ICESF
Nottingham | UK | 9–11 September 2019

Investigating the Effect of Expanding The Use of Electric Cars On The Environment - A Case Study From Scotland

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Abstract

This paper investigates that expansion of the use of electric cars on the environment; a situation in which all of the lightweight vehicles that use an internal combustion engine are replaced by electric cars in Scotland. The idea is to estimate whether it would have a positive impact on the environment. The methodology is based on analysing the most common electric and conventional vehicles helped to estimate the amount of additional electricity that would be needed to charge that expansion. The paper has also looked at the running costs. The results show that approximately 4,066 GWh per year of additional electricity will be needed to compensate for such expansion. With that rise in electricity production, the amount of carbon emissions from the electrical grid will increase slightly by 0.47 megatons CO_2 per year. Given that the carbon dioxide generated by the light internal combustion vehicles at the moment is 3.6 megatons of CO_2 per year, it is concluded that the total amount of greenhouse gases will decrease if all electric cars in Scotland are replaced by electric cars. The initial cost of an electric car is found to be higher than the conventional one, but in the long term, recharging an electric vehicle will be much cheaper.

Keywords: Electric, cars, greenhouse, emissions, carbon, vehicles

1. Introduction

The first internal combustion engine (ICE) powered by gasoline was invented in 1870 [1].

But due to its complexity, the cars were expensive to build. Surprisingly, the electric cars were more common at the end of the 19th century and it has been observed in 1899 that 90% of New York City's taxi cabs were electric vehicles [2]. However, Henry Ford has selected the internal combustion engine to be the technology used for his mass production lines which make the internal combustion engine cars affordable to the average person. The rest is history and this what made internal combustion engine the most common technology for the 20th century and beyond.

The internal combustion engine was improved greatly over the years, nevertheless even with the best improvement, internal combustion engines still produce a significant amount of carbon emission and pollution. The world population has increased approximately 7 times since 1870 [3]. With the increasing population and the increasing number of vehicles, the traffic carbon emissions increase as well. Internal Combustion Engine Vehicles (ICEV) discharge gases through their exhaust pipes as a result of the burnt fuel in the engine, directly polluting the environment. Those gases consist mainly of Carbon Dioxide (CO_2), Nitrous Oxides (NO_x) and Particulates. CO_2 and water are emitted from the burning process, Nitrogen (N) and Oxygen (O) also react during the fuel burning process forming NO_x and causing pollution. The increase in concentration in pollutants and carbon dioxide causes global warming and also causing health issues such as asthma. Different brands and models of ICE cars produce different amount of emissions. Approximately 20% of the greenhouse gases are emitted by conventional cars. A big portion of these gases is CO_2, the rest is NO_x. [4]. On the other hand, electric vehicles do not pollute the atmosphere directly, but they do contribute in greenhouse accumulation through their consumption for electricity, which is generated in power plants, who in the process produce greenhouse gases [5]. Different sources and methods for energy generation produce different amounts of greenhouse emission. The carbon factor for each source of electricity is different.

Table 1: Carbon factor of each source of electricity generation [6]

Source	Carbon Factor (gCO2eq/kWh)
Coal CCS	220
Gas CCS	170
Solar	88
Geothermal	34
Nuclear	26
Wave/Tidal	23
Wind	20
Hydro	7
Bioenergy	300

Table 2: Annual average electricity generation in Scotland and the percentage distribution of sources [7]

Source	Average Production GWh	Percentage Distribution
Nuclear	16,820	33.6 %
Coal	12,410	24.8 %
Gas	9,464	19 %
Hydro	5,290	10.5 %
Renewable	6,070	12.1 %
TOTAL	**50,054**	**100 %**

The annual electricity consumption in Scotland is roughly 38,000 GWh per year. It also has to be mentioned that the country is producing approximately 50,000 GWh of electricity a year, of which 14,000 are exported to Northern Ireland and England. The losses of electricity along the grid are estimated to be approximately 17% [8]. The price of electricity in the UK is estimated to be approximately 12 pence [9]. The source distribution of electricity production plays a vital role. If a country is generating electricity mostly from renewable sources or nuclear power, the emissions from the electricity production sector will not be high. The average annual mileage of a car in Scotland in 2015 was approximately 11,362 km and the number of light vehicles in the country for that year was about 2,240,000 [10].

