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Carbon Footprint Reduction with the Adoption of the Electricity-Powered Vehicles

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Abstract – *In the quest to reduce the global carbon footprints, many national governments are adopting the electricity-powered vehicle over conventional vehicles. However, this does not necessarily translate to a reduction of CO_2 emission, as the source of the electricity utilized for the charging/recharging of such vehicles plays a significant contribution to its emission rate. This study looks at selected economies in six different continents and the Middle East to estimate the electric vehicle adoption and CO_2 emission (kg/kWh) benchmark to make them greener than the conventional vehicles. At the current state of the emission from the conventional automobiles, CO_2 emission per kWh of generated electricity is assumed to be below 0.5495 kg for the electric vehicles to be greener, and for a matured synthetic fuel technology below 0.1923 kg. The estimates show that to ensure a transition to the adoption of electricity powered vehicles in Bangladesh and Africa, a shift in electricity generation to clean renewable sources is required.*

Keywords – *CO_2 emission, conventional automobiles, electric vehicles, global warming, greenhouse gas.*

1. INTRODUCTION

The threat of global due to emission of greenhouse gases continues to be a begging issue waiting for a resolution. CO_2 gas always comes to fore whenever greenhouse gases are mentioned because it is the largest of such gases produced globally after water vapour [1],[2]. The increase in the average global temperature over the pre-industrial era caused by greenhouse gases is a cause of major concern and also is the negative health impact [2]. Global temperatures have increased above 0.6 ^{0}C over the past century [2]-[4]. Several activities contribute to the release of CO_2 gas to the environment, among which are land use, waste management, and combustion of carbon-content materials like fossil fuels and plants [3]. Reduction of CO_2 emission is expected to be accomplished by improved efficiency in combustion plants, shift towards alternative energy use, and carbon capture and storage [2],[5],[6], moreover, it is a known fact that life cannot exist without traces of the greenhouse gases [4],[7].

While there has been a continuous improvement in the efficiency of combustion plants, the required level of reduction in the emission of CO_2 gas is yet to be achieved, and attention is now shifted to the use of alternative energy. A direct consequence of which is, many nations are pushing for the adoption of electric vehicles as a means of reducing CO_2 emission in the transportation sector [5,8,9]. The use of alternatives to fossil fuels are also being rigorously pursued in the form of biofuels [10]. The CO_2 emission rate of conventional automobiles, however, can compare favourably with that of electricity-powered vehicles based on the comparison of the Life Cycle Assessment (LCA) of such vehicles when the generated electricity source is put into consideration [5].

The electric vehicle technology has evolved with time, and some of the hitherto challenges like exorbitant cost price and low drive mileage before a recharge is gradually being overcome [11]. The tail pipe emission from electricity-powered vehicles is zero and this has always been the point of argument for their advocates, however, the electricity generation source is a critical issue which must be considered [5] in the overall evaluation of the emission value of such vehicles. While the generated electricity of some nations can be said to be 'clean', this cannot be said for most of the countries. This will result in some countries contributing to the reduction of CO_2 emission with the adoption of electric vehicles, while others will contribute to the increase.

This study, therefore, seeks to develop a benchmark of CO_2 emission from electricity generation that will make the adoption of electricity-powered vehicles environmentally friendlier in comparison to conventional automobiles, and also to determine its suitability in some selected top economies in continents.

2. ELECTRICITY GENERATION SOURCES

The global sources of electricity generation are renewable and non-renewable, with the utilization of renewable sources standing at approximately a quarter of the total based on the data available for the year 2018 [12]. Electricity generation from renewables is said to be free of emissions [13], while non-renewables are major contributors to greenhouse gas emission [5]. Although many nations are now investing heavily in electricity generation plants with renewables as an energy source, its installed capacity still hovers around a third of the total [14], and projections for the nearest future look bright putting it at about 50% by the year 2050 [13].

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However, it is imperative to note that installed capacity does not translate to generation capacity especially for the case of renewable-powered electricity generation because of the peak and low periods which is their characteristic feature making them have a low value of return on investment for some sources [15],[16].

Renewable energy sources available for electricity generation include hydropower, wind, solar, ocean power, geothermal, and biomass and biofuels, *etc*., while non-renewable sources are fossil fuels; coal, oil, and natural gas, and nuclear energy [17].

3. GREENHOUSE GAS EMISSION CONSIDERATION

The adoption of electric vehicles over the use of conventional automobiles will result into more electricity consumption and demand [5], and hence, it is required to know the energy sources and plants' efficiency to determine the CO_2 emissions from a country's electricity generation sector which will be utilized in powering the electric vehicle. Although the quality of the fuel used in the generation of electricity also plays a huge part in the level of emissions, it can, however, be assumed that the available figures for the year 2018 provided by the United States as depicted in Table 1 still subsists.

