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INDIRECT ENVIRONMENT-RELATED EFFECTS OF ELECTRIC CAR VEHICLES USE

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Abstract

The article presents a study on indirect environment-related effects of electric car vehicles use. Although electric vehicles are considered zero emission vehicles, their use may be linked to indirect pollution of environment caused by energy sources used for electricity production and also other sources of pollution such as poor recycling procedures. A computer simulation was performed to determine the energy consumption of electric vehicles available on the Romanian car market. The values obtained were correlated with emissions of CO_2, NO_x and SO_x pollutants. Furthermore, a supplementary analysis was performed to determine the necessary combination and related management of energy sources to minimize the environmental impact of electric vehicles, in order to increase their use for a future sustainable transportation domain. The study shows that SO_x emissions in particular will increase in Romania alone, as a result of the implementation of electric cars, unless alternative and renewable energy sources are implemented in the society. This study reports crucial statistics and information which outline that legislative policies must be in place before a full implementation of electric vehicles is carried out, in order to avoid increase in emissions countries without the direct access to renewable energy resources.

Key words: electric vehicles, energy sources, environment, management, pollutant emissions, modeling

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1. Introduction

According to recent scientific articles and studies, the road transport sector is responsible for 23.1% of the total emissions in the atmosphere in the European region (OECD/ITF, 2010). As an immediate response for reducing the amount of GHG (Green House Gases) emissions, the use of renewable energy resources in internal combustion engines fueled using blends of biofuels and fossil fuels was intensified (Mariasiu, 2013). Ng et al., (2010) and Moldovanu and Burnete (2013) showed that although it resulted a significant reduction in vehicle's related pollutant emissions using renewable sources, it is still necessary to continue research and development activities in the field of road vehicles to increase the efficiency of these results. At present, the use of hybrid (internal combustion engine + electric motor) and electric vehicles (EV) technologies in vehicle's powertrain appears to be a feasible solution for passenger cars. For example, the CO_2 emission of the Toyota Prius hybrid vehicle is 20% lower than emission of a similar car that using only an internal combustion engine powered with fossil fuels (Fuhs, 2009; Thompson et al., 2011). The continuous development of technology employed in electric vehicles is a promising and viable solution to the emission problems and a potential approach for significant reduction of GHG emissions (Holdway et al., 2010; Huo et al., 2010; Huang and Ren, 2013).

Even so, Grunig et al. (2011) reported that the market penetration of electric vehicles will remain low compared to conventional vehicles in the near future (the main market is represented only by passenger

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cars). Mariasiu (2012) and Liu et al. (2008) consider that the main technologically barriers for increasing the car market share for EVs are considered to be the following factors:

- the average EV purchase price is 100% greater than for a new IC engine car;
- there are serious limitations regarding the EVs autonomy and charging time (average value for autonomy is considered to be 130 km and mostly EVs need 6 hours for a complete charging cycle);
- the low capacity of electric battery;
- the usable energy depending directly on many factors (type of battery, type of powertrain, driving style, traffic conditions, ambient temperature and charging technology);
- proper recycling schemes for car batteries throughout the cradle-to-grave life cycle.

Given the above-presented barriers, at present, the EU countries and authorities are taking numerous political, economic and social measures, to promote and increase the penetration of electric vehicles in transportation domain. To achieve a target of 4,752,100 EVs for the end of 2015 at European level measures as: free parking, right to use bus-lanes, free entry to city-centers, financial subsidies and incentives, exempts from registration tax, VAT, annual car tax and congestion charges are some of adopted measures (Reiner et al., 2010; Nemry and Brous, 2010).