It is important to take into consideration the fact that different brands of electric cars have different battery capacity and electric consumption for a unit of distance.

Table 3: Top 5 electric vehicles in the UK in 2015 and their specifications [11]

Brand	Battery capacity (kWh)	Consumption (kWh/100km)	Registered cars in 2015	Price (£)	Distribution (%)
Nissan Leaf	24	14	11,000	29,000	49
BMW i3	22	13	3,574	38,000	16
Renault Zoe	22	11	3,327	21,000	15
Volkswagen e-UP	18.7	14	2,500	19,000	11
Tesla Model S	85	16.9	2000	75,000	9

It is necessary to mention that the most popular conventional cars for 2015, their carbon factor and their price on the market. The price of fuel in the UK is approximately £1.3 [12].

Table 4: Top 5 conventional cars sold in the UK for 2015, their CO_2 factor, price, Distribution and average fuel consumption [13]

Vehicle model	**CO_2 (g/km)**	**Price (£)**	**Distribution (%)**	**Registered car**	**Consumption (L/100 km)**
Ford Fiesta	147	15,400	30	133,434	4
Vauxhall Corsa	129	10,800	21	92,077	4.7
Ford Focus	159	18,000	19	83,816	3.7
Volkswagen Golf	112	20,600	16	73,409	3.9
Nissan Qashqai	162	19,800	14	60,814	4

2. Methodology

Knowing the required parameters, calculations are made for determining how much the electricity demand would rise if conventional cars to be replaced by electric ones and how that would affect the carbon emission. A comparison between the vehicles' price and cost of maintenance in the long term has also been made. In order to acquire a proper value for the average tank/battery capacity, price and emissions it is important to take into consideration the percentage distribution of different brands since they have different specifications. The formula which represents the average consumption of fuel or electricity from cars can be expressed as

$$\sum_{i=1}^{n}(C_i \times PD_i) \qquad \text{(Eq. 1)},$$

where $\boldsymbol{C}$ represents the Energy or fuel consumption, $\boldsymbol{PD}$ is the percentage distribution (value%) and $\boldsymbol{n}$ represents the number of vehicles that were part of this investigation. This equation is also used to determine the average price for both EV and ICEV and carbon emission for conventional cars.

The average annual distance traveled by cars in Scotland in 2015 was determined and after using Eq1, the average fuel and electricity required by EVs and ICEVs to travel a given distance can be calculated by using the following equation:

$$RFE = (DT \div 100) \times AFEC \qquad \text{(Eq. 2)}.$$

RFE is the Required fuel/electricity for the cars to travel the annual distance, *DT* is the Distance traveled divided by 100, and *AFEC* is the Average fuel/electricity consumption.

Eq 2 is used for both conventional and electric cars. Both values are then multiplied by the number of light vehicles in Scotland to determine the total fuel and electricity required for every car in the country. After that, both values are used to compare the annual price for the fuel and electricity needed for that distance. Determining the additional electricity needed for one year to charge the electric cars, the contribution to the production of carbon emission is calculated. The calculations have taken into account the losses through the gird and of course the distribution of the sources of electricity production. Eq 1 is used to determine the average carbon factor for ICEV, and that value is multiplied by the annual distance traveled and then by the number of ICEV in Scotland; this is performed in order to calculate how much carbon emission is produced by all cars in Scotland for a period of one year. The CO_2 emission from the possible additional annual electricity generation, including the addition from the EVs' demand and the grid losses, and from the traffic are compared. First, the amount of electricity generated per source according to the percentage allocation of the total amount of produced electricity is calculated; taken into account the carbon factor gCO_2eq/kWh for each source and the dimensions (kWh) in which the electricity consumption is measured. The amount of energy generated by each source is multiplied by its carbon factor to determine the total carbon emissions generated per source per year. This is done for both current and future possible electricity generation, in order to determine the increase in carbon emissions with the additional energy production.

