Projected Future Scenario of Electric Vehicles and Their Latent Impact on Electricity Demand in Kenya

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Abstract-This study projects the future scenario of electric vehicle (EV) adoption and its impact on electricity demand in Kenya. Using data from the Kenya National Bureau of Statistics on EVs and internal combustion engine vehicles (ICEVs) registered from 2010 to 2022. Logistic growth model (LGM) used for projections was executed using MATLAB. The projected number of EVs by 2050 for conservative (25%) moderate (50%), optimistic (75%), and original (100%) adoption rates were respectively 3,927,131; 7,475,274; 9,880,293 and 10,807,843 with corresponding electricity demand of 14.8 TWh, 28.2 TWh, 37.3 TWh and 40.8 TWh, which increases to 18.7 TWh, 35.7 TWh, 47.2 TWh, and 51.6 TWh when generation and transmission losses are added. Adding electricity demand by other sectors, net electricity generation increases in the range from 37.4 TWh to 70.3 TWh for conservative and original scenarios respectively by 2050, which represent 3-times and 5.5 times the 2022-generation of ~13 TWh. In conclusion, EVs penetration into the Kenyan market is currently low. However, their eventual replacement of ICEVs will have significant implications for electricity demand and supply, even under the conservative scenario.

Key Words: transportation, electric vehicles, energy demand, logistics growth model, climate change

1. INTRODUCTION

Transportation plays a crucial role in modern civilization and socioeconomic development of a country by facilitating mobility of both people and commodities across cities, nations and continents (McAusland, 2010). It links individuals to services and goods hence enhances trade between the people locally and abroad, provisions of living wages for masses, generating micro and macro-economic benefits (Krishna, 2021). Transportation can be executed on road (motor vehicles), sea (watercrafts) and air (aircrafts), but with different traffic concentrations and frequency. The road transportation sector is leading in terms of both the number of motor vehicles and the frequency of operation than the other two transportation methods because an individual person can own a vehicle(s). The transport industry relies entirely on crude oil, which is converted during refinery into transportable fuels (gasoline, jet fuel, and diesel fuel) and other products. The heavy reliance on petroleum fuels and the large number of fleets (vehicles, sea vessels and aircrafts) have made the transportation sector to be among the leading CO_2 emitters in the world, in the league of cement and steel industries. The World Bank, as cited by Krishna (2021), reported that the transport sector is responsible for about 64% of global oil consumption and 23% of energy generated CO_2 emissions, a figure that has raised a red card and need urgent action. The present campaign on green economy is targeting the greening of the heavy polluters and difficult to decarbonize industries in the world today, i.e., transportation, cement and steel industries.

Internal combustion engine vehicles (ICEVs), which include cars, trucks and motor cycles, are powered by petroleum or hydrocarbon fuels. These fuels are burnt by the engines to convert thermal energy into mechanical energy for vehicle propulsion. In addition, a complete combustion of the fuel produces carbon dioxide (CO_2) and water vapor (H_2O) as byproducts or exhaust gases (Martins & Brito, 2020). For instance, the complete combustion of the simplest hydrocarbon, i.e. methane, is given by:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O(g) + energy \qquad (1)$$

The energy released in Eq. 1 is used to drive the vehicle, while the exhaust gases are emitted into the atmosphere as pollutants. The mass units of CO_2 gas and H_2O vapor in Eq. 1 are 44 and 36 units respectively in the 80 mass units of products. Therefore, complete combustion of one mole of methane generates more CO_2 at 55% than water vapor at 45%, which explains the heavy GHG emissions in the transportation sector. Hydrocarbon fuels consumed in road transport have different carbon-number varying from 5-10 for gasoline, and 14-20 for diesel while for aviation and marine transport have respectively carbon-number of 10-16 for jet fuel and 20-70 for heavy fuels (Altin & Eser, 2004). As the carbon-number in these fuels increases, the CO$_2$ emitted increases proportionally

