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Sectoral analysis of natural gas demand dynamics in Nigeria – An ARIMA approach

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ABSTRACT

The study estimated Nigeria's natural gas demand across the industry, residential, and non-energy sectors, using the Box-Jenkins ARIMA model. The study collated annual historical data on natural gas demand by these sectors for the period from 1988 through 2024. While gas demand by the industry and non-energy sectors was found to be influenced by their past demand, demand for gas by the residential sector was noted to be independent of its past demand. For the predictions, demand for gas by the residential sector was forecasted to sustain a consistent growth. Industry gas demand, which was found to be low, was forecasted to gradually recover from the low level over time, while the non-energy sector was forecasted to experience a continuous demand reduction for five consecutive years. It is necessary to make investments towards expanding the gas distribution network to support the consistent demand growth in the residential sector. Policies aimed at industrial recovery should be implemented to boost gas demand, and interventions to mitigate the decline in gas demand in the non-energy sector should be considered.

Contribution/ Originality: Gas demand analysis in Nigeria has been conducted independently without recourse to sectoral comparison. A forecast analysis of this nature, which can be utilized to predict sectoral trends of gas demand in order to ensure optimal resource allocation and policy planning, is rare.

1. INTRODUCTION

1.1. Background

Natural gas, as a transition energy, has found its recognized importance in the Nigerian energy space, given its contribution to the energy requirements of key sectors of the economy. Local demand, production costs, government policy, and global market patterns are a few factors that significantly determine its price (Bawa, Abdullahi, Tukur, Barda, & Adams, 2020). The government exerts great influence on natural gas prices through regulatory mechanisms and policies to ensure supply-demand balance. As a result, prices of gas within the economy are generally lower than international prices, cushioned by government subsidies to encourage local consumption. Over the past years, the country has expedited efforts towards ensuring sustainable gas availability at competitive prices. This is in spite of several challenges confronted by the natural gas sector. While the country internally manages the domestic supply-demand-price interaction, globally, its natural gas export is subject to the world price market, which fluctuates depending on supply and demand situations. This necessitates contract price agreements such as the Henry Hub or Brent crude price alternatives (Diala, Alwell, Ezurum, & Joseph, 2024). Nigeria's sustained economic growth largely depends on the synchronization of supply, demand, and the price of natural gas. The upgrading of infrastructure for natural gas supply growth and demand management is therefore a requirement (Nduka, Obibuike, Onyejekwe, Kerunwa, & Ekwueme, 2021). This involves investment in building gas processing facilities, pipelines, storage, distribution networks, and other infrastructure projects, such as the Ajaokuta-Kaduna-Kano gas pipeline (AKK), to realize a stable gas supply-demand value chain (Nduka et al., 2020). Natural gas sector investments by locals and foreigners tend to open up the sector for increased access. This emphasizes the importance of public-private partnerships in capturing the development of gas projects in the country (Nwabueze, Joel, & Nwaozuzu, 2022).

Regular gas shortages are a serious reflection that impacts most productive sectors, particularly the production of power and manufacturing output. The energy sector, central to economic development, is distinguished by an uncertain supply of natural gas (Obaka, Ogboru, & Goshit, 2021). The power plants, reliant on the resource to a large extent, operate below capacity as a result of the lack of sufficient feedstock, thus resulting in power outages impacting daily life and businesses. The unreliability is not just tough on major industries but also on small enterprises and homes that use constant electricity for their operations (Yahaya, Obansa, & Abdullahi, 2023). Gas supply shortage is also complemented by inadequate infrastructure to process and distribute gas. Existing pipeline infrastructure is outdated and poorly maintained, and hence, it becomes inefficient and suffers high losses of gas during transit (Eweade, Uzuner, Akadiri, & Lasisi, 2022). The plants also possess limited capacities and levels of technology, which further restrict the process of converting raw gas into usable forms of energy. It is a fact that the current supply cannot meet the growing demand from other areas, such as power generation, manufacturing, and transport, due to this infrastructural shortage (Udoudo, Oduola, & Kalu, 2023). Moreover, the structure of the natural gas pricing system is not market-based. This tends to manipulate the supply-demand balance. Prices are artificially influenced by government interference and subsidies, which, while aiming to protect consumers, deter investment in the sector. This dampens investors' morale in investing in such projects that do not promise enough returns. It thus leads to underinvestment in gas infrastructure needed to increase supply capacity (Ajala, 2024).

The supply-demand imbalance has resulted in various adverse effects on Nigeria's economy. Erratic gas supply is the first of these effects, which leads to unreliable electricity supply. The unreliable electricity supply, in turn, causes frequent power outages. These power outages inhibit industrial productivity, causing losses in revenue as well as output (Baghebo & Beauty, 2015).

Firms that experience unstable power supply are disadvantaged in relation to firms located in areas where energy tends to be stable. Such risks increase business operating costs because they are obligated to resort to other, costly power sources, for instance, diesel generators, as a mechanism to hedge against the impact of electricity disruptions (Mmesomachukwu & Uchechukwu, 2024). The reliance on inferior sources of energy also imposes a heavier burden on the economy. Diesel, for instance, is sometimes more costly and worse for the environment than natural gas (Diala et al., 2024). The additional cost of energy production from diesel generators owing to increased operating costs also leads to higher prices of goods and services, hence negating consumer purchasing power. While the dependency loop on expensive energy sources damages businesses, it pushes a heavy burden on households because of the increased cost of living that comes along with the attendant high inflation (Nduka et al., 2021).

The gas-to-power projects, which increased the share of natural gas in power generation, emphasize natural gas as a major means of power production (Aniebo & Mogbo, 2024). Policies to ensure and boost the consumption of natural gas as a feedstock for thermal power generating plants have been marred by continuing regulatory issues, lack of transparency, and poor coordination among players in the industry (Oruwari, Salihu, & Obunwa, 2024). To date, the process is plagued by factors such as hindrances to implementing essential reforms, bureaucratic inefficiency, and corruption (Mmesomachukwu & Uchechukwu, 2024).

1.2. Domestic Utilization of Natural Gas in Nigeria

Nigeria's gas consumption has varied over time owing to changing factors such as population, urbanization, and policy actions towards cleaner alternatives. The local trend needs to be addressed so that national consumption of natural gas, as well as economic and energy security dimensions, can be realized (Edo et al., 2024). Application of natural gas in Nigeria is primarily focused on two sectors within the country: domestic, commercial, and residential consumption.

