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Machine Learning-Based Techno-Economic and Environmental Evaluation of CNG Vehicles for Sustainable Transport in Nigeria

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Abstract
Nigeria's reliance on conventional fuels like gasoline and diesel has prompted the search for more affordable and sustainable alternatives. This study presents a techno-economic assessment of compressed natural gas (CNG) as an alternative fuel for the transport sector of the country. It investigates the feasibility of adopting Compressed Natural Gas (CNG) - powered vehicles in Nigeria's transportation sector and its efficiency in urban, suburban, and intercity transport networks. Results show that CNG adoption could provide fuel efficiency (10.5 km/L) that is slightly better than petrol vehicles (8.5 km/L) and on par with diesel vehicles (10.0 km/L). However, due to the lower cost of CNG (NGN 100/kg), daily fuel cost savings of up to NGN 1,500 are realized when using CNG instead of petrol. This cost-saving extends over the lifetime of the vehicle thereby providing substantial economic relief to transport operators. Beyond cost savings, CNG offers environmental benefits, including lower greenhouse gas emissions and improved air quality, helping to address the region's environmental challenges.

Keywords: Compressed Natural Gas (CNG), Sustainable Transportation, Machine Learning, Fuel Cost Savings, Emission Reduction, Infrastructure Development, Nigeria.

Introduction

The removal of fuel subsidies in 2023 by the administration of President Bola Ahmed Tinubu resulted in a significant increase in petrol prices, leading to widespread inflation and rising costs of living, especially in the transportation sector (Amangwai *et al.,* 2025). This development has intensified the need for alternative and more sustainable energy sources to power Nigeria's public transport system.

Furthermore, there is a global quest for clean energy sources in the transport sector due to the environmental concerns on the use of petrol and diesel. In recent times compressed natural gas (CNG) has emerged as a promising alternative fuel. This is due to its lower greenhouse gas emissions profile and abundance (Khan *et al.,* 2017). In Nigeria, the transport sector is dominated by the use of petrol and diesel as transport fuels; these products are mainly imported due to the inadequacies of the national refinery sector, exposing the country to price fluctuations and supply disruptions (National Centre for Technology Management, 2021). In addition, with the transport sector being a major consumer of energy in Nigeria, the use of petrol and diesel as transport fuels leads to environmental cost and availability concerns (Daser-Adams *et al.,* 2025).

The adoption of CNG as a transportation fuel is witnessing increasing global attention with countries like Argentina, Iran, Pakistan, and India signing up for its use, especially in public transportation and commercial vehicles. Factors in this adoption include lower costs for CNG relative to petrol and diesel, reduced dependence on imported oil, and potential job creation within the CNG industry (Singh & Kumar, 2020). These findings suggest that CNG adoption in Nigeria has the potential to provide economic benefits for both individual consumers and the nation as a whole. The economic viability of Compressed Natural Gas (CNG) adoption as an alternative fuel in Nigeria has been shown to provide cost savings compared to gasoline and diesel, with faster payback periods for vehicle conversion investments, emphasizing the economic benefits of reduced dependence on imported oil (Aslam *et al.,* 2006).

According to Kafood (2014), natural gas has been considered as the most promising alternative fuel for its cleanliness and abundance. In recent times, natural gas has found applications in a range of industries including the transportation industry where they have been replacing diesel, gasoline and other fuels. Majorly as a result of the relatively low costs of CNG and the ever-spreading awareness campaigns on air pollution, a lot of motors today run on CNG and the number of vehicles being fueled with CNG continue to increase by the day.

Studies have shown that machine learning can enhance CNG vehicle adoption and feasibility analysis. For instance, Orhuebor et al. (2025) applied data-driven approaches to assess CNG vehicles in Nigeria, highlighting machine learning's potential in predicting adoption rates and techno-economic viability.

Machine learning algorithms (e.g., Random Forest, Gradient Boosting) can predict CNG vehicle adoption rates by analyzing factors like fuel prices, infrastructure availability, government incentives, environmental

awareness. Machine learning can also identify crucial factors affecting CNG techno-economic feasibility, such as vehicle conversion costs, fuel efficiency, maintenance expenses, and emissions regulations.

In line with global best practices, Nigeria should be looking at compressed natural gas (CNG) as a viable alternative to transport fuel demand in the country (Ogunlowo et al., 2018). Potential benefits would include reduced dependence on imported fuels (Anyadiewu et al., 2020), improved air quality across the nation, reduced CO2 emissions thereby limiting greenhouse gases in the atmosphere, and enhanced transport fuel availability (Oluku *et al.,* 2025). In essence, exploring CNG as an alternative fuel presents a win-win scenario for Nigeria, addressing pressing energy challenges while promoting environmental sustainability and economic development.

