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EFFECTIVENESS OF ELECTRIC MASS TRANSIT BUSES AS A MEANS OF PUBLIC TRANSPORTATION, LAGOS CASE STUDY

Efektywność elektrycznych autobusów komunikacji miejskiej na przykładzie Lagos

Abstract*: The world's transition to more environmentally friendly transportation modes has attracted attention to the importance of electric vehicles in reducing the negative environmental impacts of transportation. In Nigeria, where transportation services are primarily fueled by petrol and diesel, CO2 emissions amounted to approximately 27 million in 2020. Recently, two electric buses and a charging station were launched as proof of concept for a project aimed at supporting the transformation of Lagos public transportation to a carbon free mobility system. Considering that Lagos is currently dealing with rapidly increasing urbanization and a growing transportation industry, the integration of electric vehicles promises tremendous benefits but requires careful evaluation. This study therefore evaluates the feasibility of electric vehicles in Nigeria, using Lagos as a case study. The study uses a multidimensional approach involving questionnaires, interviews, inspections, and the development of an Overall Equipment Effectiveness (OEE) model. With an OEE of 51%, results indicate that the use of electric mass transit buses is sustainable. However, in order to achieve more significant impacts and better performance of the buses, it is necessary to improve the quality of public transportation and integrate renewable energy sources in Nigeria. Overall, this study contributes to the advancement of the ongoing project in Lagos, fostering a paradigm shift towards cleaner and more environmentally friendly mobility in Nigeria. Furthermore, the study promotes the development of an inclusive and broadly applicable methodology for evaluating and advancing transportation solutions globally.*

Keywords: operational effectiveness, electric buses, public transportation

Streszczenie: *Światowa transformacja w kierunku bardziej przyjaznych dla środowiska środków transportu zwróciła uwagę na znaczenie pojazdów elektrycznych w ograniczaniu negatywnego wpływu transportu na środowisko. W Nigerii, gdzie usługi transportowe są głównie zasilane benzyną i olejem napędowym, emisja CO_2 wyniosła około 27 mln ton w 2020 r. Niedawno w Lagos uruchomiono dwa autobusy elektryczne i stację ładowania, jako pilot transformacji transportu publicznego w system mobilności bezemisyjnej. Z uwagi na fakt, że w Lagos obserwowany jest wzrost urbanizacji i transportu, rozwój elektrycznych środków transportu wydaje się korzystny, ale wymaga oceny w zakresie skuteczności eksploatacyjnej. Celem pracy jest możliwość oceny skuteczności eksploatacyjnej elektrycznych środków transportu miejskiego na przykładzie Lagos. W przeprowadzonych badaniach zastosowano kwestionariusze, wywiady, inspekcje i model oceny efektywności systemu (OEE). Wskaźnik OEE na poziomie 51% wskazuje, że wykorzystanie elektrycznych autobusów w komunikacji miejskiej jest akceptowalne. Stwierdzono, że w celu uzyskania lepszych wskaźników OEE, konieczne jest podniesienie jakości transportu publicznego i zintegrowanie odnawialnych źródeł energii z ukierunkowaniem na czystszą i bardziej przyjazną dla środowiska mobilności w Nigerii.*
Słowa kluczowe: efektywność operacyjna, autobusy elektryczne, transport publiczny

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1. Introduction

The transportation industry is dealing with a number of challenges resulting from environmental pollution; electric vehicles present a suitable means of reducing the environmental impacts of transportation [4]. These vehicles have become a viable and cost-effective substitute for conventional vehicles in the modern era. The quest for technological innovation and environmental conservation makes them the future of public transportation [6]. Electric vehicles offer a higher well-to-wheel energy efficiency than internal combustion vehicles (ICVs) [4]. By decreasing noise and air pollution, their adoption in urban transportation promises to improve the quality of life [6]. Although they could be powered directly from the grid [4], battery-powered electric vehicles currently offer the most promising solution for reducing transport carbon emissions [9].

