Original Research Article

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

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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, with the 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, the study 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 addressing immediate 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 ingenuity and 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:

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

The angular velocity ($\boldsymbol{\omega_{motor}}$) 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}} \approx$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}} \approx$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:

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

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.

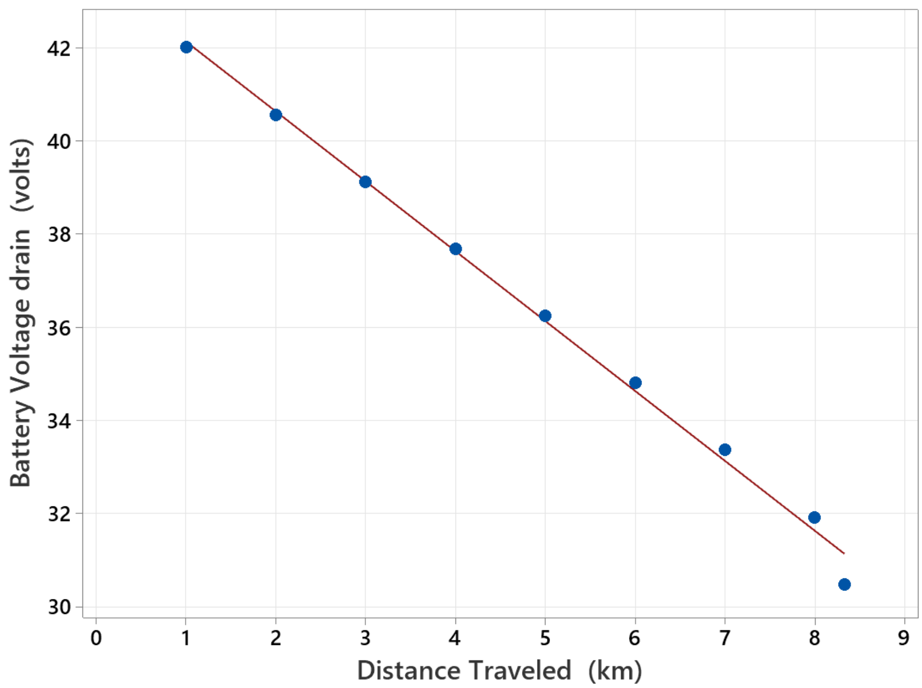

Figure 5: Fitted line plot of volt/km performance of the electric bicycle.

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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