel is mixed with up to 5 % biofuel – petrol with bioethanol and diesel fuel with biodiesel fuel. Thus, the requirements of the EU directive regarding the use of 5 % biofuel in the transport sector are complied with.

When exploiting electric vehicles, it is possible to use domestic energy sources – electric energy produced in Latvia. Besides, 70 % of this energy in Latvia is generated from renewable energy sources, for instance, at hydropower plants. The remaining 30 % of electric energy is produced at thermal power plants [1]. Based on these principles, 100 % of the energy consumed by electric vehicles would be generated in Latvia, as well as this energy could be produced from renewable sources.

The main kinds of production of renewable electric energy in Latvia are as follows:

- hydropower (up to 71 % of the electric energy produced in the country in 2011);
- wind energy;
- electric energy generated from biogas.

The production of electric energy from biogas has developed fast over the recent years. If having a special contract with the JSC Latvenergo, it is possible to charge electric vehicles with electricity produced particularly from renewable sources, i.e., a producer of renewable energy is paid for it. Thus, consumers may be convinced that they receive electricity from renewable sources.

To reduce emissions from vehicles, electric drive has to be installed in vehicles in which the combustion engine may be replaced with an electric motor. Vehicles having no motor, but in which an electric motor is installed, for instance, bicycles have no positive effect on the ecology. From the viewpoint of environmental protection, a positive effect is obtained if a consumer, when purchasing a new vehicle, buys an electric bicycle or an electric moped instead of an internal combustion moped.

The research aim is to design an algorithm, based on the standards for vehicle emissions and the number of vehicles in Latvia, for identifying the type of vehicles, the exploitation of which as electric drive vehicles is useful from the ecological viewpoint.

1. Distribution of vehicles by type in Latvia

Various types of vehicles are exploited in Latvia. Electric drive is mainly used in vehicles with a gross weight of 3.5 t or less, yet an analysis will be performed for also the vehicle group with a gross weight from 3.5 to 12 t, as the exploitation of such vehicles with electric drive might become possible in the future due to the progress in technology. According to the CSDD (Road Traffic Safety Directorate) data [2] as of 1 January 2013, the distribution of vehicles by type is presented in Table 1.

Table 1

Changes in the number of vehicles registered in Latvia that may be exploited as vehicles with electric drive

No	Type of vehicle	Number as of 1 January 2010	Number as of 1 January 2011	Number as of 1 January 2012	Number as of 1 January 2013	Kilometrage a year, km
1.	Lorries with a gross weight from 3.5 to 12 t	28407	11432	10549	9996	40000
2.	Lorries with a gross weight of 3.5 t or less	51681	37827	38955	42341	40000
2.	Cars: with a diesel engine; with a petrol engine	 227282 676984	 210075 426586	 221085 391229	 244410 378906	20000
3.	Busses with a gross weight of 3.5 t or less	2646	962	807	704	40000
4.	Motorbikes and tricycles	33590	17188	17385	17879	5000
5.	Mopeds	18373	19486	21238	23209	2000
6.	Quadrocycles	1477	1137	1142	1095	2000

According to Table 1, mainly electric drive cars are among vehicles with electric drive, yet there are also electric drive lorries, motorbikes, and mopeds. Electric bicycles with a motor capacity of more than 250 W have to be considered mopeds as well. Auto manufacturers have already designed hybrid lorries, for instance, Volvo FE Hybrid. As of 1 January 2013, 12 electric automobiles were registered in Latvia. Table 1 also summarises the average annual kilometrage for each type of vehicles.

According to Table 1, the number of vehicles significantly decreased in 2011, whereas the next year a slight increase was observed. The significant decrease in the number of vehicles may be explained by the fact that they were massively written off in 2010, as a vehicle use tax was introduced for all automobiles regardless of their use as well as the rules for writing off vehicles were simplified.

Further analysis will be performed in relation to the number of vehicles in 2013, based on an assumption that by 2020 in Latvia, 10 % of vehicles will have electric drive, while the expected number of automobiles and their percentage distribution will not significantly change.