It is also interesting to highlight that measures aimed at increase number of EVs include many subsidy programs in EU, most of which refer to taxation of CO_2 emission level ("CO_2-based car taxes"). It can be easily to see that the indirect CO_2 emissions from energy production are not perceived to be a major barrier to EVs use and are not taken into consideration (Brinkman et al., 2010; Jansen et al., 2010). Unfortunately, on closer analysis, it is evident that EVs must be powered with electricity (to charge battery), which is not obtained only from environmentally friendly sources (or at least from renewable sources) (Varga, 2013). Europe-wide primary sources for obtaining electricity rely heavily on coal, oil, gas and nuclear energy. In Fig. 1 is shown the structure of primary energy sources for electrically energy production comparatively for Europe and Romania. The coal remains an important primary source of electrical energy production with direct implications on the level and structure of pollutant emissions in atmosphere, both for EU 28 and Romania. In Romania, the use of coal for energy production is with 14.3% higher than the EU average, indicating that Romania must adopt energy policies that lead to achieving at least EUs average value. As major issue of energetic strategy, the Romanian government makes efforts to complete units 3 and 4 of Cernavoda nuclear power plant, together with the massive development of renewable energy production units. The reducing CO_2 (and also GHG) emission policy is also highlighted by government policies to support the increase of EVs market. Thus, for each EV purchased, government offers a subsidy from purchase price for a new EV acquisition.

Currently, in Romania, there are only four EV manufacturers that offer to customers a total of six models (Table 1). There are important differences in EVs models, between values pertaining to the autonomy for a full battery charge cycle. For these EVs, models available on Romania's car market, a computer simulation process was used to identify the EVs with minimum and maximum electric energy consumption during a standard NEDC test. Further, the electric energy consumption was converted to pollutant emissions, considering the particular structure of primary energy sources (POST, 2006). The scenario-based analyses were conducted in order to establish whether the indirect pollutant emissions (CO_2, NO_x and SO_x) could achieve the limits imposed by contemporary pollution norm (Euro 6), and evaluation in terms of their environmental impact.

Besides major influence on air pollution of CO_2 emissions (by increasing the greenhouse effect), and other pollutant emissions from road transport have direct influence on the environment, and their magnitude when using electric vehicles is a novelty presented in this paper. SO_x emissions were considered to be dangerous due to their contribution to the direct creation of smog and acid rain.

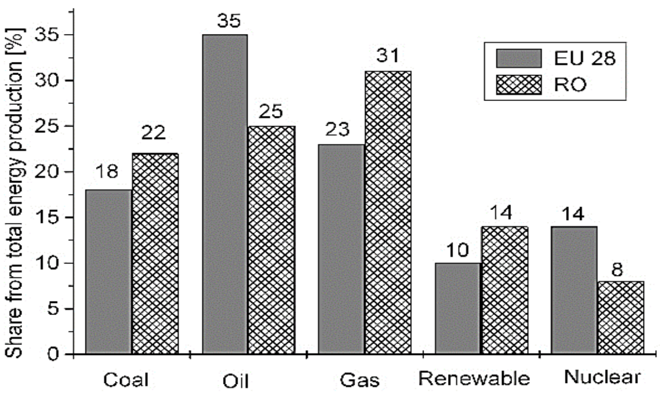

Fig. 1. Structure of primary sources for electricity production (Eurostat, 2013)

Those negative effects on environment and human health have been drastically eliminated by international norms that involving the use of fuels with low sulfur content. To present date (pending the introduction of Euro 6 pollution norm), NO_x emissions were not a major concern in terms of limiting by law to certain emission limit values.

The advent of well-documented studies regarding the effects of direct and indirect NO_x emissions on the environment and human health, were determined their influence. From an environmental perspective, the negative effects associated with NO_x emissions are soil nitrification with immediate detrimental effects on plant growth and soil microorganisms' life. Also, the toxic effect of NO_x emissions on human health manifests (especially in big cities) with respiratory and cardiovascular problems (Gustavsson et al., 2000; Weiss et al., 2012). For these reasons the present work shows a broad approach on to the quantity and composition of pollutant emissions emitted indirectly, in case of use of an electric vehicle.

2. Material and methods

Analysis and computer simulation are research tools widely used in many scientific fields. An immediate advantage of using computer simulation is the opportunity to obtain, at a relatively low cost, a multitude of experimental data and possible cases of studied phenomena. In the present work, to obtain the EVs CO_2 emission level for the standardized cycle (NEDC - testing procedure recommended by the European Union) conditions, CRUISE simulation environment were used. CRUISE software package was developed and implemented successfully in the automotive industry by AVL List GmbH (2006) (Varga, 2012).

