THE NIGERIAN ACADEMY OF SCIENCE

PROCEEDINGS OF THE NIGERIAN ACADEMY OF SCIENCE

Official Journal of the Nigerian Academy of Science

SPECIAL EDITION ON

DECARBONIZATION OF TRANSPORT

Volume 16, No 1s, 2023

ISSN: 0794-7976
E-ISSN: 2705-327X

Published by:
The Nigerian Academy of Science
Academy House
8A, Ransome Kuti Road,
University of Lagos, Nigeria.
PMB 1004, University of Lagos Post Office, Akoka-Yaba, Lagos, Nigeria.

Tel: +234 (0) 808 962 2442

Website: www.nas.org.ng
Email: admin@nas.org.ng

Journal website: www.nasjournal.org.ng
Email: proceedings@nasjournal.org.ng

The Proceedings of the Nigerian Academy of Science (PNgAS) is supported by:

Tertiary Education Trust Fund (TETFund)

Federal Ministry of Science, Technology, and Innovation (FMSTI)

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About the Nigerian Academy of Science

The Nigerian Academy of Science (NAS) is the foremost independent scientific body in Nigeria, which was established in 1977, and incorporated in 1986. NAS is uniquely positioned to bring scientific knowledge to bear on the policies/strategic direction of the country and is dedicated to the development and advancement of science, technology, and innovation (STI) in Nigeria. The aims and objectives of the Academy are to promote the growth, acquisition, and dissemination of scientific knowledge, and to facilitate its use in solving problems of national interest. The Academy strives to do this by:

- Providing advice on specific problems of scientific or technological nature presented to it by the government and its agencies, as well as private organizations.
- Bringing to the attention of the government and its agencies problems of national interest that science and technology can help solve.
- Establishing and maintaining the highest standards of scientific endeavours and achievements in Nigeria, through the publication of journals, organization of conferences, seminars, workshops, and symposia, recognition of outstanding contributions to science in Nigeria, and the development of a working relationship with other national and international scientific bodies and academies.

As with national academies in other countries, NAS is a not-for-profit organization with a total membership (since inception) comprising 289 Fellows, elected through a highly competitive process, who have distinguished themselves in their fields, both locally and internationally. Some of her members have served as Vice-Chancellors of universities, Directors-General of government Parastatals and Ministers in federal ministries. The Academy, given its influence, also has the ability to attract other experts from around the country and internationally when needed.

NAS is Nigeria's national representative on such bodies as the International Science Council (ISC) – the umbrella body for all science associations and unions – and the Inter-Academy Partnership (IAP) – the umbrella body for all national science academies globally. The Academy is also a member of the Network of African Science Academies (NASAC).

Regionally, the Nigerian Academy of Science is one of eight founding academies of the Network of African Science Academies (NASAC) and has served on its Executive Committee until date. The Academy has played a major role in the development and establishment of academies in Africa. In November 2012 and 2017, the Nigerian Academy of Science hosted the African academies for the 8th and 13th Annual Meeting of African Science Academies (AMASA), in Lagos and Abuja respectively. The Nigerian Academy of Science has signed agreements with counterparts in many African countries (and beyond) to ensure scientific exchange and partnership.

As the peak independent scientific body in Nigeria, the Academy serves as the umbrella body for all science associations in the country, speaking for the same within and outside the country. The Academy holds periodic meetings with representatives of the associations to discuss the state of science in Nigeria and proffer solutions for improvement.

Some of the recent accomplishments of NAS include:

1. The development of a training manual on getting research into policy and practice,
2. The organization of an international conference on climate change in Lagos,
3. Implementation of a project on linking agriculture and nutrition,
4. The organization of a national consensus building workshop on the prevention of maternaland child mortality in Nigeria,
5. Conveying a media roundtable meeting to discuss issues of depression and suicide prevention,
6. Conveying a roundtable meeting to discuss the issues related to the Ebola Virus Disease epidemic that recently affected the country and the West African region,
7. Implementation of an intervention program to address the social and reproductive health issues of the youth in Ekiti and Nasarawa States of Nigeria,
8. The hosting of all African academies and other scientists at an international conference onSTI education and manpower development in Africa,
9. The organization of a summit to discuss the role of women in science and sustainable development in Nigeria,
10. The organization of a workshop to discuss the evolution of big data and artificialintelligence (AI), and the impact of education on training,
11. A consensus study on the evolving science advisory landscape in Africa.

About the Proceedings of the Nigerian Academy of Science

The *Proceedings of the Nigerian Academy of Science (PNgAS)* is the peer-review official journal of the Nigerian Academy of Science, one of Africa's leading science Academies and the foremost independent scientific body in Nigeria. The regular edition of the journal is a multidisciplinary publication, with the primary objective of disseminating original research, systematic reviews, and meta-analysis in all Science, Technology, Engineering, and Mathematics (STEM) disciplines, especially those that address national and regional developmental challenges. The journal publishes articles that are based on deep-seated formative research using large and multi-center datasets that leads to a better understanding of the context of science-related developmental challenges and appropriate pathways for accomplishing change in the following scientific disciplines:

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Editorial

Towards a sustainable future: The decarbonization of transport

Akii A. O. Ibhadode[1] & Collins E. Etin-Osa[2]

Affiliation
[1, 2]Department of Production Engineering, University of Benin, Benin City, Nigeria.

***For correspondence: email:** ibhadode@uniben.edu[1], etinosa.eruogun@uniben.edu[2]

Abstract
This themed edition of the Proceedings of the Nigerian Academy of Science delves into the pivotal topic of transport decarbonization, a critical component in the global strategy to combat climate change and promote environmental sustainability. It amalgamates a rich tapestry of research, case studies, and policy analyses focused on the multifaceted challenges and opportunities inherent in transitioning to a low-carbon transport system. Key areas of discussion include the complexities of electric vehicle (EV) adoption, the potential for invigorating local manufacturing sector through EV and e-bike production, the transformative impact of removing fuel subsidies on the uptake of solar power, and the intricate policy landscapes that underpin transport decarbonization efforts. By spotlighting Nigeria's unique context, from its policy strides to innovative local initiatives, this edition not only contributes to the academic discourse on sustainable transport but also aims to inspire actionable insights and collaborative efforts towards achieving a decarbonized transport future. This compilation seeks to foster a deeper understanding of the interplay between technological innovation, policy frameworks, and community engagement in driving the shift towards sustainable mobility solutions, with the hope of catalyzing further research and implementation of sustainable transport systems globally.

Keywords: *Decarbonization, electric vehicles (EVs), sustainable mobility, policy and innovation.*

Introduction
The decarbonization of transport refers to the global shift towards reducing and eventually eliminating carbon dioxide (CO2) emissions and other greenhouse gases (GHGs) produced by vehicles and infrastructure involved in the movement of people and goods. This monumental shift not only encompasses the transition to electric vehicles (EVs) but also involves innovations in public transport systems, non-motorized transport, and the integration of sustainable practices in logistics and urban planning.

The imperative for decarbonization
Transportation is a major contributor to global CO2 emissions, accounting for about a quarter of all GHG emissions [European Commission, 2020]. The urgency to decarbonize transport is underscored by the escalating climate crisis, evidenced by rising global temperatures, extreme weather events, and diminishing biodiversity [UNFCCC, 2015]. Decarbonizing transport is not merely an environmental imperative but a societal and economic one. It promises cleaner air,

reduced noise pollution, enhanced energy security, and an overall improvement in the quality of life.

Global and regional efforts in decarbonization

The global perspective

From the Paris Agreement's ambitious climate goals to countries laying down national strategies for slashing transport emissions, the global momentum is undeniable. The International Energy Agency (IEA) maps a path to a net-zero emission transport sector by 2050, spotlighting electrification, alternative fuels, and innovative mobility solutions as the way forward [IEA, 2020].

Regional responses

Europe leads with rigorous emissions standards and investments in greener transport alternatives, targeting a dramatic 90% cut in transport emissions by 2050 [European Commission, 2020]. Meanwhile, the challenges faced by developing regions, including infrastructure deficits and economic constraints, are being met with initiatives like Africa's Sustainable Transport Forum, which fosters sustainable mobility and regional collaboration [WHO, 2021].

Nigeria's strides toward greener transport

Amidst its unique challenges, Nigeria is taking significant steps towards a sustainable transport future.

- **National Policies:** Nigeria's commitment to the Paris Agreement, aiming for a substantial reduction in GHG emissions by 2030, is shaping its transport sector's transformation. The development of an Electric Mobility Policy marks a proactive move towards embracing EVs, showcasing a commitment to reducing fossil fuel dependence [Nigeria's National Determined Contributions, (2022)].
- **Regional Cooperation:** Engaging in regional dialogues and partnerships, Nigeria is part of broader African efforts to adopt eco-friendly transport solutions [Dioha *et al*., 2022].
- **Innovative Local Initiatives:** From Lagos's Bus Rapid Transit (BRT) system, which has already made a dent in the city's carbon footprint, to pioneering solar-powered electric bikes, local projects underscore the potential for scalable, sustainable transport solutions [Osoja *et al*., 2023].

Zooming in: Actions and innovations

- **Policy and Legislative Frameworks:** The impact of governmental policies, as seen in Norway's EV incentives and California's gasoline car sales ban, underscores the power of regulatory support in driving change [IEA, 2023].
- **Technological Breakthroughs:** The path to decarbonization is paved with innovation. Advances in battery technology, hydrogen fuel cells, and digital traffic solutions are making sustainable transport both viable and economical [Dioha *et al*., 2022].
- **Community Engagement:** Changing transportation habits starts with awareness. Public campaigns encouraging carpooling, public transit use, and biking are essential in fostering a culture of sustainability [NESG, 2023].

Challenges and opportunities

Globally, despite significant progress, challenges remain. These include the high upfront cost of EVs, the need for extensive charging infrastructure, and the environmental impact of battery production. A peculiar challenge for most developing countries such as Nigeria is the poor availability of grid electric power; EVs will put a increased pressure on electric power demand for such countries requiring greater investment on power infrastructure including off-grid systems. Yet, these challenges beckon opportunities for creativity, investment, and global cooperation, particularly for developing countries. By navigating their specific hurdles, from infrastructural gaps to fostering public buy-in, these countries can carve paths that advance green transport.

Conclusion

The decarbonization of transport is a complex but achievable goal. It requires a multifaceted approach, combining policy, technology, and behavioral change. As we advance, it is crucial to ensure that the transition is inclusive, addressing the needs of all sectors of society. The journey towards a decarbonized transport system is not just about reducing emissions; it is about creating a more sustainable, healthy, and equitable world.

This themed edition of the Proceedings of the Nigerian Academy of Science, Decarbonization of Transport, is an addition to the body of knowledge on this journey to attaining the decarbonization of transport. It presents discussions on EV adoption challenges, and opportunities for local manufacturing, conversion of conventional bike to e-bike, impact of fuel subsidy removal on solar power adoption, and policy issues on transport decarbonization. It is hoped that this edition of the Proceedings will engender more work in achieving sustainable transport solutions.

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Original Research Article

Empowering sustainable mobility in Nigeria: A study of conversion of conventional bicycle to electric bicycle

Collins E. Etin-Osa[1] & Deborah E. Etin-Osa[2]

Affiliation
[1]Department of Production Engineering, University of Benin, Edo State Nigeria.

[2]Department of Biology and Forensic Science, Admiralty University of Nigeria, Ibusa, Delta State, Nigeria.

***For Correspondence: email:** etinosa.eruogun@uniben.edu; **tel**: +234 806 407 8162.

Abstract
Amid global efforts towards the United Nations Sustainable Development Goals (SDGs), Nigeria's recent decision to eliminate fuel subsidies has amplified the search for sustainable transportation alternatives. In this study, a traditional pedal bicycle was converted into an electric bike (e-bike) in order to explore it as a viable solution to promoting eco-friendly commuting and reducing carbon emissions on Nigerian roads. The conversion cost was 174,500 in Nigerian currency, withthe e-bike demonstrating a range of 8.33km per charge, under a load of 136kg on a 36V, 4.8AH battery. At a speed of 15km/h, an estimated 1.44 volts per kilometer were consumed. Notably, thestudy revealed a 99.49% correlation between voltage depletion and distance covered per kilometer, indicating a highly predictable relationship between energy consumption and travel distance. These insights highlight the e-bike's potential advantages, particularly in terms of cost- effectiveness, presenting a compelling case for the adoption of electric bicycles as a means to decarbonize transportation in Nigeria.

Keywords: *e-bike, hub, SDGs, battery, speed controller*.

1.0 Introduction

The pursuit of the United Nations Sustainable Development Goals (SDGs) has ignited a global imperative to revolutionize transportation systems, placing environmental sustainability at the forefront. The recent cessation of fuel subsidies in Nigeria, a pivotal step towards economic reform, has significantly impacted the nation's transportation landscape [Inegbedion *et al*, 2020]. With the abrupt surge in commuting costs, a critical void has emerged, compelling individuals to seek innovative, sustainable alternatives. This article embarks on an in-depth exploration of one such innovative solution – the conversion of conventional pedal bicycles into electric bikes (e- bikes) [Matey, 2017, Lemire-elmor, 2020 and Schneider, 2021]. In the absence of immediate government palliatives, this conversion process represents a unique path towards both addressingimmediate transportation needs and contributing to the decarbonization of Nigerian roads.

The United Nations, in its transformative 2030 Agenda for Sustainable Development, underscores the necessity of reshaping transportation paradigms to achieve SDG targets. SDG 11, focused on sustainable cities and communities, highlights the significance of reducing carbon emissions and enhancing the efficiency of urban transportation systems [United Nations, 2015]. Nigeria, a nation embracing both the challenges and opportunities of development, has taken a bold step in discontinuing fuel subsidies to promote fiscal responsibility and allocate resources more judiciously [World Bank, 2022]. However, this policy shift has cascading effects on the populace's ability to access affordable transportation, necessitating swift, sustainable interventions.

As Nigeria navigates this dynamic transition, the absence of immediate government interventions beckons individual ingenuity and resourcefulness [Khalid *et al*, 2014]. The e-bike conversion exemplifies a grassroots movement that addresses immediate needs while aligning seamlessly with global sustainability aspirations. By transforming pedal bicycles into electrically assisted modes of transportation, individuals can reclaim mobility without resorting to traditional fuel-dependent vehicles [Brand & Thompson, 2019]. In this context, the e-bike conversion emerges as a beacon of innovation, revealing the potential for individuals to proactively shape their transportation future.

This article embarks on an exploration of transforming conventional pedal bicycles into e-bikes, offering an affordable, eco-conscious solution to the challenge of commuting in a post-subsidy era. As government palliatives are yet to be introduced, the study showcases individual ingenuityand resourcefulness, exemplified by the successful e-bike conversion detailed herein.

2.0 Materials and methods

2.1 *Materials*

At the core of the e-bike conversion lies a meticulous integration of crucial components. The pedal bicycle before conversion is presented in Figure 1, the chosen bicycle boasts a 660mm (26-inch) rim diameter, 50mm (1.96-inch) thickness, and 36 spokes, ensuring durability and stability on diverse road surfaces.

Figure 1: Bicycle before conversion

The conversion incorporates a lithium iron battery, featuring a capacity of 4.8Ah, and a 36V, 16amps speed controller designed to regulate power delivery seamlessly. The selection of battery and controller shown in Figure 2 was based on the minimum recommendation of Battery University [2023].

Figure 2: Speed controller and Lithium iron battery

A pivotal element in the conversion is the electric hub motor, repurposed from an old scooter, with a power rating of 350W and a diameter of 135mm. Figure 3 shows some of the tools used in the conversion process.

Figure 3: hand drilling and grinding machine.

Figure 4 shows the drilling, grinding, and painting operation performed on the hub. 36 holes were uniformly drilled and distributed around its circumference using a 2.5mm drill bit, to secure and attach the motor hub to the bicycle frame.

Figure 4: Drilling, grinding, and painting operation of hub motor.

2.2 Methods

2.2.1 *Design calculations for front wheel electric bicycle conversion*

The conversion of a conventional bicycle into an e-bike requires design considerations to ensure optimal performance and safety [Electric bike report, 2021]. The power output of the motor (P_{motor}) was calculated using equation 1.

$$\boldsymbol{P_{motor}} = \boldsymbol{V_{battery}} \times \boldsymbol{I_{motor}} \quad (1)$$

where $\boldsymbol{V_{battery}}$ is the battery voltage (36V), and $\boldsymbol{I_{motor}}$ is the current drawn by the motor. Since $\boldsymbol{P_{motor}}$ is rated at 350W, $\boldsymbol{I_{motor}} \approx$ 9.72amps. the salvaged speed controller would work just fine since it has the amp rating of 16amps.

Torque ($\boldsymbol{T_{motor}}$) generated by the motor can be determined from equation 2:

$$\boldsymbol{T_{motor}} = \frac{\boldsymbol{P_{motor}}}{m_{\boldsymbol{motor}}} \quad (2)$$

The angular velocity ($m_{\boldsymbol{motor}}$) in radians per second of a 36v 350w scooter hub motor depends on the speed and the radius of the wheel. According to L-faster, [2023], the speed of a 36v 350w scooter hub motor can range from 600 to 1100 rpm, which is equivalent to 62.8 to 115.7 rad/s. Using the lower bound of 62.8 rad/s, $\boldsymbol{T_{motor}}$ ≈5.57Nm.

In the context of front wheel conversion, the torque applied to the wheel (T_{wheel}) is estimated as:

$$\boldsymbol{T_{wheel}} = \frac{\boldsymbol{T_{motor}}}{\boldsymbol{G}} \quad (3)$$

where G represents the gear ratio between the motor and the wheel. For this scenario, no gear exists so G = 1. Front wheel torque $\boldsymbol{T_{wheel}}$ ≈5.57Nm.

Furthermore, the maximum speed (S_{max}) achievable by the e-bike can be estimated using the relationship between speed, wheel diameter (D_{wheel}), and motor angular velocity of equation 4:

$$S_{max} = m_{motor} \times \frac{D_{wheel}}{2} \quad (4)$$

For wheel size of 0.6604m, $S_{max} \approx 20.74m/s$ or 74.66km/h

After the fabrication, the modified electric hub motor was given to a bicycle mechanic for spoke lacing.

Figure 5 shows the completed electric bicycle.

Figure 5: Completed front wheel ebike

3.0 Results and discussion

3.1 *Bicycle test performance*

Table 1 shows the battery usage in percentage, battery usage in volts and the distance traveled during a one-week bicycle usage test at an average speed of 15km/h and maximum weight of 136kg.

Table 1: Bicycle performance test

Battery percentage (%)	Battery Voltage drain (volts)	Distance Traveled (km)
100	42	1
88	40.56	2
76	39.12	3
64	37.68	4
52	36.24	5
40	34.8	6
28	33.36	7
16	31.92	8
4	30.48	8.33

Regression analysis was employed to analyze the performance of 4.8Ah, 36V lithium-ion battery used to power the bicycle. Equation 5 describes the mathematical relationship that exist between distance covered and battery voltage drain of the e-bike.