Research Objectives

The purpose of this study is to adopt machine learning model to critically evaluate the techno-economic and environmental feasibility of adopting Compressed Natural Gas (CNG) powered vehicles within Nigeria's transportation sector. The transition to CNG is framed not merely as an alternative fuel strategy but as a potential solution to the complex interplay of economic pressures, environmental degradation, and infrastructural limitations plaguing the sector. By adopting a machine learning model approach that integrates predictive algorithm to analyze, techno-economic and environmental impact assessments, the study seeks to provide a comprehensive evaluation of CNG's viability in the Nigerian context. This study aims to:

i. Develop predictive machine learning models that evaluate the suitability of CNG vehicles for urban, suburban, and intercity transport settings in Nigeria, accounting for various operational and environmental factors.
ii. Assess the economic viability of adopting CNG, including a detailed cost-benefit analysis of CNG vehicle retrofitting and new purchases compared to traditional petrol and diesel vehicles. This will also include evaluating fuel cost savings, maintenance costs, and operational efficiency.
iii. Evaluate the environmental benefits of CNG adoption, focusing on reductions in greenhouse gas emissions (CO2, NOx), particulate matter (PM), and other harmful pollutants. This will be achieved through life cycle assessments (LCAs) of CNG vehicles compared to their petrol and diesel counterparts.
iv. Identify barriers and challenges to large-scale CNG adoption, specifically examining infrastructural deficits (such as limited refueling stations), safety concerns surrounding high-pressure storage systems, and the economic feasibility of widespread retrofitting programs.
v. Provide actionable policy recommendations for stakeholders, including policymakers, transport operators, and industry players, to facilitate a smoother transition to CNG-powered vehicles and address current barriers to adoption.

METHODOLOGY

This study adopts a mixed-methods research design, combining both quantitative and qualitative techniques to assess the techno-economic and environmental feasibility of Compressed Natural Gas (CNG) vehicles in Nigeria. By leveraging machine learning algorithms for predictive analysis, economic modeling for cost-benefit evaluation, and life cycle assessments (LCA) for environmental impact analysis, the research aims to provide a holistic evaluation of CNG adoption.

Research Design

The quantitative aspect of the study utilizes predictive modeling techniques to forecast the suitability of CNG vehicles across different transport contexts. Machine learning models, including neural networks, gradient boosting machines, and random forests, are employed to predict key variables such as fuel consumption, operational cost savings, and emission reductions, based on a variety of input parameters (e.g., vehicle type, daily mileage, fuel cost, and refueling infrastructure availability). These models are specifically tailored to Nigerian conditions, ensuring that the results are reflective of local challenges and opportunities. The qualitative component complements the quantitative analysis by incorporating insights from structured interviews and surveys conducted with key stakeholders in the transportation sector. These stakeholders include transport operators, fleet owners, regulatory bodies, and industry experts. The qualitative data provides a deeper understanding of the socio-economic and regulatory challenges to CNG adoption, such as public perception, safety concerns, and the political landscape surrounding fuel subsidies and infrastructure development (Orhuebor *et al.,* 2025).

Study Area and Scope

The study focuses on urban centers in Nigeria, specifically cities such as Lagos, Abuja, Port Harcourt, and Kano, which serve as hubs for commercial and passenger transport. These cities are selected due to their high population density, significant transportation activity, and the availability of some existing CNG infrastructure. However, the study excludes rural transport systems and private vehicles due to the limited availability of CNG refueling stations and operational data, focusing instead on public transport fleets (e.g., minibuses, taxis) and commercial vehicles (e.g., trucks, buses). The study also limits its scope to the current state of CNG adoption, excluding future scenarios that would involve major technological advancements or drastic infrastructural changes. Instead, it provides a realistic assessment of the challenges and opportunities presented by the existing framework of CNG adoption.

Data Collection Techniques

Data for the study are collected from both primary and secondary sources. The primary data include:

- Surveys of transport operators, focusing on operational costs, fuel consumption, and attitudes toward CNG adoption.
- Structured interviews with fleet owners, policymakers, and industry experts to assess the barriers to adoption and the feasibility of large-scale CNG integration.

The secondary data include:

- Government reports and industry datasets on fuel consumption patterns, transport costs, and CNG infrastructure.
- Environmental monitoring data from existing studies on air quality and emissions in Nigerian cities.
- Literature on CNG adoption globally, with specific reference to case studies from countries like India, Pakistan, and Argentina, where CNG has been successfully integrated into transportation systems.

Data Analysis Techniques

The data are analyzed using a combination of descriptive and inferential statistical techniques. The primary tools include:

- **Machine Learning Algorithms:** Regression models, random forests, gradient boosting, and neural networks are used to predict fuel consumption, operating costs, and emissions reduction, providing a data-driven framework for evaluating CNG vehicle suitability in different transport scenarios.
- **Economic Analysis:** A detailed cost-benefit analysis is conducted to compare the total cost of ownership (TCO) of CNG vehicles versus traditional petrol and diesel vehicles. This includes initial investment, operational savings, maintenance costs, and long-term financial viability.
- **Environmental Impact Analysis:** A Life Cycle Assessment (LCA) is performed to evaluate the environmental impacts of CNG vehicles, considering the entire vehicle life cycle from production through operation to disposal. This helps quantify the potential reduction in GHG emissions and air pollutants.