Major benefit of CRUISE simulation software is its modularity and interactive process of simulation and design of model for a various type of vehicles. For brevity, specific details of using CRUISE, how to build a vehicle model and how each function is used are given in AVL User Manual (2009) and Varga (2012). Primary data used as input for the simulation model, are technical data of considered electric vehicles presented in Table 1. The method used to calculate the amount of the each considered pollutant emission is presented below, in the case of CO_2 (but applicable also for NO_x and SO_x emissions). After obtaining data related to energy consumption for an electric vehicle, the transformation into the amount of pollutant emitted into the atmosphere has been achieved, taking into account the characteristics of Romania's primary energy sources mix used for electricity production in power stations. In case of CO_2 pollutant, the following relation was used (Mariasiu, 2012) (Eq. 1):

$$EV_{CO2(g/km)} = L_{NEDC} \cdot EV_{CO2/NEDC} \cdot CO_{2energy\_source} \cdot P_{losses} \tag{1}$$

were $EV_{CO2/km}$ is the amount of CO_2 emitted by energy consumption per km, L_{NEDC} is the length of NEDC cycle (11.008 km), $EV_{CO2/NEDC}$ is the amount of CO_2 emitted by energy consumption during a NEDC cycle, $CO_{2energy\_source}$ is the amount of CO_2 emission function of energy source and the P_{losses} = 1.15-1.22 are the losses caused by electric distribution grid and internal EVs electrical circuits (Tesla Motors, 2010).

3. Results and discussion

The input data required to perform computer simulation are presented in previous sections. To obtain accurate results, the technical and operational particularities of each model of EV were taken into account (total weight of the vehicle, wheel diameter, transmission type, aerodynamic coefficient, battery type, energy efficiency and losses).

Further, the pollutant emission levels obtained for EVs operation, considered in the study, was correlated with energy sources pollutant emissions used to produce the electricity. The results analysis indicates that the lowest energy consumption is obtained for EV2 (Chevrolet Volt) and the highest for EV3 (Renault Zoe). Fig. 2 depicts battery energy consumption for Chevrolet Volt during the NEDC cycle and related cumulative results for considered EVs and obtained from computer simulation are presented in the Table 2. The amount of pollutant emissions corresponding to each source of energy for electricity production and distribution of these sources for EU28 and Romania are presented in the Table 3.

Table 1. Technical data of EVs models available on Romanian car market (Fuhs, 2009; Brooke, 2011)

EV	*Electric vehicle*	*Vehicle mass (kg)*	*Battery mass (kg)*	*Urban range (km)*	*Battery capacity (kWh)*	*Charging time (hrs:min)*	*Purchase cost (Euro)*
1	Mitshubishi iMiEV	1,080	200	160	16	07:00	37,767
2	Chevrolet Volt	1,588	170	64	16	08:00	29,347
3	Renault Zoe ZE	1,100	200	210	22	06:00	20,700
4	Renault Kangoo ZE	1,520	250	160	24	06:00	21,340
5	Renault Fluence ZE	1,600	250	160	24	06:00	26,300
6	Toyota Prius Plug-in	1,380	155	23	5.2	01:40	34,750

The EVs emission of CO_2 varies between a minimum for EV2 (98.42 gCO_2/km) and maximum for EV3 (100.84 gCO_2/km). Compared with a compact car that is powered by fossil fuels (with average of 130 gCO_2/km emission), these values are 24.3% and 22.4% lower, respectively. However, EU directives stipulate that by 2020, the value of CO_2 emissions in transport must not exceed 95 g/km (Eurostat, 2011), and values presented above are 3.47 – 6.14% higher.

In Romania, if some scenarios (Tables 6 to 8) are applied, we can analyze the environmental effects of electric vehicles use (currently available in the Romania's car market.) Different amount of coal, oil and natural gas as energy sources were replace by nuclear and renewable energy. The scenario-based analyses considers that: nuclear unit no.3 is functional in Scenario A, scenario B considers that nuclear units no.3 and 4 are functional and scenario C considers that nuclear units no.3 and 4 are functional and 14% to 20% more electrical generation from wind and solar sources (renewable sources).