associated with various health issues in people. The road transport accounts for over 70% of the total GHG emission from transportation industry as compared to the rest of the transportation methods (Higueeras-Castillo, 2021; Calderon-Tellez *et al*., 2023). The air pollution from GHG emissions by road transport is a big challenge in big cities in the world due to the large population and high traffic concentration (Jiang, 2018). This menace has made these cities unsustainable prompting the inclusion of SGD#11 on building sustainable cities (UN, 2015). There is, therefore, a need to reduce GHG emission in the transportation sector, and proposed methods include technology advancements, policy interventions, fuel switching, and shifts in consumer behavior (Ayetor *et. al*., 2021, UNECE, 2023).

Electric vehicles (EVs), unlike ICEVs, are electricity-driven and encompass cars, bicycles, motorbikes, and other battery-powered vehicles. Hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), plug-in electric vehicles (PEVs), and battery electric vehicles (BEVs) are the major variants of EVs currently existing in the market (Ghosh, 2020). The EVs are extensively cited in literature as having the potential of decarbonizing the transport sector due to their smaller ecological footprint when compared with other road transportation options (Nordelöf *et al*., 2014; Hooftman *et al*., 2016, and Costal *et al*., 2021). According to IEA (2023) report, the EVs contributed to a net reduction of about 80 million tons of GHG emission on a well-to-wheel (WTW) basis in 2022. However, there has been skepticism in some quarters on the claim that EVs are environmentally friendly because they only avoid tailpipe emission of GHGs. According to these critics, EVs can only reduce CO$_2$ emissions if renewable energy sources are utilized to generate electricity for recharging the batteries as has been reported by various researchers including Chellaswamy & Ramesh, 2017, Alimujiang *et al*., (2020), Haustein & Jensen (2018), among others. The cleanness of EVs has also been corroborated by life-cycle assessment findings, which have demonstrated that EVs have lower CO$_2$ emission compared to ICEVs even if electricity used to recharge the batteries is generated from fossil fuels (Costal *et al*., 2021). Therefore, the EVs are capable of promoting sustainable transportation and smart cities across the world as well facilitating achievement of some of the SDGs (Sudjoko, 2021; Hoogland *et al*., 2024).

The adoption of EVs has been slow across the world despite increased marketing, increasing awareness on climate change, and the numerous advantages of EVs, with developing countries trailing in the statistics as expected. According to

and hence emission levels. For incomplete combustion of petroleum fuels, other byproducts are emitted such as Sulphur hexafluoride (SF$_6$), carbon monoxide (CO), hydrocarbons and nitrogen oxides (N$_2$O) and soot or particulate matter (Ghosh, 2020). These gases cause air pollution, which has been

Global EV Outlook 2023 survey, the uptake of EVs has experienced exponential growth, constituting 5% in 2020, 9% in 2021 and 14% in 2022 of all of the new vehicles sold in the world (IEA, 2023). This survey further indicated that China continues to dominate EVs market in the world boasting of 60%, followed by European market, and in third position is USA with sales share of 8%. In 2022, over 26 million electric cars were on the road across the world, which represented an increase of 60% those in 2021 and more than five times the number in 2018. The trend of increasing sales was projected to continue in 2023 and its market share was estimated to reach 18% of all new vehicles sold at the end of the year. In addition, emerging markets outside the major markets are increasing, albeit from small base, mainly in the developing countries. Several factors promoting the ongoing increased uptake of EVs include Government policies on purchase incentives, the Tesla effect, falling battery costs, 5G rollouts, and the launch of the Battery-as-a-Service model (Bryła *et al*., 2022; Costal *et al*., 2021).

