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Original Research Article

Sustainable development of electric vehicles in Nigeria: Charging stations, research and development, and the way forward in a situation of electricity inadequacy

Abubakar S. Sambo[1] & Usman Garba[2]

Affiliation

[1,2] Faculty of Engineering and Environmental Design, Usmanu Danfodiyo University, Sokoto, Nigeria

*__For correspondence__: **email**: abubakar.sambo@udusok.edu.ng; **tel**: +234 803 311 1631

Abstract

Many nations have long been actively supporting the development of electric vehicles (EVs). The adoption of the sustainable development goals (SDGs) actions in that direction have been accelerated to ensure that the 24% of the CO_2 emission of the transport sector is brought down to the barest minimum. The focus of this paper is on the necessary measures and effective ways of acquiring EV technologies for developing countries such as Nigeria. The steps needed towards the development of the EV sector in Nigeria and the research and development strategies needed to address the challenges facing Nigeria in its quest to build a formidable EV industry are x-rayed. Finally, the opportunity for energy diversification towards confronting the challenges occasioned by inadequate electricity supply and distribution on the EV value chain is identified and analysed with recommendations made on the way forward. Since the EV industry cannot be true of zero-emission until its source of electricity is of zero-emission, the inherent potentials of using renewable electricity in the form of hydrogen fuel cells and harnessing the potential for solar photovoltaics (PV) of about 210 GW and concentrated solar power of approximately 88.7 GW is highlighted and recommended for the evolving EV market in Nigeria.

Keywords: *Electric vehicles, sustainable development, electricity inadequacy.*

1.0 Introduction

A substantial vehicle transition from traditional internal combustion (IC) vehicles to electric battery-powered vehicles is happening across the globe. The rapid transition is prompted by greater knowledge of environmental challenges such as global warming and the need to meet the greener objectives of various economies. An electric vehicle (EV) is one propelled by one or more electric motors that are powered by rechargeable batteries which are in turn charged by electricity the frequency of which depends on the capacity of the batteries and the distances travelled by the vehicles (Bawa & Nwohu, 2023). Consequently, EVs are viewed as potential replacements for IC vehicles in addressing issues such as global warming, rising pollution, decrease in available natural resources, concerted action against emissions and increased knowledge on the availability and utilisation of alternative power sources. Thus, the usual combustion of petrol or aviation kerosene or diesel in fuel vehicles and the accompanying carburetor and injector systems are all replaced by electric motors of EVs that activate the driving shafts. (Morgan, 2022) opined that the implication of this is that premium motor spirit (PMS) or simply petrol, which is the fuel for small vehicles; Automotive Gas Oil (AGO) or simply diesel, which is the fuel for large vehicles; and aviation kerosene, which is the fuel for aeroplanes, are all replaced by electricity stored in rechargeable batteries (Sambo, 2018). Nations at the forefront of the EV revolution set deadlines and make adequate plans towards transiting and converting all their fuel vehicles including motorcycles, cars, buses, trucks, tractors, trains, and aeroplanes to principles of EVs[1] (Coltura, 2021). Other nations cannot afford to be left behind.

Generally, EVs are classified on the basis of their propulsion type, usage and vehicle drive type as shown in Figure 1. As determined by the type of the vehicle, the motion can be provided by wheels or by propellers which are driven by rotating linear or straight motors (Bellis, 2022).

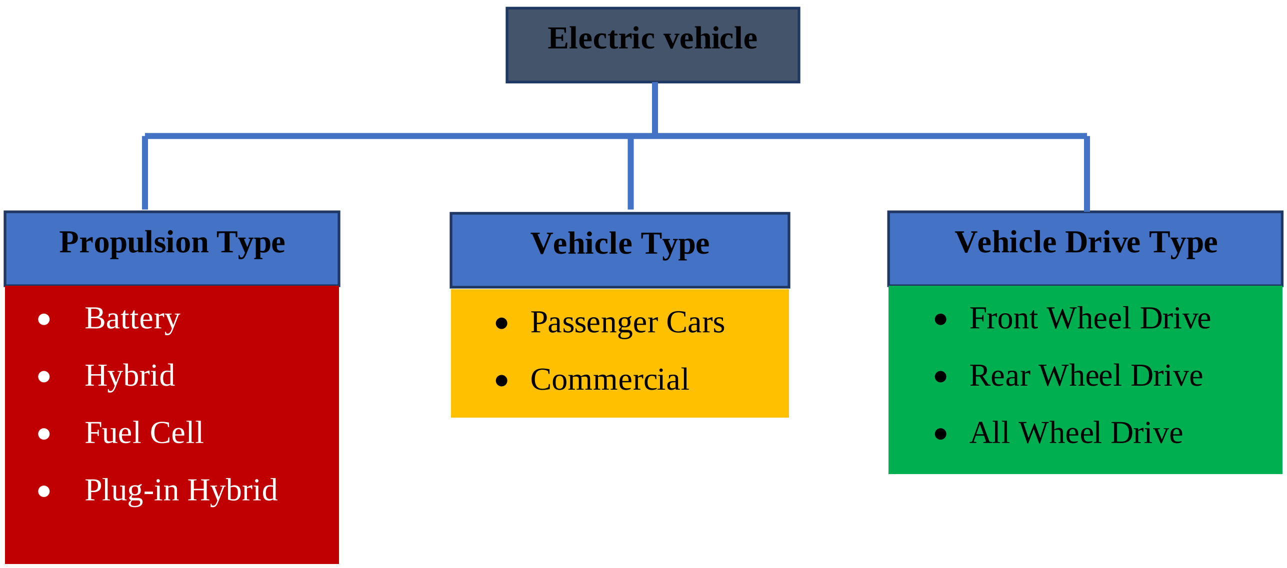

Figure 1: Major segments of Africa's electric vehicle market (Mordor intelligence, 2023)