2. An algorithm for assessing the ecological effect of electric vehicles

Based on the present electric energy accumulation technologies, it is difficult to imagine that an electric automobile might be the only vehicle in the family. There are various infrastructural solutions – fast charging when a battery is charged up to 80 % of its capacity within 30 minutes as well as battery change stations where a robot changes the battery within a few minutes. Yet, in order that these expensive infrastructure systems can function at full capacity, such systems have to be available in all countries where electric automobiles are exploited. It means that if such systems are introduced in Europe, it is possible to travel across the entire Europe and fast charge the automobile or change its battery when necessary. Unfortunately, such an infrastructure presently is not available, and the introduction of such a global system is not expected over the nearest future. Therefore, one has to conclude that the exploitation of an electric automobile is useful mainly in towns and cities where the average daily kilometrage does not exceed 120-150 km. In the case if the kilometrage is greater, it is advised to use an internal combustion engine automobile.

Over the nearest future, no mass transition to electric automobiles may take place in Latvia owing to several factors:

- users of vehicles are not ready to limit themselves to small kilometrage or impose self-control by choosing the right mode of vehicle driving in order to achieve greater kilometrage;

- relatively little information is available on electric vehicles, no reliable information on the lifespan of electric vehicle batteries as well as their exploitation specifics;
- users of vehicles are not morally prepared for exploiting electric vehicles without a network of charging stations. Efficient charging of electric vehicles, if no charging infrastructure exists, is not possible only at private homes. Separate charging stations have to be established for electric automobiles at public overnight parking lots, which requires additional electric capacity, and the owners of the parking lots might not be ready for it;
- supply of electric vehicles is still limited in Latvia, especially in the case if the supply of some brand is associated with additional requirements, for instance, battery rent;
- prices of electric vehicles, compared with analogical internal combustion engine vehicles, are very high, which deters potential buyers. The potential buyers are doubtful about how economical an electric vehicle is, as a primary investment in an internal combustion engine vehicle is smaller, whereas the exploitation opportunities of such a vehicle are greater.

Based on the previous analysis, one can conclude that, at best, we can hope that the share of electric vehicles might reach 10 %, assuming that it will take place by 2020.

The main gains if introducing electric transport:

- if electricity is produced in Latvia, for instance, at hydro power plants, domestic energy sources are exploited to power electric vehicles, besides, these sources are renewable;
- even in the case if electricity is produced from non-renewable sources, for instance, coal, electric vehicles ensure that pollution is localised at the site of electricity generation (at a thermal power plant);
- electric vehicles produce no gas emissions;
- structure and maintenance of electric drive vehicles are simpler, the motor has fewer wear parts;
- electric vehicles are not noisy, electric vehicles may be exploited in zones where noise is not recommended;
- electric vehicles need no fuel that causes a bad smell as well as the amount of such materials as oil is less consumed compared with internal combustion engine vehicles;
- net efficiency of the motor of electric vehicles is higher, power and torque curves are more effective and appropriate for vehicle driving;
- owing to the limited kilometrage, the driver of an electric vehicle sometimes has to choose a steadier mode of driving, thus saving resources.

When calculating the ecological effect, it has to be taken into consideration that two types of engines – Otto engines and diesel engines – are mainly used in the analysed vehicle groups. There are different emission standards for each of these vehicle groups, and it has to be taken into account in calculations. The general algorithm for calculating the emission amounts for the entire car fleet of Latvia has already been analysed in other research papers published by the authors of the present paper [3].

To identify the vehicle group, the introduction of electric drive in which is the most beneficial, calculations are performed for each vehicle group according to Table 1. The calculations are focused on the forecast for 2020. Owing to the fact that automobiles with an average age of 10-12 years had been exploited in Latvia over the recent 10 years, it is assumed that a similar trend will continue in the period of analysis. For this reason, the emission standard being effective for the period 2008-2010 is used for comparisons of internal combustion engine automobiles. The emission standard Euro 5 was in force in this period. Yet, the factor of depreciation for automobiles the kilometrage of which exceeds 80000 km has to be taken into account. The values of the emission standard Euro 5 and the factor of depreciation [4-6] are summarised in Table 2.