Several researchers have investigated the possible barriers slackening widespread and accelerated acceptance of EVs, which vary from technical, economic, social and environmental factors. Adib *et al*. (2019) carried out an in-depth market insight on e-mobility and identified several challenges hindering consumer adoption of EVs which include lack of infrastructure (charging stations), high upfront costs, poor consumer knowledge and wrong perceptions, pressure from oil companies and the car manufacturer lobby. Krishna (2021) investigated the consumers' opinions on adoption of EVs and gave detailed discussions on several barriers, broadly classified as sales conversion inability, lack of trust in technology, unsafe, living with technology, and desirability. Hoogland *et al*. (2024) analyzed the role of public (open to any driver to use) charging infrastructure for PEVs, and found that availability and good spatial coverage of such facilities could increase the consumer acceptance of EVs and mileage covered. Social challenges on the adoption of EVs include social and cultural values as well as political interest, which are country dependent (Costal *et al*., 2021). Darbinian *et al*. (2023) carried out a comparative analysis of the barriers to EV adoption among senior citizens in China and Russia, and found that major barrier for Chinese elders was inability to locate available charging stations while for the Russian counterparts was lack of charging infrastructure at home. Higueras-Castillo *et al*. (2021) did an empirical study in Spain on variables that predict the purchase of EVs based on beliefs, attitudes and purchase intention of potential consumers and their findings showed that range, incentives and reliability were the most reliable predictors of purchase intention. Haustein & Jensen (2018) performed online surveys in Denmark and Sweden on comparison of BEV users and ICEVs users based on socio-demographic profiles, attitudinal profiles, and mobility patterns. These authors reported that BEV users are typically male, highly educated, have high incomes and often own more than one car in their households. Additionally, BEV users perceive less functional barriers toward EV use and have more positive attitudes and norms than ICEV users.

The EVs are propelled by electric motors that draw power from rechargeable batteries, and hence the source of electricity for recharging them becomes crucial because the WTW analysis on GHG emissions is strongly dependent on the primary energy sources (Li *at el*., 2019). If the electricity is generated by nuclear power, hydropower or renewable energy sources such as biomass, solar, and wind energy, the WTW GHG emissions for EVs are much less than those for ICEVs. The introduction of EVs will increase the electricity demand in any country. It is therefore, crucial to project future growth of EVs in order to plan their electrical energy demand and generation. According to IEA (2023), the global EV fleet consumed about 110 TWh of electricity in 2022, which is projected to reach 950 TWh in the Stated Policies Scenario (STEPS), 1,150 TWh in the Announced Pledges Scenario (APS). The implications of this surge in demand extend to power systems, necessitating careful infrastructure planning and management to accommodate the increasing size of the EV fleet and mitigate challenges related to peak power demand, transmission, and distribution capacity. Accurate projections are essential for guiding policy decisions and investments in energy infrastructure, highlighting the importance of tools such as the IEA's framework for EV grid integration in shaping effective charging strategies tailored to regional contexts. Transportation sector in Kenya contributes about 8.3% of the country’s total GDP (Muigua, 2022). This sector is dominated by ICEVs including cars, passenger vans, buses, trucks and motor cycles. Like other African countries, majority of these vehicles, especially light-duty vehicles (LVDs) are pre-owned or second-hand vehicles imported from foreign countries notably Asia, America and Europe. Ayetor *et al*. (2021) investigated used LVDs imported to African continent from 2015 to 2019 using yearly trade data from International Trade Centre (ITC) and found that at least 1 million cars were imported to Africa in 2019, with Kenya ranking third with about 89,616 units. Currently, Kenya’s import regulation requires the age of used imported vehicles not to be more than 8 years old from the date of its manufacture (KEBS, 2020). The used cars are associated with high emissions, especially those used in public transport sector known in Kenya as ‘Matatu’, which are aggravated further by poor maintenance of these vehicles. The country has committed itself to the Paris Agreement and targeted transportation as one of the sectors to reduce emission in her nationally determined contribution strategy. Kenya, just like other developing countries, are among the emerging markets for EVs and are usually captured under ‘Others’ in the world’s map of electric cars. The EVs have entered into the Kenyan market, but data on these vehicles are scarce in the public domain. The EVs are strategic for decarbonizing the road transport in Kenya because electricity generation is dominated by renewable energy constituting about 90% of total of grid supply. In addition, the country has developed policy to promote EVs through such incentives as lower import taxes for EVs and charging equipment as well as development of public charging infrastructure, among others. This paper examines the present status of purely EVs in terms of the number registered from 2010 to 2022, projected growth by 2050 using Logistic Growth Model (LGM) and implication of electricity demand and supply in the country.