The domestic sector has shown an increasing trend in using gas for cooking and heating. This is mainly due to the growing access to liquefied petroleum gas (LPG) and natural gas connections, which make it easier for households to utilize these energy sources (Obaka et al., 2021). As the urban population expanded, with more and more people shifting to cities, the demand for safe cooking fuels has risen. Natural gas, being clean and efficient as opposed to traditional biomass fuels, has become the number one choice of the majority of households (Diala et al., 2024). Commercial clients such as restaurants, hotels, and small businesses also constitute a significant portion of domestic natural gas consumption. Most business centers have adopted the use of natural gas for cooking, heating, and even power generation, primarily due to its relative affordability and stability compared to other sources of power. This trend is particularly evident in urban regions with well-developed infrastructure for natural gas transportation (Nwabueze et al., 2022).

In addition to that, power generation is the largest local consumer of natural gas. Natural gas power stations are being employed to supply the country with its increasing demand for electricity (Bello & Dauda, 2022). Because Nigeria's supply of electricity has long been plagued by shortages and inefficiencies, natural gas has been increasingly utilized as a cleaner and more efficient alternative to other hydrocarbon sources of energy, such as coal and oil. It has also given a strong priority to gas-to-power ventures, targeted at raising the ratio of natural gas in the local grid. Yet, despite the rising demand for natural gas, there are challenges (Areremi & Emaviwe, 2023). Natural gas access to infrastructure is not uniform throughout the nation, and most rural areas continue to use conventional fuels. The development of the natural gas distribution network is necessary to meet the increasing demand in these areas.

Furthermore, public awareness and education on the benefits of natural gas can promote its utilization in different sectors (Adekoya, Adefemi, Tula, Umoh, & Gidiagba, 2024). The industrial and commercial sectors represent significant consumers of natural gas in Nigeria. In the industrial sector, natural gas serves as a critical feedstock and energy source. Industries such as fertilizer production, petrochemicals, and manufacturing heavily rely on natural gas for their operations (Zhang et al., 2023). The availability of natural gas has facilitated the growth of the fertilizer industry, which is essential for supporting Nigeria's agricultural sector (Abu, Patchigolla, & Simms, 2023). Natural gas is used to produce ammonia, a key ingredient in nitrogen-based fertilizers. This not only boosts agricultural productivity but also contributes to food security in the country (Felix, 2024).

1.3. Challenges to Natural Gas Demand in Nigeria

Up to this moment, adequate gas demand analytics that are required to predict and forecast in order to implement policies towards addressing supply-demand challenges remain inadequate. Demand forecasting helps to match demand and supply through the provision of accurate information to stakeholders. A dearth of information about gas consumption habits and buyers' behavior harms the market, thus leading to inefficiency in production and delivery. Nigeria requires investment in data analytics and demand forecasting systems; otherwise, decision-making capabilities will remain hindered while demand and supply get mismatched. Maximizing production volume in line with available gas reserves to match demand in the country cannot be overemphasized (Okeah & Zeb-Obipi, 2023). Price volatility is a critical concern affecting natural gas supply and demand stabilization. Price volatility in the global gas market can directly affect domestic markets, determining the levels of consumption and production. When prices rise disproportionately, consumers may substitute other alternatives and reduce the demand for natural gas. Producers, in turn, can reduce production when prices drop, perhaps reducing future supplies. Volatility can be a source of uncertainty in determining investment and production. In response to these risks, players must devise mechanisms to insulate against price volatility, for instance, through long-term contracts or hedging instruments that introduce stability to producers and consumers (Akinrele, 2016).

According to Agbonifo (2015), poor energy integration, low domestic content, and inefficiencies in the gas supply chain, as measured by the volume of locally produced goods and services, are firmly anchored in economic structure and development factors. Lijuan (2012) corroborated that there is a correlation between natural gas consumption and the degree of economic growth in a region or the entire nation. This implies that as the economic development of a country rises, its consumption of natural gas increases. Thus, the absence of energy-intensive businesses, cottage industries, and plants in Nigeria that are economically close to gas sources to absorb a large proportion of the related gas produced is a major constraint to gas demand and development. This not only makes it difficult to utilize gas but also slows economic growth in general. The potential growth of the gas industry for rapid growth has been consistently impeded by its current industry's limited capacity to use natural gas (He, Xiao, & Liang, 2015). In the country, the number of companies and industrial facilities that run on gas for operation but have shut down is increasing. This reduces the number of industries that depend on natural gas for operation. While Ajaokuta Steel Company remains moribund, the performance of Aladja Iron and Steel Factory remains sub-optimal, partly because of inadequate gas as feedstock (Vanguard News, 2025). Several other government projects that were targeted towards the utilization of flared associated gas as feedstock went out of business due to poor gas supply. These include the National Fertilizer Company of Nigeria in Warri, the petrochemical plant in Kaduna, and the Aluminium Smelter Company of Nigeria (ALSCON) in Ikot-Abasi, Akwa Ibom State (Agbonifo, 2015). The electricity thermal plants at Afam, Egbin, Sapele, Ughelli, and other sites aimed to consume a sizable amount of flared associated gas grossly suffer from inadequate supply, making them operate below 40% of their installed capacity (Agbonifo, 2015).

Some factors have been identified as contributing to the inadequacy of gas availability in key sectors of the economy. First, there is a lack of sufficient funding for necessary upstream oil and gas developments, caused by conflicting socioeconomic and political objectives. Additionally, there is an inadequacy in the gas delivery value chain infrastructure, particularly in processing and transportation (Ehanmo, 2021). Emphasis is also placed on the constraints caused by gas pipeline vandalism to gas-to-power initiatives.

2. THEORETICAL PERSPECTIVE

2.1. Ramsey–Cass–Koopmans (RCK) Model

This hypothesis is a neoclassical growth model that was expounded by David Cass and Tjalling Koopmans, adapted from the study of F.P. Ramsey. The Ramsey–Cass–Koopmans theory is distinguished from the Solow-Swan model as the savings rate is endogenized since the consumption option is clearly micro-founded at a specific period in time. Hence, a shift to the long-term steady state may not be accompanied by a consistent saving rate, in contrast to the Solow-Swan model. It was also implied by the hypothesis that the result is Pareto efficient or Pareto optimal. Ramsey first presented the model as a social planner's challenge, aiming to maximize consumption levels over generations. Subsequently, Cass and Koopmans adopted a model to describe a representative agent in a decentralized dynamic economy. The model excludes all causes of disruption, such as exogenous shocks, household heterogeneity, and market inefficiencies, and it solely attempts to explain long-term growth rather than business cycle swings. Real business cycle theory was developed by some scholars who expanded the model to include shocks from government purchases, changes in employment, and other sources of disruption. An all-encompassing production function capturing the production scenario of Inada typically described as being of the Cobb-Douglas type, is the starting point for the Ramsey–Cass–Koopmans model.

$$f(K, L) \quad (1)$$

In (1), capital and labor are inputs. Theoretically, the Cobb-Douglas production function is homogeneous to the degree of unity. Expressing the homogeneity in per capita terms gives.

$$f(K, L) = L \times F\left(\frac{K}{L}, 1\right) = L \times f(k) \qquad (2)$$

The total number of labor corresponds to the population in the economy, which is assumed to grow at a constant rate, n, that is, $L = L_0 e^{nt}$ where $L_0 > 0$ captures the population at the initial period.