Table 1. CO_2 emission based on energy source.

Energy Source	CO_2 (kg. /kWh)
Coal	1.003
Natural gas	0.418
Petroleum	0.958

Source: EIA [18].

The CO_2 emission from the renewable sources as mentioned earlier can be said to be zero, and as revealed by the literature [18]. For the United States of America, the fossil fuels powered generated electricity accounted for 99% of the CO_2 emissions despite being only 63% of the total generated electricity. Data exist for the average amount of CO_2 emission for on-the-road conventional automobiles. For petrol as fuel emission is 0.144 kg/km and for diesel 0.109 kg/km [19], and it will not be out of place to say that biodiesels and alcohols even do better. For any nation to be considered as one whose contribution to global warming is positively oriented with the adoption of the electric vehicle over the conventional vehicle, then her generated electricity must be such that in addition to some other factors when used to power the vehicles it must produce lower CO_2 emission levels. Relying on the data provided, the benchmark adopted for the maximum amount of CO_2 emission per km of road travel for the electric vehicle is put at 0.1 kg/km.

Electric vehicles depend on batteries for their energy storage [5],[20], and the common of such is the Lithium-ion batteries. Lithium-ion batteries derive their functionality from the formation and subsequent reduction of CO_2 emission [21] and the loss of which results in the damage of it. With this point in mind, asides the CO_2 emission produced during the generation of electricity used in powering the electric vehicle, it also emits due to the use of the batteries; the discharge of 1 kg. of Lithium batteries to nature is equivalent to about 12.5 kg. of CO_2 and the production of the batteries is accompanied by the emission of (90-200) kg. of CO_2 per kilogram [22], [23].

In arriving at the CO_2 emission rate of the electricity-powered vehicle, the battery contribution is not factored-in because of the non-inclusion of the emission rate during the process of refining conventional vehicles' fuel. Using the data available from electric vehicle manufacturers like Tesla, Nissan, Hyundai, Ford, the average consumed energy is about 0.182 kWh [5] per kilometer of road travel, and this is the basis for the calculation of the CO_2 emission rate of electric vehicles.

4. CASE STUDY OF SELECTED COUNTRIES

To determine the environmental suitability of the adoption of the electric vehicles, the different continents were considered with the selection of the top economies. This was characterized on the CO_2 emission rate per kWh of their generated electricity. The considered countries are depicted in Table 2.

The CO_2 emission per kWh of generated electricity of the studied countries is depicted in Table 3.

Table 2. Selected countries for studies.

Africa	Asia	Australia	Europe	*Middle East	North America	South America
Nigeria	China	Australia	Germany	Turkey	USA	Chile
South Africa	Japan	New Zealand	France	Saudi Arabia	Mexico	Argentina
Egypt	India		Italy	Iran	Canada	Brazil
Algeria	South Korea		United Kingdom	Russia	Jamaica	Peru
Morocco	Bangladesh		Spain	UAE	Panama	Uruguay

*The Middle East is not listed as a continent.

Table 3. CO_2 emission rate per kWh of electricity generation.

Country	Key	CO_2/kWh	Remarks
Nigeria	NG	0.4396	[24],[25]
South Africa	SA	0.9606	[26]
Egypt	EG	0.63	[27]
Algeria	AG	0.6642	[25]
Morocco	MC	0.7312	[25]
China	CH	0.6236	[26]
Japan	JP	0.4916	[26]
India	IN	0.7429	[26]
South Korea	SK	0.517	[26]
Bangladesh	BG	0.6371	[25]
Australia	AS	0.8	[26]
New Zealand	NZ	0.0074	[26]
Germany	GE	0.469	[26]
France	FR	0.047	[26]
Italy	IT	0.327	[26]
United Kingdom	UK	0.2773	[26],[28]
Spain	SP	0.288	[26]
Turkey	TR	0.5434	[26]
Saudi Arabia	SD	0.7176	[26]
Iran	IR	0.571	[29]
Russia	RS	0.4	[30]
UAE	UA	0.4333	[26]
USA	US	0.4759	[26]
Mexico	ME	0.464	[25],[26]
Canada	CA	0.13	[26]
Jamaica	JA	0.7961	[25]
Panama	PA	0.2768	[25]
Chile	CL	0.4086	[25]
Argentina	AR	0.3583	[26]
Brazil	BR	0.0927	[25],[26]
Peru	PE	0.2377	[25]
Uruguay	UG	0.017	[31]

Sources: References [24]-[31].

