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Evaluation of Logistics Agility of Petroleum Products Distribution in Nigeria: Economic and Environmental Implications

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Abstract: *The petroleum industry represents a significant aspect of Nigeria's economic productivity and development plans. More than 70% of energy demand in the country is derived from petroleum product and its derivatives. Agile distribution of petroleum products is a strategy towards an uninterrupted supply of products to consumers at cost-effective prices and without quality compromise. It derives from a logistics process that is lean, flexible, responsive, adaptive, resilient, and cost-efficient. The study is a survey of the downstream marketing and distribution operation of refined petroleum products in Nigeria. It is based on a review of related literature and data sourced from the National Bureau of Statistics. The log-linear model reveals that variations in petroleum pump prices are significantly driven by fluctuations in foreign exchange (FX) rates rather than global crude prices, with every 100% increase in FX resulting in a 136.7% rise in pump prices. In addition, prices of Premium Motor Spirit (PMS) and Automotive Gas Oil (AGO) strongly correlate with inflation, as reflected in the Composite Consumer Price Index (CCPI). The zonal distribution of petroleum products by road in Nigeria from 2017 to 2019, witnessed significant regional disparities in transportation volumes and associated emissions. The environmental burden from tanker trucks is highest in the South West and North Central zones. Air pollution (NO_x, PM_{10}) and greenhouse gas emissions are directly proportional to the number of trucks in each zone. The environmental pressures resulting from petroleum product distribution by road suggest the need for targeted policy interventions to enhance agility in favor of pipeline distribution. These dynamics underscore the need for logistics strategies that promote economic sustainability by reducing overreliance on road haulage, enhancing pipeline infrastructure, and reviving local refining capacity. The study situates logistics agility within broader sustainable development goals (SDGs), particularly SDG 7 (affordable and clean energy) and SDG 9 (industry, innovation, and infrastructure), recommending systemic reforms, infrastructure revitalization, and digital integration to optimize Nigeria's petroleum logistics chain. Ultimately, agile and sustainable logistics are not merely operational imperatives-they are national priorities for resilience, equity, and inclusive growth.*
Keywords: *Agility; Consumer; Distribution; Emissions; Environment; Petroleum; Supply; and Sustainability*

1. INTRODUCTION

Petroleum remains a cornerstone of modern energy systems, driving industrial output, transportation, and economic advancement. Beyond its role as a dominant source of liquid fuels, petroleum also provides the foundational raw material for a diverse array of products including petrochemicals, lubricants, and materials used in construction and manufacturing. As reported by the United Nations Department of Economic and Social Affairs [1], petroleum accounts for approximately 55% of the global energy supply and nearly 90% of the energy used in transportation globally [2]. In Nigeria, petroleum and its derivatives constitute over 70% of the national energy mix, reflecting the sector's strategic importance to development. Data from the Nigerian National Petroleum Corporation (NNPC) show a consistent upward trajectory in domestic demand for refined petroleum products, with projections indicating an increase to 17.3 million metric tonnes by 2025 - a 13.2% rise from the 15.1 million metric tonnes projected for 2020 [3]. This surge in demand is largely attributed to an imbalanced energy portfolio that underutilizes alternative sources, coupled with a deficient electricity supply that compels reliance on fuel-powered generators [4]. Additional pressures stem from population growth, rising urbanization, increasing vehicular ownership, and expansion in commercial and industrial activities, all of which intensify energy consumption, particularly in the transportation and logistics sectors [5,6]. Despite the growing demand, Nigeria's petroleum distribution framework suffers from systemic inefficiencies. Distribution operations are often plagued by supply interruptions, inflated retail prices, underperforming refineries, and weak strategic planning [7]. These constraints severely undermine the timely and cost-effective delivery of petroleum products. [8] have consistently flagged the sector's underdevelopment and managerial inefficiencies as key obstacles to meeting national energy needs. The challenges include but are not limited to pipeline vandalism, inadequate infrastructure, and the monopolistic behavior of certain market actors. Moreover, excessive reliance on road-based haulage—characterized by high lead times and logistical bottlenecks such as poor road conditions, checkpoints, and vehicle breakdowns—further constrain distribution efficiency [9,10]. The concept of logistics agility, which denotes the capacity of a supply chain to swiftly adapt to external and internal disruptions, is pivotal in addressing these challenges. In the petroleum distribution context, agility refers to the ability to efficiently adjust to shifts in global oil prices, foreign exchange (FX) fluctuations, and inflationary trends, all of which affect product accessibility and pricing. It also incorporates sustainability principles by advocating environmentally responsible logistics practices and resilience in distribution systems. Although there exists a substantial body of literature on petroleum distribution challenges in Nigeria, the issues persist and are intensifying. Given the sector's centrality to national productivity and socioeconomic development, continuous research is imperative. This study aims to contribute to this ongoing discourse by examining the agility of petroleum product distribution systems in Nigeria. Specifically, the study seeks to: (i) explore the agility-related challenges in product distribution; (ii) assess trends in petroleum pump pricing; and (iii) evaluate the implications for the cost of living in Nigeria and its impacts on the environment.