Battery voltage drain (volts) = 43.63 – 1.500×Distance (km) (5)

The model summary of Table 2 shows the regression analysis of the bicycle having an R^2 of 99.49% with minimal noise.

Table 2: Model Summary of bicycle performance.

S	R-sq	R-sq(adj)
0.300332	99.49%	99.42%

The fitted line plot from the regression analysis in Figure 6, shows good agreement between battery drain and distance covered. An estimated 1.44volts is drawn per kilometer at 15km/h.

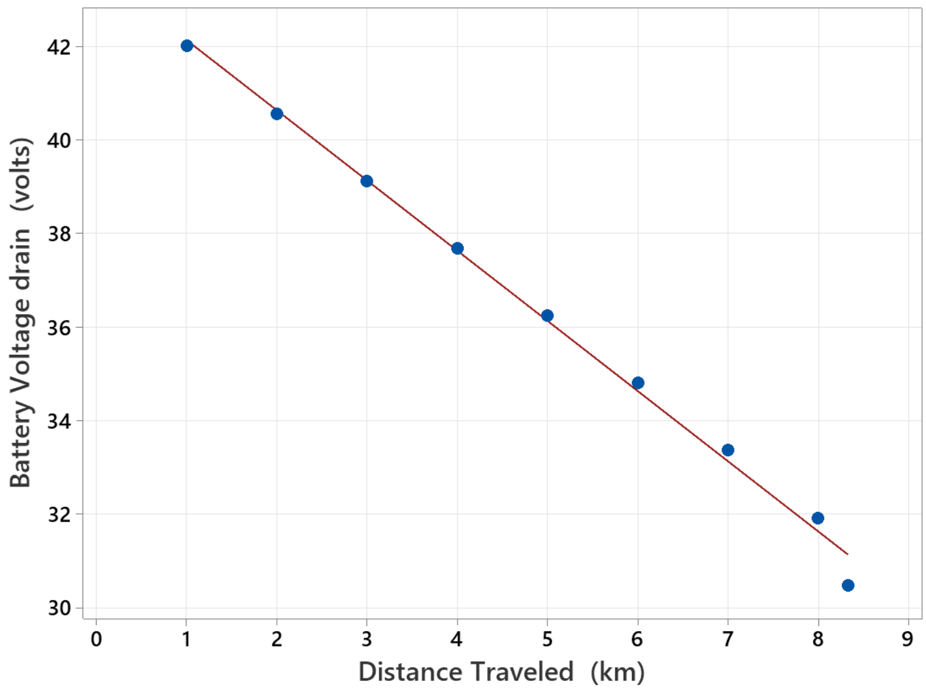

Figure 5: Fitted line plot of volt/km performance of the electric bicycle.

Given the motor's specifications, the e-bike was capable of assisting with carrying a weight of 136kg on relatively flat terrain and moderate inclines. However, the performance decreased on steeper hills and rough terrain. The observed bike max. speed ranged between 11km/h – 20km/h on a flat surface and 7km/h – 10km/h on slope roads.

A torque of 5.5Nm might be sufficient for many urban and flat terrains in Nigeria, especially if the motor is appropriately geared. However, when dealing with steep hills, rough terrain, or frequent starts and stops, a higher torque motor might provide better performance and comfort. For this design, the pedal assist connected to the rear wheel can support the front wheeled motor.

3.2 Fabrication challenges

The primary challenge encountered during fabrication involved drilling 36 holes into the hub of the electric motor. To facilitate precise drilling, it is recommended to employ a robust center punch for guiding the drill bit effectively. To achieve this, a circle matching the diameter of the hub motor was drawn on a piece of paper and divided into 36 equal sections. This paper template was then securely attached to the hub motor, aligning the centers of both the template and the hub. A center punch was subsequently used to accurately mark the drilling points.

3.3 Cost analysis

Table 3 presents the breakdown of costs associated with assembling the electric bike. Notably, this overview does not account for labor costs, given the project's DIY nature aimed at lowering transportation expenses and contributing to the decarbonization of Nigerian roads.

Table 3: Cost of fabricated the electric bike.

Item	Cost
Bicycle (Used)	N50,000
Lithium-ion battery 4.8Ah, 36V	N40,000
Speed Controller 36/48v, 500W	N28,000
Throttle	N3500
Electric Hub	N50,000
Wires	N3000
Total	**N174,500**

A commercial electric bicycle from China with same specification, cost N450,000 (minimum estimate). Fabricating this bike would save N276,000.

3.4 Comparison of the converted E-bike with conventional pedal bike

The comparison between a converted electric bike (e-bike) and a conventional pedal bike will be grounded in factors like efficiency, convenience, and energy requirements.

Advantages of the E-bike over the Conventional Bike

1. **Assisted Cycling**: E-bikes come with an electric motor that provides assistance when pedaling, which can be particularly beneficial for climbing hills or when the rider needs a break from pedaling. This makes longer distances or challenging terrains more accessible to a broader range of people.
2. **Speed**: Due to the motor assistance, e-bikes typically allow for higher average speeds compared to pedal bikes, making them a faster option for commuting, and traveling.
3. **Reduced Effort**: The motor assistance on e-bikes reduces the amount of physical effort required, which can make cycling more appealing for commuting, especially to avoid arriving sweaty at the destination.
4. **Inclusivity**: E-bikes can cater to a wider demographic, including those who may not have the physical ability or desire to exert the effort required by conventional bikes, thus promoting greater inclusion in cycling.

Energy Requirements

Conventional Bike: The energy required entirely depends on human power. According to various studies, cycling on a conventional bike requires about 30-40 calories (an approximation that can vary widely) of human energy expenditure per kilometer, depending on factors like speed, rider weight, and terrain [Brand *et al*, 2022] and [Raynolds, 2023].

E-bike: E-bikes use electrical energy to assist the rider, which means the total energy expenditure is a combination of human calories and electrical energy. The amount of electrical energy required can vary depending on the efficiency of the motor, the level of assistance used, and the conditions (terrain, weight, etc.). For example, an e-bike might consume around 5-20 Wh per kilometer (a broad range that reflects different usage patterns and conditions). The human calorie expenditure would be less than that of a conventional bike due to the motor assistance, though the exact amount would depend on how much the rider chooses to pedal [Raynolds, 2023].

E-bikes offer advantages in terms of reduced physical effort, accessibility, and potentially faster travel times. However, they require electrical energy to operate, which introduces an additional energy cost not present with conventional bikes. Nonetheless, even when considering the energy required for charging, e-bikes are generally seen as an efficient and environmentally friendly mode of transportation, especially when the electricity comes from renewable sources.

3.5 Economic and environmental advantages

The conversion of conventional bicycles into e-bikes offers compelling economic and environmental benefits, particularly in the Nigerian context. In a landscape devoid of fuel subsidies, commuting costs have escalated, placing financial strain on the populace [Kim *et al*, 2014 and Al Jazeera, 2023]. The process of converting existing bicycles into e-bikes leverages current bike parts, markedly diminishing the costs associated with acquiring brand-new e-bikes. Additionally, e-bikes contribute to a significant decrease in greenhouse gas emissions and help ease vehicle congestion on roads. The shift towards biking, as opposed to car travel, not only mitigates road congestion and the emission of harmful gases like carbon monoxide but also aligns seamlessly with the Sustainable Development Goals (SDGs) focusing on sustainable cities and climate action.

3.6 Promoting sustainable behaviour

The transformation of a traditional pedal bicycle into an electric bike shine as a powerful example, highlighting how individuals can undertake these conversions independently, bypassing the need for governmental intervention to mitigate the soaring transportation costs. This initiative goes beyond providing a solution for sustainable transport; it cultivates a mindset of active environmental stewardship. The triumph of the e-bike conversion project illustrates the significant impact of grassroots actions, driving forward a communal push towards sustainable urban transport solutions.

4.0 Conclusion

A conventional pedal bicycle was successfully converted to an electric bike. It can travel at 11km/h – 20km/h at a load of 136kg and consuming an average of 1.44 volts per kilometer. This is in stark contrast to the 30-40 calories expended per kilometer when using a conventional bicycle for daily commutes. The total cost of this conversion is estimated to be N174,500. These findings offer a compelling argument for the adoption of electric bikes (e-bikes) as a sustainable transportation solution in Nigeria, especially in the wake of fuel subsidy removals. The conversion of traditional pedal bicycles to e-bikes not only presents an eco-friendly alternative but also aligns with global sustainability goals and the urgent need for decarbonization of transportation systems. Thus, the conversion of pedal bicycles to e-bikes emerges as a viable and strategic initiative to address the dual challenges of achieving sustainable development and reducing carbon emissions in Nigeria's transportation sector. By embracing e-bikes, Nigeria can make significant strides towards environmentally sustainable commuting practices, thereby contributing to the global effort to mitigate climate change and promote sustainable living.

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Original Research Article

Opportunities for local electric vehicle manufacturing in Africa

Akii A. O. Ibhadode

Affiliation
Department of Production Engineering, University of Benin, Benin City, Nigeria.

***For correspondence: email:** ibhadode@uniben.edu; **tel**: +234 802 343 8765

Abstract
In order to achieve the Sustainable Development Goals (SDG) of the United Nations on Clean Energy, Sustainable Industrialization and Climate Change, there is an urgent call on Africa to decarbonize transportation. Achieving these goals requires that Africa grows its current, largely, non-existent EV fleet to a reasonable level in the near future, to counter harmful emissions from fossil fuel vehicles. This paper discusses the opportunities available to African entrepreneurs on investing in electric vehicle (EV) manufacturing. It also discusses the factors militating against the establishment of a viable automotive sector. To exploit the opportunities offered despite the limitations, the paper advocates a paradigm shift from the conventional vehicle assembly of foreign vehicles to one in which African original designs are made in low-cost, low-volume vehicle manufacturing plants consisting of general-purpose workshop equipment and intensive labour such that the whole value chain for vehicle manufacturing is developed.

Keywords: *Sustainable development goals, automobiles, electric vehicles, vehicle manufacturing plants.*

1. Introduction

Africa is usually not considered a manufacturing continent due to a number of factors such as poor industrial infrastructure, and lack of appropriate skills among others, despite the large reserves of raw materials. Whereas the World manufacturing output in 2022 was 16,291 billion USD, that of Sub-Saharan Africa was only 229 billion USD representing 1.4% of World manufacturing [1]. To achieve the United Nations Sustainable Development Goals (SDGs) of 7 on Clean Energy, 9 on Sustainable Industrialization and 13 on Climate Change, for which the transport sector contributes 24% of CO_2 emission [2], Africa must decarbonize its transport sector. To achieve this, a great emphasis is placed on transition from fossil fuel transportation to renewables such as electric vehicles (EVs) [3, 4].

The President of African Development Bank Group at a 2022 Investment Forum in Morocco stated that the size of global EV market is estimated to increase from the current 7 trillion USD to 57 trillion USD by 2050, and that the future depends on Africa because, Africa accounts for the largest source of green materials for the development of EVs [5]. To fully exploit this advantage would require enormous investments by African countries especially in increasing its EV fleet. If the conventional response to this increase in demand on number of EVs is to be met by importation or mere vehicle assembly, this will further exacerbate the precarious economies of African countries. Thus, there is the need for Africa to develop the value chain for EV manufacturing.

Currently, EVs are gradually gaining ground in Africa through the major pathway of global automobile companies such as Nissan Motor Co. Ltd, Volkswagen AG, Tesla Inc., Geely Auto Group, BMW AG, Kia Corporation, Volvo Car Corporation, Mercedes –Benz Group, Groupe Renault, Hyundai, etc. through assembly plants in some countries such as South Africa, Morocco, Tunisia, Algeria, Egypt, Kenya, Nigeria, etc. An example is the Hyundai Kona EV launched in 2021 in Abuja, Nigeria [6].

Other pathways of EV introduction in Africa are through (i) new start-ups, (ii) conversion of internal combustion engine (ICE) vehicles to EVs and (iii) research and development (R&D) in universities and research institutes.

From internet search, old and new EV start-ups in Africa, include Kiira Motors in Uganda; JET Motors, Innoson Vehicle Manufacturing Company, and Siltech World in Nigeria; BasiGo, Mobius Motors and Nopea Ride (though recently folded up) in Kenya; Mellow Vans in South Africa; Greenfoot Africa in Tanzania; Ampersand in Rwanda; Solar Taxi in Ghana; and EV Station, Neo Kozmo, Hubbert, and EGIKE in Egypt. Algeria, Morocco, and Tunisia also have EV companies. Of these, special mention should be made of Kiira Motors in Uganda which was started in 2008 jointly owned by the Ugandan Government and Makerere University which stemmed from a research project at the university [7]. Kiira Motors has built original designs of EVs which are yet to be in the market.

The other pathway of EV introduction in Africa is through conversion of ICE vehicles to EVs. A good example is the Nigerian company based in Maiduguri which converts petrol minibuses to EVs [8].

At the R&D level, some African Universities are developing EVs, where the Kiira Motors, Uganda is a good example that has progressed to a national investment. Other examples at low levels of investment are the EVs produced at the University of Nigeria, Nsukka and the University of Lagos both in Nigeria [3].

With these activities on EV introduction in Africa, especially at the R&D level, where original EVs are being developed, it is important for these prototype vehicles to progress to the market. Thus, this paper discusses the opportunities that exist for local EV manufacturing in Africa, with the hope that investments can be made for these locally developed vehicles to enter the automobile market.

2. Opportunities for local electric vehicle manufacturing

The following are some opportunities that could be exploited for EV manufacturing in Africa.

2.1 Simpler design of EVs

EVs have simpler vehicle structure than ICE vehicles because they do not require complex mechanical transmission parts such as gearboxes, drive shafts and axles, and such other parts as exhaust system and fuel tank. This gives more space in an EV than the equivalent ICE vehicle. The absence of an ICE in EVs eliminates substantially vibrations and noise. The ICE is inherently eccentric in operation which promotes vibrations in the vehicle. The absence of drivetrain vibrations eliminates the need for complex mountings for the drivetrain in EVs. The explosions in ICE resulting from the combustion of fuel-air mixture, produce noise, which is non-existent in EVs, to the extent that some devices are incorporated in EVs to generate noise at low speeds for pedestrian safety.

Simpler structural design of EVs will readily allow the use of standard material sizes and shapes by welded construction eliminating the use of expensive production equipment and tools in low technology environments.

2.2 Availability of raw materials

Africa is blessed with a great number of raw materials suitable for EV manufacture. Table 1 lists the main parts of an EV, the main materials required for making them, the infrastructure required, and the African countries that have these materials and infrastructure.

Table 1: EV materials and availability of infrastructure for their manufacture

Main Part of EV	Group of Materials	Infrastructure Required	Availability in Africa
Frame/chassis	High strength steels	Steel plants and mills	Africa has a number of steel plants in the countries listed below [9]: • Algeria • Angola • Egypt • Ghana • Kenya • Libya • Morocco • Mozambique • Namibia • Nigeria • South Africa • Uganda • Zimbabwe
	High strength aluminium alloys/aluminium metal composites	Aluminium smelting plants	Major mines and smelters are found in the countries listed below [10]: • Cameroon - 3 • Ghana – 2 • Guinea – 7 • Mozambique – 1 • South Africa – 1
	Magnesium (not much in use though lighter than aluminium but quite expensive)	Magnesium smelting plants	No information

Body, internals, bumpers, etc.	Steel sheets	Same as for frame/chassis	
	Aluminium sheets		
	Plastics	Petroleum Refinery and Petrochemical plants	Major refineries in Africa with 100,000 barrels per day capacities are given below [11]: (i) Algeria • Skikda Refinery (356,500BPD) (ii) Egypt • Alexandria Midor Refinery (160BPD) • Cairo Mostorod Refinery (142,000BPS) • El Nasr Refinery (132,000BPD) • Alexandria El Mex Refinery (117,000BPD) (iii) Libya • Ziwayah Refinery (120BPD) (iv) Nigeria • Dangote Refinery (650,000BPD) • Port Harcourt Refinery (210,000BPD) • Warri Refinery (125,000BPD) In addition to these there are many other smaller refineries in different African countries
Electric Motor	Magnets (iron, cobalt, nickel)	Heat treatment shops/plants	No information
	Steel sheets	As above	
	Copper wire	Copper smelters	Major copper producers in Africa are [12] • Botswana • Democratic Republic of Congo • Namibia • South Africa • Uganda • Zambia
		Electric cable manufacturers	A great number of electric cable manufacturers exist in Africa
	Insulating materials (polymer resin, ceramic filler)	• As for petrochemical plants for polymers • Ceramic materials are also abundantly available	

Battery	Lead	Lead smelters	Lead mines exist in [13] • South Africa • Tunisia • Namibia • Morocco • Algeria • Kenya • Nigeria
	Acid	Chemical plants	There are a great number of acid manufacturers in Africa
	Nickel	Nickel smelters	Nickel mines exist in [14] • South Africa • Madagascar • Ivory Coast • Zimbabwe • Zambia • Morocco
	Lithium	Lithium smelters	Leading producers are [15] • Zimbabwe • Namibia • Democratic Republic ofCongo • Mali • Nigeria
Transmission/ single-speed reducers	Steels	Machine shops	Machine shops exist all over Africa
Thermal system cooling/radiator	Steel	Radiator manufacturers	A number of manufacturers exist in anumber of African countries
	Aluminium		
Electronic devices (Power inverter, power electronics controller, DC-DC converter, on-board charger, chargeport)	Entails use of electronic components such as resistors, transistors, capacitors, inductors, diodes, etc. to design and fabricate integrated circuits and others used to build the power inverter, power controller, DC-DC converter, charger, etc.	Specialized manufacturers exist in the world from which these basic components can be sourced cheaply to make desired devices	No information

2.3 Existing vehicle manufacturing infrastructure:

Africa’s role in the global automotive industry is limited. An energy transition research and technologies company, Thunder Said Energy (https://thundersaidenergy.com/) reported that current global fleet of passenger and light commercial vehicles is 1.7 billion of which 60 million are in Africa [16]; that is, Africa has about 3.5% of global fleet compared to 20%, 18.8% and 17% of Europe, China, and the United States respectively. In a statement announcing the election of the new President of the African Automotive Association of Automotive Manufacturers (AAAM) in 2023, the President stated that it will grow Africa’s automotive manufacturing industry from the current 1.1 million to 3.5 – 5 million vehicles annually in 2035 [17].

There is some existing vehicle manufacturing infrastructure in Africa. This infrastructure exists in the following countries: South Africa, Morocco, Algeria, Egypt, Tunisia, Nigeria, Ghana, Kenya and Uganda among others. The global automotive companies, listed earlier, have manufacturing plants in them. Most of these plants are essentially assembly plants for semi-knocked down (SKD) and completely – knocked down (CKD) parts. Some of these companies especially in South Africa, Morocco and Algeria have active auto parts manufacturing sub-sector.

Aside from the popular global brands listed above, Africa is increasingly developing its own home-grown vehicles as shown in Table 2.