3. Results

The average price of electric and conventional cars and their maintenance price has been calculated by applying Eq. 1. This has revealed that the average price of electric cars in 2015 is about £ 32,239 while for conventional cars is about 16,376. Hence the cost of electric cars on average is double of the conventional car.

In relation to the required fuel and electricity to cover the annual distance traveled, using Equation (2) has revealed that the required electricity for a single EV to cover the annual mileage of 11,362 km is 1551 kW/h. For a conventional car, this would require approximately 463 liters of fuel to cover the same annual distance. When those values are multiplied by the number of light cars in Scotland (2,240,000), it has been revealed that the total electricity required for EVs would be 3,475 GWh per year, and by including an additional 17% of the grid losses that number would increase to a total of 4,066 GWh of electricity demand. As for the conventional cars, the total fuel required per year by all of the light cars in Scotland to cover the annual distance is approximately 1 billion liters of fuel. Therefore, the price of electricity per year that an EV owner has to pay to run his car is expected to be £ 218. In comparison, the amount of money the owner of ICEV has to pay annually for fuel is approximately £ 602.

Knowing that the electricity generation in Scotland is approximately 50,054 GWh per year, the electricity required by the EVs for a year are added to that amount and it is estimated that the additional annual electricity production would be around 4,066 GWh and the total amount of electricity per year will rise to approximately 54,120 GWh.

Using Equation (1) it has been revealed that the average carbon factor of ICEV is 141.8 gCO_2eq/km. A single conventional car will generate approximately 1.6 tons CO_2eq/km. When multiplying this by the number of cars in Scotland, the traffic emissions from all cars for a period of one year will be estimated to be 3.6 Megatons CO_2eq/km.

Regarding the electricity generation, Carbon emissions depend on the energy source for electricity generation. Table 5 presents the energy type mix within the grid electricity generation

Table 5: Results from comparing the carbon emissions from the current electricity generation per source and total, and the possible future emissions.

Source	**Current carbon emissions (Megatons CO_2eq/kWh)**	**Possible future carbon emissions (Megatons CO_2eq/kWh)**
Nuclear	0.44	0.47
Coal	2.7	2.95
Gas	1.6	1.74
Hydro	0.04	0.04
Renewable	0.25	0.27
TOTAL	**5.03**	**5.47**

As a result of the change from conventional to electric cars, the emissions will increase by 0.47 Megatons. Currently, the traffic of light vehicles in Scotland produce 3.6 Megatons of CO_2 per year, and that is significantly higher than the amount of emissions that would be produced from the additional electricity generation for the EVs per year.

4. Discussion

The current finding could have some limitations. For example, the results in relation to the prices of EVs and ICEVs are based on the market research of new conventional and electric cars in 2015. Through the years, those prices may vary. The paper also did not take into consideration the fact that each person who purchases an EV will be granted a subsidy of about £ 3,500 [14]. There is also a price variance on the electricity (pence/kWh) and the fuel (£/litre) through months and years. With the increase in electricity demand, the price of energy per kWh is expected to increase as well. The calculations do not take into consideration the maintenance of electric and conventional cars, particularly in relation to the life of the battery or the engine. The electricity that would be required for electric cars is based on calculations made using parameters such as the number of cars, registered cars of each brand and average electricity consumption. Such numbers are expected to vary in the future. It is also worth mentioning that the current percentage distribution of both conventional and electric cars is calculated using the current best-sold cars of both types in the UK. This could also change in the future, depending on what brand would be the most looked for.

The reduction in the use of coal in the generation of electricity and the focus on renewable energy makes the Carbon emission figures in reality much better over the coming years in Scotland.

5. Conclusions

EVs are approximately two times more expensive than ICEVs on average, but the amount of money that would be spent annually to recharge an electric car is lower than the one of refueling a conventional car. In the case where all ICEVs are replaced with EVs, the electricity demand would rise slightly and with it the carbon emissions from the grid, but removing conventional cars from the traffic will have a positive impact on the environment, with significantly lowering CO_2 emission. With all the calculations made in this paper, it can be estimated that electric vehicles will have a positive impact regarding the environment, but

economically that may bring some challenges. The paper, however, did not include the carbon emission produced during the production of the cars neither did not discuss the effect of battery production on the environment. This should be considered in future papers.

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