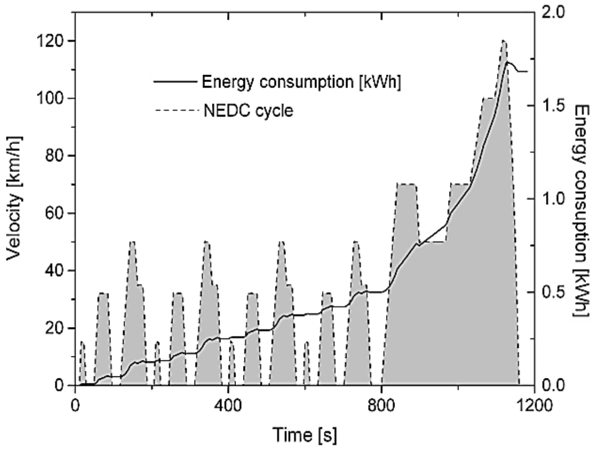

Fig. 2. Energy consumption during the NEDC cycle

The pollutant emissions data related to the use of considered EVs are presented in the Tables 3 to 5 (values were calculated using Eq. 1).

Table 2. EVs energy consumption vs. CO_2 emissions (for NEDC test)

Parameters	***Electric Vehicle (EV)***					
	1	***2***	***3***	***4***	***5***	***6***
Energy consumption (kWh)	1.711	1.672	1.713	1.678	1.689	1.688
CO_2 emission (g/km)	100.72	98.42	100.84	98.78	99.43	99.37

Table 3. CO_2 emissions depending on the nature and distribution of energy sources

Electrical Generation Sources	***Grams of CO_2 emissivity (g/kWh)***	***EU 28***		***Romania***	
		Share of energy sources	***CO_2 emission (g/kWh)***	***Share of energy sources***	***CO_2 emission (g/kWh)***
Coal	1000	18%	180	22%	220
Oil	650	35%	227.5	25%	162.5
Natural Gas	500	23%	115	31%	155
Renewable	15	10%	1.5	14%	2.1
Nuclear	5	14%	0.7	8%	0.4
Total	-	100%	524.7	100%	540

Table 4. NO_X emissions depending on the nature and distribution of energy sources

Electrical Generation Sources	***Grams of NO_X emissivity (g/kWh)***	***EU 28***		***Romania***	
		Share of energy sources	***NO_X emission (g/kWh)***	***Share of energy sources***	***NO_X emission (g/kWh)***
Coal	6	18%	1.08	22%	1.32
Oil	4	35%	1.4	25%	1
Natural Gas	1.7	23%	0.391	31%	0.527
Renewable	0.006	10%	0.006	14%	0.008
Nuclear	0	14%	0.00	8%	0.00
Total	-	100%	2.877	100%	2.855

Table 5. SO_X emissions depending on the nature and distribution of energy sources

Electrical Generation Sources	***Grams of SO_X emissivity (g/kWh)***	***EU 28***		***Romania***	
		Share of energy sources	***SO_X emission (g/kWh)***	***Share of energy sources***	***SO_X emission (g/kWh)***
Coal	13	18%	2.34	22%	2.86
Oil	12	35%	4.2	25%	3
Natural Gas	0.1	23%	0.023	31%	0.031
Renewable	1.22	10%	0.122	14%	0.17
Nuclear	0	14%	0.00	8%	0.00
Total	-	100%	6.685	100%	6.061

Considering Romania's future policy and strategy in energy production and following the above considerations and presented algorithm for calculations, the results and related discussions are presented below. CO_2 emission decreases 5.5% in scenario A, 12.9% in scenario B and 19.1% in scenario C, compared to the present situation. The target of below 95 g/km of CO_2 emissions (future Euro 6 pollution standard) is achieved in all cases of proposed scenarios (Fig. 3).