Annual amounts of emission components for internal combustion engine vehicles are calculated by the following formula:

$$\sum I_G = \frac{A_v l_g M_{km}}{10^6}, \text{ t} \cdot \text{year}^{-1}, \quad (1)$$

where A_v – number of internal combustion engine automobiles in the corresponding vehicle group;
l_g – annual kilometrage of automobiles in the corresponding vehicle group, km;
M_{km} – amount of the n-th component of automobile exhaust gases in accordance with the standard Euro 5, g·km^{-1}.

Table 2

Emission standards (g·km^{-1}) and their corrections used for calculations

No	Vehicle characteristics		Components of exhaust gases					
	Type of vehicle	Fuel	CO	CH+NO$_x$	Weight of all hydrocarbons THC	Weight of hydro-carbons, except methane, NMHC	NO$_x$	Solid particles PM
1.	Lorries with a gross weight of 3.5-12 t	D	1.5	-	0.46	-	2.0	0.02
2.	Lorries with a gross weight of 3.5 t or less	D	0.74	0.35	-	-	0.28	0.005
3.	Cars	P	1.0	-	0.10	0.068	0.060	0.005*
		D	0.50	0.230	-	-	0.18	0.005
4.	Motorbikes and tricycles	P	0.114	-	0.017	-	0.009	-
5.	Mopeds	P	0.1	-	0.063	-	0.017	-
6.	Quadrocycles	P	0.19	-	0.073	-	0.017	-
7.	Depreciation rate	P	1.3	-	1.3	1.3	1.3	-
		D	1.3	-	1.1	1.1	1.1	1.0

* Direct injection engines

According to the formula (1), the amount of emissions may be calculated only for vehicles, the test of which can be performed on a roller power test bench in accordance with the standard Euro 5 [4]. Tests of lorries with a gross weight of 3.5 t or more are performed on a stationary engine test bench, and, in accordance with the standard, the unit of measure is g·(kWh)$^{-1}$. The amount of a component of gas emissions for these vehicles may be calculated by the following formula:

$$\sum I_G' = \frac{A_k l_g M_{kWh-km}}{10^6}, \text{ t·year}^{-1}, \quad (2)$$

where A_k – number of internal combustion engine automobiles in the corresponding vehicle group;
l_g – annual kilometrage of automobiles in the corresponding vehicle group, km;
M_{kWh-km} – amount of the n-th component of automobile exhaust gases in accordance with the standard Euro 5 for automobiles tested on an engine test bench, converted into g·km^{-1}.

To calculate the amount of exhaust gases emitted per 1 km for automobiles to which the emission standard, g·(kWh)$^{-1}$, is applied, the following formula is used:

$$M_{kWh-km} = \frac{N_{e.avg} t_k}{s} m_{kWh}, \text{ g·km}^{-1}, \quad (3)$$

where $N_{e.avg}$ – average vehicle engine power in the calculated road section, kW;
t_k – vehicle movement period in the measured road section, h;
s – length of the road section, km;
m_{kWh} – amount of the n-th component of automobile exhaust gases in accordance with the standard Euro 5, g·(kWh)$^{-1}$.

By inserting Formula 3 in Formula 2 and given the fact that velocity may be expressed by the formula $v = s \cdot t^{-1}$, the following formula is obtained:

$$\sum I_G' = \frac{A_k l_g N_{e.vid} m_{kWh}}{10^6 v}, \text{ t}\cdot\text{year}^{-1}, \quad (4)$$

Results and discussion

The calculations are focused only on the toxic components of exhaust gases. The analysis of CO_2 emissions, which directly relate to fuel consumption, requires a separate and profound examination.