Table 2: Some local vehicle brands manufactured in Africa (Extracted from the internet)

Vehicle Brand	Country	Year Founded	Ownership
Innoson Vehicle Manufacturing (IVM)	Nigeria	2007	Private
Wallys Car Company	Tunisia	2006	Private
Kiira Motors Company	Uganda	2008	Government
Katanka Automotive Ile Co. Ltd.	Ghana	1994	Private
Mobius Motors Company	Kenya	2011	Private
Laraki Manufacturing Company	Morocco	1999	Private
Birkin Cars Ltd	South Africa	1982	Private
Advanced Automotive Design	South Africa	1995	Private

Thus, with the availability of these manufacturing/assembly infrastructure, they could be points for starting EV manufacturing in Africa. However, more importantly, the body of skills in these plants could be harvesting grounds for African start-ups in EV manufacture of local designs.

2.4 Growing economies

Table 3 shows the real GDP growth rates for 63 countries having a growth rate of at least 4.0%. These represent the fastest growing economies in 2023. With 29 African countries in these 63 fastest growing economies in the world, there is a high prospect that a number of African economies will continue to experience high growth rates to support local vehicle manufacturing.

Table 3: Fastest Growing Economies in 2023 (Extracted from [18])

Country	Growth Rate (%)	Remark	Country	Growth Rate (%)	Remark
Antiga and Babuda	5.6		Laos	4.0	
Armenia	7.0		Liberia	4.6	Africa
Bahamas	4.3		Libya	12.5	Africa
Bangladesh	6.0		Macao	74.4	
Barbados	4.5		Madagascar	4.0	Africa
Belize	4.0		Malaysia	4.0	
Benin	5.5	Africa	Maldives	8.0	
Bhutan	5.3		Mali	4.5	Africa
Burkina Faso	4.4	Africa	Mauritius	5.1	Africa
Cape Verde	4.4	Africa	Mongolia	5.5	
Cambodia	5.6		Montenegro	4.5	
Cameroon	4.0	Africa	Mozambique	7.0	Africa
Chad	4.0	Africa	Niger	4.1	Africa
China	5.0		Panama	6.0	
Costa Rica	4.4		Paraguay	4.5	
Djibouti	5.0	Africa	Philippines	5.3	
Dominica	4.6		Republic of Congo	4.0	Africa
DR Congo	6.7	Africa	Rwanda	6.2	Africa
Egypt	4.2	Africa	St. Kitts and Nevis	4.9	
Ethiopia	6.1	Africa	St. Vincent	6.2	
Fiji	7.5		Samoa	8.0	
Guinea	5.9	Africa	Senegal	4.1	Africa
Gambia	4.6	Africa	Seychelles	4.2	Africa
Georgia	6.2		Tajikistan	6.5	
Guinea Bissau	4.5	Africa	Tanzania	5.2	Africa
Guyana	38.4		Togo	5.4	Africa
India	6.3		Uganda	4.6	Africa
Indonesia	5.0		Turkey	4.0	
Ivory Coast	6.2	Africa	Uzbekistan	5.5	
Kazakhstan	4.6		Venezuela	4.0	
Kenya	5.0	Africa	Vietnam	4.7	
			Zimbabwe	4.1	Africa

2.5 Large population

Africa's population was put at 1,477,304,021 as of Thursday, December 28, 2023, by the United Nations [19]. Such a large population could easily support local vehicle manufacturing especially in highly populated countries such as Nigeria, Ethiopia, Egypt, DR Congo, South Africa, Tanzania, and Kenya. More emphasis would be placed on local manufacture of mass transit vehicles such as buses.

2.6 National automotive policies

A number of African countries have national policies on the automotive industry. The policies tend to have incentives to promote local industry. Table 4 summarizes the government policies on vehicle manufacturing by some African countries. It is hoped that these policies will support the rapid growth of local EV manufacturing in Africa.

Table 4: Government policies on vehicle manufacturing in some African countries

COUNTRY	POLICY	
	NAME	MAIN THRUST
Nigeria	New National Automotive Industry Development Plan (NADIP) from 2023 to 2033 [20]	Target set to reach 40% local content and 30% locally produced electric vehicles by 2033
South Africa	South African Automotive Masterplan (SAAM) 2021-2035 [21]	To produce 1% of global vehicle production, or 1.4 million vehicles, per annum in South Africa by 2035
Morocco	Plan for Industrial Acceleration / Plan d'Accélération Industrielle (PAI)/ National Pact for Industrial Development / Pacte National pour l'Emergence Industrielle (PNEI) [22]	Develop Morocco into a major sourcing base for Europe
Egypt	Egyptian Automotive Industry Development Program (AIDP), 2022 [23]	To establish itself as a main gateway for emerging vehicle markets in Africa
Ghana	Ghana Automotive Development Policy (GADP) [24]	To make Ghana a fully integrated and competitive industrial hub for the Automotive Industry in the WestAfrica sub-region
Zimbabwe	Motor Industry Development Policy 2018 – 2030 [25]	Based on five strategies-assemblyof semi-knocked down and completely knocked down kits, government support, control of second-hand imports,categorization and regulation of the industry and the development of the motor industry value chain and cluster

3. Discussion

3.1 *Major factors militating against local vehicle manufacturing*

3.1.1 *Poor learning outcomes from educational institutions*: Most African countries are suffering from the consequences of colonial educational system which trained Africans for the exploitation of natural resources for export to the colonial masters which required only the lowest levels of learning in the cognitive domain. These levels are based on knowledge of factual information which are most amenable to testing in examinations. There is little or no emphasis on "understanding at higher levels which is indicated by more complex skills in evaluation, synthesis, or the creation of new information" [26]. This is why, though Africans may excel educationally, such academic excellence is not translated to solving the myriads of problems confronting Africa. For example, providing low-cost vehicles for mass transportation is one of these problems. Most engineers who should be in the forefront of designing and developing these vehicles do not have the requisite skills needed. For example, some may find it difficult to derive differential equations for practical life situations involving variations but can provide solutions to already given differential equations. From the experience of this author in Nigerian universities, this shortcoming is shown glaringly in most final year mechanical engineering students not being able to derive from first principles the power requirement of a machine to be designed for a particular purpose.

To increase economic prosperity in Africa, African educational systems should be made functional to drive solutions to problems besetting the continent.

3.1.2 Lack of relevant technical capacity: Closely tied to poor educational system of most African countries is the lack of relevant technical capacity for development. The system places much emphasis on theoretical knowledge to the detriment of practical application of knowledge. For example, while Nigeria had 33,246 junior secondary schools and 27,042 senior secondary schools in 2018/2019 academic session, there were only 123 technical schools [27]. Virtually all secondary school students are headed to universities which only produce high level manpower. Without a lower-level technical manpower to carryout shop floor operations, the high-level manpower will be redundant. This explains why there is such a high level of unemployment of Nigerian university graduates while there is a gross shortage of craftsmen and artisans needed in industries.

African countries should study and possibly adapt the Chinese educational system that is able to produce technical skills covering virtually all aspects of industrial production.

3.1.3 Poor Industrial infrastructure: Loosely, industrial infrastructure may refer to the systems or assets that are used to produce goods and services in a country or region. The more developed this is, the more goods and services the country is able to produce such as China, the USA, Japan, Germany, etc. Many African countries have poor industrial infrastructure; and that iswhy, most are import dependent on industrial goods of which the automobile is one. To be a seriousautomobile manufacturing country, functioning steel and petrochemical plants, among others, are indispensable.

3.1.4 Poor capital availability: Henry Sheykin [28] reports that cost of establishing a vehicle production plant in the United States could range from as low as 12 million USD to 2 billion USD or even more depending on features desired. Startup cost could range from 12 million USD to 29.5 million USD, while that for an assembly plant could range from 7.5 million USD to about 27 million USD. These capital outlays are colossal, which may be beyond the reach of most African entrepreneurs.

3.2 Paradigm shift

The above factors militating against establishment of vehicle manufacturing plants for original local designs in Africa present very daunting odds despite the available opportunities identified earlier. To overcome these, a paradigm shift is required. Going through the conventional route to establish these vehicle manufacturing plants may be very difficult. Thus, we suggest a paradigm shift from the conventional assembly plant route to a vehicle manufacturing plant consisting essentially of general-purpose workshop equipment, simple materials handling equipment, and jigs and fixtures, accompanied with intensive labor. Hopefully this may drastically reduce the cost of purchase of manufacturing equipment and machinery, and for construction and setup of manufacturing facility. This paradigm shift is based on the following reasons:

i. That if Henry Ford could produce 11 - 12 cars per month of Ford Model T with 1908 technology, we in Africa may be able to do at least the same with the low-cost technology of 2024 [29].
ii. Mass commuters in Africa do not necessarily require sophisticated state-of-the-art vehicles. For example, a number of Sub-Saharan African cities use tricycle rickshaws, popularly called 'keke' in Nigeria, for mass transportation. Thus, African vehicle designs could be made very simple and as functional as the keke.
iii. There is high unemployment in a number of African countries. For example, in Nigeria, about 53.40% of youths were unemployed in 2022 according to the National Bureau of Statistics [30]. Thus, it may be more prudent to use labor-intensive production methods in such a country than using expensive sophisticated automated production facilities requiring fewer labor.
iv. Poverty rates in Africa are high. For example, Sasu, D.D [31] reported that in 2022, an estimated population of 88.4 million people in Nigeria lived in extreme poverty. With such high level of poverty, it may be difficult to find interested entrepreneurs being able to mobilize 12 million USD – 2 billion USD required to establish a vehicle manufacturing plant.

3.3 Anticipated benefits of the paradigm shift

i. It will help to have a home-grown automobile industry in which the whole value chain of automobile production becomes internalized, leading largely to non-dependence on foreign technology.
ii. As a consequence of the above, there will be proliferation of automobile parts manufacturers such as for electric motors, batteries, inverters, controllers, etc. for EV; and even internal combustion engines and their parts.
iii. Having a functional home-grown automobile industry will have a great multiplier effect on the economy creating wealth and eradicating poverty.

3.4 Low-cost vehicle manufacturing plant

Putting side by side the opportunities for establishment of vehicle manufacturing plants for original African designs and the factors militating against this, the African automotive industry could receive a boost if entrepreneurs take advantage of the paradigm shift suggested above for local EV manufacturing in Africa. A 2020 study showed that a capital investment of N838,073,958, and a one year working capital of N2,033,620,298 are required to establish a low-cost, low-volume vehicle manufacturing plant to produce 14 units per day of a one-ton utility truck. The payback period was estimated to be 14 months, based on a production cost of N1,600,000/vehicle and a selling price of N2,500,000 [32]. This 2020 study [32] suggested a paradigm shift as above, in vehicle manufacturing in a low technology environment such as obtains in most African countries. The salient points of the study which could guide investors are summarized below:

i. A lightweight utility vehicle with a load carrying capacity of 1 ton was designed and constructed. It was powered with an 8.5kW internal combustion engine and had a driving speed of about 75km/hour [33, 34].

ii. The vehicle parts were made with jigs and fixtures designed in the project, to fit with lot production.
iii. A production plant was designed to produce 14 units of the vehicle per day. The production plant occupies a space of 1.68 hectares, consisting of six separate plants, namely: Wheel Assembly Plant, Chassis & Carriage Plant, Bumper and Dashboard Plant, Seat & Carpet Plant, Painting Shop, Vehicle Assembly Plant.
iv. The overall plant also consisted of a General Mechanical & Electrical Workshop, Warehouse, and an Administrative Building
v. The plant was estimated to have 205 workers including management staff.
vi. The lightweight utility vehicle developed had over 80% local content.
vii. The most significant step in the study was to design the vehicle manufacturing plant with general-purpose workshop equipment and tools along with appropriate jigs and fixtures for mass production. This made the cost of establishing this integrated vehicle manufacturing plant (2.1 million USD) negligible compared to 12 million – 2 billion USD in establishing such a plant [28]. The downside to the use of general-purpose workshop equipment is that it will be labour intensive and low volume production. However, with the high rate of unemployment in Nigeria and the total absence of a truly Nigerian-designed production vehicle with the attendant multiplier effect on the economy, these disadvantages are more than compensated for.

To break loose from the vicious cycle of poverty pervading African countries, this vehicle manufacturing model is recommended for African entrepreneurs interested in venturing into EV manufacturing. With time, capital will be accumulated for investment in state-of-the-art vehicle manufacturing equipment.

4. Conclusion

Opportunities exist for EV manufacturing in Africa. These include simpler vehicle design compared to fuel vehicles, abundance of relevant raw materials, existence of some amount of vehicle manufacturing infrastructure, growing African economies, large African population, and favorable government policies on automobile manufacturing. However, some militating factors against this include poor learning outcomes from educational institutions, lack of relevant technical capacity, and poor industrial infrastructure. To overcome these shortcomings and take advantage of the opportunities, a paradigm shift is required in the establishment of vehicle manufacturing plants from the conventional assembly of vehicles to one of low-cost, low-volume vehicle manufacturing plant consisting of general-purpose workshop equipment, simple materials handling equipment, jigs and fixtures and intensive labor. It is hoped that this could hasten the development of the whole value chain for vehicle manufacturing in order to meet the desired EV fleet for a decarbonized transport in Africa.

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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).

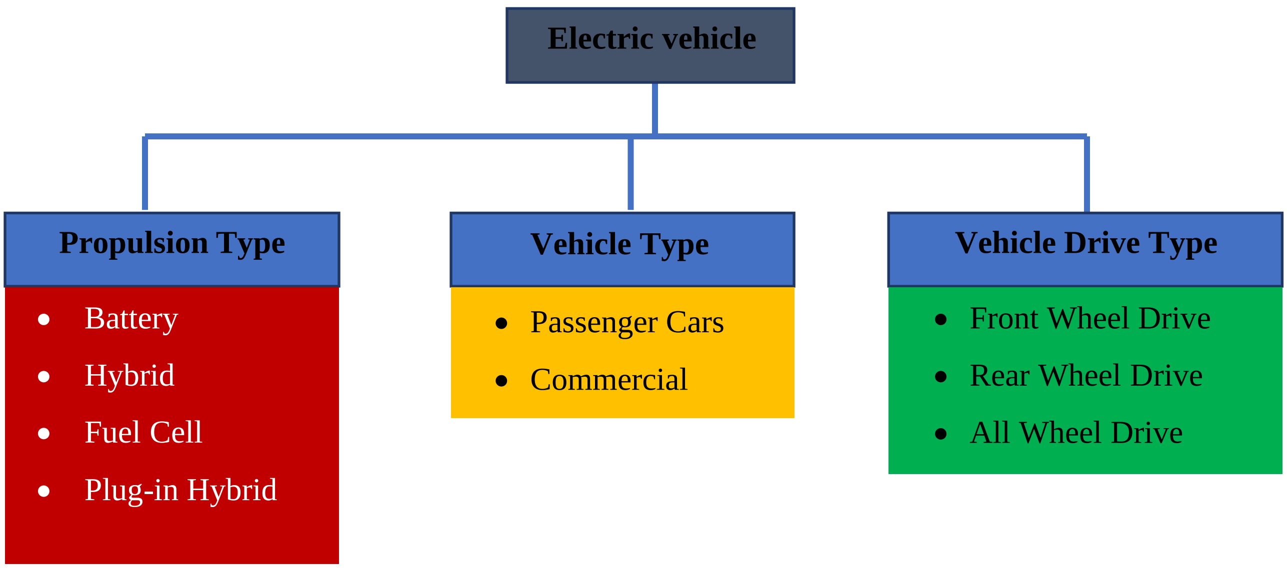

Figure 1: Major segments of Africa's electric vehicle market (Mordor intelligence, 2023)

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 isthe 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.

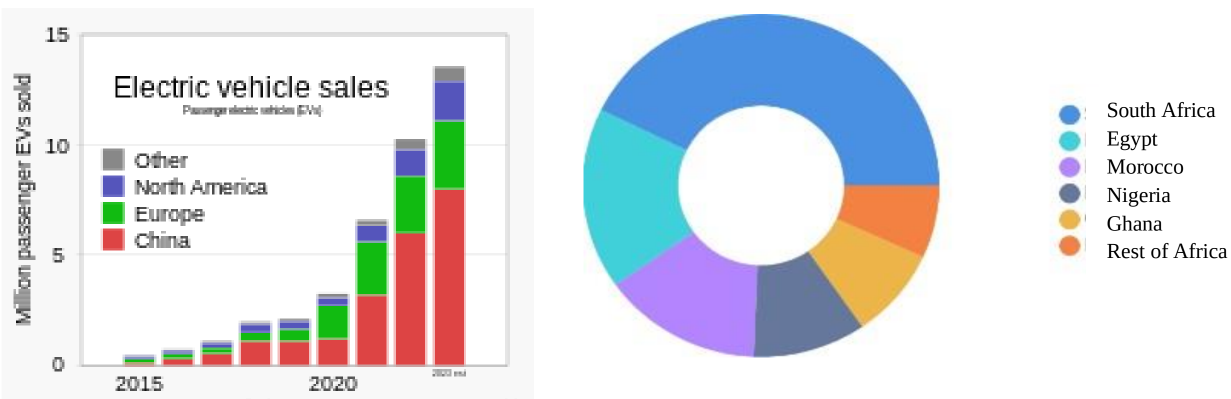

Figure 2: EV market (A) across the globe (McKerracher, 2023) and, (B) Africa's EV market, revenue share by country for the year 2021 (Mordor intelligence, 2023)

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.

(A)

(B)

(C)

(D)

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

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.

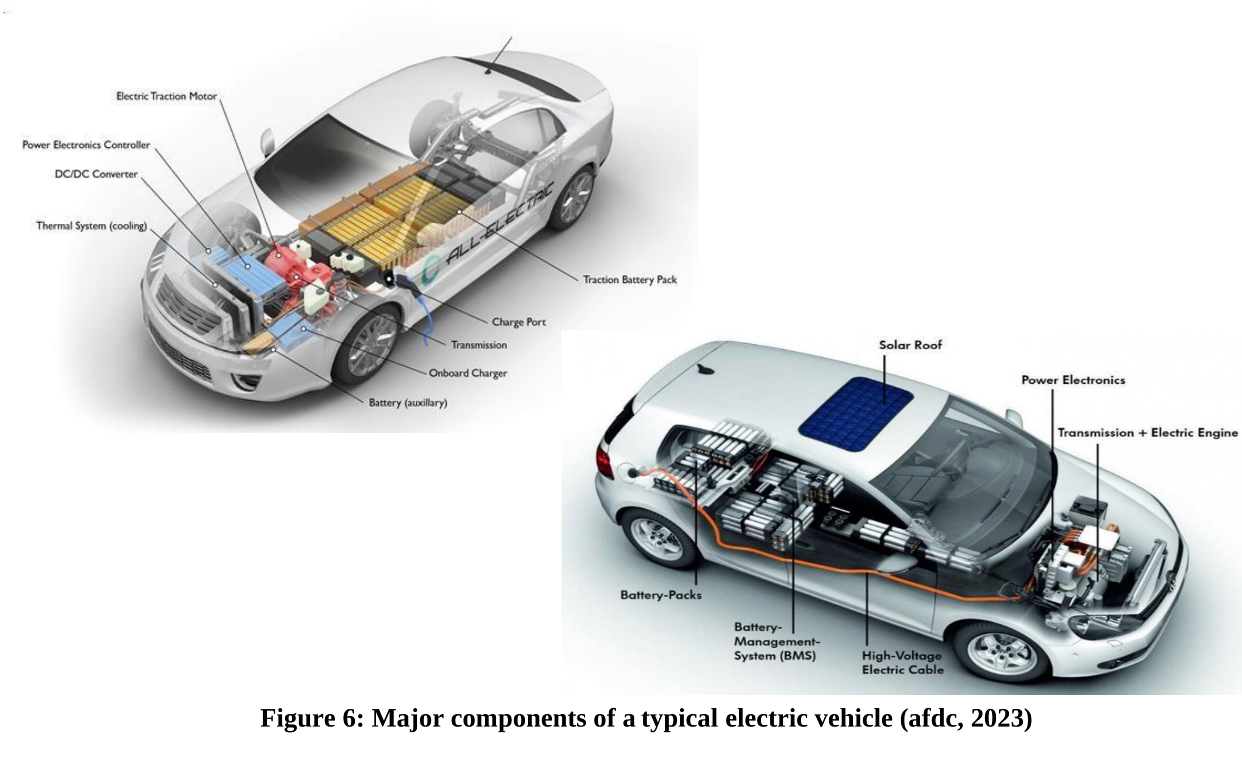

Figure 6: Major components of a typical electric vehicle (afdc, 2023)

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.