In their classification of EVs, the (Australian Electric Vehicles Association, 2022) posited that there are three major types or classes of EVs as determined by the quantity of electricity utilised as their energy source. The three classes of EVs according to the association include hybrid electric vehicles (HEVs), module or plugin hybrid electric vehicles (PHEVs, also known as Extended-Range Electric Vehicles, EREVs), and battery electric vehicles (BEVs). Generally, HEVs are propelled by a combination of gasoline and electricity. HEVs start by using electric motors. As the vehicle accelerates or the load increases, the petroleum engine takes over. The vehicle's braking mechanism generates electric energy which re-energizes the battery (regenerative braking), and the dual motors are controlled by an internal computer system that ensures the best economy for the prevailing driving conditions. On the other hand, PHEVs (or EREVs), are power-driven by both electricity and petroleum. The battery is recharged by regenerative braking and plugging into an exterior electrical charging point. In PHEVs as the battery is depleted, it is recharged by the

[1]Sambo, A.S. (2019). "The Advent of Electric Vehicles and the Implications for Nigerian Engineers". Guest Speakers Presentation at the Engineering Conference of the Abuja Branch of the Nig. Soc. of Engineers., NSE Headquarters, Abuja, 28th August 2019.

gasoline engine which also covers the vehicle's range of motion. In the case of BEVs, the power is supplied solely by electricity and hence does not have any fossil fuel engines, fuel tanks, or exhaust pipes. Comparatively, the most researched, reported and, widely used variant of the EV is the BEV, due to its superior technological and mechanical advancements, ease of use and low potential to generate pollutants (Bawa & Nwohu, 2023).

According to (Global EV Outlook, 2023), based on the global decarbonization objective, the EV market is growing. The report showed that 14% of all new cars sold in China in 2022 were electric vehicles, amounting to a total of about 26 million EVs on their roads. Hence, China, Europe, and the United States have the highest number of EVs with 13.9, 9.5, and 3 million EVs respectively. (Mordor Intelligence, 2023) reported that in 2021, the EV market in Africa was valued at $11.94 billion which is projected to reach $21.39 billion by the Year 2027. Hence, for African countries, South Africa and, to some extent, Egypt and Morocco lead the pack in the generation of revenue from the African EV market while Nigeria and Ghana follow as shown in Figure 2.

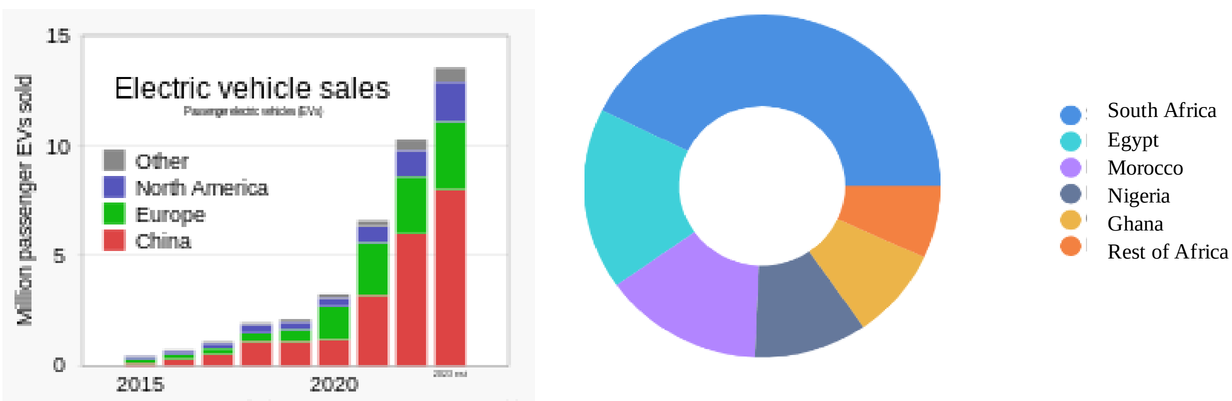

Figure 2: EV market (A) across the globe (McKerracher, 2023) and, (B) Africa's EV market, revenue share by country for the year 2021 (Mordor intelligence, 2023)

In Africa, most of the countries are investing hugely in the power sector towards expanding energy access while promoting environmental sustainability. Exponential population growth rate, increased urbanization, and the general mentality desire for the private ownership of cars as a status symbol have increasingly affected the number of cars on the roads. Thus, (Dioha et al., 2022) observed that the current global EV revolution is an opportunity for African countries to pursue this sustainable low-cost energy pathway which accords them an opportunity to avoid locking themselves in environmental and carbon-intensive energy systems. Figure 3 shows recent advances made towards launching EVs across some African countries.