2. Materials and Methods

Data were collected on the number of EVs and ICEVs registered in Kenya from 2010 to 2022, and were sourced from the Kenya National Bureau of Statistics (KNBS) database. Data on energy demand from other sectors other than transportation for the same period were also collected to give insights into overall energy consumption trends within the country. The LGM was adopted to perform a scenario based projection of EVs uptake in the country, and was selected because it is widely utilized for forecasting market diffusion and saturation of any new technology. The model was executed using MATLAB code.

3. Modeling the growth of electric vehicles

The LGM is a robust mathematical tool for estimating diffusion of new technologies, and has been widely used by various researchers to project the growth of EVs in various countries across the world. For instance, Lieven & Rietmann (2020) used LGM to model EV growth across 26 countries on five continents (Asia, North America, South America, Europe and Australia), while Castro *et al*. (2022) used it to model EV growth in the city of Campinas, Brazil, among others. The LGM is based on a growth equation developed by Castro *et al*. (2022) given as:

$$E(t) = \frac{L}{1+\left(\frac{L-E_0}{E_0}\right)e^{-kt}} \qquad (2)$$

where $E(t)$ is the number of vehicles at any time t, L is the saturation limit (i.e., maximum value that E(t) can reach), E_o is the initial vehicle population at time $t = 0$ and k is the growth rate parameter.

By fitting the ICEV registration data into Eq. 2, the parameters L and k were estimated using MATLAB software, followed by development of three scenarios to explore different pathways of replacement of ICEVs with EVs for the year 2050. These scenarios encompassed optimistic (75%), moderate (50%) and conservative (25%) adoption rates to project the EV uptake (Lieven & Rietmann, 2020).

4. Electricity Demand by Electric Vehicles

The total energy demand by a fleet of electric vehicles, E_{EV} is given by the following equation (Gryparis *et al*., 2020):

$$E_{EV} = N_{EV} \times d_{an} \times C_b \qquad (3)$$

where N_{EV} is the total number of EVs in the projected year, d_{an} is the average annual mileage and C_b is the average consumption per kilometer in a given scenario. The GIZ (2019) data gives d_{an} = 17000 km and C_b = 0.2 kWh/km.

The electricity demand at the charging point, E_{ch} can be calculated from the following equation (Gryparis *et al*., 2020):

$$E_{ch} = \frac{E_{EV}}{\varphi_{ch}} \qquad (4)$$

where φ_{ch} is the average efficiency of the charging system. Eq. 4 gives amount of electricity required at the charging port, and excludes transmission and distribution losses. The net electricity, E_{net} at the site of charging depends on both electricity demand, E_{ch} given by Eq. 4 and the annual transmission and distribution losses, E_{loss} and is given by:

$$E_{net} = \frac{E_{ch}}{E_{losses}} \qquad (5)$$

Therefore, combining Eq. 4 and 5gives net electricity to be generated as:

$$E_{net} = \frac{E_{EV}}{\varphi_{ch}(1-E_{losses})} \qquad (6)$$

Equation (6) gives the electrical energy generation required to meet the electrical energy demand of EVs. The transmission and distribution losses in Kenya are very high averaging at 21.2% of the total electricity generated annually (KNBS, 2022).

5. Results and Discussion

Figure 1 presents the number of vehicles registered per year in Kenya from 2010 to 2022, for both ICEVs and EVs. The results show that the ICEVs in Kenya has been increasing almost linearly on first approximation over the reporting period, while the EVs were non-existent or zero from 2010 up to 2015 when they began to increase from one in 2016 to about 1350 in 2022. Therefore, based on these results, the era of EVs started around 2016, just one year after SDGs were launched in 2015, and since then has also demonstrated linear growth over the reporting period on first approximation also.