However, it is important to note that a greater fraction of the studied countries have a quality supply of electricity whose uptime period is close to a hundred percent, but this cannot be said for some countries like Nigeria with only about 54.4%, South Africa with 84.4%, and Bangladesh with 88% [32]. While the electricity supply downtime for Bangladesh and South Africa can be assumed to be minimal, that of for Nigeria one cannot. Nigeria meets the shortfall of her electricity demand through self-generation basically from petroleum-fueled generators which do not pass through the grid [33], and this has to be considered in the determination of the CO_2 emission rate of her available electricity.

The adjusted CO_2 emission rate per kilowatt-hour of available electricity in Nigeria can hence be determined thus; A generation of about 30,897 GWh [34] of electricity results in an uptime percentage of 54.4 [32], an indication that with all things being equal, a generation of 56,796 GWh will give a 100% quality of supply. It is therefore assumed that the balance of 25,899 GWh of electricity is generated from petroleum. Using the emission rate based on petroleum and factoring in the efficiency ratio of thermal plants to compression ignition engines; 1:1.29 [5], the adjusted CO_2 emission rate for Nigeria electricity is depicted in Table 4.

Table 4. Adjusted CO_2 emission per kWh.

Country	Key	CO_2/kWh
Nigeria	NG	0.5778

Sources: References [24], [25].

The projected amount of CO_2 emission per kilometer of travel of an electric vehicle charged/recharged with generated electricity from the studied selected countries is depicted in Figure 1.

The country that will produce the least emission with the adoption of the electric vehicle is New Zealand followed by Uruguay, while South Africa and Australia will produce the highest rate of emission respectively. The adoption of the electric vehicle over the conventional automobiles will assist in the reduction of greenhouse gas for the countries whose emission rates are below the benchmark line. All the selected studied countries in Europe and South America fall below the benchmark. The benchmark corresponds to a CO_2 emission rate of 0.5494 kg/kWh of generated electricity, which was derived thus;

Average energy consumed per kilometer of road travel = 0.182 kWh [5].

Rate of CO_2 emission expected to make it greener = 0.1 kg/kWh

Corresponding CO_2 emission benchmark (kg/kWh) $= \frac{0.1}{0.182} = 0.5495$.

The current energy sources mix for electricity generation in Bangladesh does not favour the adoption of the electric powered vehicle. The adoption will result in more emission of greenhouse gases in comparison with the conventional vehicle as its CO_2 gas emission rate (0.6371 kg/kWh) is in excess of the modeled benchmark. To ensure the sustainability and just transition of energy in the country, it is imperative for the country to shift more to electricity generation from cleaner renewable sources. The country's three coal power plants under construction [35] will in no small way increase is CO_2 gas emission rate per kW of generated electricity. The adoption of the electricity powered vehicle should be suspended until the greenhouse gas emission from her electricity generation falls below the benchmark.

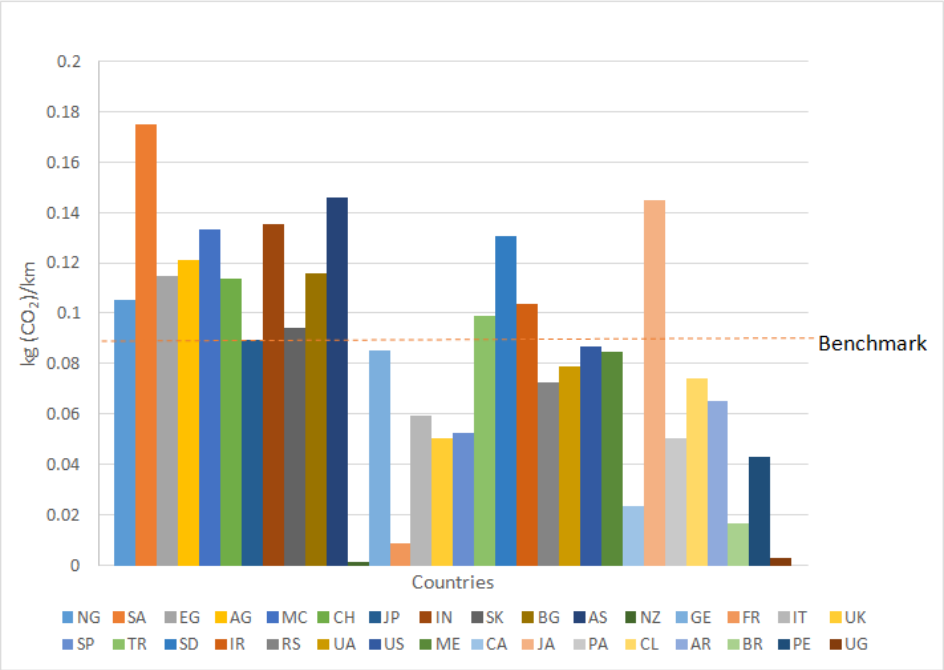

Fig. 1. Estimated CO_2 emission per kilometer of road travel by countries.

