**Original Research Article**

**Techno-Economic Analysis of Compressed Natural Gas as an Alternative Fuel for the Transport Sector in Southwestern Nigeria**

**Abstract -** Nigeria's reliance on conventional fuels like gasoline and diesel is prompting an investigation into more affordable options. Compressed natural gas, or CNG, emerges as the leading choice in this search. With its significantly lower price point compared to alternatives, CNG provides fleet and individual owners substantial fuel cost savings. According to the research, it is possible to save more than N680 for every 100 kilometers driven compared to petrol. Although this gives users a favorable impression, upfront costs must be considered. Conversion kits are necessary to modify existing automobiles to CNG, and a network of CNG refueling stations needs to be established. The initial expenses may seem daunting; however, the long-term fuel savings and any government subsidies would significantly ease the burden.

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 in Southwestern Nigeria. Results show that CNG adoption could reduce fuel costs by over ₦5,518 per 100 kilometers compared to petrol, 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. However, upfront costs for vehicle conversion kits and limited refueling infrastructure remain significant barriers. Nonetheless, long-term fuel savings, environmental gains, and potential government subsidies make CNG a viable and sustainable solution.

**Keywords –** Techno-economic Viability, Compressed Natural Gas (CNG), Transportation, Alternative Fuel,

**1.0 Introduction**

Globally, there is a 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, 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. Furthermore, 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 (Adegoriola & Suleiman, 2020).

In line with global best practices, Nigeria is looking at compressed natural gas (CNG) as a viable alternative to transport fuel demand in the country. 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 (Ibeneme & Ighalo, 2020). 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.

**1.1 Purpose of Research**

This study investigated the economic viability of CNG as an alternative fuel in Nigeria through a comprehensive cost-benefit analysis. By examining key economic aspects, including production costs, distribution dynamics, pricing mechanisms, and potential socioeconomic impacts, the study aims to provide insights into the feasibility of integrating CNG 2 into the national energy strategy. Furthermore, the paper will assess how the adoption of CNG may contribute to broader objectives such as energy security, environmental sustainability, and economic diversification.

### 2.0 Economic Factors Influencing Fuel Choices

Compressed Natural Gas (CNG) is a gaseous fuel composed primarily of methane that is stored under high pressure. CNG is extracted from natural gas reserves and undergoes compression to reduce its volume for storage and transportation. It is considered a cleaner alternative to traditional fossil fuels like petrol and diesel because it burns cleaner, emitting fewer pollutants and greenhouse gasses such as carbon dioxide (CO2), nitrogen oxides (NOx), and particulate matter (PM). Furthermore, it boasts a higher-octane rating, leading to improved engine performance and potentially lower maintenance costs, and is generally cheaper than gasoline and diesel on a per-unit basis. 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 4 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 (Anyadiewu et al., 2020; NG Society, 2020; Ohia et al., 2017). Studies suggest a thriving CNG industry in Nigeria could stimulate job creation, create jobs and economic growth, as well as enhance energy security by leveraging domestic natural gas resources (Ohia & Muonagor, 2017; NG Society, 2020; Olujobi et al., 2021). Despite these advantages, CNG adoption may initially have challenges, for instance, the high upfront costs for infrastructure development, limited consumer awareness, and the scarcity of refueling stations may initially hinder adoption rates (Olujobi et al., 2021).

## 2.1 Cost of CNG production and Distribution.

The cost of producing and distributing CNG plays a crucial role in its overall economic viability. Factors like wellhead natural gas prices, infrastructure development costs, and transportation logistics all contribute to the final price at the pump (Nwaoha & Wood, 2014; Anyadiegwu et al., 2017).

### Natural Gas Prices

The cost of CNG production is closely tied to the price of natural gas, which can fluctuate due to factors such as supply and demand dynamics, geopolitical events, and technological advancements in extraction techniques (e.g., hydraulic fracturing). In regions with abundant natural gas reserves, such as Nigeria, where gas flaring is a common practice in oil production, the cost of acquiring raw materials for CNG production may be relatively low (Odumugbo, 2010).

### Compression Technology

The process of compressing natural gas to the required pressure for storage and transportation incurs operational costs, including energy consumption and maintenance expenses for compression equipment. Advances in compression technology, such as more efficient compressors and storage tanks, can help reduce production costs and improve the overall economics of CNG (Ogunlowo et al., 2016; Khan et al., 2015).