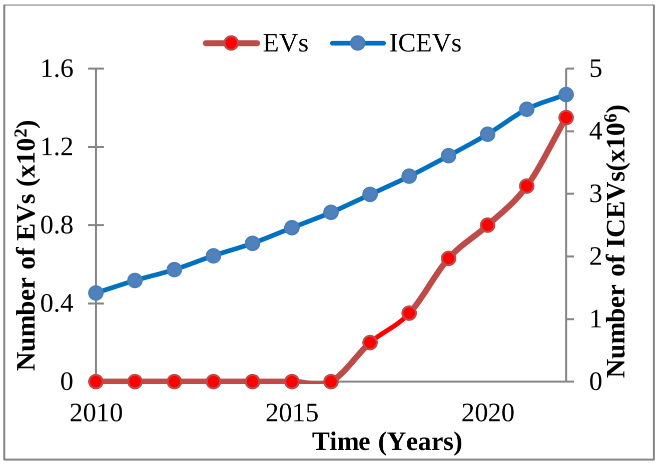

Fig-1: Trends in the Number EVs and ICEVs in Kenya (2010-2022)

Assuming linear increase of both types of vehicles from 2016 to 2022, then the growth rates from the results in Figure 1 are about 225 EVs/year and 315,000 ICEVs/year, hence EVs grow in hundreds while ICEVs grow in hundreds of thousands. The number of ICEVs was 4,587,420 units in 2022 compared to 1350 EVs, hence the latter constitutes a mere 0.03% of total number of registered motor vehicles in the country then. Therefore, the EVs are very insignificant in quantity compared to ICEVs, and de-carbonization of transport sector in the country is still negligible.

Figure 2 presents modeling results obtained from LGM forecasting of EVs adoption in Kenya, using ICEVs data from 2010 up to 2022. The values of the invested parameters are *L* = 111 94276 vehicles, with growth factor *k* = 0.13136.

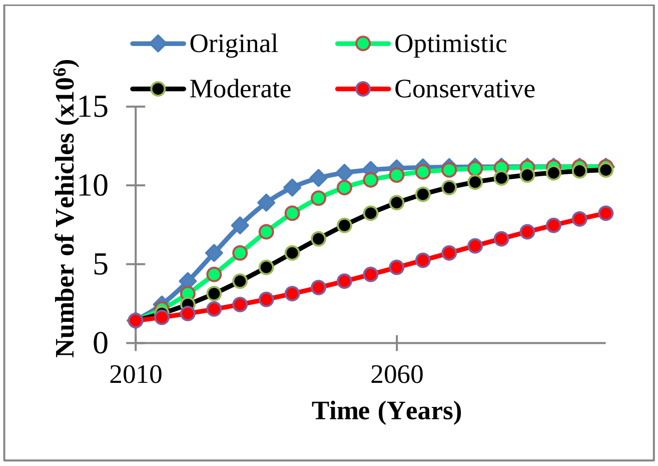

Fig-1: EV adoption projection using LGM

The original (100%) scenario predicts 10,807,843 EVs by 2050, which represents more than double the number in 2022 of 4,558,770 IECVs in Kenya. This is consistent with UNEP (2021) forecast that vehicle numbers in developing nations will double by 2050. The growth rates were adjusted to 25% (conservative), 50% (moderate), and 75% (optimistic) of the original growth rate, which yielded 3,927,131; 7,475,274 and 9,873,629 vehicles respectively for the same projection period. These projections underscore the need for strategic planning and investment of electricity generation, supply and charging points to support the transition from ICEVs to EVs in the country.