With an uptime of 88% in Bangladesh [32], the CO_2 emission rate of the country per kWh can also be adjusted to allow the downtime to be compensated with self-generation. The adjusted value based on average grid value of 13,000 MW [35] is depicted in Table 5.

Table 5. Adjusted CO_2 emission per kWh.

Country	Key	CO_2/kWh
Bangladesh	BG	0.6590

Sources: Reference [25].

It is, however, to be noted that the use of synthetic fuel will further lower the emission rate benchmark as data shows that its utilization in internal combustion engines results in about a third of the tailpipe emission of CO_2 gas [5]. The development of synthetic fuel and its wide availability will thus make the adoption of the electric vehicle greener in the hitherto qualified countries according to the depicted model in Figure 1 with emission rates that fall below the benchmark as depicted in Figure 2.

The maturity of the synthetic fuel production and supply will make the adoption of the electric vehicle powered with the current generated electricity greener only five (5) countries according to this study model; New Zealand, France, Canada, Brazil, and Uruguay. At this level, the benchmark electricity generation emission rate per kilowatt-hour for the sole use of electric vehicles to be greener will be 0.1923 kg/kWh.

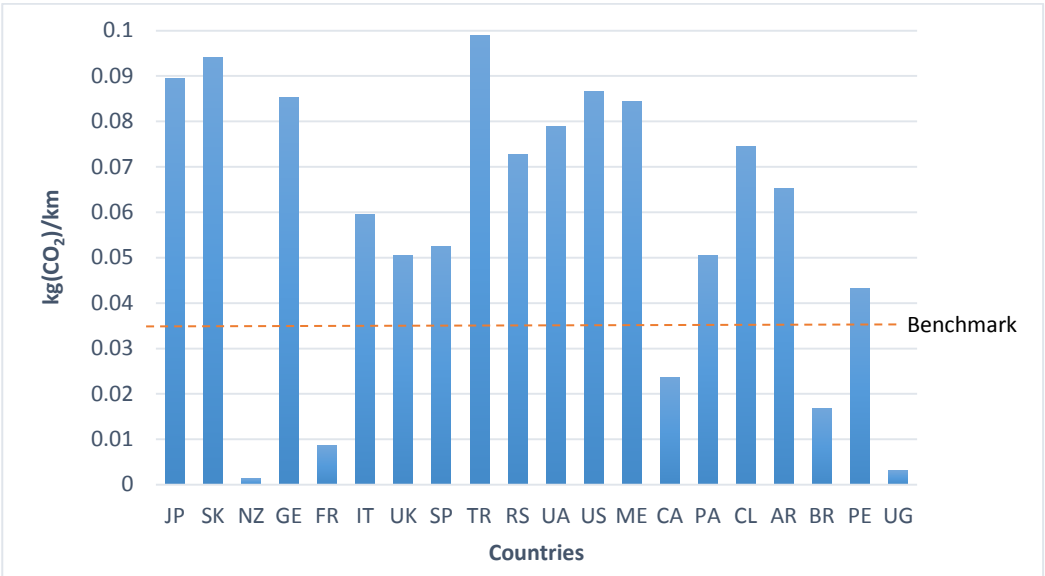

Fig. 2. Estimates based on the use of synthetic fuels.

5. CONCLUSION

The top five performing countries in six continents and the Middle East were estimated in this study to determine their contribution to greenhouse gas emission if a switch to electric vehicles from the conventional ones are done. European countries and South American countries will be greener with the adoption of electric vehicles over conventional automobiles, so will be some countries in Asia, North America, the Middle East, and Australia. However, the continent of Africa will contribute more to global warming with a switch from conventional vehicles to electric vehicles. This is due to no other fact that the major players in the continent rely on non-renewable sources for the generation of the bulk of their electricity. Bangladesh needs to shift to electricity generation to cleaner renewable sources to ensure to if electricity powered vehicles are going to be used.

The estimates also show that only five countries: New Zealand, France, Canada, Brazil, and Uruguay will be more green if the synthetic fuel technology should get matured at the present electricity generation fuel mix. The greener the electricity generation becomes, the greener will be the electric vehicle and synthetic fuel.

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