2. LITERATURE REVIEW

Petroleum resources and their derivatives play a vital role in the global energy economy, serving as indispensable raw materials across various industrial sectors. However, the geographical distribution of these resources is uneven, necessitating the global movement of both crude and refined petroleum products over vast distances. Consequently, the petroleum supply chain has evolved into a complex, transnational network involving numerous logistical operations from exploration and refining to final delivery. Compared to other industries, petroleum distribution is uniquely intricate due to the volume of operations involved at multiple stages of the value chain. The distribution process involves transporting crude oil from production fields to refineries, followed by the movement of refined products through pipelines, tankers, and storage facilities until they reach distribution depots and eventually, end-users. Disruptions at any point in this extensive chain can significantly impact operational efficiency, product quality, profitability, and customer satisfaction [6, 11-14]. Long transit distances, the need for specialized transportation infrastructure, and the requirement for significant inventory buffers all contribute to high logistics costs and increased complexity in supply chain management [15]. Given these challenges, logistics emerges as a critical strategic function to improve distribution efficiency and mitigate risks.

Optimizing the logistics system has become increasingly necessary to enhance responsiveness and reduce overall distribution costs in the petroleum industry.

2.1 Logistics Strategy and Conceptual Framework

Historically rooted in military operations, logistics has evolved into a central component of modern business operations. The Council of Logistics and Supply Chain Management Professionals defines logistics as the segment of the supply chain responsible for planning, implementing, and managing the efficient flow and storage of goods, services, and related information from origin to point of consumption to meet customer requirements. Similarly, logistics encompasses the strategic coordination of procurement, movement, and storage of materials and products, aimed at achieving cost-efficient order fulfillment both presently and in the future [16]. Contemporary logistics incorporates two primary flows—physical goods and information [17]. The material flow spans from suppliers through distribution hubs to retail outlets [18], while the information flow includes data transmitted from consumers to suppliers and vice versa. This dual structure allows for effective supply chain coordination and performance optimization. Logistics is typically divided into inbound and outbound operations, connecting firms with upstream suppliers and downstream customers, respectively [19]. A comprehensive logistics system integrates multiple functions including customer service, demand forecasting, order processing, inventory control, warehousing, transportation, materials handling, procurement, and returns management [20]. Beyond its traditional operational role, logistics has emerged as a vital corporate strategy, enabling firms to enhance shareholder value and customer satisfaction through better service reliability, cost management, and responsiveness [21]. Strategically, logistics supports key elements of marketing, particularly placing utility in the marketing mix [18]. It ensures that goods and services are available in the right quantity, condition, and time at the desired location, thus bridging spatial and temporal gaps in distribution.

2.2 Logistics Agility

The concept of agility according to [22], originally derived from biological systems, has found relevance in supply chain management, particularly in volatile and uncertain environments. Agility involves a continuous cycle of sensing (observing), interpreting (orienting), decision-making (decide), and action (act), enabling systems to adapt dynamically to changing external conditions. In business settings, logistics agility refers to a supply chain's ability to rapidly respond to fluctuations in customer demand, supply disruptions, regulatory shifts, and infrastructural constraints. Drivers of agility include the demand for faster market delivery, increasing consumer expectations, competitive pressures, technological innovation, and sustainability imperatives. Agility facilitates organizational responsiveness and flexibility, which are essential for competitiveness in dynamic markets [23]. A truly agile logistics system extends beyond processes to include organizational structure, technology, and corporate culture [24]. [18] infers that effective logistics planning revolves around three critical decision areas: location, inventory, and transportation - each directly influencing the quality of customer service. Agility enables cost reductions, improved asset utilization, and enhanced responsiveness through lean operational practices such as minimizing stock levels, reducing lead times, and eliminating non-value-adding activities [21]. Lean-agile logistics systems aim to ensure continuous product availability, matching supply with demand at minimal cost and environmental impact [17, 21, 25]. They enhance service delivery by enabling faster, more reliable, and customer-focused responses to disruptions and market changes.

2.3 Distribution Logistics Functions

Distribution logistics forms the final link in the supply chain, connecting production centers to consumers [26]. According to [27] comprises three key elements: physical distribution, distribution channels, and information flows. Physical distribution involves the actual movement of goods from producers to consumers [28]. Channels of distribution represent the network of intermediaries—such as wholesalers, dealers, and retailers - that facilitate this movement [29]. Meanwhile, information flows serve to coordinate these physical and institutional elements, enabling producers to track consumer needs and market trends, and helping customers access product-related information. The components of distribution logistics include transportation, inventory management, warehousing, materials handling,

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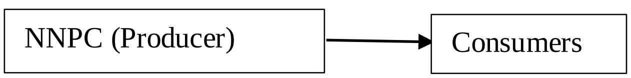
packaging, and communication systems [26, 30-32]. Together, they support the efficient delivery of products to meet customer expectations regarding time, quantity, and location [33]. In the words of [34], distribution logistics significantly affects overall organizational performance by directly influencing customer satisfaction and loyalty. It serves as a key component of the marketing strategy, ensuring the availability of goods that meet customer specifications [31]. When well-executed, distribution logistics reduce resource requirements, improve delivery speed, and enhance service quality. On the contrary, poor distribution systems can lead to product shortages, service failures, and customer dissatisfaction. Advanced distribution strategies often involve collaborative arrangements such as just-in-time (JIT) systems, vendor-managed inventory (VMI), outsourcing, and co-location of facilities. These mechanisms improve integration across the supply chain and help firms achieve economies of scale, minimize costs, and deliver greater customer value [13].