Figure 3 shows the projected electricity demand for EVs vis-à-vis other consumers, mainly domestic and industrial sectors, from 2010 to 2050. The electricity demand for EV powering was calculated using Eq. 3 and 4. The number of IECVs in Kenya in 2010 was 1.42 x 10^6 vehicles (see Fig.1) and if all of them (original scenario) were to be electrified, then the electricity demand would be 5.4 TWh. The projected electricity demand in 2050 for the EVs under the conservative, moderate, optimistic, and original growth rates were respectively 14.8 TWh, 28.2 TWh, 37.3 TWh and 40.8 TWh. This means that for the worst-case scenario, i.e. if all the vehicles were to be electrified, the electricity demand for EVs in 2050 will have be increased eight-times that in 2010. On the other hand, the conservative adaptation scenario will demand electricity supply to be increased by three-times in 2050 that of 2010. During the same period (i.e. 2010 to 2050), the domestic (which include rural electrification) and industrial (which include street lighting) will require the electricity supply to be increased from 2.5 TWh and 3.2 TWh to 9.9 TWh and 8.8 TWh. Thus, the total electricity demand in Kenya in 2050 for powering domestic, industrial and EVs is projected to range from 33.5 TWh (conservative case) to 59.5 TWh (original). Including the production and transmission losses, as calculated from Eq. 6, the net electricity generation required to meet the local demand will increase to 37.4 TWh and 70.3 TWh for the two scenarios respectively. The Kenya's total electricity generation in 2022 was about 13 TWh (KNBS, 2022), which means that the introduction of EVs will demand an increase of ~3 and ~5.5 -times for conservative and original scenarios respectively to meet the requirements for all consumers.

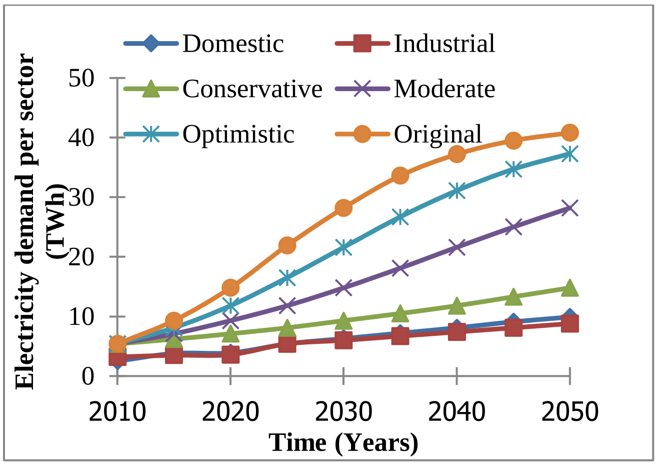

Fig-2: Projected Electricity demand for EVs and Other sectors

6. CONCLUSION

The number of registered EVs in Kenya is negligible as compared with that of ICEVs, which were respectively at 1350 and 4,587,420 units by the end of 2022. These figures indicate that the EVs constituted ~0.03% of total number of registered motor vehicles in 2022, meaning that electrification of Kenya's transport sector is still low. Therefore, to accelerate e-mobility in Kenya, it is essential to initiate comprehensive promotion campaigns that raise public awareness of the benefits of electric vehicles. These benefits include mitigating climate change, contribution of EVs to the development of smart cities, and reducing fuel costs. The projected number of EVs using the LGM showed that with 100% (original) transition of the number of ICEVs in 2022 would be 10,807,843 in 2050. However, with adjusted growth rates of the, the number of EVs would be 3,927,131 (conservative, 25%), 7,475,274 EVs (moderate, 50%), and 9,873,629 EVs (optimistic, 75%). The electricity demand in 2050 in all the four growth rate scenarios will be 14.8 TWh, 28.2 TWh, 37.3 TWh and 40.8 TWh respectively, which would increase to 18.7 TWh, 35.7 TWh, 47.2 TWh, and 51.6 TWh when generation and transmission losses are added. Adding electricity demand by other sectors (domestic and industrial sectors), the net electricity generation on the minimum and maximum ends would increase to 37.4 TWh and 70.3 TWh for the conservative and original scenarios respectively in 2050, which represent 3 and 5.5 times the generation in 2022 of ~13 TWh. Kenya is, therefore, far from electrification of road transportation in terms of number of EVs and the hidden implications of electricity demand would need to be addressed going into the future as EVs replace ICEVs.

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