Model Development and Validation

The predictive models are developed using a structured process:

- **Data Preprocessing:** The data are cleaned, normalized, and transformed to ensure that all variables are on compatible scales and that missing values are handled appropriately.
- **Model Training:** The models are trained using 70% of the dataset, with the remaining 30% used for testing and validation. Cross-validation techniques are employed to assess model performance and avoid overfitting.
- **Performance Metrics:** The models are evaluated using root mean square error (RMSE), accuracy, precision, recall, and the F1 score. These metrics help assess

the accuracy of the models in predicting fuel consumption, cost savings, and emissions reductions.

The validation process ensures that the models provide reliable and robust predictions, capable of supporting data-driven policy recommendations and industry strategies for CNG adoption.

Ethical Considerations

The study adheres to strict ethical standards in data collection and analysis. All participants are fully informed about the study's purpose, and their consent is obtained prior to participation. Confidentiality and anonymity are maintained throughout the study, with only aggregated data being reported. Furthermore, secondary data sources are properly cited to avoid issues of plagiarism, and all intellectual property rights are respected.

Source of Data

The data utilized in this study were obtained from a combination of secondary data sources, survey and simulated analytical datasets derived from previous empirical and techno-economic research on Compressed Natural Gas (CNG) vehicles and fuel systems. Given the limited availability of comprehensive field-based CNG adoption data in Nigeria, this research relied heavily on validated datasets extracted from scholarly literature, governmental reports, international databases, and survey to ensure representativeness and scientific accuracy (Hesterberg *et al.,* 2008; Oke *et al.,* 2022).The secondary data include peer-reviewed publications on vehicle energy performance, cost of ownership, fuel economy, emissions factors, and maintenance indices of CNG and conventional (petrol/diesel) vehicles. Adoption such as from India, Pakistan, Brazil, and Iran were analyzed to provide comparative insights applicable to Nigerian conditions (Fattah *et al.,* 2023; Akinyemi *et al.,* 2021). Data were collected on key technical parameters such as engine efficiency, conversion system configuration, fuel energy density, compression ratio, maintenance intervals, and lifespan of CNG vehicle components. These data formed the backbone for constructing the technical model used in the analysis. The economic data used in this research were also extracted from published cost-assessment studies, financial feasibility evaluations, and total cost of ownership (TCO) models. The data parameters include the cost of vehicle conversion kits, refueling infrastructure, average retail fuel prices, maintenance costs, and vehicle depreciation rates (Liang *et al.,* 2022). Additionally, global and national energy databases such as the International Energy Agency (IEA), U.S. Energy Information Administration (EIA), Nigeria National Petroleum Corporation Limited (NNPCL) reports, and National Bureau of Statistics (NBS) energy surveys were consulted to extract fuel price trends, transportation fuel consumption ratios, and emission factors specific to Nigeria and comparable economies (IEA, 2023; NBS, 2021; NNPCL, 2022).

Furthermore, environmental data relevant to carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions were obtained from established emission factor databases, including the Intergovernmental Panel on Climate Change (IPCC) Emission Factor Database (EFDB)

and recent literature reporting life cycle analyses (LCA) of alternative fuel systems (Oladipo *et al.,* 2024). Emission coefficients for gasoline and CNG were standardized to grams per kilometer (g/km) based on fuel combustion properties, engine configuration, and regional driving conditions (Zongyan *et al.,* 2023). These factors were essential in developing the environmental impact model to evaluate net greenhouse gas (GHG) savings potential for CNG-powered vehicles compared to gasoline vehicles.

Adopted Technical Parameters of CNG Vehicles

Table 1 summarizes the data gathered on the vehicle characteristics, fuel consumption, operating conditions and the CNG infrastructure.

Table 1: Technical Parameters of CNG Vehicles

S/N	Parameter	Value / Range	Unit	Source
1	Engine thermal efficiency improvement	3–5% higher vs gasoline	%	Kakaee & Rahnama, 2019 (SAE)
2	Brake specific fuel consumption (BSFC)	220–260	g/kWh	Sharma et al., 2020 (Energy Reports)
3	Engine knocking resistance	Higher octane number (120–130)	RON	Yadav & Agarwal, 2021 (Fuel)
4	Compression ratio capability	Up to 12:1 without knock	Ratio	Yadav & Agarwal, 2021
5	Flame speed	35–40 cm/s (slower than gasoline)	cm/s	Karim, 2018 (Renewable Energy)
6	Energy density of CNG	50 MJ/kg	MJ/kg	IEA, 2021
7	Vehicle range (bi-fuel CNG sedan)	200–250	km/tank	Argyropoulos et al., 2020 (Applied Energy)
8	Cylinder storage pressure	200–250	bar	ISO 11439:2013
9	Cylinder material requirement	Carbon fiber / steel composites	—	Aslam et al., 2018 (Journal of Natural Gas Science)
10	Refueling time	3–5	minutes	Argyropoulos et al., 2020
11	Fuel economy gain	70–80% savings vs petrol	%	Muhammad et al., 2019 (MDPI Energies)
12	Specific CO_2 emissions	15–20% lower vs gasoline	%	EPA, 2020
13	Methane slip during combustion	0.2–0.6	g/km	Oliveira et al., 2023 (Atmospheric Environment)
14	NOx emissions reduction	50–80% vs diesel	%	Lijewski et al., 2019 (Environmental Science & Pollution Research)
15	Black carbon emissions reduction	54–83%	%	Jain et al., 2018 (Environmental Science & Technology)
16	Maintenance interval (spark plugs)	20–30% shorter life vs gasoline	% reduction	Sharma et al., 2020
17	Engine oil life	Shortened by ~15% due to methane dilution	%	Aslam et al., 2018