The first major equation of the RCK model is the state equation representing capital accumulation.

$$\dot{k} = f(k) - (n + \delta)k - c \qquad (3)$$

(3) represents a non-linear differential equation similar to the Solow-Swan growth model, where k is the intensity of capital (that is, the amount of capital accessible to a worker), $\dot{k} = \frac{dk}{dt}$, c implies consumption per worker, $f(k)$ is each worker's output given k, and δ is capital depreciation. This relation implies that investment, or an increased unit of capital per labor, equates the portion of production not consumed minus the rate of capital degradation, assuming that there is no population growth. Thus, savings and investment are the same. The other important RCK equation expresses how households maximize lifetime utility.

$$max \int_0^\infty e^{-pt} \frac{c(t)^{1-\theta} - 1}{1-\theta} dt \qquad (4)$$

Subject to the resource constraint of.

$$\frac{℃}{c} = \frac{1}{\theta}(f'(k) - \delta - \rho) \qquad (5)$$

Where $f'(k)$ implies the marginal product of capital (that is, interest rate); δ means the rate of depreciation; ρ denotes the rate of time preference and θ is the elasticity of intertemporal substitution, which indicates how quickly households change consumption over time.

If the return on savings $f'(k) - \delta > impatience\ \rho$, households enhance savings → c grows, but when there are low returns, they reduce savings → c shrinks.

In relation to Nigeria's gas demand, the model is explained as follows.

$$\dot{k} = f(k) - (n + \delta)k - c \qquad (6)$$

f(k) is the output made possible by gas infrastructure (such as power or industrial output), c is the consumption of natural gas per capita (or per power/industrial consumer), n is the steady population growth, δ is the depreciation or loss of infrastructure (due to neglect or vandalism) in Nigeria, and k implies the gas infrastructure per capita (or per worker).

$$\frac{℃}{c} = \frac{1}{\theta}(f'(k) - \delta - \rho) \qquad (7)$$

The marginal benefits or gains of infrastructure are expressed by f′(k), which is the amount of additional power or industrial production plus economic return from adding pipelines and processing plants; the time preference rate or impatience is represented by ρ, capturing the preference for immediate revenue over future investment gains. Willingness or ability to adjust consumption over time (smoothing) is represented by θ. If either f′(k) is low (that is, corruption, inefficiencies, and other side effects) or ℃ is high (that is, decay, vandalism, and other dampening vices), then ℃/c may be negative, implying that consumption does not increase. This seems conceivable given the supply difficulties in Nigeria.

The RCK hypothesis demonstrates that the optimal savings in gas infrastructure investments against immediate consumption (exports and subsidies) are necessary for the country's sustained natural gas demand. The need for gas in Nigeria would increase consistently if the investments are prudently made; if not, industries would fail, and the economy would not reach its full potential.

3. EMPIRICAL REVIEW

Olorunsiwa (2025) conducted an analysis of gas demand management in Nigeria using primary data. Information on the development and use of natural gas, demand, and its socioeconomic impacts was gathered using questionnaires. It was found that the introduction of Nigeria's gas master plan and other numerous gas value-chain projects are the main drivers of the gas sector's explosive growth. With 210.5 TCF of confirmed reserves, Nigeria possesses an abundance of natural gas deposits that, if developed and exploited, can significantly boost the country's economy through production businesses. Thus, in order to meet the enormous local gas demand, the master plan seeks to enable quick and economic expansions of gas capacity. Yahya (2018) also investigated how Nigeria's national output was impacted by natural gas demand and price using Structural Vector Auto-Regressive (SVAR) between 1996 and 2016. It was found that gas prices significantly affect gas demand, which in turn influences gas pricing, and that gas demand significantly affects GDP. Furthermore, the impulse response shows that GDP responded negatively to gas demand but positively to the retail prices of gas supply and petroleum. Retail petroleum contributed the most to changes in GDP, followed by gas demand and supply, while gas price contributed the least, according to the variance decomposition.

Using panel data from Eurostat and World Bank publications, Adebowale, Ojo, and Yusuf (2023) examined the existence of a long-term relationship between natural gas consumption and its determinants. Panel data analysis was used, and a decision was made based on the Hausman test. It was found that natural gas prices significantly affect natural gas consumption, indicating that as natural gas prices rise, so does natural gas use. Hence, it will be critical for the European Union and the United Nations to act quickly to implement a radical and long-term solution to the ongoing conflict between Russia and Ukraine to prevent the war's potential to inflict further, unimaginable harm on the economies of European nations. Nwatu, Dosumu, and Nteegah (2023) sampled some selected African countries to assess gas demand and output growth among top gas-producing economies over the period 1990 through 2021. The ARDL results established that while gas price and use of gasoline for motor fuels had a favorable influence on growth, demand for gas had a negative and negligible effect. Liquefied natural gas transmission to homes and manufacturing companies may be hindered by inadequate infrastructure development and ineffective energy regulations. On the other hand, the price of gasoline, motor fuel, and natural gas made a substantial and favorable contribution towards the expansion of growth in economies of oil-dependent African nations. Hence, the study suggested that the best method of attaining sustained growth in gas-producing nations in Africa is to improve infrastructure for the utilization of natural gas while maintaining a stable and competitive pricing for natural gas.

Li, Dong, Jiang, and Dong (2022) analyzed the influence of income and gas prices on gas demand in China, taking into consideration regional heterogeneity and asymmetry. It was found that elevated gas prices have a high likelihood of reducing gas demand in urban China. Meanwhile, an average income level has the potential to effectively enhance demand for gas. A strong, alternating nexus exists between natural gas and electricity. However, such effects vary by region in China, with income having a greater impact on gas demand among dwellers in low-priced regions. While the effect of wealth is asymmetric, the impact of gas prices on urban gas consumption is consistent across regions with varying urban natural gas consumption. Furthermore, He et al. (2015) utilized SPSS to analyze the factors influencing natural gas in China over the period of 2001 to 2011. The use of natural gas is forecasted using a linear regression model. The study, therefore, predicted natural gas consumption for 2011–2013. The analysis of the results demonstrates the reasonableness and effectiveness of the SPSS-based model.