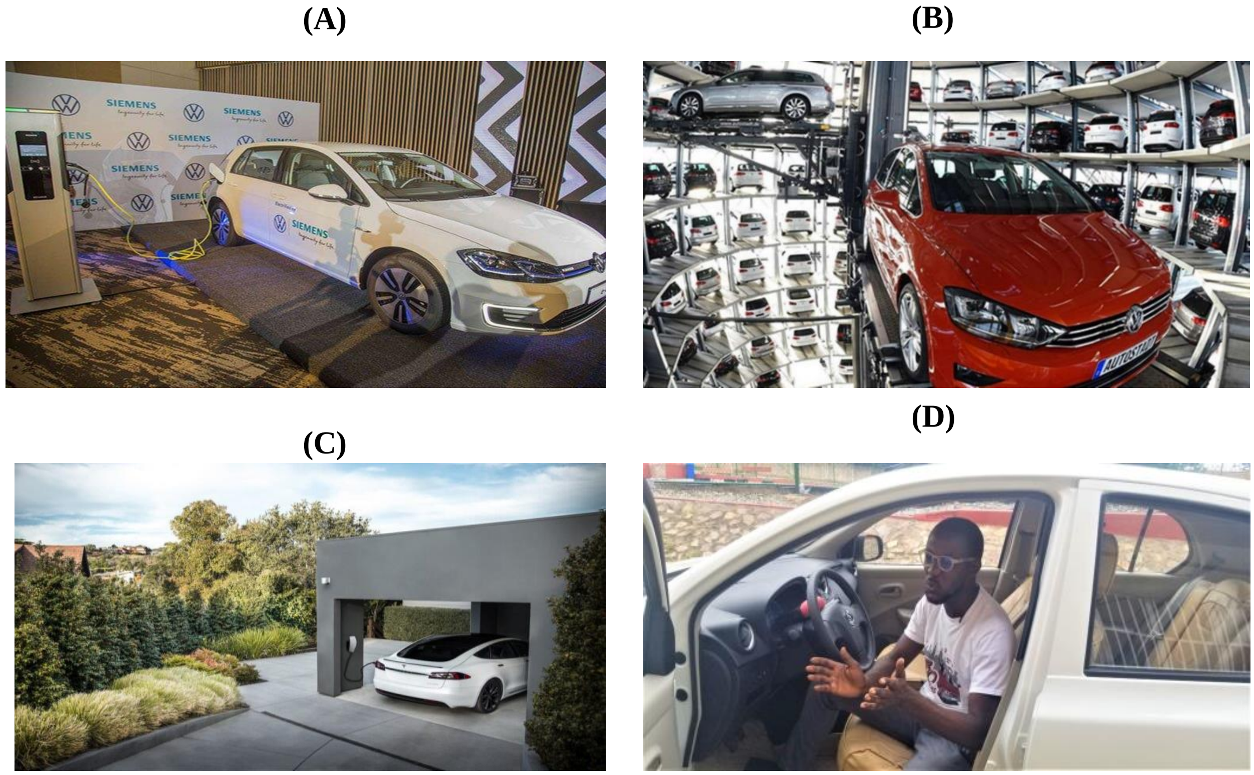

Figure 3: Recent strides towards adoption of EVs in some African countries: (A) Rwanda and Uganda's e-Golf (East African, 2019), (B) Ethiopia's first EV (Pamela, 2020), (C) Tesla's EV Chargers in South

Rwanda and Uganda are leading East Africa with their adoption of the e-Golf (East African, 2019), Ethiopia unveiled its first EV in 2020 (Pamela, 2020), Ghana's electric car transition aims to combat climate change (Zubaida, 2021) while Tesla's EV Chargers are now readily available in South Africa (Remeredzai, 2021).

According to (Mordor Intelligence, 2023), many companies, with assembly plants mostly based in Europe and Asia, have gone far in the development of EVs. In Africa, as the demand for electric vehicles continues to expand, the few dominant companies are aligning, acquiring, and making joint ventures with noteworthy industry competitors. As reported by (Ugwueze et al., 2020; Agarwal et al., 2022), the African automotive market is largely catered for by importations. The few exceptions are only South Africa and Morocco and to a lesser extent Egypt and Algeria.

At both private the individual and the National Automotive Design and Development Council (NADDC) levels, Nigeria has recorded several notable strides in the quest for the development of EVs. In 2019, a mechatronic research group at the Faculty of Engineering, University of Nigeria Nsukka (UNN) produced Nigeria's first locally made electric car codenamed 'LION Ozumba 551' from 80% local content (Tony, 2023). The first locally assembled EV, Hyundai Kona, was launched by Stallion Motors in 2021 following the unveiling of the pilot program by the NADDC which partnered with the Stallion Group and other relevant stakeholders in the automobile industry to roll out 100 solar-powered electric vehicle charging stations across the country. The Hyundai Kona can go up to a range of 482km with an acceleration of (0-100km) in 9.7 seconds on a single battery cycle of a capacity of 64 kilowatt hours (Abdullateef , 2023).

Figure 4: The Hyundai Kona – Nigeria's EV Rolled out in February 2021 (Philip, 2021)

In 2021, the NADDC in collaboration with the Usmanu Danfodiyo University Sokoto (UDUS) unveiled Nigeria's first 100 % solar-powered EV charging station which was located on the main campus of the University in Sokoto. This significant achievement which provided EV charging stations with zero emissions and zero wastes from energy generation to energy utilisation was replicated by the efforts of the NADDC in the University of Lagos and the University of Nigeria Nsukka (UNN) in 2021 and 2023 respectively (Wasilat, 2021; Kelly, 2021; Rabi'u, 2023).

Figure 5: NADDC sponsored solar-powered electric vehicle projects showing (A) solar panels in Usmanu Danfodiyo University Sokoto (Sambo, 2021).) (B) solar-powered EV station in Usmanu Danfodiyo University Sokoto (AutoReportNG, 2023) (B) solar-powered EV station in University of Lagos (Kelly, 2021) (B) solar-powered EV station in University of Nigeria Nsukka (Obafemee, 2023)

(F6S, 2023) reported that some of the EV start-ups and companies located around Nigeria include Quadcycle Automobile (Abuja), Osquareteck Ltd (Ijebu-Ode), HELLOBIKEE(Lagos), TOUR Drive NG(Ibadan), Sango Technology(Lagos), Tomoto.ng (Lagos), VoltaEV (Lagos), TREKK

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SCOOTERS (Lagos). These companies are actively involved in the assembly of various types of EVs as well as the manufacture and assembly of various forms of EV battery charge stations.

This paper highlights the most effective ways of acquiring EV technologies, especially for developing countries like Nigeria. The focus is on the research and development of the potential to exploit renewable electricity for the development of EVs in Nigeria towards fine tuning the country's EV blueprint. In addition, contributions and proposals were made to Nigeria's National Automotive Design and Development Council (NADDC), especially on the need for a deadline on the stoppage of the local production or import of internal combustion (IC) vehicles, adoption of alternative sources of powering EVs and strategies for the local production of electric drives and electric motors, rechargeable batteries and hydrogen fuel cells, EV charging stations and use of solar modules and, the integration of public-private partnership.

2.0 The Major Components of a Typical Electric Vehicle

The transmission and body of an EV are similar to those of our usual internal combustion engine vehicles (ICEV) that utilise fossil fuels. Hence, a typical EV has about 20 moving parts compared with about 200 for a typical ICEV (Alanazi, 2023; Natural Resources Canada, 2010).
Figure 6 shows the major components of a typical EV.