2.4 Petroleum Product Distribution Channels in Nigeria

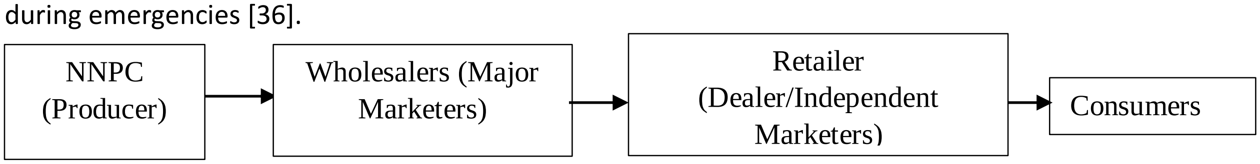
The petroleum supply chain in Nigeria is divided into three major segments: upstream (exploration and production), midstream (transportation and storage), and downstream (refining and distribution). The downstream sector, which deals with the delivery of refined products to consumers, operates through structured distribution channels involving various intermediaries [13, 30].

These channels may be either direct or indirect [35]. In direct channels, the Nigerian National Petroleum Company (NNPC) sells products directly to end-users through its retail outlets.



In indirect systems, products pass through one or more intermediaries, including major marketers and independent dealers. For instance, a one-tier channel involves NNPC selling to major marketers who then sell to consumers, while a two-tier model adds another intermediary—independent marketers—between major marketers and final consumers.

Evidence suggests that many Nigerian consumers prefer NNPC retail stations, attributing this preference to perceived reliability in pricing, quality, and service standards. Moreover, NNPC's retail network plays a strategic role in stabilizing the market, especially during periods of supply disruption. As part of its mandate under the Petroleum Industry Act (PIA), NNPC is obligated to serve as a supplier of last resort during emergencies [36].



2.5 Transportation and Distribution of Refined Products and its Implications

In Nigeria, the standard procedure for distributing refined petroleum products involves moving fuel from the nation's three main refineries—located in Port Harcourt, Warri, and Kaduna—through an established network that includes pipelines, marine vessels, road tankers, and rail wagons. These refined products are intended to be conveyed to 21 strategically located storage depots across the country, from which marketing firms are expected to collect supplies for retail distribution. This logistical network, including the depots and associated infrastructure, is operated by the Nigerian National Petroleum Company (NNPC) through its subsidiary, the Pipelines and Products Marketing Company (PPMC). The pipeline system spans approximately 3,949 kilometers, connecting refineries and port terminals to inland depots via five interconnected systems. Together, these depots have a total storage capacity of about 1.42 million cubic meters. Once imported, the products are initially received at major reception depots such as Atlas Cove [11]. From there, the products are pumped to intermediate depots like Mosimi in Ogun State before being relayed to other storage points across the nation. Booster stations are installed along these pipelines to maintain adequate pressure for product movement between depots. However, years of neglect, vandalism, and insufficient investment have left the pipeline system in disrepair, significantly reducing its reliability and capacity. Due to these issues, petroleum product distribution has increasingly shifted to road-based transport using tankers and trailers. This mode of delivery now accounts for approximately 80% of product movement within the country. The rapid increase in the number of tanker trucks reflects this shift; however, the over-reliance on road transportation introduces additional inefficiencies. Road haulage is susceptible to high transportation costs, frequent delays due to poor road conditions, and elevated risks of spillage, theft, and accidents. Furthermore, petrol tankers and trailers, as they are popularly known, pose significant environmental hazards through spillage and accidents that lead to air, soil, and water pollution and consequent health issues due to the presence of volatile organic compounds and heavy metals inherent in petroleum products [37, 38]. These incidents sometimes also result in fires, which release harmful pollutants and disrupt the urban landscape. The road transportation sector’s current contribution to greenhouse gas emissions is also exacerbated by this. In effect, the inefficacy of Nigeria’s multi-modal distribution infrastructure has weakened the resilience and efficiency of the downstream petroleum sector. The failure to maintain and secure pipeline systems, combined with underperforming refineries and a growing dependence on road transport, has made the sector vulnerable to disruptions and limited its ability to meet national demand sustainably and affordably.