Formulas 1 and 4 are used for the calculations. The calculations are based on the emission standards and depreciation rates from Table 2, and it is assumed that that electric vehicles will account for 10 % of the total number of vehicles in Latvia, their average annual kilometrage is assumed according to Table 1, the average capacity of lorries with a gross weight of 3.5 t or more while moving is 70 kW, and the average speed is 50 km·h^{-1}. The calculation results on emissions are summarised in Table 3.

Table 3

Calculation results for the toxic components of exhaust gases for 10 % of Latvian automobile fleet

No	Type of vehicle	CO	CH+NO_x	THC	NMHC	NO_x	PM
1.	Lorries with a gross weight of 3.5-12 t	109.16	-	28.32	-	123.15	1.12
2.	Lorries with a gross weight of 3.5 t or less	162.93	59.28	-	-	52.16	0.85
3.	Cars, petrol	972.00	-	97.20	66.10	58.32	3.74
4.	Cars, diesel	317.73	112.43	-	-	96.79	2.44
5.	Busses with a gross weight of 3.5 t or less	2.08	0.99	-	-	0.79	0.01
6.	Motorbikes and tricycles	1.02	-	0.15	-	0.08	-
7.	Mopeds	0.46	-	0.29	-	0.08	-
8.	Quadrocycles	0.04	-	0.02	-	0.004	-

Data on the exhaust gas components CO and NO_x are summarised in Fig.1. These components are set as standards for all the analysed vehicles.

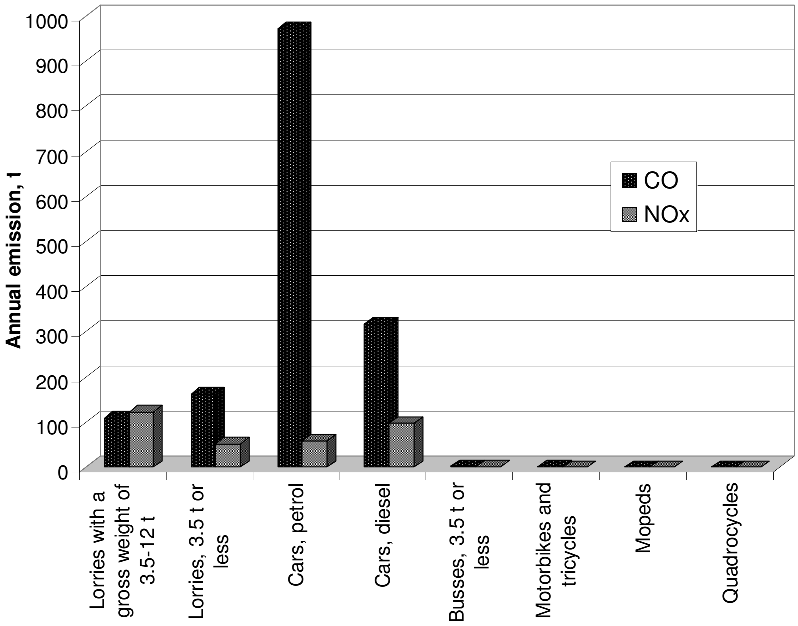

Fig. 1. **Annual CO and NO_x emissions from 10 % of the vehicle fleet of Latvia**

As Fig.1 shows, the greatest part of CO pollution in Latvia arises from cars. The annual CO emissions produced by cars with a petrol or diesel engine amount to 1289.73 t, which is almost two times more than from lorries. Due to the wide use of diesel engine lorries in the automobile sector, the total annual NO_x emissions from these automobiles are 14.3 % greater than those from cars. The total emissions produced by such vehicle categories as busses, motorbikes, mopeds, and quadrocycles in Latvia are minimal due to the small number of such vehicles.

The emission standards for other exhaust gas components (CH, NO_x and PM) are not set mainly for motorbikes, mopeds, and quadrocycles, therefore, they are not presented graphically (Fig.2).