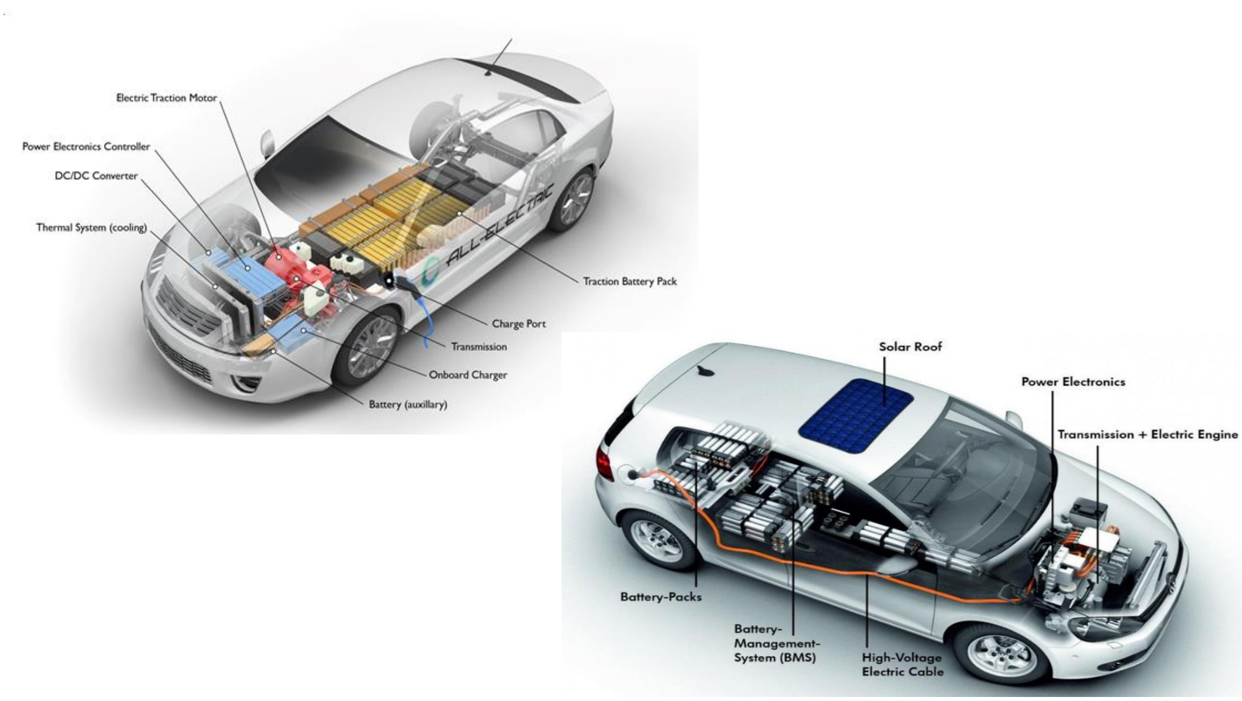

Figure 6: Major components of a typical electric vehicle (afdc, 2023)

As shown in Figure 6, the major components of an Electric Vehicle (EV) include among others, the traction battery pack which provides the electricity needed by the EV in the form of direct current (d.c); the power Inverter whose function is to convert the d.c. from the battery to alternating current (a.c.) to be used by the electric motor; the Controller which regulates the electrical energy from the batteries and inverters; the electric traction motor which uses the electricity from the inverter/batteries to activate the transmission system and, the rooftop solar modules serves to keep the EV going until it reaches the charging station. Currently, the use of solar panels and inverters seems to be the only viable commercial on-board charging of EVs.

For the Nigerian, EV industry, the steps outlined in Figure 7 for the manufacture of solar-powered traction are hereby suggested:

- Selecting an already existing EV manufacturer with the desired vehicle types.
- Enter into agreement with the manufacturer for exporting to Nigeria, in completely knocked down (CKD) or semi-knocked down (SKD) forms, the brand needed to be assembled in Nigeria.
- Agreeing with the manufacturer on the progressive increase in the local content in line with the federal government policy on local content.
- Agreeing with the manufacturer on training Nigerians on the entire value chain of EV manufacturing and assembly.
- Involving the private sector through such bodies such as the Manufacturers Association of Nigeria (MAN) and the Nigerian Association of Chambers of Commerce, Mines and Agriculture (NACCIMA) for effective public-private partnership in the EV manufacturing processes.
- Recommending the inclusion of EV manufacturing in the National Automotive Industry Development plan (NAIDP) as well as in the nation's industrial policy as a whole towards enhancing the technological and manufacturing capacity of the country.

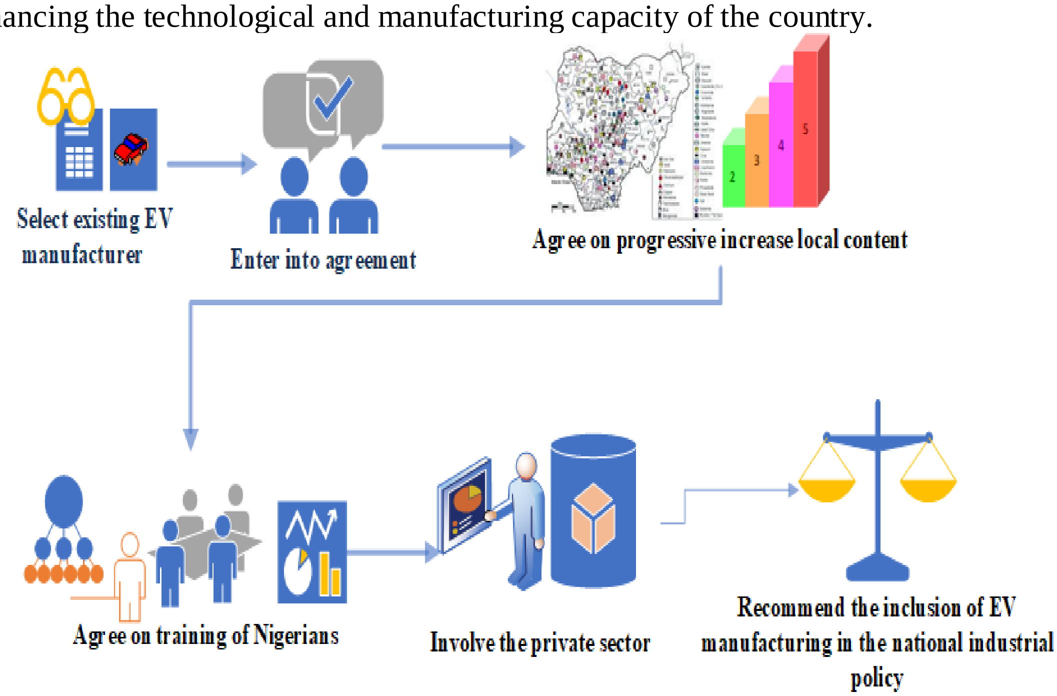

Figure 7: Recommended steps to follow towards the development of solar powered traction in Nigeria.