While electric vehicles offer various environmental benefits, their widespread adoption could affect the performance of power grids. Based on this consideration, there has been extensive research on the widespread integration of electric vehicles into power grids. Some of the research areas include the use of renewable energy sources, smart chargers with advanced communication abilities, and smart charging technologies like the Vehicle-to-Grid (V2G) technique [4]. Research has also been directed towards electric vehicle batteries, resulting in the development of regenerative braking technology, which allows vehicle motors charge while vehicles are in motion [3].

The manufacturing and disposal process is an aspect of electric vehicle batteries that presents a major environmental concern. Lithium batteries pose environmental risks due to the presence of certain metal components in them; therefore, it is essential to provide appropriate recycling processes and reduce battery power losses [4]. Ensuring safe operation and maximizing the battery life of electric vehicles are two important considerations in the design of electric vehicles. While complete battery draining could cause battery degradation, full charging produces heat and may be hazardous. The recommended range for battery charges is between 10% and 80%; to comply with this recommendation, the battery capacity should at least 30% higher than the battery's working capacity range [9].

The overall energy efficiency of electric vehicle transportation consists of various factors [2]. From a well-to-wheel perspective, the carbon emissions of electric vehicles may be comparable to those of ICVs if the source of electricity is only coal [4]. Furthermore, in addressing the decrease in carbon emissions through electric vehicle transportation, it is important to consider increasing energy efficiency because of the energy loss in each stage of electricity generation and conversion [2]. Therefore, for a significant reduction of greenhouse gas emissions through the use of electric vehicles, different sources of energy should be integrated [4].

As countries and governments set goals aimed at reducing greenhouse gas emissions and encouraging sustainable mobility, the implementation of electric vehicle transportation remains a global topic of interest. Several notable trends, including the integration of electric vehicles with enhanced connectivity and autonomous driving features, are driving the increasing adoption of electric vehicles today. Before the adoption of electric vehicles in a particular area, a feasibility study is necessary to offer valuable insights about the practicability of implementing electric vehicles in that area. Feasibility studies facilitate successful transitions to electric mobility by enabling well-informed decisions and mitigating potential obstacles.

This study evaluates the efficiency and feasibility of electric vehicles in Lagos State, Nigeria, using a case study of the recently launched electric buses and charging stations by Oando Clean Energy Limited (OCEL) and Lagos Metropolitan Area Transport Authority (LAMATA). In assessing these buses, this study uses the OEE model, a key performance indicator tool used by various researchers for assessing the efficiency of machines and initiatives, including transportation initiatives. Previous studies that applied OEE to transportation analysis defined the model’s quality element in terms of vehicle punctuality. To the best of our knowledge, this study is the first to relate quality to the perception of passengers, defining quality in terms of safety, reliability, comfort, and the overall experience of passengers. This approach fosters an inclusive and widely applicable methodology for assessing the efficiency of public transportation, taking into account regions where schedules for public transportation are not yet in place.

1.1. Electric mobility in Lagos, Nigeria

Nigeria's CO_2 emissions amounted to approximately 27 million in 2020 [12]. In 2021, the institutional and planning framework on climate change underwent many updates. The Climate Change Act was signed, setting a net zero target for the 2050 – 2070 timeframe, and the Energy Transition Plan was adopted [14]. There is definitely an urgent need to address the contribution of emissions from the transport sector, estimated at 62% [13]. One main option to consider in reducing carbon emissions from the transport sector is electric mobility. Electric mobility promises benefits to human health and the environment, as well as to Nigeria's business model of off-grid systems, encouraging the use of photo-voltaic as a local source of energy in rural areas [14]. Furthermore, electric mass transit could reduce Nigeria's financial burdens by limiting the country's importation of petroleum products [12].

Half of Nigeria's natural gas emissions originate in Lagos, as noted in the 2008 Lagos Air Quality Monitoring Study. The study reveals that 43% of Lagos' air pollution is caused by traffic emissions. The Lagos non-motorized transport policy released in 2018 by the Lagos State Ministry of Transportation and LAMATA provides for the adoption of electric vehicles; however, Nigeria has the highest energy access deficit in the world, with 43% of its total population lacking access to electricity. Nine out of eleven power distribution networks face generation and transmission constraints that limit energy supply. It is therefore necessary for the government to collaborate with the private sectors to create demand, supply, and facilitate the use of electric vehicles [14].