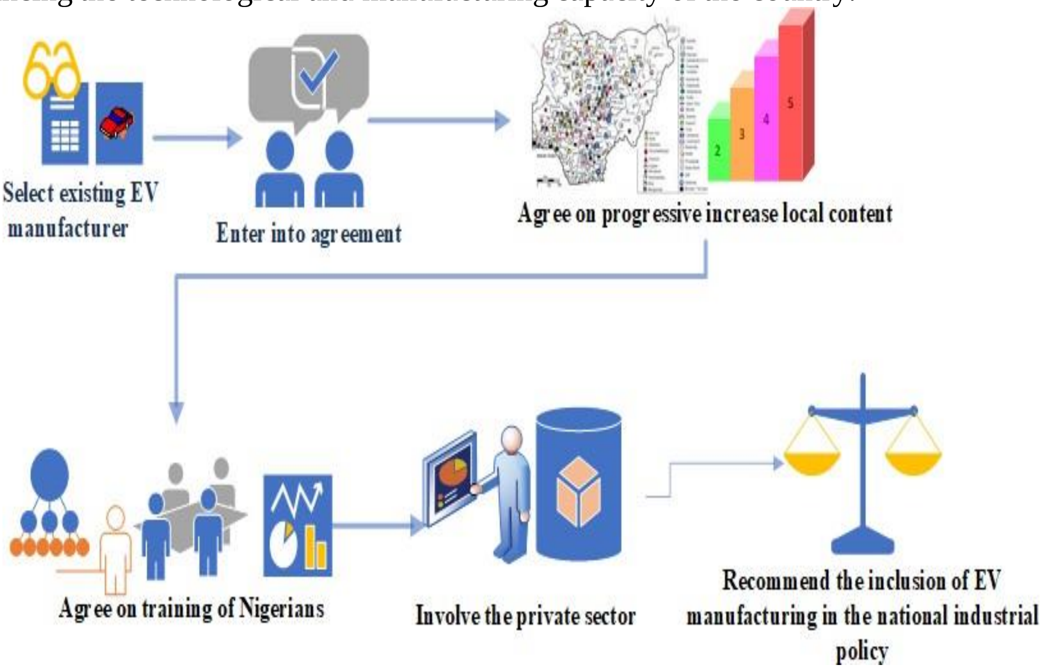

Figure 7: Recommended steps to follow towards the development of solar powered traction in Nigeria.

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.

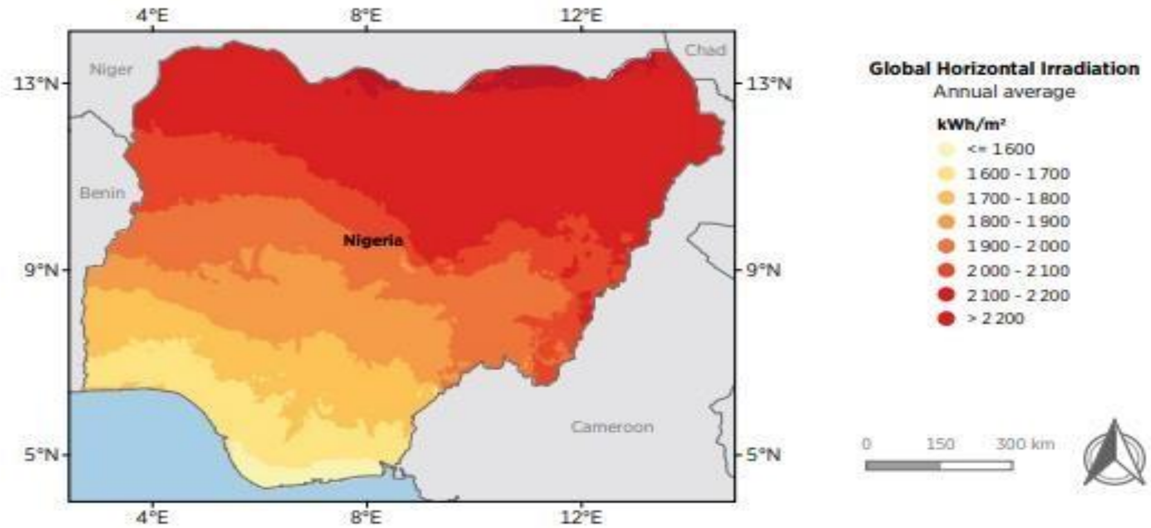

Figure 8: Average annual global horizontal irradiation in Nigeria (Global Solar Atlas (2020)

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.

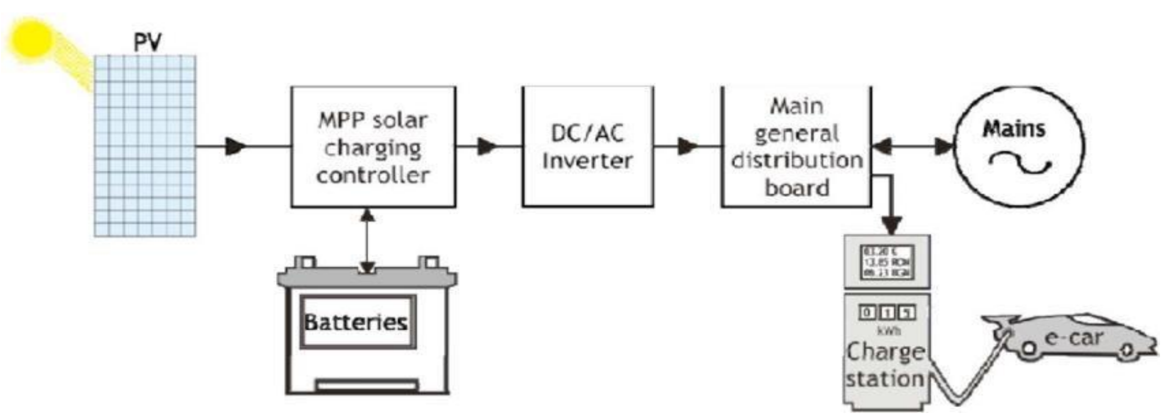

Figure 9: Schematic diagram of a typical solar-powered charging station (Nedev, 2014)

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 ofthe 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.

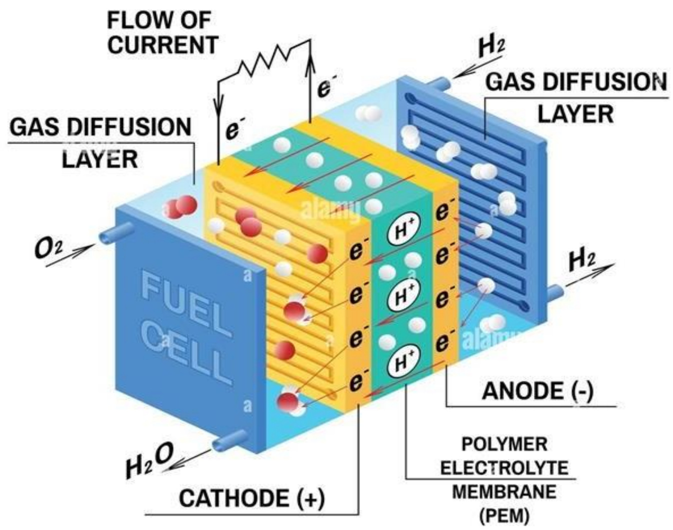

Figure 10: Cross-sectional view of a typical polymer electrolyte membrane fuel cell (Bronkhorst. (2023)

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 intohydrogen 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.

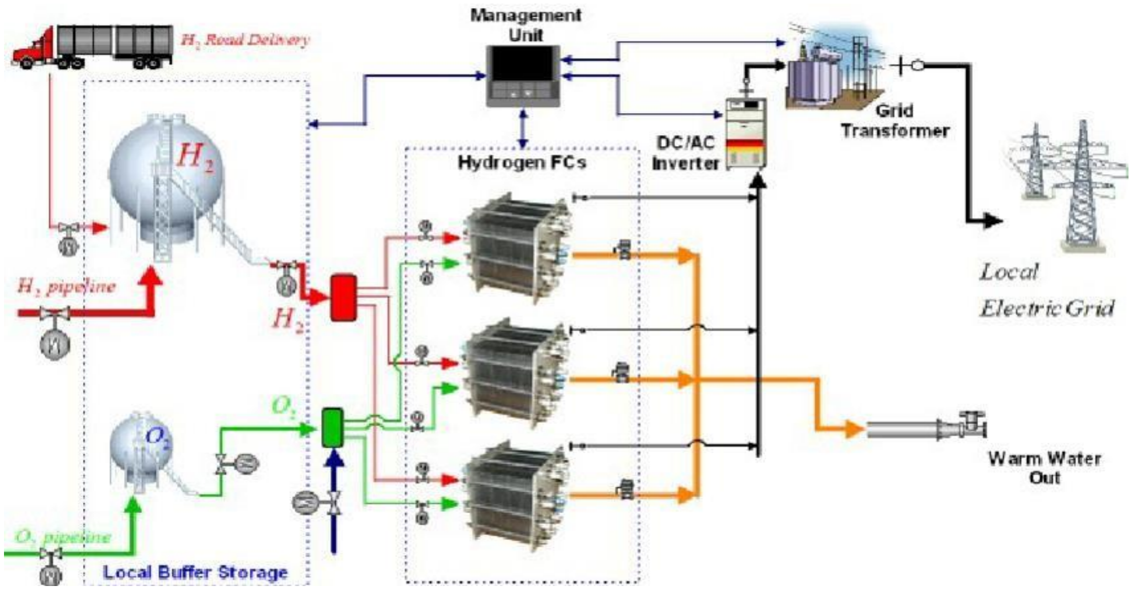

Figure 11: Flow Diagram of hydrogen electrical fuel cell power plant (Alves, 2008)

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 sectorin 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 butto 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 onlythe 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 andits 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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Original Research Article

The impact of petrol subsidy removal on the adoption of solar power in Nigeria

Utazi N. Divine*[1], Audu T. Stephen[2], Soretire K. Lanrewaju[1], & Ani O. Hillary[2]

Affiliation
[1]Department of Mechanical Engineering, Air Force Institute of Technology Kaduna, Nigeria.

[2]Department of Mechanical Engineering, Caritas University Amorji-Nike Enugu, Nigeria.

***For correspondence**: **email:** divinendubuisi@gmail.com; **tel:** +234 803 541 6525

Abstract
For decades, the Nigerian government has subsidized the price of petrol, making it one of the lowest in the world. Historically, the country has relied significantly on petrol subsidies to make energy more affordable to its inhabitants. This policy, however, has imposed a significant budgetary burden, fostered smuggling and corruption, and discouraged investment in renewable energy sources. Additionally, it cuts down on the resources that governments may devote to achieving other development goals as well as sustainable development goals. With a growing global emphasis on renewable energy sources and the need to reduce carbon emissions, Nigeria faces the challenge of transitioning from its traditional reliance on fossil fuels to more sustainable alternatives. To determine the impact of petrol subsidy removal on the adoption of solar power in Nigeria, we present a cost analysis comparing the acquisition and operation of a 2.5 kVA solar PV system to that of a petrol generator of the same capacity. The cost analysis shows that the solar PV system is a more cost-effective and sustainable option for power generation than petrol generators, especially in the long term. The paper emphasised the need of harnessing Nigeria's tremendous solar potential and reducing carbon emissions through solar power adoption. The study also shed light on the potential benefits and challenges of promoting solar energy as a viable alternative to traditional electricity supply in Nigeria.

Key Words: *Subsidy, petrol, solar, carbon emission.*

1.0 Introduction
Energy subsidies are government interventions that serve to maintain prices below market rates in general [1], [2]. Energy subsidies' main objectives are to promote rural and industrial development [3], [4], support domestic producers in their competition with foreign rivals [5], and increase the security of the energy supply [6], [7]. Nigeria's fuel subsidy was about $5 billion in 2021 (Figure 1) [8]. This level of energy subsidies places financial strain on governments [9], lowers energy prices and encourages excessive consumption [10], [11], raises carbon emissions [12], and reduces the competitiveness of investing in renewable energy technologies [13]. For decades, Nigeria has relied significantly on petrol subsidies to reduce the cost of energy for its citizens, which resulted in huge financial burdens and inefficiencies. However, the development of renewable energy sources like solar power has been hampered by this subsidy-driven strategy.

Subsidies for fossil fuels have a significant negative impact on the environment because they encourage people to switch from renewable sources of energy, resources, and labour to fossil fuels, slowing down the transition to a low-carbon economy. There is growing interest in gradually eliminating subsidies for fossil fuels to decrease energy use and energy-related greenhouse gas emissions. It is a prevalent belief in policy discussions that fossil fuel subsidies promote energy waste and that eliminating them would reduce energy-related carbon dioxide (CO_2) emissions. However, it is still unclear whether this is the case and how much pollution will be reduced as a result of cutting back on fossil fuel subsidies. [12].

Long-term power sector analyses have focused on the potential of renewable electricity technologies to lower GHG (greenhouse gas) emissions and improve the security of the energy supply [14]– [18]. The majority of renewable energy technologies are still in the development stage, and their high production costs remain a significant impediment to their widespread market adoption [19], [20]. Despite the country's maximum sunlight exposure and potential for solar photovoltaic (PV), solar energy provides just a small portion of power output in Nigeria. Nigeria is located in the solar belt, which increases its solar potential; yet the prospects for harvesting renewable energies remain limited and impractical when compared to conventional electricity [21].

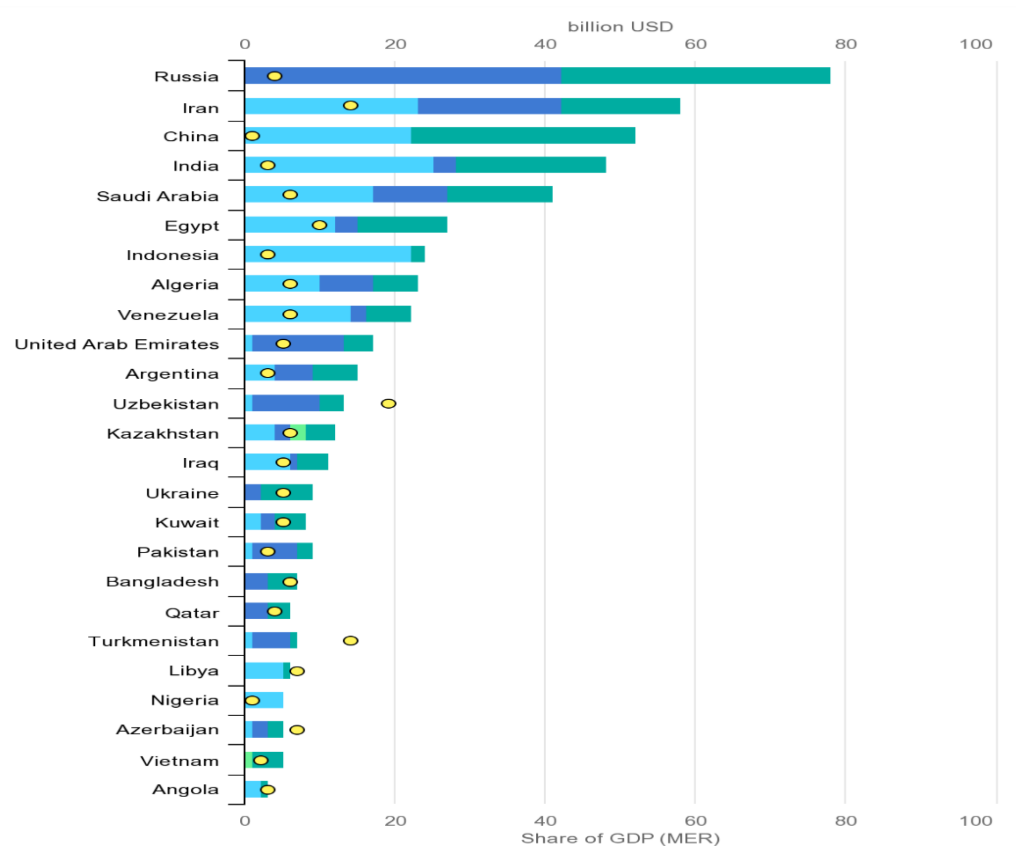
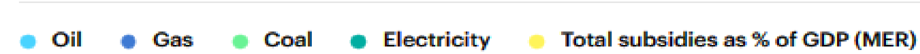


Figure 1: Value of fossil-fuel subsidies by fuel in the top 25 countries, 2021[8].



2.0 Nigeria's petrol subsidy regime

According to Bakare [22], to subsidize is to sell a product at a lower cost of manufacture. Thus, in the Nigerian context, petrol subsidy involves selling premium motor spirit (PMS) below the cost of imports. The federal government, believing that the cost of production and transportation would be too high for the poor Nigerian masses to bear alone due to the rise in the price of fuel during the military era, decided to pay a portion of the total fuel cost to make the product available and affordable. This military intention of a petrol subsidy functioned from March 31, 1973, until 1986, when Gen. Ibrahim Babangida, the previous Head of State of Nigeria, raised the fuel pump price of petroleum from 20k to 39.5k, a 97.5% rise. According to sources, the situation worsened with the advent of democracy when, on June 1st, 2000, Chief Olusegun Obasanjo raised the pump price of fuel from 20 to 30 naira (a 50% rise) [23].