3.0 The Electricity Needs of The Electric Vehicle Industry in Nigeria

Nigeria's current installed electricity generation capacity is about 13,000MW. However, the actual generation capacity is about 7,500 MW. Electricity despatched to the grid for distribution to consumers ranges between 4,000 - 5,000 MW which works out to an annual average electricity consumption per capita for the 200 million Nigerians of 175.2 – 219 kWh. In 2019, an

International Energy Agency (IEA) analysis (Energy & Special, 2019) shows that the average annual electricity consumption for sub-Saharan Africa was500 kWh while for the whole World it was 2,604 kWh.

For Nigeria to be at the Sub-Saharan Africa's average, annual electricity consumption per capita of 500 kWh, will require the nation's electricity generation to be about 11,500 MW. For it to be at World average annual figure of 2,604 kWh will require electricity generation of about 59,000 MW. The Energy Commission of Nigeria which conducts energy demand projections for Nigeria for the major economic sectors of industry, services, transport and households estimates the electricity demand of Nigeria at about 35,000 MW currently, 63,000 MW for 2030 and 152,000 MW for 2050 (Energy & Special, 2019).

The industrial sector, to which the automotive industry belongs, currently needs about 17% of Nigeria's total electricity demand. Presently, the Nigerian EV Industry generates more than 80% of its total electricity needs. The electricity needs of the EV industry in Nigeria is part of the needs of the assembly plants that produce the vehicles which as mentioned earlier is part of the power needs of Nigerian industries. A significant energy need of EVs is the energy needed to charge the vehicles in the most sustainable manner and in view of the current gross limitations of the Nigerian Electricity Supply Industry this has to come, from off-grid sources.

While EVs are generally seen as zero-emission vehicles, they are not completely environment-friendly since the production of the electricity they require might generate emissions. For Nigeria and indeed majority of developing nations, off-grid solar plants are ideal for EV charging stations. The following specifications adopted by the NADDC for its pilot charging stations are recommended nationwide:

- The charging stations contain arrays of solar modules with 86.4 kW/hr capacity.
- The solar modules are coupled to three online-offline hybrid inverters with 5kVA each and synchronized to produce an output of 15kVA/48Watts.
- The system's energy storage is made up of 36 units of deep-cycle gel batteries with an output of 48V/ 1980A.
- A positive encouragement of the public-private partnership is to associate public EV charging stations with the sale and service of EVs in the country.

A renewable natural resource that can be utilized to power the EV industry is solar energy. Nigeria, like many other countries, has enormous underexploited natural renewable energy resources which will be essential for the development of the EV industry of the country. In 2023, the International Renewable Energy Agency (IRENA) reported that Nigeria's solar resource potential is characterized by an average annual global horizontal irradiation range of 1,600 – 2, 200 kWh/m^2.

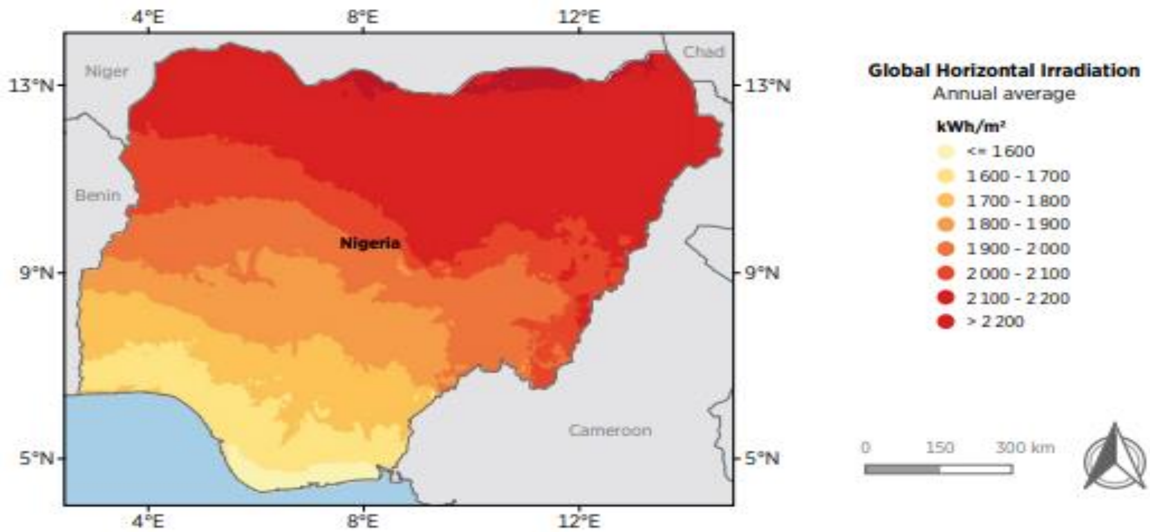

Figure 8: Average annual global horizontal irradiation in Nigeria (Global Solar Atlas (2020)

As shown in Figure 8, the maximum values (>2,000 kWh/m^2) are recorded in the northern parts of the country where the direct normal irradiance is highest (2013; IRENA, 2023). Based on the data above, the technical potential for solar photovoltaic (PV) in Nigeria is estimated to be about 210 GW (IRENA and AfDB, 2022), and the potential for concentrated solar power (CSP) as approximately 88.7 GW (Ogunmodimu, 2013).