From 1992 to 2018, Akokaike et al. (2021) used panel data to assess the nexus between natural gas consumption and economic growth in Africa, with reference to Nigeria, Algeria, Egypt, South Africa, Gabon, and Angola. The variables such as real GDP, gas consumption, oil consumption, electricity consumption, capital stock, and labor stock were captured in the study. The findings show that natural gas and economic growth are positively correlated under fixed effects and least squares dummy variables, respectively. For all panel approaches utilized in the oil example, the study also indicates a negative connection and significant impact on RGDP. However, there is a positive correlation between RGDP and electricity consumption, which is also statistically significant. Conclusively, in Nigeria, Angola, Gabon, Algeria, South Africa, and Egypt, the use of natural gas is favorably correlated with economic growth.

Abdulqadir (2021) provides an exploration of the growth threshold effect on the consumption of renewable energy in sub-Saharan Africa. Using dynamic panel threshold regression estimation, the research reveals that renewable energy consumption has a positive correlation with economic growth only when the economy achieves a certain threshold level. This suggests the important part played by the maturity of the economy in using renewable energy and implies that policy interventions that contribute to economic development may also aid in sustainable energy use. Similarly, Barasa, Bogdanov, Oyewo, and Breyer (2018) explore the feasibility of achieving a 100% renewable energy supply in sub-Saharan Africa by 2030. Their research employs a descriptive analysis, concluding that renewable energy can meet significant electricity demands while addressing water desalination needs. Emanating from the study findings, it was suggested that developing economies can leapfrog traditional energy models, although it also raises questions about the infrastructural and capital investments needed to realize such ambitions.

Atalla, Gasim, and Hunt (2018) treated gasoline demand and gas oil pricing policy in Saudi Arabia using an Autoregressive Distributed Lag (ARDL) model. The study finds that gasoline usage is price inelastic, that is, increasing prices would not be an efficient way of curbing usage. This has implications for policymakers since it means other than price adjustments, there are other policies that must be employed in order to manage fuel usage in a sustainable process. Agbanike et al. (2019) similarly, in a related context, analyze the oil price dynamics, energy consumption, and CO_2 emissions dynamics for Venezuela. Their ARDL outcome reveals that higher crude oil prices raise energy use and government expenditure, thus producing increased CO_2 emissions. The existing study helps to add complexity to the complex energy price and environmental sustainability nexus, where a rise in oil revenues can discouragingly negate emission reduction. Misund and Oglend (2016) also used VAR to analyze the dynamics of the nexus between gas price volatility and the daily shocks in U.K. gas demand and supply. The authors found that daily deviations in aggregated gas demand had a significant influence on volatility. It was confirmed that flexible sources of supply, like LNG, storage, and interconnector flows, respond to shocks in retail demand, reducing their potential effects on volatility.

Dabachi et al. (2020) analyze this nexus in African OPEC countries with Granger causality models. The results support bidirectional causality between energy consumption and economic growth, indicating that energy is both a cause and a consequence of economic activity. This finding aligns with the study of Hasan and Raza (2022), which also identifies a two-way causality between Chinese GDP growth and natural gas consumption, reinforcing the idea that energy is a fundamental component of economic growth. Rafindadi and Ozturk (2015) examine the relationship between natural gas consumption and economic growth in Malaysia and conclude that economic growth does not Granger-cause natural gas consumption. This disparity in conclusions highlights the heterogeneity of energy-economic relationships across contexts, implying that local factors play a notable role in shaping these dynamics.

The Vector Error Correction Model (VECM) was used by Nwabueze et al. (2022) to examine the relationship between natural gas consumption and economic growth in Nigeria from 1990 to 2020. Their findings show a significant positive correlation between natural gas consumption and economic growth, which suggests that natural gas will play an important role in attaining sustainable economic development. The current research is in line with Diala et al. (2024), who also employ an Autoregressive Distributed Lag (ARDL) model to confirm that natural gas supply positively contributes to Nigeria's GDP. In addition, Agbonifo (2015) sampled Nigeria to examine the challenges, opportunities, and obstacles of natural gas on growth and sustainable development. The development of natural gas has several essential advantages, including the creation of wealth, jobs, the environment, social progress, and sustainable development. Although there are some priceless opportunities from natural gas, there also seem to be some challenges. The study found that the lack of infrastructure for gas collection and distribution, budgetary and regulatory policies, funding, as well as the current security situation in the Niger Delta are the main challenges.

Abdulkareem, Okoroafor, Awelewa, and Adekitan (2019) used quadratic regression models with a moderating term to predict Nigeria's long-term household electricity demand from 2015 to 2029. From the findings, household power consumption will reach 6521.09 MW/h in 2029. It was also found that the population is favorable and relevant for both short- and long-term forecasting. Due to the fact that the quadratic models with moderating effects have the greatest coefficients when compared to linear models, the study concluded that they are more accurate at predicting electricity demand.

Using the ARIMA model, Turkey's energy consumption was analyzed by Mahia, Dey, Masud, and Mahmud (2019) between 1970 and 2015. The research covered natural gas, coal, oil, renewable energy, and total energy use. The findings showed ARIMA (1, 1, 1), ARIMA (0, 1, 0), and ARIMA (0, 1, 2) for total energy consumption for coal, oil, natural gas, and renewable energy. It was therefore concluded that, by the end of 2040, the country's energy consumption will increase. Specifically, it was found that natural gas, coal, renewable energy, oil, and total energy consumption would witness average increases of 4.87 percent, 3.92 percent, 1.64 percent, 4.20 percent, and 4.87 percent, respectively. Similarly, the VARIMAX model was employed by Haiges, Wang, Ghoshray, and Roskilly (2017) to forecast carbon emissions from energy consumption in Thailand's petroleum, chemical, and rubber industries over the period of 2000 to 2015.

Two sections of the model exist, with the first section proposing ARIMA and a 10-year forecast ranging from 2016 to 2025 (2,1,2). The findings showed that the country would experience 17.65% greater carbon emissions than energy consumption in 2025. However, the second model proposed ARIMA and a 30-year projection spanning from 2016 to 2045 (2,1,3). It was found that in 2025, the country's carbon emissions will exceed the energy-consuming sectors by 39.68%. It was therefore concluded that increases in carbon emissions from energy use have a detrimental impact on the ecology and the entire economy.

From 1990 to 2017, Nkemnole and Akinola (2020) utilized the Harvey, Autoregressive, and Markov chain models to forecast Nigeria's energy generation and consumption from 2018 to 2037. The results show that the Markov chain method was the most accurate in forecasting power production. However, the Harvey approach provided the best predictions.