Since 2012, the issue of petrol subsidy removal or retaining the subsidy regime has been a significant topic of public debate. The fuel subsidy, which was initially intended to last six months, was introduced as a temporary measure in 1988 by the federal government of Nigeria as part of its Structural Adjustment Program (SAP), as a stop-gap measure while refineries were being rebuilt and to stabilize the price of petroleum products. The federal government has claimed that the fuel subsidy policy has prevented them from addressing issues with our nation's infrastructure, including roads, power, agriculture, fixing the refineries, etc. These unintended consequences and malpractices include the smuggling of petroleum products out of the country. The price of petrol subsidies has kept rising dramatically. This is due in part to the rising price of fuel, which forced the government to spend more money to maintain low domestic prices, as well as the pressures brought on by Nigeria's growing population, which led to higher fuel consumption. Taken together, these factors have made the cost of the fuel subsidy unsustainable. By 2011, the subsidy accounted for 30% of government spending in Nigeria, which was equivalent to 4% of the Gross domestic product (GDP) and 118% of the capital budget. The report of the Farouk Lawan-led House of Representatives Ad-hoc committee on the management of fuel subsidy discovered that over 232 billion naira in the form of subsidy was paid to marketers for PMS in 2011 yet the PMS was not supplied, and this subsidy has become a scheme for mismanagement of revenues. He discovered that subsidy computation is in two segments - (landing and distribution cost), the Landing Cost constitutes (total cost = 153.64 naira)**:-** Products, Insurance, and Freight: 141.40 naira; Lightering Expenses (SVH): 4.03 naira; Traders Margin: 1.19 naira; Storage Charges: 2.60 naira; Nigeria Ports Authority (NPA) charge: 0.62 kobo Jetty Depot throughout charge: 0.80 kobo; and, Distribution Cost includes (total cost = 15.49 naira):- Retailer's Margin: 4.60 naira; Transporters' Margin: 2.99 naira; Dealers' Margin: 1.75 naira; Marine Transport Average (MTA): 0.15 kobo; Budgeting Fund: 5.85 naira; Administrative Charges: 0.15 kobo [24].

Furthermore, during the administration of President Goodluck Ebele Jonathan, the Subsidy Reinvestment Programme (SURE-P) was established to use the funds made available by the partial withdrawal of subsidies to improve a lot of Nigerians as a whole. The purpose of the committee's formation was to supervise and guarantee the prompt and efficient execution of projects that would be paid for with federal savings from the elimination of subsidies. SURE-P is primarily intended to lessen the effects of eliminating fuel subsidies and to hasten economic growth by funding urgently needed infrastructure. According to them, savings from the removal of subsidies under SURE-P are to be spent in important economic areas including power, health, the Niger Delta, youth, etc. Sure-P estimates that 41% of interventions are handled by the federal government, 54% by state and local governments, and 5% by ecology [25]. Due to the inefficiencies and corruption that plagued Nigeria's petrol subsidy regime, the Federal Government confirmed the total removal of the subsidy on petrol on May 29, 2023, resulting in a significant increase in energy costs in the country and further undermining Nigerians' ability to access affordable power. According to some petroleum marketers, the price of petrol at the pump might triple or even quadruple as a result of this removal. In comparison to the initial average price of N196 per litre, many gas stations are currently dispensing the product at more than N600 per litre. With the global push for sustainability, now may be is the greatest time for the country to explore and transition to a clean energy source such as solar energy.

3.0 Nigeria power supply scenario

Nigeria is facing significant issues in terms of electricity generation and supply. Continuous fluctuations, frequent power outages, and system instability characterize the national grid supply [26]. According to Oseni [27], a typical Nigerian home has access to an average of five hours of electricity supply daily from the national grid. According to Ajayi and Ajayi [28], self-generation using conventional biomass and fossil fuels has been encouraged because the Nigerian national grid has not been able to provide enough energy to meet the nation's demand. The demand and supply gap is fast expanding since the supply is extremely insufficient and inadequate to meet the population's rising demand. Nigeria has a population of approximately over 225 million people [29] and a total installed capacity of 14380 MW from 27 generation stations nationwide, of which approximately 7527.5 MW is available and between 3800 and 4700 MW is delivered to consumers [30]. Lack of investment, gas pipeline vandalism, system losses, a poor maintenance culture, and limited power evacuation all contribute to the low percentage of delivery capacity [30]. To address the problem, Nigeria’s government took some serious steps to combat the country’s problems, including partial liberalisation of the power sector. It created a new national regulatory authority, the Nigerian Electricity Regulatory Commission (NERC), and unbundled or separated the electricity sector into separate components, notably state-owned grid operators with contracted-out management. It also divided the distribution network into regional distribution companies (DISCOs) and established six fully privatized independent generating companies (GENCOs). In addition to partial market liberalisation, the government undertook to significantly increase the country's on-grid electricity capacity from an insignificant 12,667MW in 2018 to 22,958MW by 2023. Recognizing the difficulties, the Nigerian government developed a Power Sector Recovery Programme. Renewable energy is expected to grow from 13% of total power generation in 2015 to 23% by 2025, accounting for 10% of total energy consumption. Another goal has been to raise electrification rates from 42% in 2005 to 60% in 2015, and 75% by 2025. The strategy calls for growing small hydropower capacity from 600MW in 2015 to 2,000MW by 2025. There is also a proposal to create 500MW of solar PV and 40MW of wind power, as well as to increase biomass-based power plant generating capacity from 50MW in 2015 to 400MW by 2025. [31].

It is noteworthy to observe that despite numerous attempts, the Federal Government has not been successful in resolving the energy situation. Citizens in the country are still forced to generate their energy using fossil fuels because the country's electricity supply is insufficient and unstable. These have detrimental effects on the environment and health.

4.0 Overview of the residential energy situation in Nigeria

The Nigerian household sector's energy consumption is made up of demand from both rural and urban areas. An increase in per capita GDP, improved lifestyle, and population growth have all contributed to an increase in the energy demand of Nigeria's residential sector throughout the years.

The sector's energy mix includes traditional solid biomass (wood and charcoal), electricity, kerosene, petrol, and liquefied petroleum gas (LPG) [32]. Households use energy to provide various services such as cooking, lighting, heating, and running appliances such as refrigerators, fans, air conditioners, televisions (TVs), and so on [33]. Electricity access in rural areas remains limited, with just approximately 41% of households electrified. Access to clean cooking utensils that use cleaner and more environmentally friendly energy sources for cooking is even more limited. Modern cooking fuels are only available to roughly 3.5% of rural homes. Few households use transition fuels like kerosene for cooking, but the vast majority use traditional biomass. However, access to electricity in urban areas has improved significantly over the years, with 86% of urban households being electrified, whereas just 8.5% have access to modern cooking fuels. The energy requirements for cooking in the Nigerian residential sector are variable. Cooking fuels include wood, charcoal, kerosene, LPG, and, to a lesser extent, electricity [34]. Fuelwood is the most often used cooking fuel in Nigeria, particularly in rural regions. In rural areas, it is mainly harvested from the forests surrounding settlements, however in urban areas, it is obtained from local vendors for a relatively low price when compared to alternative cooking fuels such as kerosene and LPG [33]. In Nigeria, the significant reliance on fuelwood for cooking has led to the destruction of numerous natural habitats and the depletion of numerous forests [35]. Figure 2 shows the share of rural and urban households for different energy sources for cooking [34].

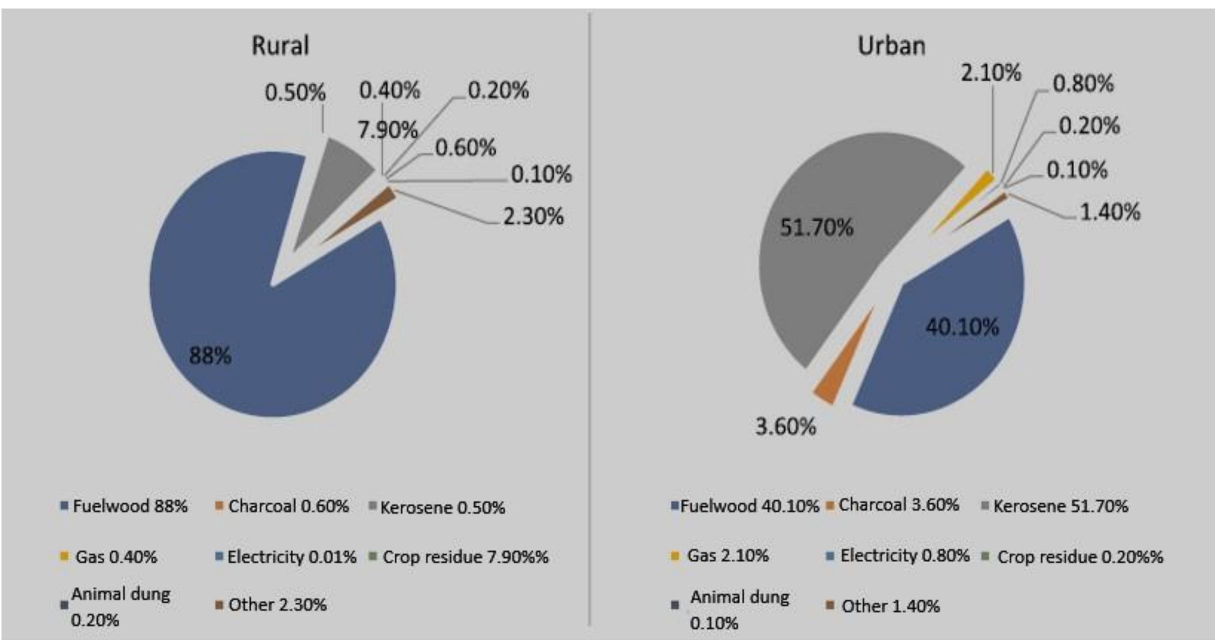


Figure 2: Share of rural and urban households for different energy sources for cooking [36].

It can be seen that the usage of contemporary cooking fuels such as electricity and LPG is quite limited and is mostly found in metropolitan houses. This can be linked to many Nigerian households' low-income levels, which inhibits their capacity to ascend the energy ladder [37]. However, other minute elements, like accessibility and cultural standards, have an impact on the choice of cooking fuels [32]. There have recently been a lot of attempts and political discussions to supply modern cooking equipment to all Nigerian households by 2030. Many actors (government and civil society) have keyed into this, but it remains to be seen how much of their good intentions will be realized in the near future [36].

With respect to lighting, Nigerian households depend on electricity, kerosene, dry cell battery, candle, grass, etc., but at the national level, electricity and kerosene constitute the main sources of lighting for the vast majority of households [34]. Electrical appliances such as refrigerators and air conditioners are mainly in urban households [32]. The majority of domestic appliances in Nigeria are quite old and inefficient. Some of them are imported from Western countries after their usable life has expired. This shows that there is a lot of room for energy savings in the sector [36] by Implementing policies and incentives to encourage the use of energy-efficient appliances because the old, imported appliances are less energy-efficient due to their age.

5.0 Nigeria solar energy outlook

Nigeria has significant solar energy potential that is largely untapped. Nigeria's location in the tropical region exposes it to excessive sun radiation. Nigeria has an average of 6.25 hours of sunlight per day, ranging from 9.0 hours in the far Northern boundary to about 3.5 hours in the coastal areas, implying that Nigeria receives about 12.6 MJ/m^2/day at the Southern coastal latitudes and about 25.2 MJ/m^2/day in the far Northern part of the country, giving the mathematical average as 18.9 MJ/m^2/day [38]–[41]. This translates to an equivalent of 229.1667 W/m^2 in power terms. Global Solar Atlas (GSA) [42] provided the details of direct normal irradiation across Nigeria, with an average of about 724 kWh/m^2 in the far Southern part and 1653 Wh/m^2 in the far Northern region. This translates into a PV power potential of 1248 kWh/kWp in the South and 1756 kWh/kWp in the North, and this information is further illustrated in Figure 3. With a total land area of 923,786 km^2, Nigeria typically receives an impact of solar radiation of about 1500 × 109 MWh annually, with an annual average of 19 MJ m^{-2}day^{-1} [41].

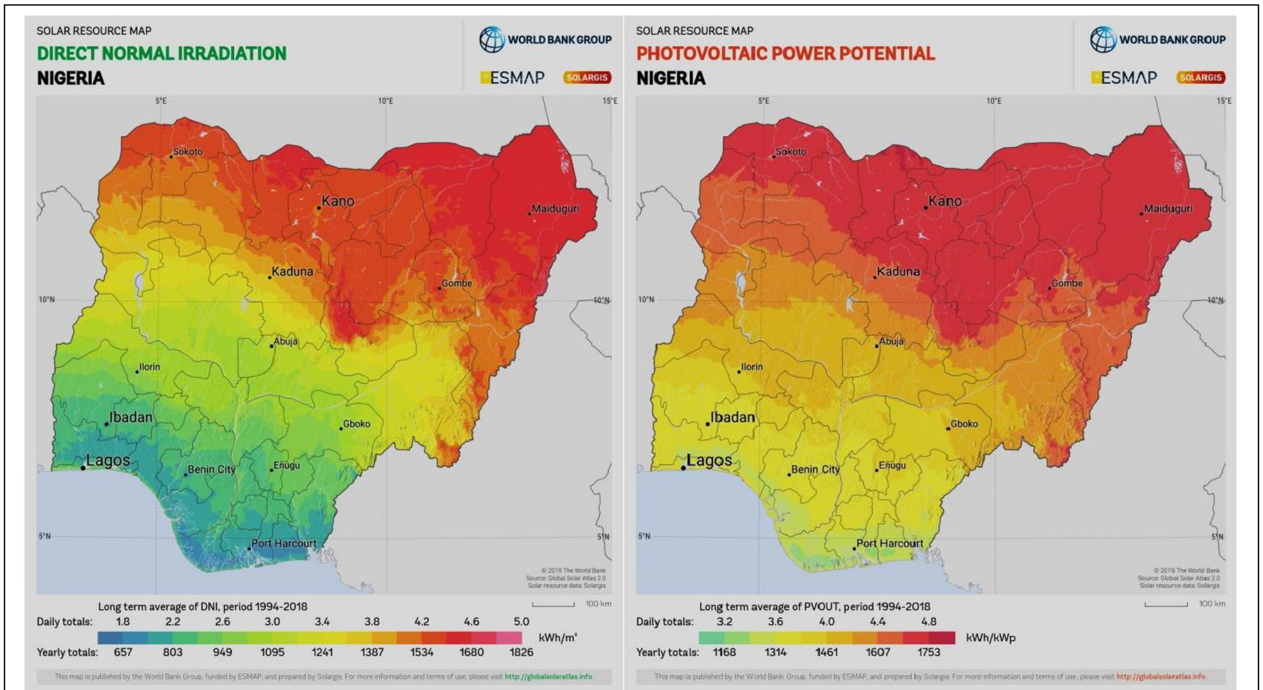


Figure 3: Direct normal irradiation and PV power potential [42].

An average of 6, 372, 613 PJ year^{-1} (approximately 1770 × 103 TWh year^{-1}) of solar energy received in the entire land area is 120,000 times the total PHCN (Power Holding Company of Nigeria) electricity generating capacity of 2002, and this energy value was estimated at 115,000 times the electrical energy generated by PHCN and about 27 times the value of total fossil fuel resources in the country [43].

Solar energy is limitless and non-polluting, making it a viable prospective source for green electricity generation. Despite the vast amount of solar energy reaching the earth's surface, numerous underdeveloped countries, including Nigeria, are having difficulty utilizing the resource [44]. According to Mohammed et al. [45], several developed countries have seen electrical stability following solar investment. Investing in solar energy harvesting technologies has the potential to decrease or eliminate energy poverty in developing countries while also promoting the reduction of greenhouse gases (GHG).

6.0 Solar technology penetration challenges in Nigeria

Nigeria has a lot of solar potential. However, the amount of PV installation is meagre than other developing countries in the region (Figure 4). Countries with lower energy demand than Nigeria and a smaller population experience significant adoption rate of photovoltaic (PV) systems [44].

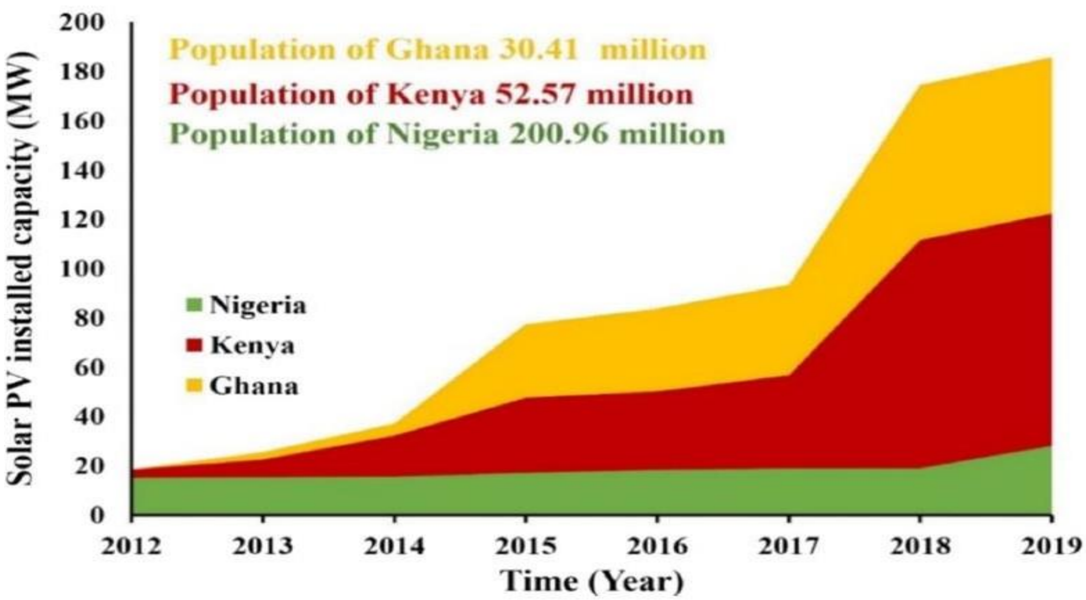


Figure 4: PV installed variation among three sub-Saharan countries [46].

The initial cost of installing solar photovoltaic technology is relatively high when compared to other energy harvesting methods such as diesel generators. However, the technology is significantly less expensive in the long run. Low-income earners will have affordability issues, as most people who do not have access to the national grid will be unable to acquire the equipment [47]. The vast majority of people are sceptical about using solar energy technology for energy generation due to inadequate information being disseminated about the great solar energy potential in the nation and a lack of awareness regarding the enormous benefits of solar PV [45], [48]–[50]. There is also little or no awareness of climate change and the repercussions of GHG emissions from the use of fossil fuels in energy generation [44].

With regard to including solar energy in the mix of national supplies, the Nigerian government has made policy implementation U-turns over time. However, the Nigeria Renewable Energy and Energy Efficiency Policy (NREEEP) is available [48] but has not yet been fully implemented because the government has not yet fully implemented some of the sub-policies such as incentives and any other palliative mechanisms to encourage and attract potential investors to the sector. NREEEP aims to contribute about 3% in 2020 to about 6% in 2030 of solar energy to the national supply mix [45], [47], [48]. There are high hopes that the recently signed Electricity Act 2023 by the federal government shall introduce tax incentives that are necessary to promote and facilitate the generation and consumption of energy from renewable energy sources.