OCEL, a private organization, in partnership with LAMATA, accomplished a revolutionary milestone by launching the pilot operation of its sustainable transport initiative for Lagos in 2023. By means of this initiative, OCEL has illustrated that the private sector possesses the ability to stimulate change and create innovative solutions to address present day challenges. OCEL's electric mass transit buses in Lagos support the transformation of Lagos public transportation to a carbon free mobility system [13].

Currently, electric buses are the most promising application of electric vehicles in Nigeria, particularly in Lagos, where Bus Rapid Transit (BRT) buses are already operating and transportation seems more organized [14]. Electric mass transit systems have the potential to address the environmental problems faced by Lagos and Nigeria as a whole [12]. One goal for electric bus implementation should be to integrate them into Lagos BRT, ensuring that they are used on all suitable routes and powered by renewable energy sources. This would be in line with Lagos State Electric Policy and Lagos State Off-Grid Electrification Strategy and Action Plan, which emphasize off-grid solutions. Standards for buses and charging stations should be established alongside regulations for battery recycling [14].

1.2. Battery charging stations and operations

Electric vehicle charging methods vary depending on vehicle types and the power levels required [3]. While considering customer wait times, it is important to locate charging stations where they best fulfil electricity supply requirements [4]. Today, the most widely used charging stations are plug-in charging stations because of their efficiency, ease of installation, and ability to work with both alternating current (AC) and direct current (DC) systems. Plug-in charging involves charging the vehicle through a cable connected directly to the power source. While AC charging takes a long time as a result of its low energy, DC charging is faster because of its unlimited power rate [3].

At pantograph charging stations, DC charging systems are installed on infrastructure above the vehicle [4]. Charging is done generally at a rate of 450 – 600 kW in 4-6 minutes by connecting the DC systems to the roofs of the electric vehicles [3].

Another type of station is the battery swapping station, which allows customers to exchange their dead batteries for charged ones [4]. The three components required for this kind of station for bus services are Battery Swappable Smart Electric Buses (BSSEB), bus control systems with Smart Bus Information Service (SBIA), and the battery swapping station. Battery swapping stations, on the other hand, are expensive because they require a large number of backup batteries [3]. Furthermore, the estimated state-of-health for batteries in the stations may be unreliable [4].

Wireless charging is a distinctive technique that has the ability to start and stop the charging process without human intervention. The dynamic type of wireless charging allows vehicles to charge while in motion, but the static type is done at stops where charging coils are installed. Wireless charging is about 73% less efficient than other methods [9]. The challenges of this method include low energy transfer, expensive installation costs, and human exposure to magnetic fields and radio frequency radiation [4].

The successful development of an electric mass transit system in Lagos depends on the establishment of a robust charging infrastructure [12]. It is recommended that standards be established for charging stations in Nigeria [14]. This study provides guidelines for establishing standards for plug-in charging stations, which are currently the only type of charging stations in Nigeria.

Transport system effectiveness model

The Overall Equipment Effectiveness (OEE) model is one of the Key Performance Indicators (KPIs) for evaluating the use of an industrial asset [5]. It is used to measure the efficiency of technical resources and improve the performance of production processes [7]. Although OEE is traditionally used for measuring production performance, it could be applied as a metric for process improvement initiatives in other contexts [8]. Various OEE

variations have been created specifically for the transportation sector, all of which assess the efficiency of vehicles based on their availability, performance, and quality [5].