As a result, the study recommends using the Markov-Harvey technique to predict electricity production and consumption over a 20-year period. Also, carbon dioxide emissions in India were predicted by Farajian, Moghaddasi, and Hosseini (2018) based on various energy consumption sources, both linear and PSO algorithm nonlinear regression methods were used in the research. The findings show that the PSO model generates a more accurate estimate than the multiple linear regression technique. Carbon emissions over the period of 2017 to 2030 were predicted by the PSO.

Consequently, the study recommends taking the necessary actions to lower carbon emissions, which could influence the environment. Furthermore, to predict Morocco's wind and solar energy capacity in 2030, Ozturk and Ozturk (2018) analyzed annual data to forecast from 2017 to 2030 and specifically used additive and multiplicative models. The findings show that Morocco has the potential to produce renewable energy, especially solar and wind energy. Thus, by 2030, 52% of the country's installed electrical capacity will be derived from renewable energy sources.

4. METHODOLOGY

4.1. Type and Source of Data

The study adopted the use of annual secondary data on natural gas demand by the industry, residents, and non-energy sectors in Nigeria between 1988 and 2024, spanning 36 years. The data set was gathered from the official website of the International Energy Agency, IEA https://www.iea.org/. The dataset underscores the study's analysis.

4.2. Autoregressive Integrated Moving Average (ARIMA) Model

In recent times, several studies have employed a variety of forecasting models to anticipate energy consumption in various countries. However, time series-based models appear to be the most straightforward method, as stated by Jamii and Maaroufi (2021). Time series models can be used to predict future events by analyzing past occurrences. Hence, the Autoregressive Integrated Moving Average (ARIMA) model is one of the most popular techniques for estimating energy consumption, especially natural gas, through time series data (Jamii & Maaroufi, 2021; Mahia et al., 2019). To objectively analyze the attributes of a time series variable and identify the suitable model, Box and Jenkins developed the ARIMA technique in 1976 to forecast future values, and this method relies on historical data rather than explanatory variables.

4.3. Model Construct

To make accurate predictions, ARIMA models use autocorrelation processes (Mahia et al., 2019) and are created by combining three different random processes, which are represented by ARIMA (p, d, q). Here, AR (p) is the order of the autoregressive process; I(d) indicates the order of the integration process; and MA(q) signifies the order of the moving average technique. When the sample data is not stationary, the I(d) process is used (Henry & Peter, 2023; Mahia et al., 2019). Hence, the generalized baseline of the ARIMA (p,d,q) model is stated as follows.

$$Y_t = \alpha + \phi_1 Y_{t-1} + \cdots + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q} \quad (8)$$

The individual form of the model takes the form below.

$$(1 - \textstyle\sum_{i=1}^{p} \emptyset i\, \beta^i)\,(1\text{-}\beta)^d Y_t = (1 + \textstyle\sum_{j=1}^{p} \emptyset j\, \beta^j)\varepsilon_t \quad (9)$$

Where: Y_t is the dependent variable (the time series being modeled), α is the constant term; ϕ_1 implies the Autoregressive (AR) coefficient of order 1; β is the bracket shift operator ($\beta Y_t = Y_{t-1}$); Y_{t-1} is the first lag of the differenced series; ε_t is the random error term (white noise); θ_1 represents the moving average (MA) coefficient of order 1; d degree of differencing to achieve stationarity; ε_{t-1} is the lagged error term.

To allow for sector-specific analysis, separate univariate versions of (9) above are specified for each of Industry gas demand, Resident gas demand, and Non-energy gas demand. The influence of trends, seasonality, and shocks such as policy changes and economic factors in the energy market on each sector's gas demand are independently captured. The models are thus specified as.

$$(1 - \textstyle\sum_{i=1}^{p} \emptyset i\, \beta^i)\,(1\text{-}\beta)^d INDUSTRY_t = (1 + \textstyle\sum_{j=1}^{p} \emptyset j\, \beta^j)\varepsilon_t \quad (10)$$

$$(1 - \textstyle\sum_{i=1}^{p} \emptyset i\, \beta^i)\,(1\text{-}\beta)^d RESIDENT_t = (1 + \textstyle\sum_{j=1}^{p} \emptyset j\, \beta^j)\varepsilon_t \quad (11)$$

$$(1 - \textstyle\sum_{i=1}^{p} \emptyset i\, \beta^i)\,(1\text{-}\beta)^d NON\ ENERGY_t = (1 + \textstyle\sum_{j=1}^{p} \emptyset j\, \beta^j)\varepsilon_t \quad (12)$$

$INDUSTRY_t$, $RESIDENT_t$ *and* $NON\ ENERGY_t$ represent gas demand across the three sectors under study.

In analyzing ARIMA, identification is the first step; the second stage is estimation, followed by diagnostic checks, while forecasting is the fourth stage. The Box-Jenkins approach is designed to take these phases into account. The identification method requires determining the model specification parameters p, d, and q. The Autocorrelation Function (ACF) and the Partial Autocorrelation Function (PACF) are the two main aspects of the identification process.

5. PRESENTATION OF RESULTS

5.1. Trends

Prior to the first stage of optimal ARIMA, as explained by Box and Jenkins (1976), the study analyzed movement in natural gas demand by the industry, residents, and non-energy sectors in Nigeria during the study period, as shown in Figure 1. Subsequently, Table 1 explained the attributes of the series on gas demands by the three sectors under study. The data were subjected to the ADF unit root test, as shown in Table 2. Thereafter, the ARIMA process to determine the optimal ARIMA (p, d, q) specification was presented in Table 3, using a correlogram with 16 delays to achieve a genuine result.