A solar-powered EV charging station will comprise the solar array, battery bank and charging station/charge controller. A schematic diagram of a solar-powered charging station is shown in Figure 9. The solar array is an attached assembly of photovoltaic cells that capture and convert sunlight into electrical energy. Typically, the panels are installed on the roof of the charging station or structures near the charging station. The battery bank stores excess solar power for use during periods of high demand or low sunlight (Sagar et al., 2021; Hattaraki et al., 2023). The charge controller regulates the voltage and current supplied from the solar panel to the battery and thus prevents the battery from overcharging.

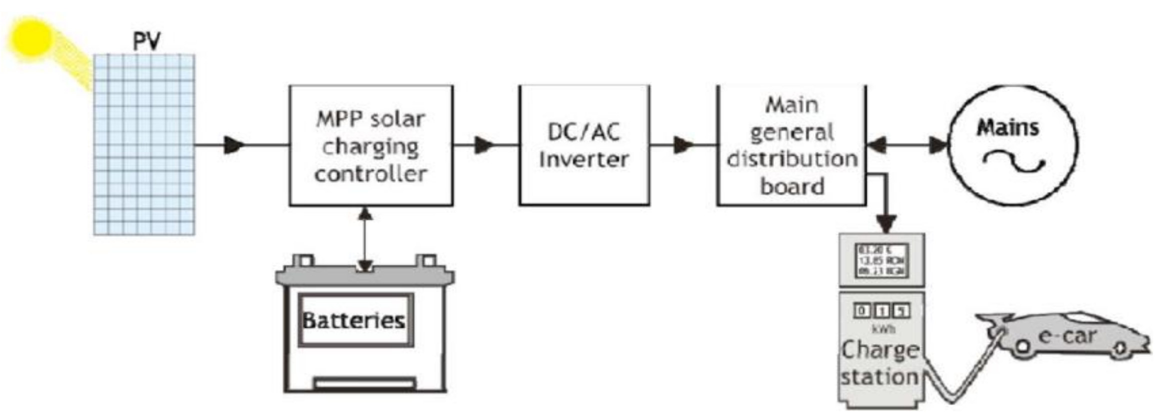

Figure 9: Schematic diagram of a typical solar-powered charging station (Nedev, 2014)

To boost electricity needs of the electric vehicle industry in Nigeria, another source of electricity is the use of fuel cells. The fuel cell stack is made up of separate membrane electrodes that enable an electrochemical reaction between hydrogen and oxygen, resulting in electricity production with water as the by-product (Ajao and Sadeeq, 2023). Fuel cells are classified mainly by the type of electrolyte they use since the electrolyte determines the type of electrochemical reactions that occur in the cell, the type of catalysts needed, the operating temperature range and other factors of the cell. These factors, in turn, determines the applications for which these cells are most suitable. There are several types of fuel cells including polymer electrolyte membrane (PEM). direct methanol, alkaline, phosphoric acid, molten carbonate, solid oxide and, reversible fuel cells (Bengt, 2019). A schematic diagram of the section of a PEM fuel cell is shown in Figure 10.

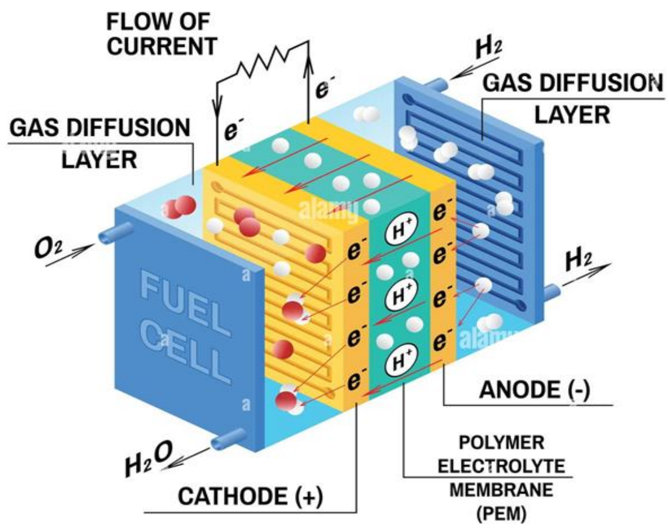

Figure 10: Cross-sectional view of a typical polymer electrolyte membrane fuel cell (Bronkhorst. (2023)

Another means of powering EVs is the use of hydrogen fuel cells. Hydrogen can be generated from natural gas or from the electrolysis of water but for enhanced sustainability, the latter is preferred. Since hydrogen is an energy carrier, hydrogen fuel cells produce electricity by combining hydrogen and oxygen atoms. The hydrogen reacts with oxygen across an electrochemical cell (the fuel cell) similar to a battery to produce electricity, water, and some heat. The technology is being promoted by some advanced nations as a major emerging clean source of electricity. It is increasingly used in EVs as a replacement of rechargeable batteries. Electrolysis of water is increasingly being undertaken with a renewable energy power source to split water into hydrogen and oxygen. Apart from power supply, hydrogen with fuel cells are being used in EVs. A global flow diagram for a hydrogen electrical fuel cell power station which runs on renewable hydrogen is shown in Figure 11.