7.0 Harnessing renewable energy for decarbonization and sustainable development

Global warming and climate change have elevated to the forefront of public discourse. Burning fossil fuels, such as coal, oil, petrol, and natural gas, damages the environment by releasing a significant amount of greenhouse gases (GHGs), mainly carbon emissions (CE) [51]. The necessity to eliminate CE has recently grown more pressing. To address this issue, at the United Nations climate summit in Paris in December 2015, all nations agreed to work together to reduce global GHGs and slow climate change. States pledged in 2015 to keep global warming below 2°C and to achieve carbon neutrality by 2050 under the Paris Agreement [52].

Renewable energy is a feasible option for achieving carbon neutrality, as recent studies have shown that renewable energy consumption can reduce CE [51], [53], [54]. In addition, it emphasizes the significance of using renewable energy instead of fossil fuels and optimizing energy efficiency to achieve carbon neutrality by 2050. As a result, we must urgently implement a global energy transition to achieve Sustainable Development Goal 7 (SDG 7), which consists of three key objectives: making modern energy services affordable, reliable, and accessible; making renewable energy a more prominent part of energy systems; and accelerating the pace of global energy efficiency improvements [55]. The transition to low-carbon energy is critical, as fossil fuel-related CE accounts for two-thirds of global GHG emissions [56]. Technological improvements, particularly those linked to renewable energy, are essential to this energy transition. Due to the capital-intensive nature of renewable energy, financial development (FD) is required for its adoption [52].

The FD could improve environmental sustainability by lowering CE through technical advancement, research, and development (R&D) [57]. Furthermore, capital markets could aid renewable energy R&D by attracting foreign corporations capable of exporting these innovations to local firms [58]. Green technology, together with the use of renewable energy sources and FD, is essential for achieving sustainable development without harming the environment [59], [60]. Green technology is the use of technologies to create and consume energy to increase energy efficiency and reduce negative environmental effects. According to the International Energy Agency's 2021 study, if the world is to reach carbon neutrality by 2050, further oil, natural gas, and coal mining and development must halt by 2021. Green technologies are therefore crucial for the transition from conventional to renewable energy. They also help to bridge the rhetorical and real-world realities of net-zero CE [52].

The Nigerian transport sector is solely dependent on fossil fuels, which are a chief driver of global warming. Hence, there is a need to start now to prepare for a significant presence in the electric vehicle market. Changing the climate-unfriendly attitude towards transportation and investing in research and development to harness renewable energy potential can serve as effective means to achieve a decarbonised transport system [61].

8.0 Cost analysis of a Solar PV system as compared to petrol generator.

A cost analysis of acquiring and operating a 2.5 kVA solar PV system installed in a middle-income residential 2-bedroom apartment in Mando, Kaduna State for a year, compared to acquiring and operating a petrol generator of the same capacity, is presented.

- ***Solar PV System***

The cost requirement of the solar PV system is shown in Table 1.

Table 1: The bill of engineering measurement and evaluation for the 2.5 kVA solar PV system.

S/N	Requirement	Quantity	Rate (₦)	Amount (₦)
1	200Ah, 12V Deep cycle Battery	2	150,000	300,000
2	250W Solar PV panel	2	60,000	120,000
3	2.5 kVA, 24V Hybrid solar inverter	1	160,000	160,000
4	Battery rack	1	10,000	10,000
5	Solar panel rack	1	5,000	5,000
6	Cables and accessories		30,000	30,000
7	Installation		15,000	15,000
Total Cost				640,000

The cost of using solar system to power the case study at a load of 1500*W* for 5 hours/day in one year period is:

Cost of acquiring and installation = N640,000
Assume coat of maintenance (Annual) = N10,000
Total = N650,000

- ***Petrol Generator***

A 2.5 kVA, 220 V, 50 Hz, Elepaq petrol generator is selected. The petrol consumption rate is *1.23 litres per hour* for a load of 1500*W* [62]. Consequently, the cost of using the petrol generator to power the case study for 5 hours per day, at a 1500*W* load, over the course of one year, is as follows:

Cost of 2.5 kVA generator = N167,400
Cost of petrol = N620/litre
Petrol consumption per day (5 – hour period) = 1.23 x 5 = 6.15 *litres*
Cost of petrol per pay (5 – hour period) = 6.15 x 620 = N3,813
Assume cost of Annual maintenance = N30,000
Cost of using petrol generator considering one year period,
= 167,400 + (3,813 x 365*days*) + 30,000 = N1,589,145

Table 2 and Figure 5 present the costs of operating the two power systems for four years assuming all factors are constant over the four-year period.

Table 2: Four-year costs for operating the power systems.

Year	Solar PV System (₦)	Petrol Generator (₦)
1st year	650,000	1,589,145
2nd year	660,000	3,010,890
3rd year	670,000	4,432,635
4th year	680,000	5,854,380

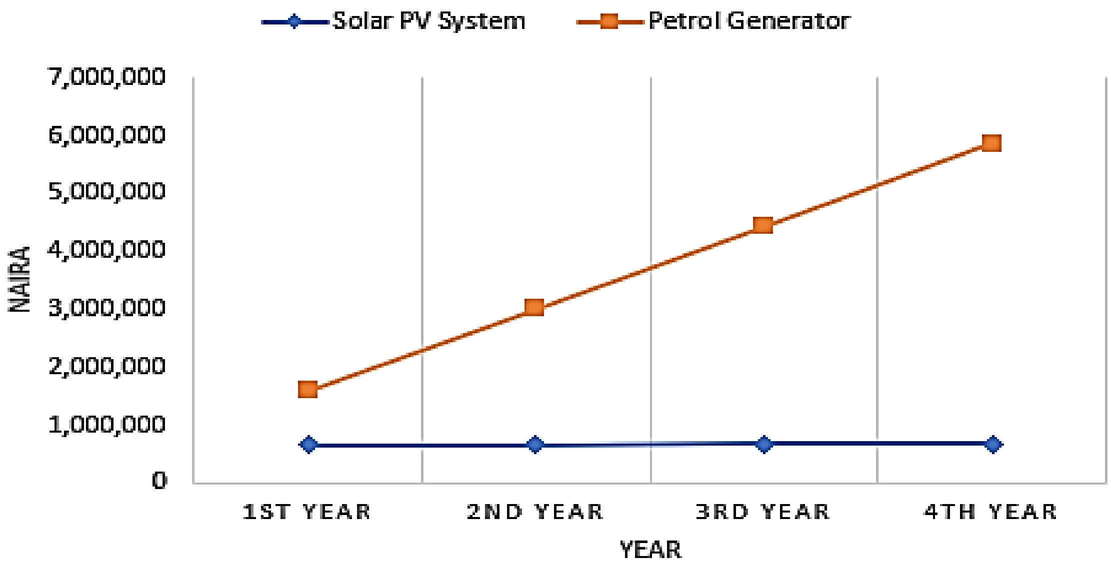


Figure 5: Four-year costs comparison of solar PV system and petrol generator.

9.0 Discussion

The cost analysis shows that the initial cost of acquiring a solar PV system is notably higher than that of a petrol generator. However, in the first year, the cost of acquiring and operating a solar PV system is lower (650,000 Naira) than that of a petrol generator (1,589,145 Naira). This significant difference indicates that the barrier to entry for solar power adoption is higher due to the upfront investment required. Over the four-year period, the cost of operating the solar PV system increases gradually, with increments of 10,000 Naira each year. In contrast, the cost of operating the petrol generator experiences a sharp increase each year, with the cost more than doubling from the first to the second year and increasing by substantial amounts in subsequent years. The relatively moderate increase in operating costs for the solar PV system contrasts sharply with the rapid growth in operating costs for the petrol generator. This trend underscores the long-term cost savings and stability associated with solar PV system compared to petrol generators, which are subject to volatile fuel prices and maintenance expenses.

It should be noted that these results are based on assuming constant prices over the four-year period under consideration. However, the maintenance cost for the solar-PV system is not likely to increase substantially over that period compared to petrol price which is usually volatile.

The results of the cost analysis comparing the acquisition and operation of a 2.5 kVA solar PV system versus a petrol generator of the same capacity reveal significant insights into the economic implications and potential impact of petrol subsidy removal on the adoption of solar power, particularly in regions like Mando, Kaduna State. Thus, more households would tend to adopt solar-PV power system because of the substantial savings compared to fossil fuel use.

10. Conclusion

The removal of petrol subsidies could exacerbate the financial burden of operating petrol generators, further amplifying the economic advantages of solar power. Without subsidies, the cost of fuel would likely increase, driving up the operational expenses of petrol generators and diminishing their cost competitiveness compared to solar PV systems. Consequently, the removal of petrol subsidies could incentivize individuals and households to transition to solar power as a more sustainable and cost-effective alternative. The long-term savings and stability offered by solar energy become even more compelling in a scenario where fossil fuel prices are subject to market fluctuations without government intervention. Thus, the impact of fuel subsidy removal would be to encourage more households to adopt solar-PV power systems, which can play a leading role in Nigeria's quest to achieving the United Nations' Sustainable Development Goals (SDGs) by 2030.

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Review Paper

A comprehensive assessment of transportation emissions in Nigeria: Trends, drivers, and impacts

Adeniyi O. Oluwakoya

Affiliation
Department of Transport Management, Redeemer's University, Ede, Osun State.

***For correspondence: email**: oluwakoyaa@run.edu.ng

Abstract
This study presents an in-depth investigation into the complex dynamics surrounding transportation emissions in Nigeria against the backdrop of rapid urbanization, population growth, and economic development. Through an extensive analysis of historical trends and recent developments, the article elucidates the escalating challenges posed by emissions. Examining the drivers of transportation emissions, including population growth, economic development, and fuel choices, the study underscores the significant correlation between economic growth and emissions while scrutinizing their environmental and public health ramifications. It also explores the prevalent use of fuels in Nigeria's transportation sector, highlighting the imperative of transitioning to cleaner energy sources and leveraging technological innovations for emission reduction and sustainability. Evaluation of existing policy frameworks and regulatory mechanisms offers insights into their efficacy in emission mitigation, along with emphasizing Nigeria's commitmentsunder international agreements like the Paris Agreement and Sustainable Development Goals. The socioeconomic impacts of transportation emissions, encompassing public health costs, economic losses from traffic congestion, and broader economic implications, are scrutinized. The study concludes with a compelling call to action for immediate policy reforms, sustainable transportation solutions, and international collaboration. As the world grapples with climate change and environmental degradation, this comprehensive assessment aims to inform policymakers, researchers, and stakeholders, serving as a crucial resource for charting a sustainable course for Nigeria's transportation sector.

Keywords: *Transportation emissions, Nigeria, trends, drivers, impacts, public health, air quality, climate change, sustainable transportation, policy recommendations*

1.0 Introduction

Nigeria, often referred to as the "Giant of Africa," boasts a vast and dynamic transportation sector that plays a pivotal role in the country's economic growth and societal development (Offiong et, al 2021). With a population exceeding 200 million people and a landmass covering 923,768 square kilometers, Nigeria's transportation system is a complex web of roads, railways, ports, airports, and inland waterways (Oluwakoya and Ogundipe, 2021). This extensive network facilitates the movement of goods, people, and services across the nation, connecting urban centers with rural areas and supporting various industries, including agriculture, manufacturing, and commerce. Understanding the nuances of Nigeria's transportation sector is essential to grasp the magnitude of its emissions challenges (Poulsen & Sampson, 2019).

The significance of studying transportation emissions in Nigeria cannot be overstated (Oyebode, 2022). In recent decades, the country has experienced rapid population growth, urbanization, and economic development, all of which have led to an exponential increase in transportation activities. While this growth has undeniable benefits, it has also contributed to escalating levels of pollution, greenhouse gas emissions, and negative impacts on public health (Adedolapo, 2022). As the world grapples with the consequences of climate change and environmental degradation, addressing transportation emissions in Nigeria has become imperative for both local and global well-being (Mei et.al., 2023).

The primary purpose of this article is to provide a comprehensive assessment of transportation emissions in Nigeria. By examining the trends, drivers, and impacts of emissions, this article aims to shed light on the complex interplay between the transportation sector and the environment, economy, and society. It seeks to contribute to a better understanding of the challenges Nigeria faces in mitigating emissions and transitioning to a more sustainable transportation system. Furthermore, this article aims to offer actionable insights and policy recommendations to guide future efforts in reducing emissions and fostering sustainable development.

2.0 Transportation emission trends in Nigeria

2.1 *Historical overview of transportation emissions*

To comprehend the current state of transportation emissions in Nigeria, it is essential to examine the historical trajectory. Over the past few decades, Nigeria has witnessed a significant transformation in its transportation sector. The country has transitioned from a primarily agrarian society to one with rapidly growing urban centers, expanding industries, and increased mobility demands.

Historically, Nigeria's transportation emissions were relatively modest. The use of traditional modes of transportation, such as bicycles and animal-drawn carts, predominated in rural areas, while cities were characterized by limited motorized transportation. However, with urbanization and economic development, there has been a substantial rise in the use of motor vehicles, particularly gasoline and diesel-powered cars, trucks, and motorcycles. This shift might have correspondingly led to a marked increase in transportation-related emissions.

The historical overview provides a critical context for understanding the challenges posed by emissions today. By tracing the growth of the transportation sector and the evolution of transportation modes, we gain insights into how emissions have become a pressing issue.

2.2 Recent developments and changes

In recent years, the transportation landscape in Nigeria has experienced significant developments and changes. Several factors have contributed to these shifts:

1. **Rapid urbanization**: Nigeria has one of the fastest urbanization rates globally, with millions of people migrating to cities in search of economic opportunities. This trend has led to increased demand for transportation services and the proliferation of vehicles in urban areas.
2. **Economic growth**: Nigeria's economic growth, particularly in sectors like manufacturing, commerce, and construction, has resulted in greater mobility requirements, leading to an upsurge in transportation emissions.

3. **Diversification of transportation modes**: The transportation sector has diversified with the introduction of new modes, including ride-sharing services, increased air travel, and expanded railway networks. Each of these modes has its own emission profile, contributing to the complexity of the issue.
4. **Shift in energy sources**: The country has witnessed shifts in the sources of energy used in transportation. While gasoline and diesel remain prevalent, there is a growing interest in alternative fuels such as compressed natural gas (CNG) and electric vehicles (EVs).
5. **Policy interventions**: The Nigerian government has introduced various policies and initiatives to address emissions, including fuel quality standards, emission controls, and incentives for cleaner transportation technologies.

2.3 Key statistics and data sources

Comprehensive research into transportation emissions requires reliable data sources and key statistics. In Nigeria, obtaining accurate emission data can be challenging due to various factors, including limited monitoring infrastructure and data collection mechanisms. However, some key sources and statistics can provide valuable insights:

1. **National emission inventories**: These inventories, compiled by environmental agencies, provide estimates of emissions from various sectors, including transportation. They are crucial for understanding the overall emissions landscape.
2. **Fuel consumption data**: Data on fuel consumption, sourced from government agencies, industry reports, and oil companies, offer insights into the volume and types of fuels used in transportation.
3. **Vehicle registration and sales data**: Information on the number and types of vehicles registered and sold in Nigeria can shed light on the growth of the automotive sector and its emissions impact.
4. **Air quality monitoring data**: Data from air quality monitoring stations in major cities can provide information on pollutant levels and their variations over time, offering insights into local emissions.
5. **Policy and regulatory documents**: Government policy documents, such as national emission reduction strategies and transportation regulations, offer valuable context and insights into the regulatory landscape.
6. **International reports**: Reports from international organizations, such as the United Nations and the World Bank, often include data and analysis on transportation emissions in Nigeria, providing a global perspective.

By examining historical trends, recent developments, and relying on these key statistics and data sources, researchers can paint a more accurate picture of transportation emissions in Nigeria. This foundation of knowledge is essential for crafting effective mitigation strategies and policies to address the environmental and societal challenges posed by these emissions.

3.0 Drivers of transportation emissions

3.1 *Population growth and urbanization*

1. **Impact on transportation demand**:

Nigeria, experiencing rapid population growth, has witnessed a significant surge in transportation demand (Ilesanmi, 2010). The burgeoning population, especially in urban centers, has led to increased mobility requirements, translating into higher vehicle usage, more public transportation utilization, and heightened demand for goods and services. This heightened demand significantly contributes to transportation emissions as the existing infrastructure struggles to keep pace with the population's mobility needs.

2. **Urban planning challenges:**

Urbanization in Nigeria has posed substantial challenges in urban planning and transportation infrastructure development. Rapidly growing cities face difficulties in effectively organizing transportation systems, resulting in traffic congestion, inadequate public transportation, and poor road conditions. The lack of efficient urban planning exacerbates emissions by encouraging individual vehicle usage and prolonging travel times, ultimately leading to increased emissions.

3.2 Economic development and energy demand

3. **Correlation between GDP growth and emissions**:

Economic development, often measured by Gross Domestic Product (GDP) growth, is intricately linked to transportation emissions. As the economy expands, the demand for transportation services escalates. Industries, trade, and commerce flourish, necessitating transportation for the movement of goods and services. This correlation implies that economic growth can lead to a subsequent rise in transportation emissions unless coupled with efficient policies to decouple growth from emissions.

4. **Energy sources in transportation**:

The energy sources utilized in transportation significantly influence emissions. Nigeria's transportation sector primarily relies on fossil fuels, particularly gasoline and diesel. These fossil fuels are carbon-intensive, emitting greenhouse gases and air pollutants upon combustion. To mitigate emissions, a transition to cleaner energy sources such as electricity, biofuels, or compressed natural gas is imperative.

3.3 Fuel types and technology

1. **Overview of common transportation fuels used**:

The transportation sector in Nigeria predominantly relies on fossil fuels, including gasoline, diesel, and liquefied petroleum gas (LPG). Gasoline, used in cars and motorcycles, is a major contributorto emissions due to its carbon content. Diesel, widely used in trucks and buses, also emits greenhouse gases and particulate matter. LPG, although cleaner compared to gasoline and diesel, still produces emissions upon combustion.

2. **Technological advancements and efficiency gains**:

Advancements in transportation technology play a vital role in emission reduction. Modern vehicles often incorporate technologies such as fuel injection, hybridization, and electric powertrains to improve fuel efficiency and reduce emissions. Additionally, developments in vehicle design, engine efficiency, and aerodynamics contribute to lowering the carbon footprint ofthe transportation sector.

3.4 Policy and regulatory framework

1. **Existing policies and regulations**:

Nigeria has instituted various policies and regulations to address transportation emissions. These include emission standards for vehicles, fuel quality standards, and regulations promoting cleaner transportation technologies. However, enforcement and compliance with these policies remain a challenge, hindering their effectiveness in mitigating emissions.

2. **Policy impact on emissions reduction**:

The impact of policies and regulations on emissions reduction can be measured by assessing emission levels before and after policy implementation. Effective policies drive the adoption of cleaner fuels, encourage public transportation usage, and incentivize the adoption of low-emission vehicles. A comprehensive evaluation of the impact of policies is essential to refine and strengthen the regulatory framework for further emissions reduction.