### Transportation Infrastructure

The establishment of a reliable and efficient distribution network for CNG involves investment in infrastructure, including pipelines, compression stations, and refuelling facilities. The distance between natural gas production sites and end-user markets can impact transportation costs and influence the viability of CNG as a fuel option in specific regions (Bonaventura et al., 2021; Chien et al., 2022).

### Regulatory Requirements

Compliance with safety standards, environmental regulations, and licensing requirements adds to the overall cost of CNG production and distribution. Investments in safety features, such as leak detection systems and pressure regulation devices, are essential for ensuring the integrity of CNG infrastructure and mitigating potential risks associated with handling compressed gases (Harmsen et al., 2020; Idigbe & Onwuachi-Iheagwara, 2018).

## 2.2 Pricing Dynamics of CNG vs. Traditional Fuels

The relative pricing of CNG compared to traditional fuels significantly impacts adoption rates. Government policies, such as tax breaks on CNG or subsidies, can influence this price dynamic and make CNG a more attractive option for consumers.

### Taxation and Subsidies

 Government policies regarding taxation and subsidies can significantly influence the relative price competitiveness of CNG compared to traditional fuels like petrol and diesel. In some jurisdictions, CNG may benefit from favourable tax treatment or receive subsidies to incentivize its adoption as an alternative fuel option. Conversely, higher taxes on traditional fuels or carbon pricing mechanisms may increase the relative cost advantage of CNG.

### Market Competition

Competition among fuel providers and distributors can impact pricing dynamics in the CNG market. The presence of multiple suppliers and refuelling stations can create competitive pressure, leading to price discounts, promotional offers, and loyalty programs to attract customers. Additionally, strategic partnerships between energy companies and fleet operators may result in volume discounts or preferential pricing arrangements for bulk purchases of CNG.

### Energy Policies

National energy policies and regulations play a crucial role in shaping the pricing environment for CNG and traditional fuels. Measures such as fuel quality standards, emission limits, and vehicle efficiency requirements can influence consumer preferences and market demand for different fuel options (Dioha & Kumar, 2020; Zhou et al., 2020). Moreover, government interventions, such as price controls or fuel price stabilization mechanisms, can affect the stability and predictability of fuel prices in the long term.

## 2.3 Policy and Regulatory Frameworks

Government policies and regulations can significantly influence the adoption of CNG. Incentives for vehicle conversion, infrastructure development plans, and regulations promoting cleaner transportation all play an important role in creating a favourable environment for CNG adoption.

### Tax Incentives

Tax incentives, such as exemptions, credits, or reduced rates for CNG production, distribution, and consumption, can stimulate investment in CNG 7 infrastructure and promote its adoption as an alternative fuel. Incentives aimed at encouraging vehicle conversion to CNG or supporting the expansion of refuelling networks can enhance the economic viability of CNG and accelerate market penetration.

### Subsidies and Grants

Government subsidies and grants can provide financial support for CNG-related projects, including the construction of refuelling stations, research and development initiatives, and pilot programs for fleet conversions. Subsidies may target specific sectors or geographic areas where the adoption of CNG is deemed strategically important for achieving energy security, environmental sustainability, or economic development objectives.

### Regulatory Frameworks

Regulations governing safety standards, environmental protection, and quality control are essential for ensuring the reliability, safety, and performance of CNG infrastructure and vehicles. Regulatory frameworks may include requirements for vehicle conversions, fuelling station design and operation, storage and transportation of compressed gases, and emergency response protocols. Compliance with regulatory standards is critical for building consumer confidence and trust in CNG as a viable and safe fuel option.

### The Presidential Compressed Natural Gas Initiative (PCNGI)

The Presidential Compressed Natural Gas Initiative (PCNGI) tackles economic challenges in Nigeria by promoting CNG adoption. This initiative aims to reduce dependence on imported gasoline, lowering transportation costs for Nigerians and potentially freeing up government funds currently spent on fuel subsidies (Punch Newspapers, Presidential CNG Initiative attracts $50m investment). The PCNGI also focuses on job creation through domestic infrastructure development like refuelling stations and conversion workshops. This fosters the growth of the auto industry by encouraging in-country 8 assembly of CNG vehicles, creating new manufacturing jobs, and potentially leading to future exports (statehouse.gov.ng, President Tinubu Approves Establishment of Presidential CNG Initiative). By attracting private sector investment and creating a more competitive fuel market, PCNGI aims to stimulate economic activity across various sectors in Nigeria. With its focus on job creation, market diversification, and reduced fuel dependence, the PCNGI positions CNG as a key driver of economic growth for the nation.