OEE is a product of availability, performance, and quality, as expressed in [11]. Availability is defined as the total amount of time that a machine is available for use, taking into account losses due to malfunctions, switchovers, or configuration changes. Performance is a measure of the total effectiveness of output, which could be decreased by a reduction in machine speed, internal breaks, or unforeseen circumstances. Quality is a measure of the correctness of manufactured products. The OEE model is a useful tool for evaluating the efficiency of public transportation services [7]. In the context of vehicles, the OEE (Overall Equipment Effectiveness of the system) may be expressed as shown below:

$$OEE = A \cdot P \cdot Q \tag{1}$$

where:

A – availability of the vehicles, $A = \frac{t_a - t_s}{t_a}$ (2)

P – performance of the vehicles, $P = \frac{P_r}{P_t}$ (3)

Q – quality of transportation system, $Q = \frac{Q_r}{Q_t}$ (4)

t_a – time available for vehicle operation,

t_s – vehicle service time (e.g. breakdowns and downtimes),

P_r – average number of passengers transported between successive stops on the examined route,

P_t – capacity of the bus (e.g. number of available seats)

Q_r – number of buses' (in use) late departures,

Q_t – total number of buses' (in use) departures.

OEE has been applied in transportation management [10]. The model has been used to assess the level of use of public transportation vehicles in Przemysl, Poland [7]. In Bogota, Columbia, the OEE model was used to address the optimization of freight transportation [8]. Based on OEE, a metric was developed to assess the efficiency of automated handling by automated guided vehicles [11]. Practical and academic interest in using the OEE model has led to its systematic review [10]. Based on these indications of the effectiveness of the OEE model in assessing transportation initiatives, this study applied the model to evaluate the use of electric mass transit buses in Lagos, Nigeria.

2. The plug-in charging station for the electric mass transit in Lagos

The plug-in charging station for the electric mass transit proof of concept in Lagos shows Figure 1. The inspection carried out at the charging station revealed that its performance is reasonably acceptable. Indicators and results for the inspection were divided into three groups as shown in tables: Guidelines for the charging device (Table 1), Guidelines for user information and experience (Table 2), Guidelines for the charging site (Table 3).

Fig. 1. Oando charging station [1]

Table 1

Guidelines for the charging device

Charging Device		
Indicators	**Recommendations**	**Assessment Result**
Placement	Clearly identifiable Clearly labelled components Positioned to be safely operated without obstructing sightlines or hindering the accessibility of the environment	✓
Height	0.9m - 1.2m, considering users with various heights and mobility aids	✓
Plug handle	Easy to grip without slipping	✓
Cable weight	Approximately 3kg to allow the cable to be manageable for everyone	✓
Cable length	Not more than 7.5m, i.e., long enough to reach varying socket positions on vehicles without becoming a trip hazard	✓
Charging socket	Clearly visible Tilted upwards to allow tall users to see the socket without compromising its use by seated users Easy insertion and removal of the charging cable	✓

Screen interface	Touch sensitive for easy use Adequate contrast and brightness Tilted between 0° and 20° from the vertical plane towards users to enhance readability	✓
User Interface	Clearly distinguished buttons and controls	✓
Payment options	User friendly payment methods, such as contactless cards and smart phone applications	Not applicable
Electricity supply	Constant electricity supply	✓
	Integrated renewable energy sources	×
Emergency	Availability of an emergency-stop button and an auto reset system	✓
Base Clearance	300mm height clearance to the base for wheelchair footplates	✓
Walking aid holder	Availability of a space designed for keeping walking aids	×

Table 2

Guidelines for user information and experience

User Information and Experience		
Indicators	**Recommendations**	**Assessment Indication**
Mobile applications	Provision of information about the location, characteristics, and use of the charging station on mobile applications Control of certain charging functions on the charging device through smartphones, e.g., checking charging status	×
Digital interface	Clear and simple visual instructions on charging devices and applications, following best practice in information design	✓
Signages	Clear, visible and well-placed signages to direct navigation Display of warnings and key information about charging on the charging device and at strategic locations	✓
Charging feedback	Indication of operational stages of the charging process, e.g., light cues and audio cues Direction on next steps where the charging process fails	✓
Customer Service	Constant customer support service Responsive assistance through a call, text, voice command or a help button when customer care representatives are unavailable.	×
Internet Connection	Sufficient cell phone or internet coverage to enable the use of mobile applications while charging.	✓