Understanding these drivers of transportation emissions is essential for developing effective strategies and policies to mitigate the environmental impact of the transportation sector in Nigeria. By addressing population growth, economic development, fuel types, and policy frameworks, Nigeria can work towards a more sustainable and environmentally friendly transportation system.

4.0 Environmental impacts of transportation emissions

4.1 *Air quality*

1. **Effects on public health**:

Transportation emissions in Nigeria have significant and far-reaching effects on public health (Raimi et, al., 2021). The release of pollutants such as particulate matter (PM), nitrogen oxides (NOx), volatile organic compounds (VOCs), and carbon monoxide (CO) from vehicles contributes to poor air quality, especially in urban areas. These pollutants can exacerbate respiratory diseases, increase the risk of cardiovascular problems, and have adverse effects on vulnerable populations, including children and the elderly. Prolonged exposure to polluted air is linked to higher mortality rates and a higher burden of diseases, placing considerable strain on healthcare systems (Raimi et, al., 2021)

2. **Air quality monitoring and data**:

Monitoring air quality is critical to understanding the extent of the problem. Nigeria has established air quality monitoring stations in major cities, including Lagos, Abuja, and Port Harcourt, to measure pollutant levels (Abaje, et. al.,2020). Real-time data from these stations provides valuable insights into air quality trends, allowing authorities to take corrective actions. However, challenges persist, including the need for expanded monitoring networks in smaller cities and rural areas to comprehensively assess air quality throughout the country (Abaje, et. al.,2020)

4.2. Climate change

1. **Contribution to greenhouse gas emissions**:

Nigeria's transportation sector is a significant contributor to greenhouse gas (GHG) emissions, primarily in the form of carbon dioxide (CO2) and methane (CH4). The specific percentage attributed to transportation varies depending on the source and methodology of assessment. However, estimates suggest that transportation contributes a significant share of Nigeria's total GHG emissions, with figures ranging from approximately 18% to 30% (Abam, et. al. 2021). These emissions stem primarily from the combustion of fossil fuels such as gasoline and diesel in vehicles, as well as from other sources like methane emissions from livestock and waste management practices. Globally, transportation is responsible for around 14% of total GHG emissions, making it one of the leading sectors contributing to climate change on a worldwide scale (Creutzig, et. al., 2015). Carbon emissions arise from the combustion of fossil fuels, such as gasoline and diesel, in vehicles. Methane emissions often result from leaks in natural gas pipelines used for transportation and compressed natural gas (CNG) vehicles. These emissions have regional and global implications, as GHGs are major drivers of climate change. Nigeria's emissions contribute to the collective challenge of global warming and climate variability.

2. **Climate change impacts on Nigeria**:

The consequences of climate change are already affecting Nigeria. Rising temperatures, changing rainfall patterns, and extreme weather events like floods and droughts have far-reaching effects on agriculture, water resources, food security, and human settlements (Olaniyi et al, (2013). Vulnerable communities, particularly those in coastal areas and arid regions, face displacement and heightened risk. Addressing transportation emissions is crucial in mitigating the exacerbationof climate change impacts and building resilience in the face of these challenges.

It is evident that transportation emissions in Nigeria not only deteriorate air quality, jeopardizing public health but also contribute to global climate change, with repercussions for the country's long-term sustainability and development (Onwudiwe, 2023). To combat these environmental impacts, comprehensive strategies, including clean energy adoption, enhanced public transportation, and stringent emission standards, must be implemented to reduce emissions and promote a healthier, more climate-resilient Nigeria.

5.0 Socioeconomic impacts of transportation emissions

5.1 Health consequences

1. **Healthcare costs and challenges**:

The health consequences of transportation emissions in Nigeria are multifaceted and exert a significant burden on the healthcare system. The exposure to air pollutants, particularly fine particulate matter (PM2.5) and ground-level ozone (O3), contributes to respiratory illnesses, cardiovascular diseases, and other health issues (Abaje et. al. 2020). These health problems necessitate increased healthcare spending, including hospitalization, medication, and treatment. The costs associated with addressing air pollution-related health problems strain an already overburdened healthcare system, diverting resources away from other critical healthcare needs.

2. **Mortality and morbidity rates**

High levels of transportation emissions are correlated with elevated mortality and morbidity rates in Nigeria (Matthew et. al.,2018). Studies have demonstrated a direct link between air pollution and premature death, with vulnerable populations, such as children and the elderly, at heightened risk (Matthew et. al. 2018). Long-term exposure to polluted air also increases the incidence of chronic respiratory diseases, such as asthma and bronchitis, as well as heart diseases. Elevated mortality and morbidity rates not only devastate families but also undermine the nation's human capital and economic productivity.

5.2 Economic costs

1. **Traffic congestion and productivity losses**:

Traffic congestion contributes to transport emissions in Nigerian cities, resulting in substantial productivity losses (Adeyanju & Manohar 2017). Congestion leads to increased travel times, fuel wastage, and decreased efficiency in supply chains and logistics. Workers spend more time stuckin traffic, reducing their available working hours and productivity. Additionally, businesses incur higher operational costs due to delays in transporting goods. The cumulative effect of traffic congestion has a detrimental impact on Nigeria's economic competitiveness and growth potential.

2. **Economic implications of emissions**:

The economic implications of transportation emissions extend beyond congestion-related losses. Emissions can also result in increased maintenance costs for vehicles due to engine wear and tear caused by traffic congestion that leads to increased wear and tear of the vehicle including the whole drivetrain, braking system, etc. The way in which pollution may affect the wear and tear of the engine is if the emissions are abrasive or corrosive and get into the engine cylinder.) Furthermore, healthcare expenditures associated with treating pollution-related illnesses divert resources that could otherwise be invested in other essential sectors, such as education and infrastructure development. Additionally, the global community is increasingly scrutinizing the carbon footprintof products and services, potentially affecting Nigeria's international trade and market access.

Addressing the socioeconomic impacts of transportation emissions in Nigeria requires a holistic approach that not only prioritizes public health and environmental well-being but also considers the economic consequences. Implementing cleaner transportation technologies, enhancing public transportation systems, and strengthening policy frameworks can help alleviate these impacts and create a more sustainable and prosperous future for Nigeria.

6.0 Nigeria's commitments and international agreements

6.1 *Nigeria's commitment to emission reduction*

Nigeria, as a responsible global citizen, has demonstrated its commitment to addressing climate change and reducing emissions. Several key initiatives and commitments underscore the country's dedication to mitigating the impact of transportation emissions:

1. **Nationally Determined Contributions (NDCs)**: Nigeria submitted its NDCs under the Paris Agreement, outlining its commitment to reducing greenhouse gas emissions (Dioha, & Kumar. 2020). While the NDCs encompass emissions from various sectors, including transportation, they signal the country's intent to implement policies and strategies to curtail emissions.
2. **Sustainable Development Goals (SDGs)**: Nigeria has aligned its national development plans, such as the Economic Recovery and Growth Plan (ERGP) (Shaibume, & Patrick. 2023)., with the United Nations' SDGs. Several of these goals relate to climate action, sustainable cities, and clean energy, highlighting Nigeria's intention to integrate emission reduction efforts into its development agenda.
3. **African Union's Agenda 2063**: Nigeria is a member of the African Union and is actively engaged in the agenda 2063 initiative (Addaney, 2018), which envisions a prosperous and sustainable Africa. This initiative includes strategies for improving transportation and reducing the environmental footprint of the sector.
4. **Domestic policies**: Nigeria has introduced domestic policies and initiatives aimed at reducing emissions, including the National Automotive Industry Development Plan (NAIDP) (Ayetor et.al., 2021)., which encourages local production of energy-efficient vehicles.

6.2 Global agreements and targets relevant to Nigeria

Nigeria, as a signatory to various international agreements, aligns its transportation emissions goals with global efforts to combat climate change and promote sustainable development:

1. **Paris agreement**: Nigeria is a signatory to the Paris Agreement, which sets the goal of limiting global warming to well below 2 degrees Celsius above pre-industrial levels. This agreement commits Nigeria to reducing emissions across all sectors, including transportation,to contribute to global climate stabilization.
2. **Sustainable Development Goals (SDGs)**: Nigeria endorses the SDGs, particularly Goal 11

(Sustainable Cities and Communities) and Goal 13 (Climate Action), which emphasize sustainable urbanization, clean energy, and the reduction of greenhouse gas emissions.

3. **African Union Agenda 2063**: Nigeria's participation in the African Union's Agenda 2063 aligns with the continent-wide aspiration to create integrated, prosperous, and sustainable economies. This includes promoting sustainable transportation systems and reducing emissions.
4. **Economic Community of West African States (ECOWAS)**: As a member of ECOWAS, Nigeria is part of regional efforts to address transportation emissions. ECOWAS has initiatives to promote energy efficiency and renewable energy adoption in the transportation sector.

Nigeria's commitment to international agreements and targets underscores its recognition of the importance of addressing transportation emissions as part of a broader effort to combat climate change and promote sustainable development. By aligning domestic policies with these global agreements and targets, Nigeria aims to play a pivotal role in mitigating the environmental impacts of transportation emissions while pursuing economic growth and social development.

7.0 Policy recommendations

7.1 Emission reduction strategies

1. **Short-term and long-term measures**:

Short-term measures: Implement immediate actions to reduce emissions, such as optimizing traffic flow through intelligent transportation systems (ITS), promoting ridesharing, and carpooling, and implementing vehicle emissions testing programs.

Long-term measures: Develop a comprehensive long-term strategy that includes transitioning to electric vehicles (EVs), improving fuel efficiency standards, and incentivizing the adoption of low-emission vehicles through subsidies and tax incentives. Long-term measures should also include investments in sustainable transportation infrastructure.

2. **Technological innovations**:

Research and development: Invest in research and development to support the creation and adoption of innovative technologies, such as electric and hydrogen fuel cell vehicles. Promote collaboration between academia, industry, and government to drive innovation.

Fleet modernization: Encourage the gradual replacement of older, high-emission vehicles with newer, more efficient models. Provide incentives for vehicle manufacturers to produce low-emission and fuel-efficient vehicles locally.

7.2 Sustainable transportation solutions

1. **Promotion of public transportation:**

Infrastructure investment: Invest in the development and expansion of efficient and reliable public transportation systems, including buses, trams, and commuter rail services, particularly in urban areas with high population densities.

Pricing policies: Implement congestion pricing and efficient fare structures to encourage public transportation usage and reduce the number of single-occupancy vehicles on the road.

2. **Adoption of alternative fuels**:

Diversify fuel sources: Promote the use of cleaner and more sustainable fuels, such as compressed natural gas (CNG), liquefied natural gas (LNG), biofuels, and hydrogen. Develop a comprehensive strategy for the production and distribution of alternative fuels.

Incentives for electric vehicles (EVs): Offer incentives, tax breaks, and subsidies to encourage the adoption of electric vehicles. Develop EV charging infrastructure to support widespread EV usage.

7.3 Strengthening the regulatory framework

1. **Policy reforms and enforcement mechanisms**:

Stricter emission standards: Strengthen and enforce emission standards for vehicles, ensuring that imported and locally manufactured vehicles comply with international emission norms.

Regular emission testing: Implement mandatory emission testing for vehicles at regular intervals and enforce compliance through penalties for non-compliant vehicles.

2. **International cooperation and partnerships**:

Information exchange: Collaborate with international organizations and other countries to exchange best practices, share data on emissions, and access technical expertise for emissions reduction strategies.

Climate finance: Seek international climate finance and support for implementing sustainable transportation projects and initiatives, including funding for the development of clean transportation infrastructure.

These policy recommendations aim to address transportation emissions comprehensively in Nigeria. By combining short-term and long-term strategies, promoting sustainable transportation solutions, and strengthening the regulatory framework, Nigeria can make substantial progress in reducing emissions, improving air quality, and contributing to global efforts to combat climate change while fostering economic growth and enhancing the well-being of its citizens.

8.0 Conclusion

Addressing transportation emissions is not only an environmental imperative but also a moral obligation to safeguard the well-being of present and future generations. With concerted efforts, collaborative partnerships, and informed decision-making, Nigeria can forge a path towards a sustainable, low-emission transportation future, ensuring a greener, healthier, and more prosperous nation for all.

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Review Paper

Carbon-neutral aviation in Nigeria: Assessing the feasibility and impacts of sustainable aviation fuel adoption

Adeniyi O. Oluwakoya

Affiliation
Department of Transport Management, Redeemer's University, Ede, Osun State.

***For correspondence: email:** oluwakoyaa@run.edu.ng

Abstract
This study investigates the feasibility and potential impacts of transitioning Nigeria's aviation industry towards carbon-neutral operations through the adoption of Sustainable Aviation Fuel (SAF). By examining Nigeria's aviation landscape, international efforts for carbon-neutral aviation, and factors such as feedstock availability, infrastructure, and economic considerations, the paper assesses the viability of SAF adoption. Environmental and economic benefits, including reduced carbon emissions, improved air quality, job creation, and economic diversification, are explored. Challenges such as regulatory hurdles, investment requirements, and public awareness are analyzed, with recommendations provided for policy support, industry collaboration, research and development, and public education campaigns. Despite the absence of specific SAF adoption case studies in Nigeria, insights from international experiences inform the recommendations. The findings suggest Nigeria's potential to lead in SAF adoption regionally, contributing to environmental sustainability and economic growth in the aviation sector, while also offering broader implications for the global industry's transition towards a more sustainable future.

Keywords: *Carbon-neutral aviation, sustainable aviation fuel (SAF), Nigeria, feasibility, environmental impact, economic benefits.*

1.0 Introduction

The aviation industry in Nigeria has witnessed substantial growth and development over the years (Oluwakoya and Ajayi 2021). Nigeria is home to several international airports, including the Murtala Muhammed International Airport in Lagos, Nnamdi Azikiwe International Airport in Abuja, and many regional and domestic airports across the country (Oluwakoya and Ogundipe, 2022). The industry plays a pivotal role in connecting the country both domestically and internationally, facilitating trade, tourism, and economic growth (Barkas, Honeck, & Rubio. 2020). However, like the global aviation sector, it faces significant challenges related to environmental sustainability, particularly regarding greenhouse gas emissions and their impact on climate change.

With growing concerns about climate change and its adverse effects, the global community is increasingly focusing on reducing carbon emissions across various industries (Fawzy et. al, 2020). The aviation sector is a significant contributor to greenhouse gas emissions, prompting a concerted effort to achieve carbon-neutral or net-zero carbon aviation (Soria Baledon, et. al., 2022). This involves a commitment to offsetting or reducing the carbon dioxide emissions generated by aircraft operations, either through technological advancements, operational efficiency, or the use of sustainable aviation fuel (SAF) and other innovative solutions (Chiaramonti 2019).

The purpose of this study is to assess the feasibility and potential impacts of adopting sustainable aviation fuel (SAF) in Nigeria's aviation industry as a pathway towards carbon-neutral aviation. By analyzing the current state of aviation emissions in Nigeria, evaluating the viability of SAF adoption, and examining the potential environmental and economic impacts, this study aims to provide valuable insights into the feasibility of transitioning towards a more sustainable aviation sector in the country. Understanding the viability and impact of SAF adoption is crucial for policymakers, industry stakeholders, and environmental advocates seeking to promote sustainable practices within the aviation sector.

2.0 Current state of aviation emissions

The aviation sector is a significant contributor to global carbon emissions. It is estimated to account for approximately 2-3% of the world's total carbon dioxide (CO2) emissions. While this percentage may seem relatively small compared to other sectors, such as energy and transportation, the aviation industry's emissions have been steadily increasing due to the growing demand for air travel worldwide.

2.1 Factors contributing to aviation emissions:

a. Jet Fuel: The primary source of carbon emissions in aviation is the combustion of jet fuel in aircraft engines. Jet fuel releases CO2 and other pollutants, including nitrogen oxides (NOx) and particulate matter, into the atmosphere during flight.
b. Long-Haul Flights: Long-haul flights, which cover vast distances and often use larger, less fuel-efficient aircraft, tend to have higher emissions per passenger kilometer.
c. Rapid Growth: The aviation industry has experienced rapid growth in recent decades, driven by increased global connectivity, rising middle-class populations, and expanding tourism. This growth has led to a corresponding increase in emissions.
d. Limited Alternatives: Unlike some other sectors, aviation does not have widely available alternatives to fossil fuels, making emissions reductions more challenging.

2.2 Nigeria's contribution to global aviation emissions

Nigeria, as one of the most populous countries in Africa and a growing economic hub, has a burgeoning aviation industry. While Nigeria's aviation sector contributes to global emissions, its overall share is relatively small compared to countries with larger aviation industries, such as the United States, China, and European countries. However, Nigeria's emissions are on the rise due to increased air travel and the expansion of its aviation infrastructure.

1. Domestic and Regional Flights: Nigeria's aviation sector mainly consists of domestic and regional flights connecting major cities within the country and neighboring West African nations. These shorter routes often involve smaller aircraft and result in lower emissions per flight compared to long-haul international flights.
2. Growth Potential: Nigeria's aviation industry has substantial growth potential, and as the demand for air travel increases, so too will emissions unless measures are taken to mitigate them.

2.3 Environmental challenges and concerns

The environmental challenges and concerns associated with aviation emissions are significant and multifaceted:

1. Climate Change: The carbon emissions from aviation contribute to global warming and climate change. The sector's emissions include not only CO2 but also non-CO2 effects, such as the formation of contrails and the release of NOx, which can amplify the industry's climate impact.
2. Local Air Quality: Aviation emissions can have detrimental effects on local air quality, especially around airports. NOx emissions can lead to the formation of ground-level ozone and contribute to air pollution, impacting the health of nearby communities.
3. Biodiversity and Land Use: Expansion of airports and associated infrastructure can lead to habitat destruction and encroachment on biodiversity-rich areas.

In light of these concerns, there is a growing imperative for the aviation industry, including Nigeria's aviation sector, to take measures to reduce its environmental footprint and transition towards more sustainable practices, including the adoption of sustainable aviation fuel (SAF). This shift is essential not only for environmental reasons but also for the long-term viability and competitiveness of the industry.

3.0 Sustainable Aviation Fuel (SAF) as a solution

3.1 *What is sustainable aviation fuel?*

Sustainable Aviation Fuel (SAF) is a type of aviation fuel designed to significantly reduce the carbon emissions associated with aircraft operations. SAF is often referred to as an eco-friendly alternative to traditional fossil-based jet fuels. What sets SAF apart is its composition, as it is produced from renewable or sustainable feedstock and undergoes a process that results in lower lifecycle greenhouse gas emissions compared to conventional jet fuel (Peres et. al. 2022).