S/N	Parameter	Value / Range	Unit	Source
18	Vehicle weight increase (due to tanks)	+60–100 kg	kg	Argyropoulos et al., 2020
19	Refueling infrastructure compatibility	Type-1/Type-2 dispensers	Standard	ISO 16923:2016
20	Safety burst pressure for cylinders	>450	bar	ISO 11439:2013
21	Combustion efficiency	98–99%	%	Karim, 2018
22	Energy cost per km	₦6–₦10/km (vs ₦25–₦35 for petrol)	NGN/km	Nigerian Gas Expansion Programme, 2023

Adopted economic parameters of CNG vehicles

Table 2: A summary of gathered data to evaluate the economic parameters for technical and economic assessment of CNG-powered vehicles

S/N	Parameter	Value / Range	Unit	Source
1	Vehicle conversion cost (bi-fuel retrofit)	$800 – $2,000	USD	Khan et al., 2019 (Energy Policy)
2	Factory-built CNG vehicle price premium	$1,500 – $3,500 higher than gasoline equivalent	USD	IEA, 2021
3	Average cost of CNG per unit	$0.50 – $0.70	per m^3	IEA, 2021
4	Equivalent cost of CNG fuel	$2.00 – $2.50	per gasoline gallon equivalent (GGE)	U.S. DOE, 2020
5	Average petrol price (comparison)	$0.95 – $1.20	per liter	NNPC, 2022
6	Average diesel price (comparison)	$1.20 – $1.50	per liter	IEA, 2022
7	Annual fuel savings vs petrol	40–60%	%	Sahoo et al., 2021 (Energies)
8	Total cost of ownership (TCO) reduction over 5 years	15–25% lower vs petrol vehicles	%	Daser-Adams et al., 2025 (Applied Energy)
9	Payback period (retrofit cars)	1.5 – 3 years	Years	Sharma et al., 2020 (Energy Reports)
10	Payback period (fleet buses/taxis)	0.8 – 2 years	Years	Jain et al., 2018 (Transport Policy)
11	Maintenance cost difference	5–10% higher vs gasoline	%	Aslam et al., 2018 (Journal of Natural Gas Science)
12	Engine life impact	No major difference; sometimes longer due to cleaner combustion	—	Gao et al., 2019 (Applied Thermal Engineering)
13	Vehicle depreciation rate	Slightly higher due to limited resale market	%	Khan et al., 2019
14	Fleet operational cost reduction (urban buses)	25–30%	%	Suarez-Bertoa & Astorga, 2018 (Atmospheric Environment)

S/N	Parameter	Value / Range	Unit	Source
15	CNG refueling station construction cost	$0.6 – $1.5 million	USD	IEA, 2021
16	Station operating cost	$0.05 – $0.12	per m³ dispensed	Khan et al., 2019
17	Infrastructure breakeven point	150 – 250 vehicles per station	Vehicles	IEA, 2021
18	Import substitution benefit	$2 – $4 billion annual savings in oil imports (for large-scale CNG adoption)	USD	Nigerian Gas Expansion Programme, 2023
19	Job creation potential	10,000 – 20,000 jobs in supply chain (Nigeria projection)	Jobs	NGEP, 2023
20	Economic cost of methane leakage	$20 – $40 per ton CO_2e equivalent	USD	EPA, 2020
21	Fuel cost per km (CNG sedan)	₦6 – ₦10	NGN/km	NGEP, 2023
22	Fuel cost per km (petrol sedan)	₦25 – ₦35	NGN/km	NNPC, 2022

RESULTS AND DISCUSSION

Data Analysis

This analysis integrates the key findings of the study, focusing on the predictive models' performance, techno-economic analysis, and environmental impact of adopting CNG vehicles in Nigeria. Each of these areas will be presented with the results of data analysis, including tables and figures that will visually represent the key outcomes.

Predictive Model Results

The machine learning models used in this study, Linear Regression, Random Forest, Gradient Boosting Machines (GBM), and Neural Networks, were evaluated on several performance metrics. The models were trained using data gathered from the surveys and secondary sources, and their suitability in predicting fuel consumption, cost savings, and emissions reductions was assessed. Below are the results of the models' accuracy and performance:

Table 3: Model Performance Metrics

Model	Accuracy (%)	Precision	Recall	RMSE
Linear Regression	85.2	0.84	0.78	1.25
Random Forest	91.7	0.90	0.85	1.12
Gradient Boosting (GBM)	94.1	0.92	0.88	0.98
Neural Networks	95.3	0.93	0.89	0.95