Table 3

Guidelines for charging site

Charging Site		
Indicators	**Recommendations**	**Assessment Result**
Charging bay	Well designated with signs and markings Designed to allow the safe manoeuvring and parking of all vehicles Designed to allow all kinds of users to enter, leave, and move around their vehicles safely.	✓
Trip and crash hazards	Absence of obstacles to movement. Where necessary, wheel stops, bollards, safety barriers, drainage infrastructure, or kerbs should be well placed and clearly designated.	✓
Ground surface	Flat and stable surface directly under the charging device Suitable ground surface gradient (e.g., 1:50) and water drainage facilities (where applicable) to avoid the formation of pools around the charging device. Where height disparities between the ground surface and the roadway are unavoidable, accessible features like ramps and dropped kerbs should be provided.	✓
Amenities	Charging station's proximity to surrounding amenities and services Seats where applicable, i.e., where they do not cause obstructions	✓
Weather protection	Provision of charging station shelters to minimize adverse weather conditions for users	×
Safety/Security	Location of charging station at a safe area, preferably a highly trafficked area.	✓
	Clearly visible security cameras	×
Lighting	Adequate lighting to enable users use the charging device and navigate the environment safely at different times of the day.	✓
Ticketing Machine	Constant accessibility of ticketing machines to prevent hindering the use of charging devices	Not applicable
Maintenance	Routine maintenance of charging station	✓

There were no payment options or ticketing machines for using the charging station because it was specifically being used by the two electric buses being tested. It should be

noted that the failure of the charging station to meet certain indicators on these tables could be a result of the fact that the charging station is operating as a proof of concept. According to [1], OCEL and LAMATA are actively working on developing a robust electric vehicle infrastructure ecosystem. Furthermore, it should be noted that the recommendations on the tables cover everybody, including the disabled. However, where recommendations for disabled people are not feasible, charging bays may be designed separately for them.

3. Effectiveness research of the selected transport system

Lists of indicators for assessing the performance of charging stations were developed from a literature review. Based on these lists, an inspection was carried out at the Oando charging station for the pilot operation of the two electric mass transit buses in Lagos.

Questionnaires were distributed to a sample of 50 passengers to understand their perception of the electric buses, and an interview was conducted with the Lagos Metropolitan Area Transport Authority (LAMATA) to obtain data on the performance of the buses. In order to obtain more information about the availability and performance of the buses, a survey was carried out on the vehicles for a period of seven days. The results of the survey, along with the responses from the questionnaires and interviews, were used to develop an overall Equipment Effectiveness (OEE) model for assessing the efficiency of the deployed electric buses in Lagos State.

At the time of the survey for this study, the Yutong E12 73-passenger (42 seated and 31 standing passengers) electric buses were being tested on two routes: the Ikorodu -TBS route with 27 bus stops and the Oshodi - Ajah route with 15 bus stops. Considering the higher number of bus stops, the survey was carried out on the Ikorodu-TBS route.

The Overall Equipment Effectiveness indicator of the bus-based transportation system has been expressed by equation 1.

The two electric buses were always available during the period of survey for this study; thus, availability was calculated to be 100%. According to LAMATA, the vehicles had yet to experience any breakdowns because of the routine maintenance carried out on them. Challenges experienced were rather related to drivers' unfamiliarity with electric vehicles and the instability of electric power supply, which had been addressed through training programmes for drivers and a dedicated source of power supply for the charging station. Availability may have also been influenced by the 422 kWh batteries and the regenerative braking systems of Yutong E12 buses, which extend the range up to 40% depending on the route. According to LAMATA, the electric buses could travel up to 280 km on a full battery charge.

The average number of passengers after boarding and alighting at each of the 27 bus stops along the Ikorodu-TBS route amounted to 64 passengers. When divided by the 73-passenger capacity of the electric buses, the performance of the buses was calculated to be 88%.