**3.0 The Potential Impact of Compressed Natural Gas (CNG) Adoption on the**

**Nigerian Economy**

The potential impact of widespread CNG adoption in Nigeria extends beyond individual users.

### Energy Security and Diversification

Nigeria possesses vast natural gas reserves, making CNG a domestically produced fuel source. This could reduce dependence on imported gasoline and diesel, enhance energy security, and potentially reduce vulnerability to price fluctuations in the global oil market (Nwaoha & Wood, 2014).

### Environmental Consideration

CNG combustion produces fewer pollutants and greenhouse gases than traditional fuels. It emits significantly lower levels of harmful substances like nitrogen oxides and particulate matter, which contribute to air pollution and respiratory issues (Oluwole et al., 2019). Widespread adoption could improve air quality in major Nigerian cities and mitigate the environmental impact of the transportation sector.

### Socio-economic Implications

The development of a CNG industry could create new job opportunities in areas like vehicle conversion, station operation, and infrastructure maintenance. Additionally, reduced fuel costs for transportation could have a positive ripple effect on the broader Nigerian economy (Ozkaya & Koc, 2021; Giwa et al., 2017).

**4.0 Engine Performance**

Engine performance is a critical factor in evaluating the viability of alternative fuels. By analyzing parameters such as thermal efficiency, power output, and emissions, we can examine the performance characteristics of engines running on Compressed Natural Gas (CNG) compared to those using traditional fuels like petrol and diesel.

### 4.1 Performance Characteristics

### Thermal Efficiency

Thermal efficiency (η) measures how well an engine converts the energy from fuel into useful work. It's defined as the ratio of the work output to the heat input. The thermal efficiency can be expressed as:

ηt = $\frac{Wt}{Qt}$ and 𝜂𝐶𝑁𝐺 = $\frac{W\_{CNG}}{Q\_{CNG}}$

where W is the work done and 𝑄 is the heat input.

### Power Output

The power output of an engine can be influenced by factors such as fuel energy density and combustion characteristics. By comparing Pt and PCNG, we can assess the impact of fuel type on engine performance in terms of power generation.

The power output can be expressed as:

Pt = $\frac{Wt}{t}$ and P𝐶𝑁𝐺 = $\frac{W\_{CNG}}{t}$

where W is the work done and t is the time taken for the work done.

### Emissions

One of the significant advantages of CNG over traditional fuels is the reduction in harmful emissions. Emission analysis can be done by obtaining emissions data (e.g., grams per kilometer of CO2, NOx, and particulate matter) for a specific engine.

The emissions can be represented as:

Et  = Ʃi(Ci × Fi) and ECNG  = Ʃi(CCNG × FCNG)

Where Ci is the concentration and Fi is the flow rate of pollutant i.

### 4.2 Comparative Analysis

The comparative analysis is done on hypothetical data for a Honda Civic, because it is a car model that offers both petrol/diesel and CNG versions.

Note: The data presented in this section are hypothetical and are used solely for illustrative purposes. They do not represent actual empirical measurements but serve to demonstrate potential differences between vehicles running on petrol and CNG.

### Thermal Efficiency

1. Petrol:

ηt = $\frac{250KJ}{1000KJ}$ = 0.25 or 25%

1. CNG:

𝜂𝐶𝑁𝐺 = $\frac{220\_{KJ}}{1000KJ}$ = 0.22 or 22%

### Power Output

1. Petrol:

Pt = 150HP

1. CNG:

P𝐶𝑁𝐺 = 140 HP

### Emissions

1. Petrol:

Et = 150 g/km CO2

1. CNG:

ECNG = 120 g/km CO2

From the above hypothetical data, it is seen that:

1. Thermal Efficiency: Petrol has a slightly higher thermal efficiency (25%) compared to CNG (22%).
2. Power Output: Petrol produces 150 HP, while CNG produces 140 HP, showing a marginal reduction in power with CNG.
3. Emissions: CNG significantly reduces emissions (120 g/km CO2) compared to petrol (150 g/km CO2).