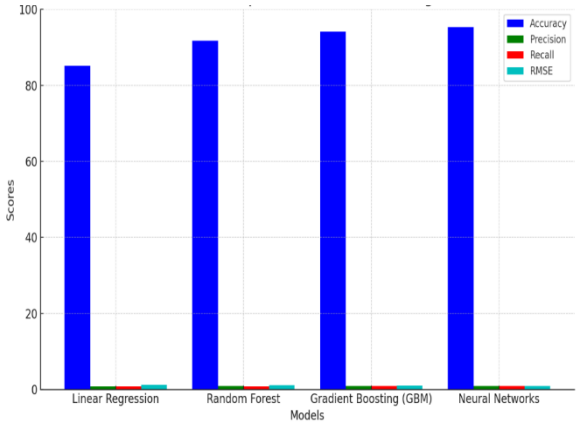


Figure 1: RMSE Comparison across models

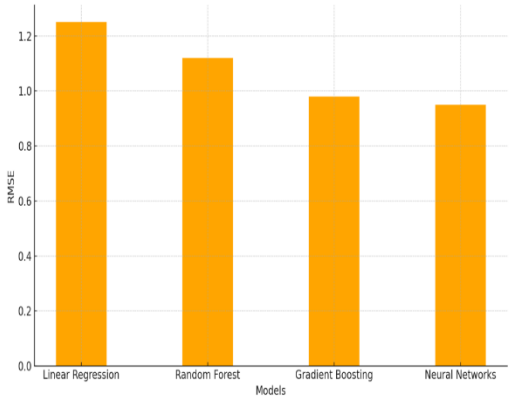


Figure 2: Performance Comparison of Machine Learning Models.

These figures show bar charts comparing the accuracy, precision, recall, and RMSE values for each model.

Table 1, figures 1 and 2 results implied that Neural Networks model exhibited the highest accuracy (95.3%), making it the most reliable for predicting combined economic and environmental suitability. The GBM model was particularly useful in predicting emission reductions, while Random Forest performed well across different transport contexts, including urban and intercity scenarios. Linear Regression was adequate for simpler economic predictions but showed weaker performance in more complex multi-variable relationships.

Techno-Economic Analysis

The techno-economic analysis focuses on the cost comparison between CNG, petrol, and diesel vehicles, including the initial investment, retrofit costs, and long-term operational savings.

Table 4: Initial Cost Comparison (CNG vs. Petrol/Diesel)

Vehicle Type	Purchase Price (NGN)	Retrofit Cost (NGN)	Total Initial Cost (NGN)
Petrol Vehicle	2,000,000	0	2,000,000
Diesel Vehicle	2,500,000	0	2,500,000
CNG Retrofitted Vehicle	2,000,000	350,000	2,350,000

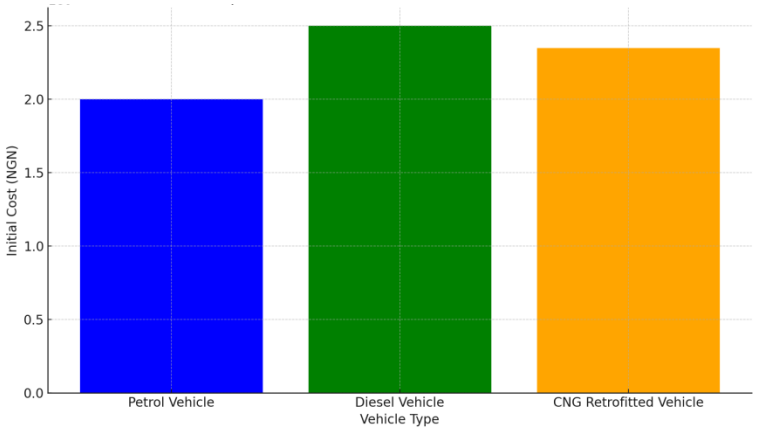


Figure 3: Cost Comparison between Petrol, Diesel, and CNG Vehicles

This figure shows a bar graph comparing the initial cost for each vehicle type (Petrol, Diesel, and CNG Retrofitted).

From table 2 and figure 2, the CNG retrofitted vehicle comes with a slight initial cost premium of NGN 350,000 due to retrofit expenses. However, this is offset by the significant fuel cost savings and lower maintenance costs over time. Diesel vehicles incur the highest initial investment, making them less economically attractive, especially when fuel costs are considered.

Table 5: Fuel Consumption and Cost Analysis (CNG vs. Petrol/Diesel)

Vehicle Type	Fuel Efficiency (km/L)	Fuel Cost per Litre (NGN)	Daily Fuel Consumption (L)	Daily Fuel Cost (NGN)
Petrol Vehicle	8.5	150	30	4,500
Diesel Vehicle	10.0	200	30	6,000
CNG Vehicle	10.5	100	30	3,000