2.6 Theoretical Framework

This study is anchored on three complementary theoretical constructs that explain the dynamics of supply chain adaptability and resilience in volatile environments: the Dynamic Capabilities Theory (DCT), the Supply Chain Resilience Framework (SCRF), and Transport Optimization models. Dynamic Capabilities Theory (DCT) postulates that an organization's ability to adapt to rapidly changing environments depends on its internal competencies and its capacity to reconfigure those resources effectively. In the context of Nigeria’s petroleum downstream sector—characterized by regulatory uncertainties, infrastructural degradation, and volatile market conditions—this theory is especially relevant. The theory underscores the importance of firms being able to sense, seize, and transform operational routines in response to environmental changes. The adoption of emerging technologies, such as artificial intelligence (AI) and big data analytics, offers practical applications of DCT principles. By incorporating real-time data analysis and predictive modelling into their operations, petroleum distributors can better anticipate demand fluctuations, optimize supply routes, and respond swiftly to disruptions. As shown in [39], the integration of digital tools significantly enhances organizational agility and bolsters overall supply chain performance. SCRF provides a complementary lens through which the robustness of petroleum product distribution systems can be assessed [40]. This framework focuses on the capacity of supply chains to anticipate, absorb, and recover from disruptive events. In Nigeria, such events often include pipeline sabotage, erratic fuel imports, infrastructure bottlenecks, and FX volatility. Effective inventory management strategies, such as maintaining buffer stocks and adopting dynamic stock replenishment models, have been shown to improve resilience in the petroleum sector. These measures help stabilize product availability and reduce the risk of supply shortages, especially during periods of market or geopolitical turmoil. [41] explored a critical enabler of both agility and resilience is digital transformation. The deployment of digital technologies across the supply chain allows firms to respond more flexibly to demand-supply imbalances. Predictive maintenance, sensor-based tracking, real-time visibility, and automated decision systems contribute to a more agile and resilient logistics system. Research into the intersection of digitalization and supply chain agility emphasizes the co-evolutionary nature of these constructs, suggesting that digital capability both enables and is enhanced by agile operational practices. In the case of Nigeria, the strategic application of these frameworks - through advanced transportation models [42] and digital infrastructure - could help mitigate distribution inefficiencies. For instance, the use of linear programming models to optimize tanker routing has shown promise in reducing delivery costs and enhancing efficiency in petroleum logistics. Together, DCT, SCRF, and Transport Optimization models offer a robust analytical foundation for examining the agility and sustainability of petroleum product distribution in Nigeria. These frameworks highlight the imperative for organizations to not only build adaptive capacity but also to embed flexibility and resilience into their core operational strategies.

3. METHODOLOGY

This research employed a descriptive survey approach to investigate the downstream marketing and distribution of refined petroleum products within Nigeria. The methodological framework relied predominantly on secondary data sourced from official datasets, particularly from the National Bureau of Statistics (NBS) e-library. The study was grounded in empirical analysis informed by extant literature and statistical modeling techniques to evaluate petroleum logistics agility and its economic implications. The scope of data spans from 2017 to 2024, allowing for a temporal analysis of trends in pump prices, global crude prices, and FX rates. All datasets were subjected to inferential statistical analysis, with an emphasis on identifying the interrelationships among variables influencing petroleum product pricing and cost of living. The python's pandas were used for data analysis to uncover the key patterns in terms of zonal distribution trends and the environmental implications. Environmental tools of Calculation of Emissions from Road Transport (COPERT) emissions based on fuel type and volume, vehicle type (tanker trucks, distance traveled, and emission factors (kg CO_2/litre, etc.) were utilized. The log-linear model presents a system of equations showing the AGO and PMS Average Prices as a function of World Crude Price (WCP) and Average FX Rate (AFX) as shown in equations 1 and 2. In addition, the Composite Consumer Price Index (CCPI) is a function of PMS Average Price and AGO Average Price.

AGO and PMS Average Prices = f (WCP, AFX) (1)

AP= f (WCP, AFX) (2)

Composite Consumer Price Index = f (PMS Ave. Price, AGO Ave. Price) (3)

CCPI = f (PMS, AGO) (4)

The log-transformed versions of the equations are multiplicative relationships, implying elasticity-based interpretation.

$$LnAP_t = b_0 + b_1LnWCP_{t-1} + b_2LnAFX_{t-1} + e_{t-1} \quad (5)$$

$$LnCCPI_t = b_0 + b_1LnPMS_{t-1} + b_2LnAFX_{t-1} + e_{t-1} \quad (6)$$

In the log-linear model, a time series $\{Y_t\}$ is second-order stationary if:

$$\text{Mean: amp; } \mathbb{E}[Y_t] = \mu \text{ (constant)}, \quad \text{Covariance: amp; } Cov(Y_t, Y_{t+\tau}) = \gamma(\tau) \text{ (depends only on lag } \tau). \quad (7)$$

Strict stationarity requires all joint distributions to be invariant to time shifts.

In the petroleum distribution models, errors ε_t are often interpreted as structural shocks or innovations. For a regression model:

$$y_t = \beta x_t + \varepsilon_t, \quad (8)$$

where ε_t may follow an autoregressive process (e.g., AR (1)):

$$\varepsilon_t = \rho\varepsilon_{t-1} + u_t, u_t \sim IID(0, \sigma^2). \quad (9)$$

Also, a variable x_t is weakly exogenous for parameter β if the conditional model f(y_t | x_t, β) can be estimated without modeling f(x_t). Formally:

$$\text{Conditional expectation: amp; } \mathbb{E}(y_t|x_t) = \alpha + \beta x_t, \quad \text{Exogeneity condition: amp; } \mathbb{E}(\varepsilon_t x_t) = 0. \quad (10)$$

The log-linear model identification requires exclusion restrictions. For the petroleum distribution system:

$$y_t amp; = \beta_1 x_t + \gamma_1 z_t + \varepsilon_{1t}, \quad x_t amp; = \beta_2 y_t + \gamma_2 z_t + \varepsilon_{2t}, \quad (11)$$

Identification is achieved if at least one instrument (e.g., z_t) is excluded from each equation.

Statistical estimation was conducted using SPSS, with results reported in terms of coefficient significance, R-squared values, and model fitness tests such as the F-statistic and associated p-values. Robust standard errors were applied to account for heteroskedasticity and serial correlation. This methodological framework provides a rigorous basis for assessing how fluctuations in global oil prices and FX rates influence pump prices, and by extension, the cost of living in Nigeria.