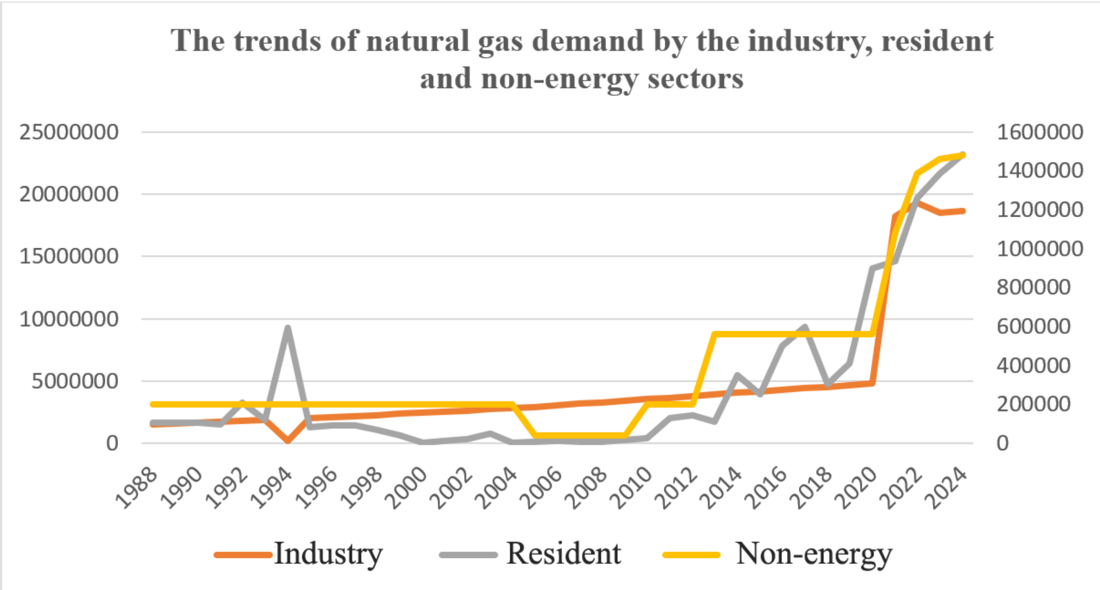

Figure 1. Trends of Natural Gas Demand in Nigeria between 1988 and 2024.

The movement of natural gas demand between 1988 and 2024 for different sectors (industry, domestic, and non-energy) shows a pattern of fluctuations with both upward and downward trends. There was a consistent demand for gas by the non-energy sector from 1988 to 2004, with approximately 200,000 TJ being consumed by this sector. However, the sector experienced a sharp decline in gas demand, with a reported 40,000 TJ over five consecutive years (2005 through 2009). This decline was attributed to policy inconsistency and price volatility, which discouraged some sectors from continuing to rely on natural gas and prompted a shift to alternative energy sources. In 2010, the demand rate for natural gas by the non-energy sector rebounded to 200,000 TJ and further increased to 560,000 TJ over the next eight years, reaching a peak of nearly 1,480,000 TJ in 2024. For the industrial sector, demand fluctuated over several years but surged in 2024, reaching its highest point at 148,000 TJ. Residential demand recorded its highest value of 19,303,200 TJ in 2022, reflecting significant consumption in the domestic sector.

The lowest demand for natural gas by the industry was noted in 2000 at 2,580 TJ, but it started increasing significantly in 2011 at 130,000 TJ. This increase could be attributed to increased industrial manufacturing in the country, which requires more energy. However, fluctuations were also observed in subsequent years, which could be attributed to the economic recessions experienced in the country in 2015 and 2020, respectively. The increasing residential demand for natural gas was evident in the early years due to the rising population in the country, which in turn stretched the energy base of the country. Residential gas demand was 196,500 TJ in 1994, representing the sector's lowest demand. However, the demand gradually increased at a slow pace, indicative of increased integration of natural gas in domestic energy use. By 2024, the residents and non-energy sectors experienced an upward demand trajectory. This is an indication of ongoing policy initiatives targeted at expanding access to natural gas and its applications.

Table 1. Descriptive statistics of natural gas demand.

Statistics	Natural gas (Industry)	Natural gas (Resident)	Natural gas (Non-energy)
Mean	4612824.	287483.2	380712.2
Median	3024000.	106000.0	200000.0
Maximum	19303200	1485000.	1480000.
Minimum	196500.0	2580.000	40000.00
Std. Dev.	5071675.	405935.9	386018.5
Skewness	2.327081	1.776597	1.799322
Kurtosis	6.826874	5.072960	5.370702
Jarque-Bera	55.97205	26.08863	28.62947
Probability	0.000000	0.000002	0.000001

The average natural gas demand by the industry stood at 4,612,824 TJ. While the minimum gas demand by the sector was around 196,500 TJ, the maximum value stood at 19,303,200 TJ. It was further indicated that industrial natural gas demand has a moderate tail to the right with a positive skewness of 2.32 on the distributional channel. The kurtosis is leptokurtic in nature because its value of 6.86 exceeded the normal expectation of 3 on the distribution table. The degree of gas demand fluctuation for the industry recorded about 5,071,675 TJ within a specific period based on the conditions of the country's economy. Demand for natural gas by the residents has a mean value of 287,483.2 TJ with a minimum of 2,580 TJ and a maximum of 1,485,000 TJ. The maximum figure is an indication of increased gas demand by the residential sector as an alternative fuel in the face of economic hardship brought about by the high pump prices of petrol, diesel, and other energy sources in the country. The degree of variable fluctuation showed a value of 405,935.9 TJ. The variable has a short tail to the right with a positive skewness of 1.78. The variable is highly peaked at 5.07. Furthermore, the mean usage of gas by the non-energy sector stood at 380,712.2 TJ. The least demand for gas by the sector is 400,000 TJ, while the maximum value stood at 1,480,000 TJ. The degree of variable fluctuation showed a value of 386,018.5 TJ. While the variable is positively skewed at 5.37, it's peaked at a high value of 5.37, signaling a leptokurtic movement.

5.2. Tests for Stationarity

The table below reports the results of the Augmented Dickey-Fuller random walk test conducted on the series.

Table 2. ADF unit root test.

Statistics	Natural gas (Industry)	Natural gas (Resident)	Natural gas (Non-energy)
Level (t-stats)	-4.35	-1.35	-0.69
P-value	0.008	0.60	0.84
1st diff (t-stats)	-	-7.88	-5.69
P-value	-	0.00	0.00

Before subjecting the series to a unit root test, the data were converted into logarithmic forms to ensure consistency among the variables and to prevent violations of ARIMA assumptions (Mahia et al., 2019). The Augmented Dickey–Fuller (ADF) test was conducted to assess the stationarity of the series. The results indicated that natural gas demand by the industry is stationary at level, that is, I(0), (*INDUSTRY*: ADF = –4.35, p = 0.01). However, natural gas demand by residents and the non-energy sectors was found to be stationary at first difference, that is I(1), (*RESIDENT*: ADF = –7.88, p < 0.00; *NON-ENERGY*: ADF = –5.69, p = 0.00). This implies that the series for residents and non-energy sectors are integrated of order one, I(1), thus indicating d=1 in the ARIMA model.

5.3. ARIMA Output and Demand Forecast

5.3.1. ARIMA Output

Results of the autoregressive integrated moving average model selection in the study are reported in Table 3.

Table 3 shows the optimal ARIMA model selection process.