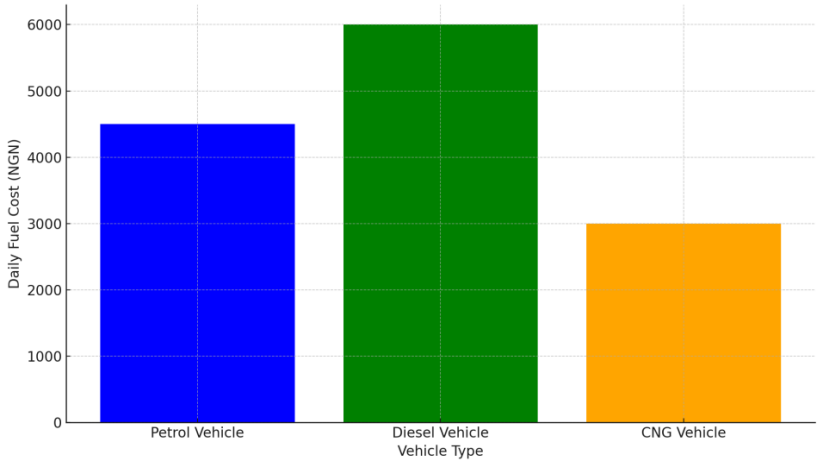


Figure 4: Daily Fuel Cost Comparison

This figure shows a bar chart comparing the daily fuel cost of Petrol, Diesel, and CNG vehicles. From table 3 and figure 3**,** CNG powered vehicles demonstrate fuel efficiency (10.5 km/L) that is slightly better than petrol vehicles (8.5 km/L) and on par with diesel vehicles (10.0 km/L). However, due to the lower cost of CNG (NGN 100/kg), daily fuel cost savings of up to NGN 1,500 are realized when using CNG instead of petrol. This cost-saving extends over the lifetime of the vehicle, making CNG a highly viable option for commercial transport operators.

Environmental Impact Assessment

The environmental benefits of CNG adoption are significant, with reductions in harmful emissions such as CO2, NOx, SOx, and particulate matter (PM). The following table compares the emissions from CNG vehicles against petrol and diesel vehicles.

Table 6: Emission Comparison (CNG vs. Petrol/Diesel)

Emission Type	Petrol Vehicle (g/km)	Diesel Vehicle (g/km)	CNG Vehicle (g/km)	Reduction in CNG (vs Petrol) (%)	Reduction in CNG (vs Diesel) (%)
CO2 (Carbon Dioxide)	185	210	150	18.92	28.57
NOx (Nitrogen Oxides)	2.5	4.0	1.2	52.00	70.00
SOx (Sulfur Oxides)	0.3	0.5	0.1	66.67	80.00
PM (Particulate Matter)	0.02	0.05	0.01	50.00	80.00

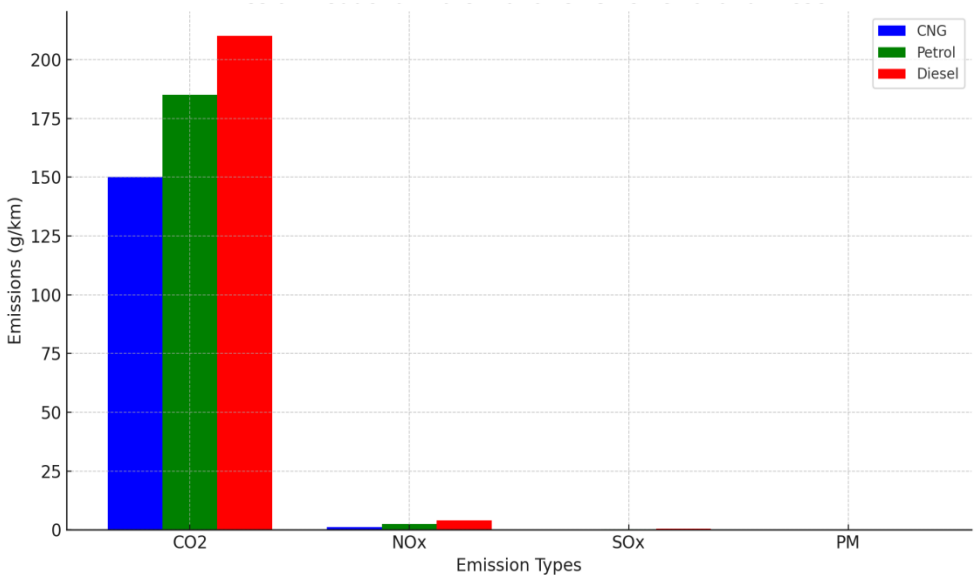


Figure 5: Emissions Reduction from CNG Adoption

This figure shows a bar graph illustrating the reductions in CO2, NOx, SOx, and PM emissions between CNG, Petrol, and Diesel vehicles.

Table 4 and figure 4 clearly shows that CNG vehicles offers significant emissions reductions across all pollutants:

- CO2 emissions are reduced by 18.92% compared to petrol and 28.57% compared to diesel vehicles.
- NOx emissions are reduced by 52% compared to petrol and 70% compared to diesel.
- PM emissions show a remarkable reduction of 50% compared to petrol and 80% compared to diesel.

These reductions have substantial public health and environmental implications, especially in urban areas where vehicle emissions contribute significantly to air quality deterioration.

Collaboration with Government for Financial Support

Transport operators should actively engage with the government and financial institutions to access low-interest loans and subsidies aimed at reducing the cost of vehicle retrofitting and refueling station installation. By collaborating with policymakers, operators can lower their upfront costs and improve the long-term economic feasibility of CNG adoption (Fattah *et al.,* 2023; Daser-Adams *et al.,* 2025).