Key characteristics of SAF include:

1. Renewable Sources: SAF is derived from renewable feedstocks, such as plant-based oils, animal fats, municipal waste, and agricultural residues. It can also be synthesized through advanced processes using carbon capture and utilization (CCU) technologies (Peres et. al. 2022).
2. Drop-in Compatibility: SAF can be blended with traditional jet fuel or used as a pure drop-in replacement without any modifications to existing aircraft engines or infrastructure. This compatibility makes SAF an attractive option for the aviation industry.
3. Carbon Reduction: SAF production methods result in a significant reduction in greenhouse gas emissions, making it an effective tool for mitigating the environmental impact of aviation.

3.2 Types and sources of SAF

There are several types of SAF, each sourced from different feedstock materials and produced using various processes. Some common types of SAF include:

1. Hydroprocessed Esters and Fatty Acids (HEFA): HEFA SAF is primarily made from feedstocks like vegetable oils and animal fats. These feedstocks are refined and then hydroprocessed to produce a SAF that is chemically similar to traditional jet fuel (Usman et. al., 2023)

2. Fischer-Tropsch (FT): FT SAF is produced through a gas-to-liquid (GTL) process, where carbon-rich feedstocks like natural gas or biomass are converted into liquid hydrocarbons. FT SAF is known for its high energy density and cleanliness (Richter et al.,2018).
3. Alcohol-to-Jet (ATJ): ATJ SAF is synthesized from alcohols, such as ethanol or butanol, and converted into hydrocarbons that can be used as aviation fuel. This type of SAF has the potential to be produced from a variety of sustainable feedstocks (Usman et. al., 2023).
4. Synthesized Paraffinic Kerosene (SPK): SPK SAF is created through a process called the Fischer-Tropsch synthesis, where carbon-containing gases like carbon dioxide and hydrogen are used to produce liquid hydrocarbons (Montoya Sánchez, et al.,2022). This process can utilize carbon capture technology to reduce emissions.
5. Biomass-to-Liquid (BTL): BTL SAF is derived from biomass feedstocks like wood, crop residues, or algae. These feedstocks are converted into liquid hydrocarbons through processes like pyrolysis or gasification (Habermeyer, et al.,2023).

3.3 Benefits of SAF adoption in the aviation sector

The adoption of SAF in the aviation sector offers a range of benefits:

1. Carbon Emission Reduction: SAF significantly reduces carbon emissions compared to traditional jet fuels. It can achieve carbon reductions of up to 80% or more, depending on the feedstock and production process (Usman et. al., 2023).
2. Improved Air Quality: SAF produces fewer harmful emissions, such as sulfur compounds and particulate matter, contributing to better air quality near airports and along flight routes.
3. Energy Security: Diversifying the aviation fuel supply with SAF reduces dependence on fossil fuels, enhancing energy security and resilience in the aviation sector.
4. Compliance with Regulations: Many countries and regions are implementing regulations and targets to reduce aviation emissions. SAF adoption helps airlines meet these requirements and avoid penalties.
5. Market Opportunities: The production and use of SAF create new economic opportunities, including jobs in feedstock production, fuel processing, and distribution.

3.4 International efforts and policies promoting SAF use

Several international efforts and policies aim to promote the adoption of SAF in the aviation sector:

1. ICAO CORSIA: The International Civil Aviation Organization's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is a global market-based measure designed to stabilize CO2 emissions from international aviation at 2020 levels (Strouhal, 2020). SAF can be used to offset emissions and comply with CORSIA requirements.

2. National Initiatives: Many countries have introduced policies and incentives to support SAF production and use, including research funding, tax incentives, and blending mandates (Pavlenko, 2021).

3. Industry Commitments: Leading airlines, manufacturers, and industry associations have made commitments to increase the use of SAF in their operations, promoting sustainable aviation practices (Mousavi & Bossink 2017).

4. Research and Innovation: Governments and organizations are investing in research and development to advance SAF technologies, improve production processes, and lower costs (Zhang, et al.,2020).

In summary, Sustainable Aviation Fuel (SAF) holds great promise as a sustainable solution to reduce carbon emissions in the aviation sector. Its compatibility with existing aircraft and infrastructure, as well as its potential for significant carbon reductions, make it a key component of efforts to achieve carbon-neutral aviation worldwide. International policies and industry commitments are driving the adoption of SAF, signaling a positive shift toward more environmentally responsible air travel.

4.0 Feasibility of SAF adoption in Nigeria

4.1 *Availability and production capacity of SAF in Nigeria*

1. Feedstock Resources: Nigeria possesses a wealth of potential feedstock resources for the production of Sustainable Aviation Fuel (SAF). These resources include abundant biomass from agriculture and forestry, waste oils and fats, and algae (Ezeonu and Ezeonu, 2016). These feedstocks can serve as the foundation for local SAF production.
2. Research and Development: Initiatives to explore and harness local feedstocks for SAF production have been underway. Research institutions and universities in Nigeria have been engaged in studies to identify suitable feedstock sources and develop cost-effective conversion processes (Yang, 2014).
3. Potential for Domestic Production: Nigeria has the potential to establish SAF production facilities that can cater to both domestic aviation needs and contribute to the global SAF market. Investment in research and development, as well as collaboration with international partners, can accelerate progress in this regard.

4.2 Infrastructure and technical considerations

1. Refining Infrastructure: Establishing SAF production facilities in Nigeria would require the development or retrofitting of existing refineries or biofuel production plants. This entails technical upgrades and modifications to align with SAF production processes.
2. Distribution and Supply Chain: The infrastructure for transporting SAF from production facilities to airports would need to be established or expanded. This includes pipelines, storage facilities, and logistics for the safe and efficient distribution of SAF.
3. Aircraft Compatibility: SAF should meet international standards and specifications to ensure compatibility with aircraft engines. Technical adjustments and approvals may be necessary to ensure the safe and efficient use of SAF in Nigeria's aviation sector.
4. Research and Innovation: Investment in research and innovation is crucial to address technical challenges and optimize the production and distribution of SAF within the country. Collaboration between government agencies, research institutions, and the private sector can drive advancements in SAF technology.

4.3 Economic feasibility and cost implications

1. Initial Investment: Establishing SAF production facilities and infrastructure represents a significant upfront investment. Government incentives, subsidies, or public-private partnerships may be necessary to attract investors and reduce the financial burden.
2. Production Costs: The cost of producing SAF from different feedstocks can vary. Factors such as feedstock availability, processing technology, and economies of scale influence production costs. Economies of scale can be achieved through increased SAF production and utilization.
3. Price Competitiveness: The economic feasibility of SAF adoption in Nigeria will depend on the price competitiveness of SAF compared to traditional jet fuel. Market dynamics and global SAF pricing will play a role in determining its cost-effectiveness.

4. Job Creation: The SAF industry has the potential to create jobs in feedstock cultivation, processing, production, and distribution, contributing to economic growth.

4.4 Government and industry support for SAF adoption

1. Policy Framework: The Nigerian government can play a pivotal role by implementing supportive policies, such as tax incentives, research grants, and blending mandates, to promote SAF production and adoption in the aviation sector.
2. Industry Collaboration: Collaboration between the government, airlines, airports, and SAF producers is essential for the successful integration of SAF into Nigeria's aviation industry. Public-private partnerships can facilitate the development of SAF infrastructure and supply chains.
3. Education and Awareness: Raising awareness among industry stakeholders and the public about the benefits of SAF adoption is crucial. Education campaigns can foster acceptance and drive demand for SAF.
4. International Cooperation: Nigeria can benefit from international partnerships and collaborations with countries that have advanced SAF industries. These partnerships can provide knowledge transfer, technical expertise, and investment opportunities.

In conclusion, the feasibility of Sustainable Aviation Fuel (SAF) adoption in Nigeria depends on various factors, including feedstock availability, technical readiness, economic viability, and government and industry support. With the right policies, investments, and collaborations, Nigeria has the potential to become a regional leader in SAF production and use, contributing to both environmental sustainability and economic growth within the aviation sector.

5.0 Environmental and economic impacts

5.1 *Reduction in carbon emissions and environmental benefits*

1. Greenhouse Gas Emissions Reduction: The adoption of Sustainable Aviation Fuel (SAF) in Nigeria's aviation sector would lead to a substantial reduction in carbon emissions. SAF can achieve carbon reductions of up to 80% or more compared to traditional jet fuel. This reduction in greenhouse gas emissions contributes significantly to mitigating climate change and aligning with international emissions reduction targets.
2. Lower Particulate and NOx Emissions: SAF also reduces emissions of particulate matter and nitrogen oxides (NOx) by 70% (Habermeyer, et al.,2023) which have detrimental effects on air quality and human health. Lowering these emissions near airports and along flight routes improves local air quality and public health.
3. Reduced Contrail Formation: SAF's cleaner combustion process can lead to fewer contrail formations, which have a warming effect on the atmosphere. This can help mitigate aviation's non-CO2 climate impacts.
4. Biodiversity and Land Use: By reducing the demand for traditional jet fuel, SAF adoption can alleviate pressure on ecosystems and biodiversity-rich areas that may otherwise be impacted by fossil fuel extraction and transport.

5.2 Potential for job creation and economic growth

1. SAF Production Jobs: The establishment of SAF production facilities in Nigeria has the potential to create jobs in feedstock cultivation, processing, and refining. These jobs span

various skill levels and can contribute to employment opportunities in both urban and rural areas.
2. Supply Chain and Logistics: The distribution and supply chain for SAF, including transportation, storage, and logistics, can generate additional employment opportunities in the aviation sector.
3. Economic Diversification: SAF production can diversify Nigeria's economy by adding a new sector that is less reliant on oil and gas revenues. Economic diversification enhances resilience to market fluctuations.
4. Increased Investment: The development of a local SAF industry can attract investment from domestic and international sources, stimulating economic growth and technology transfer.

5.3 Impact on airfares and consumer perception

1. Airfare Considerations: The cost of SAF production and distribution may initially be higher than that of conventional jet fuel. This could potentially lead to higher ticket prices for air travelers. However, the extent of the impact on airfares depends on various factors, including the availability of SAF, production costs, government incentives, and market dynamics.
2. Consumer Perception: The aviation industry's commitment to sustainability and reduced carbon emissions through SAF adoption can positively influence consumer perception. Passengers may be more willing to pay a premium for flights associated with lower carbon footprints, fostering a sense of environmental responsibility.
3. Market Differentiation: Airlines that actively promote their use of SAF may gain a competitive edge by appealing to environmentally conscious travelers who prioritize sustainable travel options.
4. Industry Leadership: Nigeria's aviation industry has the opportunity to demonstrate leadership in sustainable aviation practices, setting an example for the region and the global aviation community.

5.4 Case studies of SAF adoption in other countries

Examining case studies of SAF adoption in other countries provides valuable insights into the potential benefits and challenges of integrating SAF into Nigeria's aviation sector:

1. United States: The United States has seen significant progress in SAF adoption, with various airlines committing to purchase and use SAF. Initiatives such as the Sustainable Aviation Fuel Grand Challenge seek to promote SAF production and use (Jensen et, al.,2023)
2. European Union: The European Union has set ambitious targets for SAF use in aviation as part of its Green Deal and Flightpath initiatives. European countries are investing in SAF production facilities and infrastructure development (Finger et. al., 2021).
3. Singapore: Singapore has made strides in SAF production and has established a SAFinitiative, aiming to supply SAF to airlines operating at Changi Airport. The country's effortsshowcase the feasibility of SAF adoption in an Asian context (Sreenath et al., 2021).
4. Australia: Australia has initiated SAF production projects, leveraging its vast biomass resources. These projects demonstrate the potential of SAF adoption in countries with abundant agricultural and forestry resources (Lebrouhi et al., 2022).

These case studies highlight diverse approaches to SAF adoption, emphasizing the role of government support, industry collaboration, and technological innovation in advancing sustainable aviation practices. They provide valuable lessons that can inform Nigeria's efforts to integrate SAF into its aviation sector.

6.0 Challenges and barriers

6.1 *Regulatory and policy hurdles*

1. Lack of Regulatory Framework: One of the primary challenges in adopting Sustainable Aviation Fuel (SAF) in Nigeria is the absence of a comprehensive regulatory framework that governs SAF production, distribution, and use. Clear and supportive regulations are essential to provide a legal framework for SAF operations.
2. Certification and Approval: SAF must meet stringent aviation safety and quality standards before it can be used in aircraft. Ensuring that SAF produced in Nigeria complies with international standards and securing necessary approvals can be a complex and time-consuming process.
3. International Coordination: As aviation is an international industry, harmonizing SAF regulations and standards with international bodies like the International Civil Aviation Organization (ICAO) is crucial. Nigeria may need to align its regulations with global aviation agreements.

6.2 Investment and funding challenges

1. High Initial Investment: Establishing SAF production facilities and infrastructure requires significant capital investment. Attracting investors and securing funding can be challenging, particularly in the early stages when returns on investment may be uncertain.
2. Access to Financing: Access to affordable financing and investment capital for SAF projectsmay be limited. Public-private partnerships, grants, and subsidies may be necessary to incentivize investment.
3. Price Volatility: The price of feedstocks and SAF production can be subject to fluctuations. Predicting and managing these price variations is essential for the economic feasibility of SAF projects.

6.3 Technological limitations

1. Technology Development: Developing and optimizing technology for SAF production from local feedstocks may require extensive research and development efforts. Nigeria may face technological challenges in scaling up production processes efficiently.
2. Infrastructure Upgrades: Retrofitting or building new infrastructure for SAF production, refining, and distribution may require substantial technical expertise and investments. Developing the necessary infrastructure can be a barrier.
3. Availability of Sustainable Feedstocks: While Nigeria has abundant agricultural and forestry resources, ensuring a consistent and sustainable supply of feedstocks for SAF production can be challenging. Competition with other industries for these resources may arise.

6.4 Public awareness and education

1. Lack of Awareness: Public awareness of the benefits of SAF and the importance of sustainable aviation practices may be limited in Nigeria. Educating the public, including passengers and communities near airports, is crucial to foster support and demand for SAF.

2. Stakeholder Engagement: Engaging with various stakeholders, including government agencies, airlines, airport authorities, and environmental organizations, to build consensus and support for SAF adoption can be time-consuming and challenging.
3. Perceptions and Misconceptions: Addressing potential misconceptions or skepticism about SAF, including concerns about safety, affordability, and effectiveness, is essential to ensure public acceptance and support.
4. Workforce Training: Training and preparing the workforce for SAF-related roles and responsibilities, from feedstock cultivation to SAF production and distribution, is essentialfor a smooth transition to SAF adoption.

In conclusion, while the adoption of Sustainable Aviation Fuel (SAF) offers significant environmental and economic benefits, several challenges and barriers must be addressed in Nigeria. Overcoming regulatory hurdles, securing funding, advancing technology, and enhancing public awareness and education are critical steps in facilitating the successful integration of SAF into the country's aviation sector. Collaboration between government, industry, and international partners is key to overcoming these challenges and realizing the potential of SAF in Nigeria.

7.0 Recommendations for a carbon-neutral aviation future in Nigeria

7.1 *Policy recommendations*

1. Develop a comprehensive SAF policy: Create a dedicated policy framework specifically focused on Sustainable Aviation Fuel (SAF) production, distribution, and use in Nigeria. This framework should include incentives, mandates, and standards to support SAF adoption.
2. Incentives for SAF production: Provide financial incentives, tax breaks, or subsidies to encourage private sector investment in SAF production facilities. These incentives can help offset the high initial capital costs associated with SAF production.
3. Blending mandates: Introduce blending mandates that require a certain percentage of SAF to be used in aviation fuel. Gradually increase the blending targets to stimulate demand forSAF within the aviation sector.
4. Support for research and innovation: Allocate government funding for research and development initiatives related to SAF technology, feedstock development, and production process optimization.
5. International agreements: Actively participate in international agreements and initiatives, such as CORSIA, to align Nigeria's aviation emissions reduction efforts with globalstandards.

7.2 Industry collaboration and partnerships

1. Public-Private partnerships: Foster collaboration between government agencies, aviation industry stakeholders (airlines, airports, and aircraft manufacturers), research institutions, and private companies to jointly invest in and promote SAF adoption.
2. Supply chain development: Facilitate partnerships between SAF producers, logistics companies, and airports to develop a robust SAF supply chain, including storage and distribution infrastructure.
3. Airlines' commitment: Encourage airlines operating in Nigeria to commit to SAF adoption through voluntary agreements, thereby driving demand and setting a positive example.
4. Knowledge sharing: Collaborate with countries and organizations that have advanced SAF adoption to share best practices, technologies, and lessons learned.

7.3 Research and development initiatives

1. SAF technology centers: Establish research centers or hubs dedicated to SAF developmentand innovation. These centers can focus on improving feedstock cultivation, processing techniques, and conversion technologies.
2. Feedstock research: Invest in research into locally available and sustainable feedstock sources for SAF production. This includes studying crop residues, algae, municipal waste, and other potential feedstocks.
3. Efficiency improvements: Fund research projects aimed at increasing the efficiency of SAF production processes, reducing production costs, and enhancing the environmental benefitsof SAF.
4. Carbon capture technology: Explore and invest in carbon capture and utilization (CCU) technologies that can capture carbon dioxide emissions and convert them into SAF, further reducing the carbon footprint of aviation.

7.4 Public awareness and education campaigns

1. Public engagement: Launch public awareness campaigns to educate the public, passengers,and communities near airports about the benefits of SAF adoption, its safety, and its role inreducing aviation's environmental impact.
2. Industry outreach: Work with aviation industry associations to promote SAF adoption and educate aviation professionals about its use and benefits.
3. Educational programs: Collaborate with educational institutions to develop programs and courses related to sustainable aviation practices and SAF production. This can help create a skilled workforce for the SAF industry.
4. Media and marketing: Engage with the media to disseminate information about SAF adoption and showcase the efforts of Nigerian airlines and airports in adopting sustainable practices.

Thus, achieving a carbon-neutral aviation future in Nigeria requires a multifaceted approach involving policy support, industry collaboration, research and development, and public awareness efforts. By implementing these recommendations, Nigeria can position itself as a leader in sustainable aviation practices within the African region, contributing to both environmental preservation and economic growth in the aviation sector.

8.0 Conclusion

Nigeria has the potential to become a leader in carbon-neutral aviation due to its abundant feedstock resources, growing aviation sector, and commitment to environmental sustainability. Achieving this goal will require dedicated efforts, international cooperation, and addressing regulatory, financial, technological, and awareness challenges.

Nigeria's actions in adopting SAF and reducing aviation emissions can set an example for other African nations and emerging economies, signaling that sustainable aviation practices are viable globally. These efforts align with international initiatives like CORSIA, contributing to the collective goal of mitigating climate change in the aviation industry.

Thus, Nigeria's pursuit of carbon-neutral aviation through SAF adoption demonstrates the transformative potential of sustainable aviation practices globally, inspiring the broader aviation industry's transition to a more sustainable and environmentally responsible future.

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THE NIGERIAN ACADEMY OF SCIENCE

Academy House
8A Ransome Kuti Road
University of Lagos, Akoka, Lagos.
P.M.B 1004 University of Lagos Post Office Akoka, Yaba, Lagos, Nigeria.
Tel: +234 808 962 2442
Email: admin@nas.org.ng
Website: www.nas.org.ng