4. RESULTS AND DISCUSSION

4.1 Challenges to Distribution Agility

The study sought as its first objective to explore agility-related challenges in petroleum product distribution. Achieving agility in the distribution of petroleum products entails ensuring the timely and continuous availability of fuel to end-users across diverse locations, without compromising quality or affordability. However, the Nigerian petroleum distribution network is persistently undermined by several longstanding structural and operational deficiencies that compromise supply chain flexibility, responsiveness, and reliability. Despite its vast crude oil reserves, Nigeria faces recurring fuel shortages, erratic pump prices, and widespread logistical disruptions. These issues are symptomatic of deeper systemic failings, ranging from underperforming infrastructure and planning inefficiencies to regulatory bottlenecks and entrenched governance challenges. Below is a detailed examination of the key obstacles that hinder the development of a truly agile and resilient petroleum logistics system in the country.

4.1.1 Recurrent Product Scarcity

Fuel scarcity is a frequent and disruptive phenomenon in Nigeria, often occurring multiple times annually [43]. This recurrent issue stems primarily from an inadequate supply of petroleum products, often due to delays or shortfalls in replenishing inventories. The root cause lies in the nation’s chronic inability to refine sufficient quantities of crude oil to meet domestic consumption needs [44-48]. Although Nigeria is one of the world’s leading oil producers, the country's dependence on imported refined petroleum products renders it vulnerable to external shocks such as geopolitical unrest, labor disputes, and adverse weather events in supplier nations. The problem is exacerbated by Nigeria’s dormant refinery infrastructure, which has remained largely non-operational despite repeated and costly government-led rehabilitation efforts [48]. [46] remarks over the years, various policy initiatives aimed at expanding domestic refining capacity - such as the approval of modular refineries - have yielded minimal results. Only a small fraction of licensed facilities have commenced operations. Private investors have been deterred by factors including the distortionary effects of fuel subsidies, limited access to credit facilities, and an opaque regulatory environment [48]. These deterrents have curtailed investment in local refining, perpetuating reliance on imports and exposing the country to external supply chain disruptions. Additionally, the economic incentive for fuel smuggling into neighboring countries—where pump prices are considerably higher—further depletes local supply. Corrupt practices among depot operators, marketers, and public officials have also contributed to product diversion, artificial scarcity, and price manipulation.

4.1.2 Weak Distribution Network

One of the most critical impediments to agile fuel distribution in Nigeria is the dilapidated state of its pipeline network. Pipelines play a vital role in transporting crude oil to refineries and refined products to storage depots and marketing terminals. However, years of underinvestment, poor maintenance, and rampant vandalism have rendered many of these pipelines non-functional [49]. Refineries that rely on pipelines for crude feedstock are often forced to suspend operations, while the failure to distribute refined products through pipelines leads to an over-reliance on road transportation [50, 51]. This shift to trucking has resulted in several inefficiencies, including longer delivery times [52], increased transportation costs, and higher exposure to risks such as accidents, theft, and extortion at road checkpoints. Pipelines offer significant advantages in terms of cost, safety, and volume capacity when compared to road haulage [11, 53]. For example, in developed economies like the United States, pipelines account for over 60% of petroleum product transportation, enabling timely and large-volume distribution [54]. In contrast, Nigeria’s reliance on road transport—estimated at over 80% of internal petroleum product movement—introduces logistical bottlenecks that limit the system’s responsiveness to demand fluctuations. In the Niger Delta, where most oil infrastructure is located, socioeconomic grievances and environmental degradation have led to sabotage and theft. Militant groups often target pipelines as a

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means of gaining political leverage, while local communities resort to illegal tapping and bunkering as a form of economic survival or protest. These activities have repeatedly disrupted the nation's fuel supply chain and undermined investments in pipeline infrastructure.

4.1.3 Ineffective Energy Planning

Another major constraint to distribution agility is the lack of a coherent and data-driven national energy planning framework. Despite the importance of petroleum products to economic and social life, there is no reliable estimate of daily national consumption [47]. Agencies such as the NNPC, the Ministry of Petroleum Resources, and regulatory bodies often provide inconsistent figures, leading to planning inefficiencies and resource misallocation [55-57]. The absence of strategic stockpiling mechanisms further compounds the vulnerability of the fuel supply chain. With no buffer reserves to cushion supply shortfalls, the system remains reactive rather than proactive, responding to crises only after scarcity becomes acute [58,59]. Additionally, the monitoring of depot stock levels and scheduling of replenishment orders is plagued by lax oversight. According to [47], the inability to accurately track consumption data and detect diversion or hoarding makes it difficult to ensure a consistent supply. In some cases, smuggled products meant for domestic consumption end up in neighboring markets, exacerbating local shortages and wasting public resources.

4.1.4 Escalating Fuel Costs

Fuel prices in Nigeria have increased dramatically in recent years, driven primarily by the country's dependence on imports, depreciation of the Naira, and inefficiencies in the distribution system. The collapse of domestic refining has exposed the economy to global oil price volatility and FX market pressures [60]. As import costs rise, so do pump prices - especially in the absence of subsidies. From 2017 to 2024, the price of Automotive Gas Oil (AGO) rose by over 540%, while Premium Motor Spirit (PMS) increased by 386%. Deregulation policies and the subsequent withdrawal of fuel subsidies in 2023 have further intensified the burden on consumers, particularly in a context where incomes are stagnating and inflation is rising. High pump prices have a ripple effect across the economy [61]. Transportation costs soar, the price of goods and services inflates, and overall living standards decline. For businesses, the increased cost of energy inputs reduces competitiveness and erodes profit margins. Without a reliable local refining base and cost-effective distribution system, price stabilization remains elusive.