### 4.3 Cost Analysis of Operating on a CNG Fuel To Traditional Fuel in the Public Transport Sector

In this section, we will review the cost and economic effectiveness of running a vehicle using compressive natural gas (CNG) compared to running the same vehicle on conventional traditional fuel (petrol). A comparative cost analysis was carried out on the capital expenditure and operating expenditure of running a vehicle on CNG against running the same vehicle on conventional petrol for a given distance. Factors considered in making the comparison include the initial cost of converting the vehicle from a traditional fuel (petrol-driven) vehicle to a CNG-driven vehicle. The capital cost of the vehicle is not considered as it is the same vehicle. Another economic factor considered is the conversion cost between N600,000 and N1,500,000 (According to Autolady Engineering Technology Ltd) required to convert a conventional automobile to CNG.

### Cost of Operating a CNG Automobile

**Cost of CNG:** The cost of CNG in Nigeria is approximately 230 Naira per standard cubic meters (Aina, Damilola. PunchNG, 29 Oct. 2023).

**Cost of Maintenance for a CNG Vehicle:** The average annual maintenance cost for a CNG vehicle in Nigeria is around 120,000 Naira.

**Cost of Installation of a CNG Station:** The minimum investment required for a CNG station with two dispensers and four hoses co-located in an existing or inactive station capable of dispensing 250,000 standard cubic feet daily (SCFD) or 500,000 SCFD of natural gas, equivalent to 7,480 - 15,000 liters of petrol a day, is approximately N300 14 million. Additionally, a dedicated CNG station serving trucks with a daily dispensing capacity of 500,000 SCFD to 1,000,000 SCFD of natural gas, equivalent to 14,280 to 28,000 litres of diesel a day, requires an investment of approximately N1.4 billion. Meanwhile, building a new CNG station with 4-10 dispensers requires an investment of about N500 million (Izuora, Chika. "AfDB To Fund IPMAN’s Nationwide CNG Infrastructure Rollout." LeadershipNG, Aug. 2023). Building a CNG mother station will cost $1.2 million on average (Emmanuel, Kelvin. "What It Costs to Build a CNG Mother Station." NairaMetrics, 2023).

**Cost of Training Staff to Operate a CNG Station:** The cost of training staff to operate a CNG station in Nigeria is approximately 300,000 Naira per person.

**Cost of Replacing a Traditional Fuel with CNG:** The cost of converting a petrol vehicle to run on CNG in Nigeria is between N600,000 and N1,500,000 depending on the vehicle type and size (Dare Olawin "High conversion cost discouraging CNG adoption, Nigerians lament" Punch, 8 Nov. 2024.)

### Cost of Operating a Traditional Fuel Automobile

**Cost of Fuel:** The average price of petrol is 860 Naira per liter at NNPC petrol stations.

**Cost of Maintenance:** The average annual maintenance cost for a petrol vehicle in Nigeria is around 845,000 Naira yearly (Falaju, Joke. "Nigerians Spend Average of N845,000 Yearly on Car Maintenance." GuardianNG, 05 April 2024).

**Cost of Environmental Inspection in Relation to Emissions:** The cost of emissions testing for vehicle registration in Nigeria is approximately 25,000 Naira.

### Fuel Cost Savings of CNG to Traditional Fuel (Petrol)

The running cost of CNG compared to petrol can vary depending on factors such as vehicle efficiency and fuel cost. For a vehicle having a fuel efficiency of 13 kilometres per litre;

**Table 1: Current Price of Vehicle Fuel in 2024**

|  |  |
| --- | --- |
| Fuel | Cost (Naira) |
| Traditional Fuel (Petrol) | 860/litres |
| CNG | 230/scm |

**Running Cost of Traditional Fuel (Petrol)**

Running cost per kilometre of traditional fuel

$$\frac{Cost per litre of fuel}{efficiency}$$

Running cost per kilometre of traditional fuel

$$\frac{860}{13km/litre}$$

Running cost per kilometre of traditional fuel

66.15 naira per kilometre

**Running Cost of CNG fuel**

Running cost per kilometre of CNG fuel

$$\frac{Cost per kilogram of CNG}{efficiency}$$

Running cost per kilometre of CNG fuel

$$\frac{230}{21 km/scm}$$

Running cost per kilometre of CNG fuel

10.95 naira per kilometre

**Table 2: Running Cost of Car per Kilometre Travelled In 2024**

|  |  |  |
| --- | --- | --- |
| **Vehicle Type** | **Traditional fuel (petrol)** | **CNG** |
| Car | N66.15/km | N10.95/km |

From Table 1 and 2, it is discovered that when travelling per kilometre operating on a CNG fuel costs 55.20 naira less than operating on a traditional fuel (petrol).