Comparative analysis of NO_x emissions (compounded emissions of N_2O and NO_2) depending on the energy source used for electricity generation and selected scenarios are presented in the Table 7. It is worth mentioning that with the introduction of Euro 6 emission norms for road vehicles (EC, 2007), NO_x emissions are taken into account in evaluating the performance of a car (pollutant emissions). The maximum accepted by Euro 6 norm is considered to be 0.06 g/km for passenger cars. By using electric vehicles considered in the study, a maximum level of emissions of SO_x (1.1 g/km) results, considering the current structure of energy sources used to produce electricity.

If we consider the most favorable case of EV2 type use, the CO_2 emissions (from energetic source mix) are shown in the Fig. 3, in line with considered scenarios (reducing the share of energy from coal and increase in same time the energy share from renewable sources and nuclear).

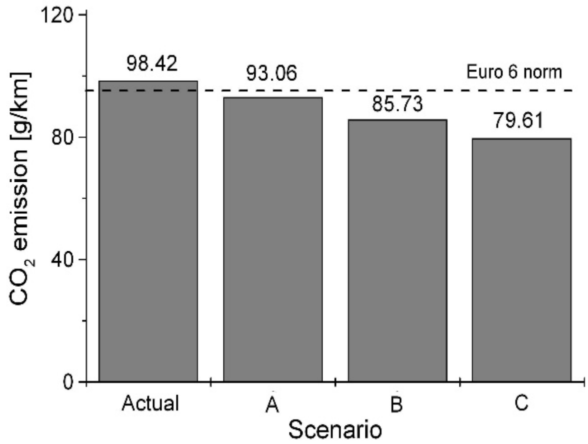

Fig. 3. EV2's CO_2 emission function of scenarios

Table 6. Scenarios on the share of primary energy resources - CO_2 case

Electrical Generation Sources	*Scenario A*		*Scenario B*		*Scenario C*	
	Share of energy sources (%)	*CO_2 emission (g/kWh)*	*Share of energy sources (%)*	*CO_2 emission (g/kWh)*	*Share of energy sources (%)*	*CO_2 emission (g/kWh)*
Coal	19	190	15	150	15	150
Oil	25	162.5	25	162.5	22	143
Natural Gas	31	155	31	155	28	140
Renewable	14	2.1	14	2.1	20	3
Nuclear	11	0.55	15	0.75	15	0.75
Total	100	510.55	100	470.35	100	436.75

Table 7. Scenarios on the share of primary energy resources - NO_X case

Electrical Generation Sources	*Scenario A*		*Scenario B*		*Scenario C*	
	Share of energy sources (%)	*NO_X emission (g/kWh)*	*Share of energy sources (%)*	*NO_X emission (g/kWh)*	*Share of energy sources (%)*	*NO_X emission (g/kWh)*
Coal	19	1.14	15	0.9	15	0.9
Oil	25	1	25	1	22	0.88
Natural Gas	31	0.527	31	0.527	28	0.476
Renewable	14	0.008	14	0.008	20	0.012
Nuclear	11	0.00	15	0.00	15	0.00
Total	100	2.675	100	2.435	100	2.268

Table 8. Scenarios on the share of primary energy resources - SO_X case

Electrical Generation Sources	*Scenario A*		*Scenario B*		*Scenario C*	
	Share of energy sources (%)	*SO_X emission (g/kWh)*	*Share of energy sources (%)*	*SO_X emission (g/kWh)*	*Share of energy sources (%)*	*SO_X emission (g/kWh)*
Coal	19	2.47	15	1.95	15	1.95
Oil	25	3	25	3	22	2.64
Natural Gas	31	0.031	31	0.031	28	0.028
Renewable	14	0.17	14	0.17	20	0.244
Nuclear	11	0.00	15	0.00	15	0.00
Total	100	5.671	100	5.151	100	4.862

Note that using electric vehicles, the accepted level is exceeded more than 8 times (Fig. 4), with values between 0.49 g/km (scenario A) and 0.41 g/km (scenario C).