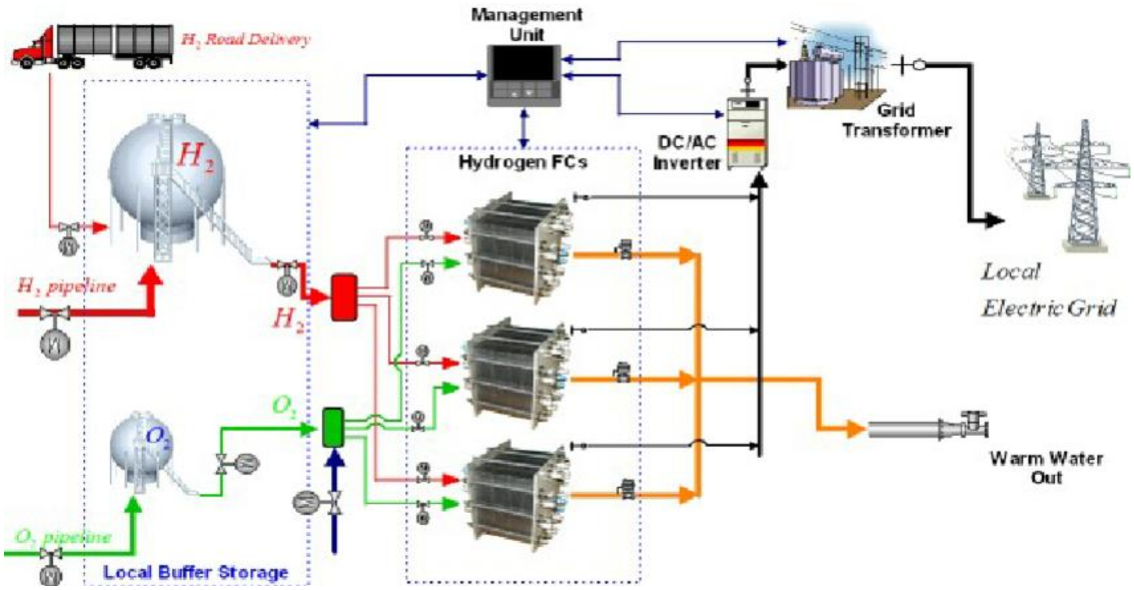

Figure 11: Flow Diagram of hydrogen electrical fuel cell power plant (Alves, 2008)

In the hydrogen electrical fuel cell power plant, generated hydrogen is stored and then delivered to a set of hydrogen fuel cells that are arranged to generate electricity with an average hydrogen to electrical efficiency of about 60 % along with low enthalpy warm water. The generated DC electricity is sent to an inverter for conversion to AC before being delivered to the national grid via the grid transformer (Alves, 2008).

4.0 Enhancing EV local content through results-oriented R&D programmes

As earlier indicated, the most cost-effective way for Nigeria to domesticate EV technology is through assembly as it is already happening. However, there should be a deliberate plan to increase the local content of the locally assembled EVs. This will call for research and development (R&D) in the following three thematic areas:

i. Electric drives and electric motors
ii. Rechargeable batteries and hydrogen fuel cells and
iii. EV charging stations and use of solar modules.

Intensive studies and research into electric drives and electric motors are necessary to come up with several options for the EVs being assembled in the country. R&D on existing EVs drives and motors will need to focus on how their choices can be optimised for all types of vehicles currently being assembled in the country and for those to be produced in the future.

Worldwide, the most effective off-grid and indeed mini-grid electricity systems are those based on renewable energy sources. The renewable electricity sources include solar photovoltaics, wind energy, hydropower, biofuels, and hydrogen fuel cells. From the efforts of some nations in the forefront of EVs development the most practical ways of powering the vehicles charging stations is by use of off-grid/ mini-grid solar PV powering systems and hydrogen fuel cells. This should be the position of Nigeria.

Local development of rechargeable batteries will reduce the cost of EVs just like local production of fuel cells and the hydrogen they need. A study is needed to focus on the battery-producing plants that closed following the nineties and how best they can be re-opened to produce deep-cycle rechargeable batteries for the nation's EV industry. Hydrogen fuel cell R&D should be taken in two parts the first of which is to domesticate hydrogen production, delivery, and storage for Nigerian EVs. The second part will be on how best to domesticate the production of fuel cells in Nigeria and to investigate how best to acquire fuel cells and its complete technology in the country. The functional similarities of batteries and fuel cells it is logical to conduct detailed research on the cost-benefit analysis of the two EV powering systems.

Studies are needed related to the numerous options for solar powered EVs charging stations along with optimum rooftop solar systems to ensure EVs reach charging stations. The three suggested R&D thematic areas should be domiciled, one in each of the three universities with the NADDC solar Charging Stations. This will call for R&D at the following institutions:

- Usmanu Danfodiyo University, Sokoto
- University of Lagos and
- University of Nigeria, Nsukka

All the three universities have Faculties of Engineering and National Energy Research Centres. The three thematic areas could be assigned based on one thematic area to one Research Centre while the maintenance and general upkeep of the model EV charging stations could be assigned to the faculties of engineering. Alternatively, NADDC can request each of the universities to set up Electric Vehicles Committees, comprising staff from their Energy Research Centres and Faculties of Engineering, to undertake research in the assigned areas, again based on one research centre to be assigned one thematic area, and to look after the EV Charging Stations in their institution. There is a need for the NADDC to identify the EV producers that can take the outputs of the R&D from the three thematic areas and test them in their factories to get the optimised products for final adoption[2].

5.0 Facilitating the growth of EVs by adopting a deadline for banning local production of IC Vehicles

A premium motor spirit phase-out also called an internal combustion engine ban has been shown to be an effective strategy for facilitating the coming on stream of EVs in different parts of the world.

Nations at the forefront of the EV revolution plan to transit all their fuel vehicles including motorcycles, cars, buses, trucks, tractors, trains, and aeroplanes to the principles of EVs.

Literature has several accounts that show that the nations at the forefront of EVs development are those that adopted deadlines for ending the assembly or import of IC vehicles. The European Union wants to phase out PMS car sales by 2035 and many of its member states have announced similar plans. Indeed, many countries have also indicated their plans to adopt EVs in their entire transportation value chain (Broadbent & Metternicht, 2018; Statistics, 2022). Towards achieving the maximum benefit of utilizing EVs, several countries across the globe have set deadlines for

[2] Sambo, A.S. (2021). "Solar Powered Traction and Manufacturing: Imminent Success and Failures". Presentation at the Seminar/Workshop Organised by NADDC on "Electric Vehicles and Solar-Powered Traction in Nigeria: Prospects and Challenges, Abuja, 20th October 2021.

banning the use of IC vehicles. Some of the countries had already implemented such deadlines as indicated in Table 1.

Table 1: Date of ban and implementation of the use of fuel vehicles in some countries

Country	Ban Announced	Ban Commences
Austria	2016	Effective
Cape Verde	2021	2040
China	2017	2040
Denmark	2018	2030
France	2017	2040
Germany	2016	2030
India	2017	2030
Ireland	2018	2030
Israel	2018	2030
Japan	1996	Effective
Netherlands	2017	2030
Norway	2016	2025
Portugal	2010	Effective
South Korea	2016	Effective
Spain	2017	Effective
Taiwan	2018	2040
United Kingdom	2017	2040

In Africa, even though Agenda 2063 (adopted in 2013) of the African Union mandated member states to produce their Nationally Determined Contributions (NDCs) for abating climate Change, so far it is only Cape Verde that announced 2040 as the year of ending emission in its transportation sector.