Industry			
Model	**AIC**	**SIC**	**H-QC**
ARIMA (1 0 1)	1.77	1.95	1.84
ARIMA (1 0 2)	1.89	2.07	1.96
ARIMA (1 0 3)	1.89	2.07	1.96
ARIMA (1 0 4)	2.39	2.57	2.46
RESIDENT			
ARIMA (1 1 1)	2.91	3.08	2.97
NON-ENERGY			
ARIMA (5 1 5)	1.14	1.31	1.19

To verify suitable Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) processes, several ARIMA specifications were reported in the correlogram, while information criteria were also compared, as shown in Table 3. There are four specifications for gas demand by the industry. These include ARIMA (1 0 1), ARIMA (1 0 2), ARIMA (1 0 3), and ARIMA (1 0 4). Based on the lowest AIC, SIC, and H-QC, ARIMA (1 0 1) was eventually selected as the preferred model for natural gas demand by the industrial sector. However, only one specification each was found for gas demand by the residents and non-energy sectors. These are ARIMA (1 1 1) and ARIMA (5 1 5), respectively. Table 4 presents ARIMA output results.

Table 4. ARIMA output results.

Industry			**Resident**			**Non-energy**		
Var	**Coeff.**	**P value**	**Var**	**Coeff**	**P value**	**Var**	**Coeff.**	**P value**
C	15.25	0.00	C	0.07	0.59	C	12.48	0.00
AR(1)	0.96	0.00	AR(1)	-0.05	0.94	AR(5)	0.18	0.81
MA(1)	-0.47	0.06	MA(1)	-0.28	0.68	MA(5)	0.13	0.87
SIGMASQ	0.27	0.00	SIGMASQ	0.86	0.00	SIGMASQ	0.85	0.00

From the industry gas demand results, the constant value, which represents the mean value of the gas demand after accounting for the lag effect, shows a positive coefficient of 15.25 and a p-value of 0.00. This implies the model is highly significant, and the coefficient of 15.25 contributed meaningfully to the model. The autoregressive coefficient at lag 1 (coefficient 0.96) indicates a strong positive relationship between the current value of industry gas demand and its value in the preceding year. Since its p-value is statistically significant, it implies high persistence, meaning the current gas demand by the industrial sector depends heavily on its own previous year. This confirms that the industry's gas demand is path-dependent, with the previous year's demand influencing the current year's demand. However, the moving average term, which measures the effect of past shocks (errors) on the current gas demand, exhibits a negative coefficient of -0.47. This implies that the preceding shock hampers the industry's gas demand in the current period. The variance of the residual ($\boldsymbol{\sigma}^2$), which measures unexplained variations between AR and MA effects, shows a coefficient of 0.27 and a p-value of 0.00. These indicate that the model fairly fits the data, and the residual variance is non-zero since its p-value is statistically significant at the 5% threshold.

The resident gas demand output showed an average value of 0.07 and a p-value of 0.59. This implies that the mean of the series is not statistically different from zero, indicating neither a strong downward nor an upward slope. The AR coefficient, which shows the dependence of current gas demand by the sector on its previous value, has an insignificant value of 0.94. This indicates that the previous year's gas demand by the residents does not significantly impact demand in the current year. The MA coefficient exhibits a negative coefficient (-0.28) and a p-value of 0.06. These reflect that past random shocks have no meaningful influence on the current gas demand of the resident sector. However, the unexplained model's randomness is statistically significant (p = 0.00), implying that there are random variations in the data, making the variable behave like a white-noise process with minimal predictive structure. The constant value of the coefficient of the non-energy sector gas demand shows 12.48 with a p-value of 0.00. This indicates a stable mean level of the series. The AR shows the impact of the fifth lag (last five years) of the sector's gas demand on its current value. This is estimated to be 0.18, indicating a positive reaction of the sector's current gas demand to its 5-period-lagged value. However, the model is not statistically significant at a p-value of 0.81, which is over 80%. The MA coefficient exhibits 0.13 with a p-value of 0.87, which explains that the fifth lag period's random shock influences its current gas demand, but this shock has no significant impact. The variance of the residual indicates a better fit at 0.85 and a significant impact at 0.00, indicating that the residual is non-zero, as expected.

5.3.2. Forecasting Performance

The sample forecast tracks for actual demand by the sectors under review for the period from 2025 to 2029 are shown in Figure 2. The forecasts were reported in percentages, as the data series has been normalized to prevent spurious predictions.

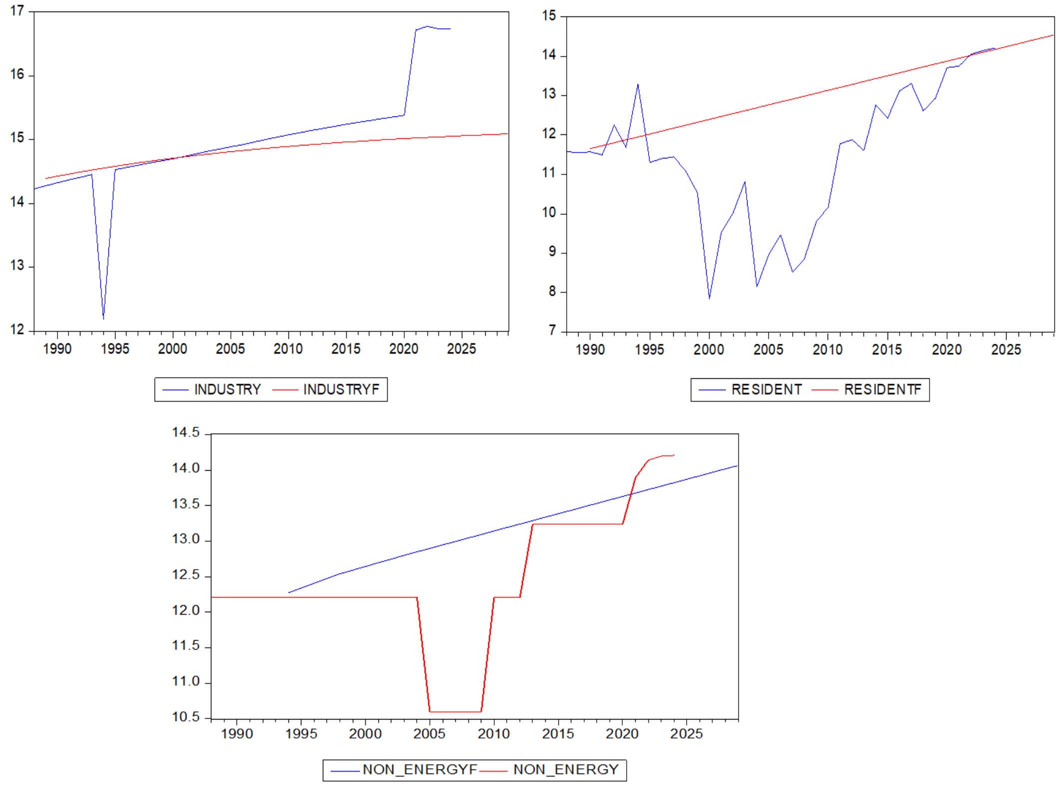

Figure 2. Five-year sectoral gas demand prediction, 2025-2029.