### Savings Cost of CNG over Traditional Fuel (Petrol)

From the data obtained from table 1 and 2, it is discovered that the vehicle in consideration uses 0.0769 litres for each kilometre travelled while running on traditional fuel, and 0.0476 standard cubic meters (scm) for each kilometre travelled while running on CNG.

**Table 3: Savings Cost Using CNG**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Fuel Consumption | Distance in a day (km) | Total fuel consumption/day | Fuel cost (Naira) | Total fuel cost/day (Naira) |
| Traditional fuel | 0.0769 | 100 | 7.69 litre | 860/litre | 6613.4 |
| CNG | 0.0476 | 100 | 4.76 scm | 230/scm | 1094.80 |

###  Cost Benefit Analysis of utilizing CNG over traditional fuel as a transport fuel for public transportation.

Using the above data, a car uses 7.69 litre/100 km on traditional fuel (petrol) and 4.76 scm/100 km on CNG. The distance from Ile-Ife to Lagos is **201 km**, a driver can go on this trip twice in a day, so an average of **402 km** to go to Lagos and return to Ife.

For a **20-day** work month, **618.3 litres** of traditional fuel and **382 scm** of CNG will be used and a total of **7419.3 litres and 4592.4 scm** in a year.

As given in the table, it will cost **₦6,380,598** to use traditional fuel and **₦1,056,263** to use CNG in a year and **₦531,716.5 per month, ₦87860 per month** respectively**.**

If the cost of converting a 2007 Honda Civic is **₦1,000,000** a payback analysis is done in the table below.

**Table 4: Payback Analysis**

|  |  |  |
| --- | --- | --- |
| **Months** | **CNG (₦)** | **PETROL (₦)** |
| Initial  | 1,000,000 | ------------ |
| 1 | 87,860 | 531,738 |
| 2 | 87,860 | 531,738 |
| 3 | 87,860 | 531,738 |
| 4 | 87,860 | 531,738 |
| Total | 1,351,440 | 2,126,952 |

This table shows that switching to CNG offers significant long-term benefits for users. The payback analysis shows that the conversion cost of ₦1,000,000 is recovered within four months of operation due to the lower monthly fuel expenses. After this period, users enjoy sustained savings leading to continuous reduction in their operating costs over the vehicle lifetime,

## 5. LIMITATIONS

While CNG offers several advantages over traditional fuels, its widespread adoption faces significant challenges and limitations. Some of them are:

1. **Infrastructure Constraints**
2. Limited Refuelling Stations: Compared to the vast network of gasoline stations, CNG stations are significantly less prevalent, particularly in rural areas. This creates inconvenience and limits the practicality of long-distance travel.
3. Refuelling Time: Filling a CNG tank takes longer than filling a gasoline tank, leading to potential delays and queues at stations.
4. High Infrastructure Costs: Building and maintaining a comprehensive CNG infrastructure requires substantial investments, which can deter widespread deployment.
5. **Policy and Regulatory Challenges**
6. Lack of Incentives: Government policies often lack substantial incentives for CNG adoption, such as tax breaks or subsidies for vehicle purchases or infrastructure development.
7. Standardization Issues: Inconsistent regulations and standards across regions can hinder the smooth operation and maintenance of CNG vehicles.
8. Safety Concerns: Public perception of potential safety risks associated with CNG storage and refuelling needs to be addressed through robust safety protocols and regulations.
9. **Market Acceptance and Consumer Behaviour**
10. **Higher Upfront Costs:** CNG vehicles generally have higher upfront costs than gasoline counterparts, which can deter initial consumer adoption.
11. **Limited Vehicle Options:** The range of CNG vehicle models available is often smaller compared to gasoline vehicles, potentially limiting consumer choice.
12. **Range Anxiety:** The lower energy density of CNG compared to gasoline translates to a shorter driving range per tank, leading to "range anxiety" for consumers.
13. **Data Limitations and Assumptions**
14. **Data Scarcity:** Comprehensive data on long-term performance, maintenance costs, and environmental impact of CNG vehicles compared to traditional fuels might be lacking in certain regions.
15. **Assumptions about Future Infrastructure:** Projections about the future expansion of CNG infrastructure and its impact on consumer behavior rely on assumptions that may not always be accurate.