4.1.5 Corruption, Sharp Practices and Mismanagement

Finally, systemic corruption and institutional malpractice continue to undermine distribution efficiency and public trust in the petroleum sector [62]. A network of vested interests—comprising marketers, transport operators, depot managers, and complicit public officials—has emerged, capitalizing on regulatory loopholes and weak enforcement to manipulate the supply chain [47]. Cases of allocation diversion, deliberate hoarding, and cross-border smuggling are widespread. Reports indicate that up to 30% of fuel allocations are smuggled to neighboring countries, where they are sold at inflated prices. This diversion is often facilitated through falsified documentation, underhanded deals, and connivance with regulatory personnel. Corrupt actors within the subsidy regime have been known to claim reimbursement for products never supplied, inflating subsidy bills and misappropriating public funds [63]. These fraudulent practices distort market dynamics and perpetuate scarcity, often at the expense of ordinary consumers. Efforts to reform the system have been slow and met with resistance from entrenched interests. Without robust governance mechanisms, transparency in allocation, and effective enforcement of supply chain regulations, distribution agility will remain aspirational rather than achievable.

4.2 Trends in Pump Prices of Petroleum Products

The study also sought to examine the pump price of petroleum products and to determine the effect of product importation and Global Crude Prices on pump prices. The focused products are PMS and AGO which are the most widely used products in the country for industrial, commercial, transport, and domestic energy supply.

Table 1. AGO and PMS Prices for the Period of 2017 to 2023.

Year	AGO Average Price	PMS Average Price	YOY Change in Average Price of AGO	YOY Change in Average Price of PMS
2017	212.73	146.4	0%	0%
2018	210.79	154.82	-1%	6%
2019	227.19	145.45	8%	-6%
2020	223.69	147.77	-2%	2%
2021	248.95	166.47	11%	13%
2022	664.81	181.01	167%	9%
2023	1017.91	430.71	53%	138%
2024	1365.21	710.91	34%	65%
Total Price Change 2017-2024			542%	386%

Source: E-library, National Bureau of Statistics (nigerianstat.gov.ng). Legend: YOY- year-on-year

Table 1 presents the prices of PMS and AGO from 2017 to 2024. The data is sourced from the NBS e-library. The year-on-year (YOY) price change of the products for the period under review is also presented. Concerning the 2017 pump, the price of the products has increased YOY except for the years 2018 and 2020 when the price of PMS experienced a decrease of 1% and 2% respectively. Likewise in 2019, AGO witnessed an annual decrease of 6%. The price decrease could be linked to fluctuations in global oil prices as products consumed are significantly imported. Other factors may include changes in FX, landing costs, and increased government subsidies. The AGO records the highest price increase of 167% in 2022 and the PMS in 2023 with a 138% price change. The government had increasingly reduced subsidy payments on AGO in 2022 and by April 2023 it had announced the complete removal of subsidies on all products and complete deregulation of the industry. Generally, from 2017 to 2024, the price of AGO and PMS has increased by 548% and 386% respectively.

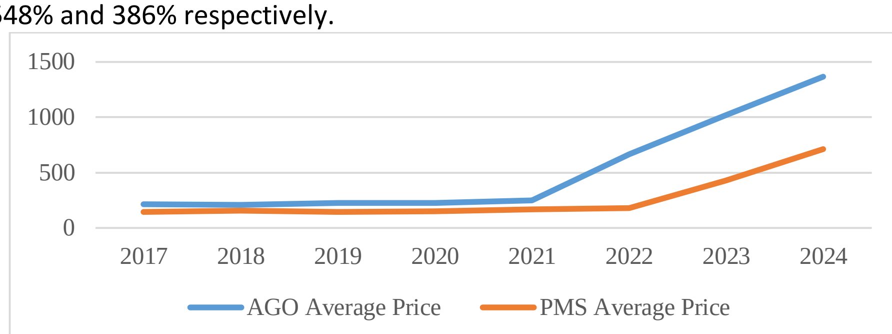


Figure 1. Line graph of AGO and PMS Pump Prices from 2017 to 2023.

Figure 1, a line graph illustrating pump price movements over time, shows a consistent upward trajectory, with the most pronounced changes occurring in the 2021–2024 period. This reflects both the depreciation of the naira and the global energy price volatility experienced during this time, particularly in the wake of global crises such as the Russia-Ukraine conflict.

4.3 The Effect of Fuel Import Dependence and Global Oil Prices on Pump Prices

Significantly the Nigerian government has relied on product importation over the years to service local consumption demand. It is argued that this over the years has made the country vulnerable to fluctuations in global oil prices and FX. Product importation has continued to mount immense pressure on FX leading to Naira depreciation and increasing pump prices. Products imported at high FX rates translate into high lading costs and the marketers must make a profit. This at best has been a theoretical analogy with no known empirical analysis. In this regard, the study through a regression. To empirically assess the extent to which pump prices are influenced by external economic variables, the study employed a log-linear regression model with average fuel price as the dependent variable and global crude oil price (WCP) and average FX rate (AFX) as explanatory variables. The model was estimated using annual data spanning 2017 to 2024.