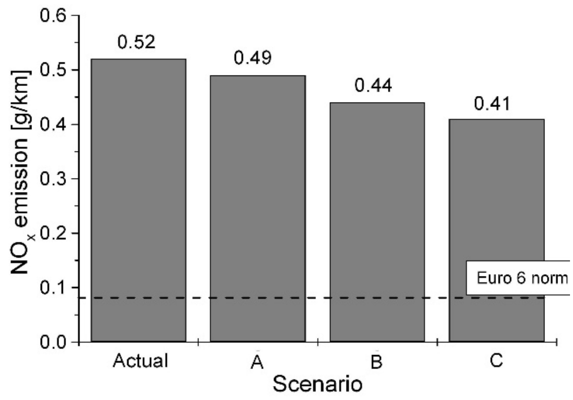

Fig. 4. EV2's NO_x emission function of scenarios

SO_x emissions are directly responsible for the existence of acid rain, rain that present an immediate danger potential on the environment and human health. SO_x emissions are high due to the high proportion of use of coal in electricity production, both for Romania (22% of total energy production), as well as in the case of Europe (18% of total energy production).

In case of programs and / or policies to improve the structure of energy sources through intensive use of renewable and/or non-fossil (Table 8, scenario C), emissions of SO_x emissions may reach a minimum estimated value of 0.89 g/km, but still remain a great value considering that actually the emission of a passenger car is limited to 0.02 g/km (Fig. 5).

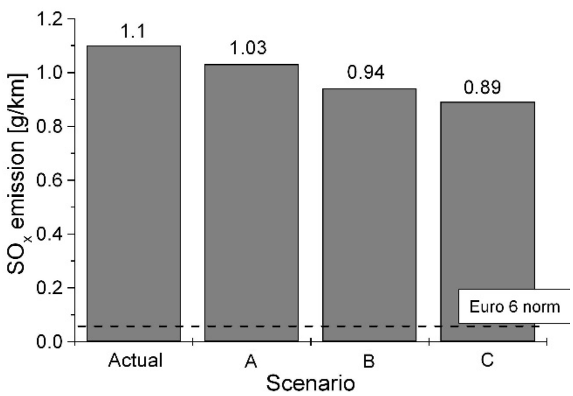

Fig. 5. EV2's SO_x emission function of scenarios

The proposed scenarios offer the possibilities to reduce (but not to eliminate) the negative effects on environment of acid rain.

4. Conclusions

This study evaluates the importance of indirect emissions as environmental barrier for EVs rapid and consistent car market penetration. EVs are considered zero-emission vehicles; however, electricity (used to recharge the EV's battery) produced in power plants is still predominantly based on the fossil fuel usage and thus directly affects the quantity (amount) of pollutant and greenhouse gases emissions.

Given the structure of energy sources mix (in particularly, for Romania' case) used for electricity generation, the major pollutant emissions originating from the combination of these energy sources (related to energy consumption of available EVs on Romanian market) was determined.

In terms of compliance with future European standards of pollution emissions (95 gCO_2/km – 2020), the calculated CO_2 indirect emissions of EVs use, failed to achieve the imposed limits, considering the actual mix of Romania's energy sources for electricity production (scenarios A and B). If a part of coal share (only 4%) will be replaced with renewable and non-fossil (nuclear) sources, the EVs use indirect CO_2 emission is with 2% lower than the future EURO 6 pollution standards. Worryingly are the high values of indirect NO_x and SO_x emissions that occur when using electric vehicles, which can lead to increasing the frequency of occurrence of acid rain, with immediate adverse effects on the environment and human health.

As a major conclusion, it can be said that, before introducing EVs on car market, economic policies and management of energy sources mix used for electricity production must take into account the indirect environmental effects that may occur as a consequence of this initiative. Prior to make major investments in recharging infrastructure of EVs batteries and related policies to encourage the EVs market penetration, it is necessary to invest in modernization of actual power plants (increasing production efficiency and reducing pollutant emissions) and the structure of energy sources used (renewable and/or non-fossil sources).

However, even if electric vehicles use poses certain problems of indirect pollutants emissions high levels, there is the possibility of better management regarding technologies applied to reduce pollution. Reduction may be made directly to the source (power plants) as a whole, with much better results than implementing clean technologies (catalytic converter) for each vehicle that uses an internal combustion engine. It can thus achieve an economic cost optimization in the reduction process of pollutant emissions; differences can be used and/or directed to other programs to increase environmental quality.

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