The quality of transportation was not calculated based on the punctuality of departures, as done by [7], because mass transit buses in Lagos do not work according to schedule. Data on the quality of transportation was obtained from the questionnaires distributed to passengers. This was reflected in passengers' responses on comfort, safety, reliability, and the overall experience of using electric buses. Passengers seemed to be receptive to the introduction of the electric mass transit buses in practice. Passengers' perception of the comfort, safety, reliability and overall experience of electric vehicles were rated on a scale of 1-5 (1 being poor and 5 being excellent). The quality element in this study was thus derived from the percentage of the average rate of the four elements in the questionnaires distributed (Figure 2), which was calculated to be 58%.

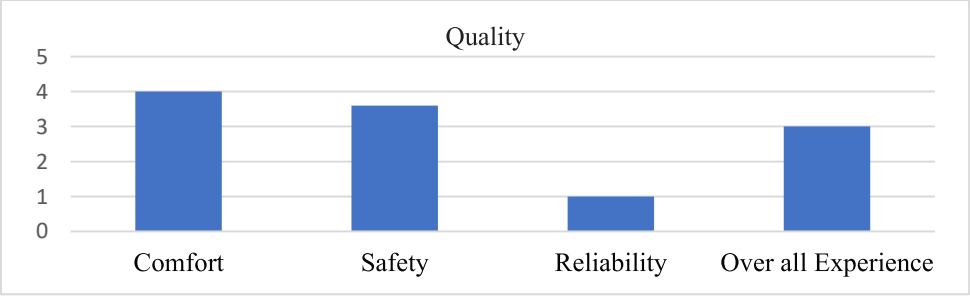

Fig. 2. Passengers' perception of the quality of the electric buses

OEE indicator of the vehicles (subject of research in selected transport system) resulted to 51% (Table 4) which is much higher than any of the OEE presented in paper [7]. However, 51% is only an average percentage when compared to the individual sub-indicators for availability and performance. It can be observed from that the average OEE outcome was influenced by the percentage for quality, which was in turn influenced by passengers' poor perception of the reliability of the buses as reflected in Figure 2.

Table 4

OEE for the electric mass transit buses along the Ikorodu-TBS Route

Availability	Performance	Quality	OEE
100%	88%	58%	51%

4. Conclusions

This study evaluated the feasibility of electric vehicles in Lagos State (Nigeria) using the recently launched electric buses and charging stations in Lagos as a case study. The evaluation was done through a multidimensional approach that involved questionnaires, interviews, inspections, and the development of an OEE model. Considering the results of this study and the recent updates made to the institutional and planning framework on climate change in Nigeria, the use of electric mass transit buses is sustainable. In support of this notion, this study has recommended guidelines for establishing plug-in electric vehicle charging stations.

However, the scenario under study is merely a proof of concept, and as such, it faces certain limitations and issues. To improve efficiency, there is a need to improve the quality of public transportation and passenger experience in Nigeria. Public transportation should be operated based on established schedules accessible online or on mobile applications, along with other information related to the use of the vehicles. Natural gas is a major source of electricity in Nigeria; therefore, it is necessary to integrate renewable energies sources to reduce significant impacts of electric vehicles on environmental pollution. LAMATA's response indicates that there are plans to integrate renewable energy sources into the ongoing project in Lagos. This is actually expected because OCEL, LAMATA's project partner, is the renewable energy business subsidiary of Oando Energy Resources. OCEL's commencement of this project indicates the potential of the private sector to partner with the Federal Government in fostering transportation solutions in Nigeria.

Overall, this study contributes to the advancement of the ongoing OCEL-LAMATA project in Lagos, fostering a paradigm shift towards cleaner and more environmentally friendly mobility in Nigeria. It promotes the development of an inclusive and broadly applicable methodology for evaluating and advancing sustainable transportation solutions globally. Further research could look into other types of charging stations and methods, such as wireless charging technology and pantograph charging stations. This widened focus would provide more comprehensive guidelines for the establishment of charging stations. Furthermore, it would be necessary to investigate Nigeria's planned strategies for managing electric vehicle batteries. Along with the increasing adoption of electric vehicles, there is growing concern about the management of their batteries because improper handling of these batteries could yield negative environmental effects. Examining Nigeria's policies and initiatives regarding battery disposal, recycling, and management practices is essential to fostering a more sustainable and environmentally friendly mobility in Nigeria.

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