Table 2. Global Oil Price and Pump Price in Nigeria.

Year	AGO Average Price	PMS Average Price	Average Pump Price (AP)	World Crude Oil Average Price (WCP)	Average FX Rate (AFX)
2017	212.73	146.4	179.565	79.15	333.71
2018	210.79	154.82	182.805	77.64	361.29
2019	227.19	145.45	186.32	94.53	360.06
2020	223.69	147.77	185.73	68.17	380.26
2021	248.95	166.47	207.71	39.68	403.58
2022	664.81	181.01	422.91	56.99	423.72
2023	1017.91	430.71	724.31	65.23	635.24
2024	1365.205	710.9133	1038.059	50.80	1361.30

Sources: https://www.macrotrends.net/1369/crude-oil-price-history-chart/; https://www.exchangerates.org.uk/USD-NGN-spot-exchange-rates-history-2024.html and E-library, National Bureau of Statistics (nigerianstat.gov.ng).

Table 2 presents the raw data, including WCP, AFX, and the average prices of AGO and PMS. The regression output indicates a high coefficient of determination (R^2=0.832), suggesting that approximately 83.2% of the variation in average pump prices can be explained by changes in FX rates and global oil prices.

Table 3a. Estimated Results of Effect of Fuel Importation and World Crude Price on Pump Price

Variable	Parameter Estimates
Average FX rate (AFX)	1.367** [0.007]
World Crude Oil Average Price (WCP)	-0.027 [0.961]
Constant	-1.122 [0.966]
R^2	0.832
Adjusted R^2	0.765

1. Model: Dependent variable = Ln (Average Pump Price);
2. Standard errors in brackets are robust to heteroskedasticity and serial correlation
3. * p < 0.05, ** p < 0.01, *** p < 0.001; Statistics of the first stage

Source: Authors.

The model summary shows a correlation coefficient (R) = 0.912 and R Square (R^2) = 0.832 indicating a strong positive relation between the dependent variable (AP) and the predictors variables (AFX and WCP). A large proportion of variation (83.2%) in the dependent variable is explained by the predictor variables. Generally, a 91.2% increase in the pump is associated with changes in global crude price and FX.

Table 3b. ANOVA of the Effect of Fuel Importation and World Crude Price on Pump Price

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.555	2	.277	12.380	.012[b]
	Residual	.112	5	.022		
	Total	.667	7			

a. Dependent Variable: AP
b. Predictors: (Constant), WCP, AFX

The analysis reveals a statistically significant and positive relationship between pump prices and the FX rate. Specifically, the regression coefficient for AFX is 1.367 (p < 0.01), indicating that a 100% increase in the exchange rate is associated with a 136.7% increase in pump prices. Conversely, the world crude oil price has a statistically insignificant coefficient (-0.027, p > 0.05), suggesting that pump prices in Nigeria are less sensitive to global oil prices than to exchange rate movements. The regression coefficients determine the significance of the predictor variables to the regression model and measure the average functional relationship with the dependent variable. The coefficients of regression are -0.027 at P value > 0.05 and 1.367 at P value < 0.05 for the predictor variables of WCP and AFX respectively. This shows only the predictor variable of AFX is statistically significant to the regression model. Whereas the changes in petroleum pump prices are significantly associated with variations in FX, the variation in world crude price does not significantly explain the variations in petroleum pump prices. Every 100% change in the FX rate leads to a 136.7% change in petroleum pump price but variations in world crude price do not have a significant effect on pump price in Nigeria. In other words, there is an elastic relationship between AP and FX. The regression model (eqn_1) is estimated thus:

$$LnAP = -1.122 - 0.027LnWCP + 1.367LnAFX + 0.14966 \quad (12)$$

The statistical significance of the model is confirmed by the ANOVA test ($F = 12.380$, $p = 0.012$), validating the robustness of the regression results. This finding implies that Nigeria's dependence on imported refined petroleum products—financed through foreign currency—exerts greater influence on domestic fuel prices than changes in crude oil benchmarks. It underscores the vulnerability of the fuel pricing system to macroeconomic pressures stemming from currency depreciation.

4.4 Pump Price Effects on the Cost of Living

Petroleum Product distribution agility is a strategy for making petroleum products consistently available to consumers at affordable prices bearing in mind the economic consequence of high prices and the resultant effect on cost of living. The petroleum products significantly AGO and PMS are integral to economic growth and productivity in Nigeria. Being a major source of energy for industrial operation, commerce, business logistics, and transportation, they represent up to 70% of the cost price of goods and services in the country, significantly influencing end customer prices.

Table 4. CPI, PMS, and AGO Price for the Period of 2023 to 2024.

Year	Month	Composite Consumer Price Index (CCPI)	PMS Average Price	AGO Average Price	PMS and AGO Average Price (AP)
2023	January	508.7	257.12	828.82	797.32
	February	517.4	263.76	836.91	809.04
	March	527.0	545.83	842.51	957.67
	April	537.0	254.06	842.16	816.61
	May	547.5	238.11	844.28	814.94
	June	559.1	545.83	815.83	960.38
	July	575.3	600.35	794.48	985.07
	August	593.6	626.70	854.32	1037.31
	September	606.0	626.21	890.80	1061.50
	October	616.5	630.63	1004.98	1126.05
	November	629.4	648.93	801.09	1039.71
	December	643.8	671.86	1126.69	1221.18
2024	January	660.8	668.30	1153.01	1241.06
	February	681.4	679.36	1257.06	1308.91
	March	701.9	696.79	1341.16	1369.93
	April	718	701.24	1415.06	1417.15
	May	733.4	769.62	1403.96	1453.49
	June	750.3	750.17	1462.98	1481.73

Source: E-library, National Bureau of Statistics (nigerianstat.gov.ng).