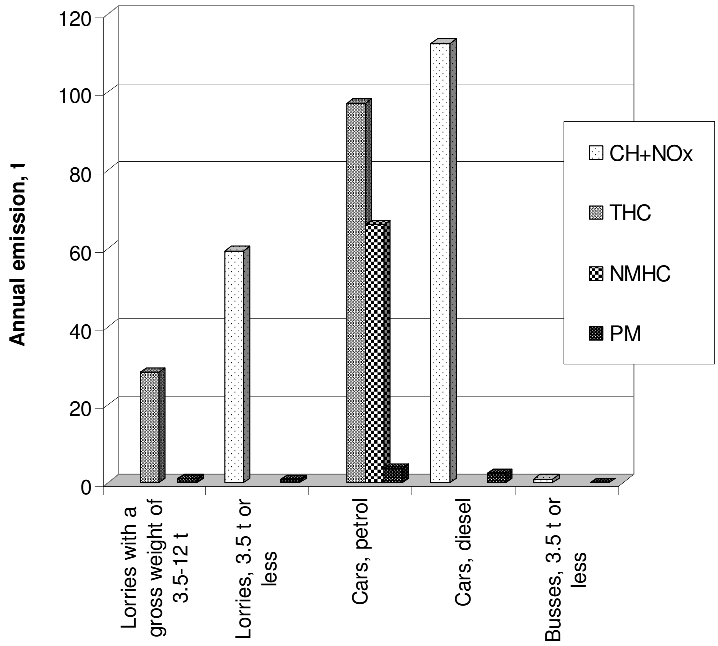

Fig. 2. **Annual CH, NO_x and PM emissions from 10 % of the vehicle fleet of Latvia**

The annual CH emissions from lorries are 3.2 times greater than those from cars. The emissions of solid particles from cars are 3.1 times greater than those from lorries.

According to the calculation results, the largest pollution in the emission balance of Latvia arises from cars. As regards all the components of emissions from cars, they exceed emissions from other vehicles by even several times. Only NO_x emissions from lorries are slightly greater. Based on these calculations, one can conclude that from the viewpoint of environmental protection in Latvia, it is particularly beneficial to use electric drive cars. If 10 % of the conventional cars were replaced with electric drive cars in Latvia, it would be possible to decrease CO emissions by 1289.73 t, CH+NO_x emissions by 112.43 t, total hydrocarbon emissions by 97.20 t, NO_x emissions by 115.11 t, and PM emissions by 6.18 tons a year. It has to be noted that another positive aspect is that a low noise level is specific to electric vehicles, which reduces the overall noise level; it is especially important in cities.

The use of electric drive in motorbikes, mopeds, and quadrocycles is beneficial; yet, their effect on total emissions is insignificant, especially if compared with the emissions produced by lorries and cars.

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Conclusions

1. At the beginning of 2013 in Latvia, the number of registered cars is almost 12 times greater than that of the lorries with a gross weight of less than 12 t.
2. The calculation method of automobile exhaust gas components was approbated and recognised as useful both for assessing the effect of certain vehicle groups and for comparative analyses of toxic emissions from various vehicles depending on their kilometrage.

3. The total CO emissions from cars – 1289.73 t per year – are 4.74 times greater than those from lorries.
4. Regardless of the wide use of diesel engine lorries and their large engine capacities, NO_x emissions from these automobiles are only 13 % greater than those from cars.
5. If 10 % of conventional cars were replaced with electric drive cars in Latvia, the following ecological effects in relation to emission reductions would be achieved: 1289.73 t of CO, 112.43 t of $CH+NO_x$, 97.20 t of C_nH_m, 155.11 t of NO_x, and 6.18 t of PM a year.
6. The use of electric drive in motorbikes, mopeds, and quadrocycles can reduce noise in cities, yet, their ecological effects are small in Latvia due to the small number and the small annual kilometrage of such vehicles.
7. The calculation algorithm approbated in the present research may be employed for calculations of CO_2 emissions and other exhaust gas components.

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