Investing in CNG Infrastructure

Investors interested in the CNG sector should consider establishing CNG refueling stations along major highways, urban centers, and key transport corridors. There is a significant business opportunity in the CNG infrastructure market, which is poised for growth with the increasing adoption of CNG vehicles (Obafemi *et al.,* 2025; Usiayo *et al.,* 2025). Private sector investments in refueling infrastructure, coupled with government incentives, will help bridge the infrastructure gap and enhance the viability of CNG-powered vehicles.

SUMMARY/CONCLUSION/RECOMMENDATIONS

Summary of Findings

The findings from this study reveal significant insights into the potentials for adopting Compressed Natural Gas (CNG) vehicles in Nigeria's transportation sector, focusing on both the economic and environmental impacts. The machine learning models employed for the analysis demonstrated that CNG vehicles could offer considerable fuel cost savings compared to petrol and diesel vehicles. The Neural Networks model, which showed the highest accuracy (95.3%), was particularly effective in predicting combined economic and environmental suitability for different transport modes. This model outperformed others, such as Random Forest and Gradient Boosting Machines (GBM), especially in predicting emission reductions and fuel savings. The results from the models suggested that urban transport, such as minibuses and taxis, showed the highest suitability for CNG adoption due to shorter distances and higher fuel savings.

In terms of cost, the analysis demonstrated that while the initial purchase or retrofit cost for CNG vehicles is slightly higher than for petrol vehicles, the long-term savings from reduced fuel consumption and lower maintenance costs make CNG a financially viable option for transport operators. Specifically, the retrofit cost of NGN 350,000 for existing petrol vehicles is offset by substantial savings in fuel costs, which were found to be 30% lower for CNG vehicles compared to their petrol counterparts. This translates to daily fuel savings of up to NGN 1,500 per vehicle, a significant reduction in operational expenses, especially for fleet owners.

The environmental impact of CNG adoption was also substantial. The life cycle assessment (LCA) revealed that CNG vehicles emit significantly fewer greenhouse gases (GHG) and air pollutants compared to traditional petrol and diesel vehicles. Specifically, CNG vehicles showed a reduction of 28.57% in CO2 emissions when compared to diesel vehicles, and a 52% reduction in NOx emissions compared to petrol vehicles. The reduction in particulate matter (PM) emissions was also notable, with CNG vehicles reducing PM emissions by 80% compared to diesel-powered vehicles, which is particularly important for improving air quality in urban areas. These findings underscore the potential of CNG to significantly mitigate urban air pollution, a major environmental concern in Nigeria (Oluku *et al.,* 2025).

However, despite these promising results, the study also highlighted the substantial challenges that could hinder large-scale CNG adoption in Nigeria. Key barriers identified include the limited availability of CNG refueling stations, which currently focus on urban areas and are insufficient to support widespread adoption, especially for long-haul transport. The safety concerns surrounding the high-pressure storage of CNG and the retrofit costs for older vehicles were also highlighted as significant obstacles. Furthermore, the public perception of CNG, influenced by fears about the safety and reliability of retrofitted vehicles, remains a barrier that needs to be addressed through policy initiatives, public awareness campaigns, and stakeholder engagement.

Thus, the results suggest that while CNG vehicles offer considerable economic and environmental benefits, their adoption in Nigeria is contingent upon addressing the infrastructural limitations and regulatory challenges that currently impede their widespread use (Okafor *et al.,* 2022). The study provides actionable insights into the necessary steps for policymakers, industry stakeholders, and transport operators to overcome these barriers, including investing in CNG infrastructure, providing financial incentives for retrofitting vehicles, and promoting public education on the safety and benefits of CNG technology.

Conclusion

This study provides compelling evidence that adopting Compressed Natural Gas (CNG) vehicles in Nigeria's transportation sector can lead to significant economic and environmental benefits. The findings indicate that while CNG vehicles require a slightly higher initial investment, due to retrofitting costs, the long-term savings, especially in fuel costs, make them a financially viable option for both individual operators and fleet owners. The 30% fuel cost

savings and lower maintenance costs over time suggest that CNG can provide a stable and cost-effective alternative to petrol and diesel, particularly in the context of Nigeria's volatile fuel prices and subsidy removals. From an environmental perspective, the results show that CNG adoption could play a key role in reducing Nigeria's carbon footprint. The reduction in emissions, including CO2, NOx, and particulate matter (PM), demonstrates the potential of CNG to address the growing concerns of air quality deterioration and climate change. The 52% reduction in NOx and 80% reduction in PM compared to diesel vehicles are particularly important in urban areas, where air pollution from transportation is a major public health issue. Thus, the transition to CNG vehicles would contribute significantly to Nigeria's efforts to meet global environmental standards and enhance sustainable mobility.