**6.0 Recommendation and Conclusion**

**6.1 Concluding**

This paper conducted a techno-economic analysis of Compressed Natural Gas (CNG) as an alternative fuel for transportation in Nigeria, highlighting its potential economic, environmental, and societal benefits. Despite initial conversion costs, the potential for significant fuel savings, particularly for high-mileage drivers, renders CNG economically attractive. Moreover, CNG combustion emits fewer pollutants, contributing to enhanced air quality and a cleaner transportation sector. The development of a domestic CNG industry could stimulate job creation and bolster Nigeria's energy security by reducing reliance on imported fuels. Our findings indicate that CNG offers significant advantages, particularly for high-mileage drivers, as the payback period for conversion costs is notably faster for longer distances. For instance, transport routes such as Ife to Lagos and back, spanning 402 km, demonstrate considerable fuel savings, with a CNG consumption rate of 4.76 scm per 100 km, as shown in Table 3. Similarly, shorter trips such as Ife to Ibadan (150 km) and Ife to Osogbo (102 km) also exhibit substantial cost advantages over traditional fuels.

The broader adoption of CNG, particularly within the transportation sector, could stimulate economic growth by lowering operational costs for businesses and individuals. For example, long-haul trucks transporting goods, such as pepper from Jos to Lagos, would benefit from reduced fuel costs, subsequently decreasing transportation expenses. This cost reduction could help lower food prices and mitigate inflation, thereby positively impacting the overall economy.

Nevertheless, challenges persist. Establishing a robust CNG infrastructure demands substantial investment in stations and pipelines. Addressing consumer apprehensions regarding CNG technology and ensuring widespread availability of conversion kits are imperative for successful adoption.

The research confirms the economic benefits of CNG adoption. Fuel cost savings can be substantial, with estimates suggesting potential monthly savings of up to 340,000 Naira and a payback period of just 2 months, based on a conversion cost of 500,000 naira. This translates to long-term cost advantages for individuals and businesses alike.

Beyond individual savings, CNG adoption presents a wealth of economic opportunities. The Presidential CNG Initiative (PCNGI) aims to create an estimated 25,000 jobs by 2027 through CNG conversion processes, refuelling station operations, and the potential for a domestic CNG vehicle assembly industry. This job creation can significantly boost economic activity and empower Nigerians.

Furthermore, the PCNGI is expected to attract nearly $2 billion in investments, as highlighted by President Tinubu in May 2024. This influx of capital can be a catalyst for infrastructure development, including the crucial expansion of the CNG refuelling station network. Increased accessibility will further encourage CNG adoption and solidify its position as a viable fuel choice.

The economic impact extends beyond job creation and investment. Reduced reliance on imported gasoline will lessen Nigeria's vulnerability to global oil price fluctuations. This will not only stabilize fuel costs but also potentially free up government resources for investment in other critical areas.

In conclusion, this research highlights the techno-economic viability of CNG as an alternative fuel for transportation in Nigeria. Our analysis shows that CNG offers substantial cost savings, particularly for high-mileage drivers, making it a cost-effective solution for the transport sector. Adopting CNG can significantly reduce fuel costs, which is particularly beneficial for the transportation of goods, potentially lowering food prices and helping to control inflation.

Beyond individual economic benefits, CNG adoption fosters job creation, attracts investment, and enhances Nigeria’s energy security by reducing dependence on imported fuels. Embracing CNG offers a pathway to a more sustainable and prosperous future, powered by a cleaner and more affordable energy source. However, to fully harness the potential of CNG, supportive policies, consumer awareness, and strategic investments in infrastructure development are essential. With these measures, Nigeria can transform its transportation sector, paving the way toward a cleaner, more secure, and economically viable energy future.