Nigeria pledged at the 26th Conference of the Parties (COP26) that it will end emissions by 2060. It is therefore reasonable that Nigeria should adopt the policy to ban the production or import of IC vehicles 10 years earlier and that is in 2050. Adopting a deadline for banning the production of IC vehicles in Nigeria will facilitate the growth of the EV Industry in Nigeria.

6.0 Development of the EV industry in Nigeria

The solar-powered EV charging stations developed by the NADDC at Sokoto and Lagos each has about 60 solar modules with each module rated at 280W. For planning purposes, it is advised that the NADDC should work towards the development, on Public-Private Partnership (PPP) basis, of 10 such solar-powered EV charging stations in each of the 774 LGAs of the country by 2023. This will translate to 464,400 solar modules. By 2030 such EV charging stations should be 30 per LGA and by 2050 they should reach 50 per LGA. These will respectively require 1,393,200 and 2,322,000 solar modules. To supply these quantities of solar modules, the electricity need of the module manufacturing plants will require the completion and expansion of the 5MW solar plant at UDU Sokoto, the 7.5MW NASENI plant at Abuja, and the 40MW plant in Borno state. These three plants with a combined annual capacity of 52.5 MW will each need to be expanded to capacities of 100MW and complemented with three more 100 MW solar PV plants, to be established on PPP.

Assembly plants should also be established to produce the requisite number of the balance of systems components of inverters and charge controllers. The involvement of NACCIMA and MAN as well as the African Development Bank (AfDB) will facilitate -access to funding by the private sector groups. A positive development to this idea was the AfDB President's recommendation to Nigeria at the Mid-Term Ministerial Performance Review Retreat in Abuja, Nigeria on 11 October 2021 when he called for the local production of solar PV components in Nigeria that could even be marketed to the whole continent and beyond under the African Continental Free Trade Area (AfCFTA).

As earlier indicated the most cost-effective way for Nigeria to domesticate EV technology is through assembly as it is already happening. However, there should be a deliberate plan to increase the local content of the locally assembled. This will call for R&D in the following three thematic areas: electric drives and electric motors, rechargeable batteries, and hydrogen fuel cells, EV charging stations, and the use of solar modules.

Recommendations

The NADDC should appoint a Technical Committee to produce the nation's Electric Vehicles blueprint for inclusion into the NAIDP as well as the National Industrial Policy that will include: Comprehensive policy positions fully embracing the key SDGs (7 on clean energy, 9 on sustainable industrialisation and 13 on climate change). Steps for partnering with the private sector in line with the FG's PPP policy in the manufacture of EVs, their solar-powered charging stations, and their deep cycle rechargeable batteries all of which should start with local assembly at first but to have increasing local content with time in line with Government's Local Content Policy.

Procedure for partnering with Universities and Research Institutes for capacity building of Nigerians to acquire the complete know-how in the entire EV value chain and to conduct R&D for increasing the local content in the local manufacture of EVs and their major components. Also, the procedure for the introduction of EVs into the curriculum of the entire educational system of the country from Primary Schools to Trade Test Certificate Programmes to Craft Schools/Technical Colleges/Secondary Schools to Polytechnics and to universities.

Carrying out a comprehensive study for proposing the date of when the local production/assembly, as well as import, of fuel vehicles, should be banned in Nigeria is an important step towards actualizing the country's EVs blueprint for inclusion into the NAIDP as well as the National industrial policy. Also, the appointment of a Technical Committee by the NADDC is the way to go towards the production of the nation's Electric Vehicles blueprint. The nine agenda items listed for the meeting of the NADDC Technical Committee on the Electric Vehicle Development Plan for Nigeria, held in Abuja on 11-17 April 2022, will enable NADDC to fine-tune areas to be included in the blueprint and the NAIDP as well as in the National Industrial Policy.

On electricity needs for a sustainable EV industry in Nigeria, charging stations should be powered by off-grid and mini-grid solar photovoltaic power systems fitted with solar modules and the balance of system components of inverters, rechargeable battery banks, and charge controllers. The charging stations should be of several designs starting with those with a semblance of petrol service stations to those that are for supermarkets, office blocks, residential housing estates, and for individual residences in addition to hotels, barracks, and schools. Finally, there is a need for the inclusion of rooftop solar powering systems on EVs to ensure that the vehicles will have the minimum needed power systems to take them to the nearest charging points. There is also the need for the eventual development of EVs that will be powered by hydrogen fuel cells which have been shown to be effective and possess great potential in reducing the carbon footprints of the transport sector.

Conclusion

The focus of this study was on the measures and effective means of acquiring EV technologies for developing countries like Nigeria. The potentials of energy diversification towards mitigating the challenges posed by inadequate electricity on the EV value chain were x-rayed. A holistic overview of a green energy solution that ensures a zero-emission EV industry that explores and utilises the inherent potentials of using renewable electricity in the form of hydrogen fuel cells is advocated. Also, harnessing the potential for solar photovoltaics (PV) of about 210 GW and concentrated solar power of approximately 88.7 GW is highlighted and recommended for not only the evolving EV market in Nigeria but also for the sustainable supply of electricity for the whole nation. In addition to advocating for setting deadlines for placing a ban on the importation and assembling of IC vehicles, which can speed up all aspects of the EV roadmap of the country, the study also identified and highlighted major areas for intensive research and development projects and programmes which include the manufacture of electric drives and electric motors, rechargeable batteries, and hydrogen fuel cells, EVs charging stations and the use of solar modules as onboard charging facilities. Hence, for a sustainable Nigerian EV industry, charging stations powered by off-grid and mini-grid solar photovoltaic power systems fitted with solar modules and its balance of system components as well as EVs powered by hydrogen fuel cells are essential. More so, for the next couple of decades, the focus on the R&D needs of the Nigerian EVs should be towards domesticating the vehicles in the country by the gradual increase in the local contents of the vehicles being produced from assembly plants.

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