Natural gas demand by the industry may likely experience a decline in 2025 at a 15.06% rate, compared to 16.74% in 2024. The possible fall in gas demand could be attributed to the policies of subsidy removal and the elimination of the dual exchange rate market implemented by the Nigerian government. This could lead to currency depreciation and a surge in inflation, ultimately having a negative effect on industry productivity. However, the forecast shows a tendency for a marginal rise in the demand for natural gas by the industry from 2026, which may continue until 2029. The forecast also reveals a tendency for consistent growth in the demand for natural gas by residents in Nigeria. The rate of gas demand as of 2024 was estimated at 14.21%, with a tendency to rise to 14.24% in the following year. The growth in demand is expected to be sustained, with projections reaching 14.54% by the end of 2029. This indicates a high and increasing level of demand for natural gas by the sector in Nigeria. Regarding the gas demand prediction for the non-energy sector, there is a possibility that this sector will experience a decline in natural gas demand throughout the five-year projection period. To a large extent, this could be attributed to government policy shifts in the country. Natural gas demand by the non-energy sector appears to mirror the decline patterns observed in the industry gas demand during the forecast period.

5.4. Diagnostic Test

To ensure the validity of the estimated ARIMA output and the forecast performance, heteroskedasticity and correlogram diagnostic tests were carried out and reported. Table 5 shows the results of the test for heteroskedasticity.

Table 5. Heteroskedasticity test.

Heteroskedasticity test: ARCH for industry			
F-statistic	1.23	Prob. F(1,34)	0.28
Obs*R-squared	1.26	Prob. Chi-Square (1)	0.26
Heteroskedasticity test: ARCH for resident			
F-statistic	0.04	Prob. F(1,33)	0.85
Obs*R-squared	0.04	Prob. Chi-Square(1)	0.84
Heteroskedasticity test: ARCH for non-energy			
F-statistic	0.17	Prob. F(1,33)	0.69
Obs*R-squared	0.18	Prob. Chi-Square(1)	0.68

The heteroskedasticity tests indicate no significant ARCH effects for the industry, resident, and non-energy sectors, as their respective p-values of 0.26, 0.84, and 0.67 exceeded the 5% threshold. Consequently, the residuals behave like white noise, suggesting that ARIMA models have effectively captured the structure in gas demand for the sectors examined in Nigeria. Additionally, a correlogram was employed to assess the adequacy of the models. This analysis was conducted on the residuals obtained from the estimated ARIMA models for natural gas demand across the industry, residents, and non-energy sectors. The autocorrelation and partial autocorrelation results, as indicated by the Ljung–Box Q-statistics for the three sectors, confirmed the absence of residual autocorrelation in the models.

6. VALIDATION OF FINDINGS

Current gas demand by the industry sector is greatly influenced by its past demand, with high persistence. This underscores the performance of the industry in relation to gas availability, cutting across power, manufacturing, and various other real sectors of the economy. The establishment of the fact that previous gas demand by residents does not influence their current demand may be said to align with the discerning mind of concerned members of the sector to base their demand on current perception rather than past influence. Furthermore, the constraints of infrastructure and supply of gas could cause irregular patterns of consumption by the sector, thus resulting in a weak connection between the current and previous gas demand. The same pattern was revealed between current gas demand by the non-energy sector and its past years' demand. This could, however, be attributed to price volatility and market uncertainty, forcing users in the non-energy sector to adjust their gas demand, leading to a weak time-spanning persistence. implementation

The forecasted decrease in gas demand by the industry sector is likely to be a response to the government's policy to remove subsidies from energy sources and the elimination of the dual exchange rate market implementation (Warsame, 2022). This policy may lead to currency depreciation and a surge in inflation, which could negatively affect the productivity of Nigeria's industrial sector. The suggested marginal increase in gas demand by the sector indicates a gradual recovery of industrial activities, which will boost economic growth in the country. This aligns with the findings of Mahia et al. (2019) and Nwabueze et al. (2022). However, Yahya (2018) argued that national output negatively responds to natural gas demand but positively to petroleum products. From the forecast for 2025 to 2029, a consistent growth in natural gas demand by households in Nigeria is projected. The forecast of continuous growth in gas demand by residents reflects the current high level of demand for gas, especially for cooking and heating, which indicates increased gas demand in the future. This is also found by Nkemnole and Akinola (2020) and Ozturk and Ozturk (2018), who confirmed a consistent growth in energy demand and production. However, Haiges et al. (2017) confirmed that excessive usage of gas has the potential to increase carbon emissions into the environment. The non-energy sector was forecasted to experience a continuous reduction in gas demand for five consecutive years. This decline could lead to sluggish growth in non-gas-dependent production firms, reduced value addition, and stunted economic growth. This is especially true as it was established that disparity between natural gas supply and demand could slow down growth (Rafindadi & Ozturk, 2015). Abdul-Mumuni, Insaidoo, Musah, and Akotoa (2023) also argued that to encourage energy demand, such as natural gas, prices and their volatilities, which may have far-reaching effects, need to be monitored by the government.

7. CONCLUSION AND RECOMMENDATIONS

The study estimated Nigeria's natural gas demand in various sectors—industry, residential, and non-energy—using the Box-Jenkins ARIMA model. While gas demand by the industry and non-energy sectors was found to be influenced by their past demand, demand for gas by the residential sector was noted to be independent of its past demand. Demand for gas by the residential sector was forecasted to sustain a consistent demand growth. While industry gas demand, which was found to be low, was forecasted to gradually recover from the low level over time, the non-energy sector was forecasted to experience a continuous demand reduction for five consecutive years.

Based on the findings, the study provides the following recommendations.

i. It is necessary that investment be made towards expanding the gas distribution network and ensuring affordable access to meet the increasing demand from households, supporting the consistent growth in demand as shown in the residential sector.
ii. Policy implementation that is targeted towards industrial recovery should be embarked upon. This will help boost gas demand in the industry sector.
iii. To address the non-energy sector decline in gas demand, the government needed to investigate the cause(s) of the continuous demand reduction being experienced in the sector. This will help to develop interventions that will mitigate the decline.
iv. Policymakers are urged to utilize forecast results in predicting the trends of gas demand across sectors to ensure optimal resource allocation and policy planning.

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Data Availability Statement: Upon a reasonable request, the supporting data of this study can be provided by the corresponding author.
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