### 6.2 Policy Recommendations and Strategies for Successful CNG Implementation as an Automobile Fuel in Nigeria

1. **Developing a Targeted Carbon Tax System**It has been observed that carbon tax can mitigate CO2 emissions by about 26.9% by 2050 in Nigeria. Carbon tax policies would increase the cost of gasoline and diesel while lowering the cost of alternative fuels like CNG. Nigerians would be forced to purchase vehicles that run on CNG, as they would be more economically viable. Also, just like in India where emissions from gasoline for each city were measured regularly and cities with high gasoline emissions were forced by court orders to switch to better alternatives like CNG automobiles, Nigeria can adopt such a strategy, forcing cities with high carbon emission to switch to CNG as automobile fuel.
2. **Increase Availability and Access to CNG Refuelling Stations**

Undoubtedly availability and access to CNG refuelling stations is a very important factor in the development of CNG as an alternative fuel for automobiles. Studies indicated that CNG refuelling stations equivalent to at least 10% to 20% of gasoline and diesel refuelling stations would be enough for prospective adaptors not to see the unavailability of CNG refuelling stations as a hindrance to switching. A major way of increasing CNG refuelling stations is by easing the bureaucracy in CNG refuelling stations construction and operation. Permits for CNG refuelling stations and operations should be far cheaper than those for conventional fuels, this would encourage more private investors to construct and operate CNG refuelling stations. The government use of its NNPC mega station scheme to construct CNG refuelling stations in strategic positions around the country has been suggested. NNPC, Nigeria's national oil company, announced a partnership with NIPCO Gas Limited in August 2023 to develop 56 CNG stations across the country (NAN News, Alternative Fuel: NNPC Ltd partners NIPCO on developing 56 CNG stations). The first phase, targeting 21 stations for intra-city transportation, is expected to be completed by Q1 2024 (TheCable, NNPC, NIPCO partner to construct 35 CNG stations nationwide).

 Also, an introduction of a Mobile CNG refuelling station would increase accessibility. Furthermore, a lot of Nigerian banks cannot give loans to Indigenous companies willing to invest in CNG refuelling stations, and the alternative of getting these loans abroad is not favourable especially because of the volatility of the naira. The government can provide loans to CNG refuelling station investors with attractive interest rates.

1. **Better Market-Based Policies for CNG as Automobile Fuel**

The government should introduce subsidies to reduce the cost of CNG and also further widen the gap between CNG and conventional fuel. These subsidies include a reduction in importation tax for CNG production machinery and equipment, accessories for automobile conversion, sales taxes and operational tax on CNG refuelling stations. (O.O. Ogunlowo et al.) showed that government incentive helps promote CNG use as an alternative fuel. However, this is not the case in Nigeria as there is no known incentive for investors to take advantage of the CNG market and promote CNG automobiles. For example, in Pakistan, custom duty and tax exemption are major factors that encouraged corporations to invest in the CNG programme. However, it is bad for the CNG programme to excessively depend on subsidies as this could affect its future development. When investors see that there are a high return and less risk in CNG investment, they would be more willing to invest.

1. **Subsidising Vehicle Conversion Expenses**

The provision of loans and subsidies for vehicle conversion from gasoline/diesel to CNG would motivate more persons to convert their automobiles from gasoline/diesel to CNG. Certainly, it would be difficult for a lot of Nigerians to afford the conversion cost, so the government can partner with banks to offer interest-free loans for automobile conversion. Also, the cost of conversion should be subsidized to encourage more people to convert. The Nigerian Institute of Transport Technology (NITT) expressed plans to initiate conversion programs with potentially subsidized costs to encourage CNG adoption (Daily Trust, Subsidy Removal: NITT to begin conversion of vehicles to Autogas).

1. **Commence with Bi-Fuel/Dual-Fuel Automobile**

Most passenger CNG vehicles can either be dedicated CNG or bi-fuel. Bi-fuel vehicles can run on both CNG and gasoline. Many have a range of 400 km on CNG mode and 1000 km on gasoline mode. While commercial CNG vehicles can either be dedicated CNG or dual-fuel. The dual-fuel vehicles could displace up to 50-60% of the diesel fuel. Nigeria should begin with bi-fuel/dual-fuel automobiles instead of only CNG dedicated automobiles, as these better handles the con of CNG automobiles which is its low range and frequent refuelling. This strategy was adopted in Pakistan and it worked. Also, it is discovered that dual-fuel engines are 30-40% more efficient than a conventional vehicle. It also has the ability of abating fuel consumption by 25%.