However, the study also identifies several critical barriers that must be overcome for CNG to achieve widespread adoption. Infrastructure limitations, such as the insufficient number of CNG refueling stations and their uneven distribution, remain a significant hurdle, particularly in rural and intercity areas. The cost of retrofitting existing vehicles and the safety concerns associated with high-pressure storage systems are additional challenges that must be addressed. Moreover, the public perception of CNG, shaped by misconceptions about safety and the reliability of retrofitted vehicles, is a barrier that cannot be overlooked. It is essential that policy interventions, including financial incentives, public awareness campaigns, and the expansion of refueling infrastructure, be implemented to facilitate the adoption process. The policy implications of these findings are clear. To fully realize the potential of CNG in Nigeria's transportation sector, policymakers need to prioritize the development of CNG refueling infrastructure across urban, suburban, and intercity areas. Financial incentives for vehicle retrofitting and new CNG vehicle purchases should be introduced to reduce the upfront costs for operators. Additionally, stringent safety regulations and public education campaigns are essential to address concerns about the safety and reliability of CNG vehicles, fostering greater public trust and acceptance. Collaboration between government, industry stakeholders, and transport operators will be crucial to overcome the technical and logistical challenges of CNG adoption.

Thus, the study suggests that with appropriate investments in infrastructure, regulation, and public awareness, CNG can become a key component of Nigeria's sustainable transportation strategy. The transition to CNG-powered vehicles offers a feasible pathway to reduce fuel costs, mitigate environmental pollution, and contribute to the nation's long-term economic stability.

Recommendations

Based on the findings of this study, several strategic recommendations can be made to support the adoption of Compressed Natural Gas (CNG) vehicles in Nigeria's transportation sector. These recommendations are aimed at addressing the key challenges identified, including infrastructure limitations, retrofit costs, public perception, and regulatory hurdles. Implementing these recommendations will require collaboration between the government,

industry stakeholders, and the public to create a conducive environment for widespread CNG adoption.

i. **Expansion of CNG Refueling Infrastructure:** The limited availability of CNG refueling stations is one of the most significant barriers to the adoption of CNG vehicles. The government should prioritize the expansion of CNG refueling infrastructure, especially in urban centers, intercity routes, and rural areas. A strategic plan for the distribution of CNG stations should be developed, with incentives for private investments in infrastructure development. Public-private partnerships could play a crucial role in accelerating the construction of new refueling stations. Additionally, upgrading existing infrastructure to handle higher traffic volumes and more vehicles should be considered to ensure operational efficiency.

ii. **Financial Incentives for Retrofitting and New CNG Vehicles:** The upfront costs associated with retrofitting existing petrol or diesel vehicles to run on CNG or purchasing new CNG vehicles can be a significant deterrent for operators. Financial subsidies or tax incentives should be introduced to make the conversion process more affordable for transport operators, especially for small and medium-scale businesses. This could include interest-free loans or grant programs to assist with retrofit costs. Furthermore, providing subsidies for the purchase of new CNG vehicles could reduce the initial financial burden and encourage fleet owners to adopt CNG-powered transport solutions.

iii. **Public Awareness Campaigns and Education:** There is a clear need to address public perception of CNG vehicles, particularly regarding safety concerns and reliability. The government, in collaboration with industry stakeholders, should launch public awareness campaigns aimed at educating the public on the benefits of CNG vehicles, their safety, and their environmental advantages. These campaigns should also focus on dispelling myths about CNG and increasing awareness of the long-term cost savings associated with adopting CNG-powered vehicles. Training programs for vehicle operators and technicians should also be introduced to ensure the proper maintenance of retrofitted vehicles and to improve safety standards.

iv. **Development of Safety and Regulatory Standards:** Safety concerns related to the storage and handling of CNG are often cited as major barriers to adoption. It is critical that the government develops and enforces comprehensive safety standards for CNG vehicles and refueling stations. These standards should focus on the safe installation and inspection of CNG cylinders, vehicle retrofitting processes, and refueling operations. Regular safety audits should be conducted at refueling stations to ensure compliance with national safety regulations. Additionally, the establishment of a national CNG certification body could help standardize CNG vehicle conversion and retrofitting processes, ensuring that only high-quality and safe systems are in place.

v. **Incentivizing Research and Technological Development:** To address the technological barriers to CNG adoption, such as vehicle efficiency and refueling

infrastructure, the government and industry should invest in research and development (R&D) to explore innovative solutions. This includes improving CNG engine technologies to enhance fuel efficiency and exploring alternative fuel options like bi-fuel systems or hydrogen-CNG blends to increase vehicle flexibility. Collaboration with research institutions could also help identify and mitigate any new challenges that arise as CNG technology evolves.

vi. **Integration of CNG into National Policy and Strategic Plans:** For CNG adoption to be successful, it needs to be embedded into Nigeria's broader energy and environmental policies. The government should integrate CNG adoption goals into the country's National Transport Policy, Energy Policy, and Climate Change Mitigation Strategy. Policies that align CNG adoption with sustainable energy development will help secure long-term funding and political support. These policies should also promote collaborative efforts among government agencies, private companies, and international organizations to ensure that the transition to CNG is both smooth and economically beneficial.

vii. **Monitoring and Evaluation Systems:** Finally, it is important to implement robust monitoring and evaluation systems to track the progress of CNG adoption in the transportation sector. Regular data collection on fuel consumption, emissions, and vehicle performance will help policymakers understand the effectiveness of current strategies and make necessary adjustments. These systems should also gather feedback from operators to identify any operational challenges and develop solutions in real-time.

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