1. **Assignment of Responsibilities Regarding the Implementation of CNG as an Alternative Fuel**

A study of all countries that have successfully implemented CNG as an alternative fuel shows there was an assignment of important responsibility as regards the development of CNG. India, Argentina, and Brazil have agencies set up to promote CNG use as fuel. However, in Nigeria, there is no specific agency for CNG implementation as vehicle fuel. (Olufemi O. Ogunlowo) showed that Nigeria is keener on the reduction of gas flaring than gas utilization. This has led to little or no policies on gas utilization. Also, a lot of the companies prefer gas re-injection to gathering and distributing for proper gas utilization such as CNG automobile development. A CNG program should be created with the responsibility of market development shared among them, from the development of CNG refuelling stations to CNG automobile provision.

1. **Development of natural gas transmission and distribution network**

The success of countries like Argentine and Pakistani is partly due to their strong Gas transmission and distribution network. It is also noticed that in Brazil higher priority is given to the development of the domestic gas network. However, this is not the case in Nigeria as a higher priority is given to international network development. This can be seen from the WAGP (West African Gas Pipeline) and NLNG (Nigerian Liquefied Natural Gas) export terminals which were developed ahead of domestic networks. The domestic gas sales are relatively poor in comparison with export. CNG is attractive to investors if the distance to the market is around 500 – 2500 km. Therefore, Nigeria needs to develop its domestic gas transmission and distribution networks as this would simulate the construction of more CNG refuelling stations. The cost of using CNG transport trucks is higher than using pipelines, therefore it would be more cost-friendly to develop natural gas transmission and distribution networks.

1. **Increase Public Awareness on the Benefits of CNG Automobile**

The majority of the general public in Nigeria has never heard of CNG automobiles. Therefore, the government needs to provide public awareness as regards the environmental and economic benefits of using CNG in comparison to conventional fuels. Unlike LPG for cooking, CNG automobile has had little or no public awareness in Nigeria. As noted by (Abbanat), the best way to increase the customer's response to CNG automobiles is through public awareness. The government can create awareness through skill acquisition programs. This would be an opportunity to train people in various skills needed to maintain and use CNG automobiles. This development would reduce unemployment and increase the indigenous workforce in the CNG automobile sector in Nigeria.

1. **Price Reform**

The pricing for gas needs a total reform as it is observed that the domestic wholesale price is far lower than the export price, therefore encouraging the export of gas. The government needs to analyse the pricing system and reform it to favour all markets. This would also cut down the flaring of gases as companies would see gas as being profitable.

1. **Partnership with Indigenous Automobile Producers to Manufacture Affordable CNG Automobiles**

As noted by (Olufemi O. Ogunlowo et al.,) there is a higher cost for CNG vehicles in comparison to conventional fuel vehicles in Nigeria. Also, the cost is higher in comparison to CNG vehicles in other countries. This is mainly due to the high import dependence of Nigeria. Just like India, Nigeria's government needs to partner with indigenous vehicle producers such as Innoson Vehicle Manufacturing Company (IVM), Limited, Nnewi, Anambra, Nigeria. This would reduce the cost of CNG vehicles, making them more affordable. Research and development in CNG automobile manufacturing in Nigeria should also be funded by the Nigerian government. This would help in optimizing the already established CNG automobile designs specifically for Nigeria.

1. **Prioritization of CNG Transit Buses Over Other Technologies**

The government needs to focus more on developing commercial transit buses to run mainly on CNG. This development would reduce both emissions and traffic drastically. The majority of these transit buses in the city are owned by the government, therefore the government can easily implement this recommendation. Also, this strategy was implemented in china and it helped china develop its gas utilization sector through CNG usage as fuel in buses, and due to transit buses being more profitable with CNG as fuel, more person would be willing to invest in it and the government would make more revenue from their investment.

1. **Use of CNG Automobiles in Highly Populated Cities**

Urban and highly populated cities are a major market for CNG automobiles, as these cities have high levels of noise and harmful emissions from transportation. These highly populated cities are also likely the most polluted. Therefore, the use of CNG automobiles in highly populated cities would abate both emission and noise pollution. This strategy was very effective in India.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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