The research through a regression model sought to empirically determine the effect of petroleum pump prices on the cost-of-living in Nigeria. Research data presented in Table 3 consists of PMS and AGO prices and CIP for the periods of January 2023 to June 2024. The CPI is a widely acknowledged economic instrument for measuring inflation and the cost of living [64]. It is a crucial metric that measures the rate of change in prices of goods and services, providing insight into the inflation rate in a country over a specific period [65]. Given the central role of petroleum products in Nigeria's economy, changes in their prices are expected to have broad inflationary effects. This study investigates the relationship between pump prices and the Composite Consumer Price Index (CCPI), a proxy for the cost of living. Using monthly data from January 2023 to June 2024, a log-linear regression model was estimated, with CCPI as the dependent variable and PMS and AGO prices as explanatory variables. The results, summarized in Table 5, show that both PMS and AGO prices significantly influence CCPI, with coefficients of 0.120 and 0.367 respectively ($p < 0.001$). This means a 1% increase in PMS or AGO prices results in a 0.12% and 0.37% rise in the CCPI, respectively. The regression analysis consists of correlation, Analysis of Variance (ANOVA), and test of coefficients. The panel data result is presented as follows.

Table 5. Estimated Results of Effect of Pump Price on Cost of Living

Variable	Parameter Estimates
PMS Average Price (PMS)	0.120*** [0.000]
AGO Average Price (AGO)	.367*** [0.000]
Constant	1.359*** [0.000]
R^2	0.920
Adjusted R^2	0.910

1. Model: Dependent variable = Ln (Composite Consumer Price Index) (CCPI).
2. Standard errors in brackets are robust to heteroskedasticity and serial correlation
3. * p < 0.05, ** p < 0.01, *** p < 0.001; Statistics of the first stage

Source: Authors.

The model summary shows a correlation Coefficient of R = 0.959 and $R^2 = 0.920$. This indicates a strong positive correlation between the dependent variable and explanatory variables. And that a large portion of variation (92%) in the dependent variable is explained by the predictor variables.

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.046	2	.023	86.670	<.001[b]
	Residual	.004	15	.000		
	Total	.050	17			

a. Dependent Variable: CCPI
b. Predictors: (Constant), AGO, PMS

The ANOVA result shows F-ration = 86.670 and P value 0.000 < 0.05 indicating alongside $R^2 = 0.920$ that the overall regression is statistically significant. The regression model is a good fit for the response and explanatory variables. The ANOVA test supports the model's validity, with an F-statistic of 86.670 and p-value < 0.001, indicating strong statistical significance. The coefficients determine the significance of the explanatory variables to the regression model and measure the degree of change in the response variable for a unit change in the explanatory variables. The coefficient of PMS = 0.120 and AGO = 0. 367 is significant at P value < 0.05 respectively. This shows the explanatory variables are statistically significant to the regression model. There exists a statistically significant relationship between the response and explanatory variables. The prices of PMS and AGO contribute significantly to variation in CCPI in the country. The regression model is estimated thus:

$$LnCCPI = 1.359 + 0.120LnPMS + 0.367LnAGO + 0.01634 \quad (13)$$

These findings demonstrate that fuel price inflation directly contributes to higher living costs. As petroleum products form a critical input in transportation, manufacturing, and power generation, any increase in their prices translates to higher costs of goods and services across the economy.

4.5 Environmental Implications of the Volumes of Zonal Distribution of Petroleum Products by Road

Tables 6 and 7 present the zonal product demand consumption for the period of 2017 to 2019. The data is a summation of product trucks out of the various states in the zones. In the year 2017, the Southwest zone records the highest volume (litres) of product consumption 8.4 billion with PMS 5.6 billion having the highest volume of product consumption. North East has the lowest volume of product consumption 1.4 billion with PMS 1.3 billion having the highest volume. In 2018, North Central topped the South West in recording the highest volume of total product consumption, 8.1 billion. This is attributed high volume of HHK consumption, 598 billion recorded for the year. This is followed by North West at 4.8 billion with PMS having the highest Volume litre, 4.8 million. South East 2.4 billion recorded the lowest volume for the year. In 2019 South West recorded the highest volume of product consumption, 9.2 billion with PMS, 6.2 billion having the highest consumption volume. This is followed by North Central's 4.6 billion volume consumption. The lowest volume consumption, 1.6 billion is recorded by North East with PMS 1.4 billion having the highest volume consumption.

Table 6. Zonal Product Consumption Distribution

YEAR	ZONES	PMS (in litres)	AGO (in litres)	HHK (in litres)	ATK (in litres)	`Total
2017	North Central	3,691,407,933.00	741,988,403.00	146,825,253.00	51,795,857.00	4,632,017,446.00
	North East	1,278,039,135.00	149,389,664.00	22,988,392.00	4,098,000.00	1,454,515,191.00
	North West	2,972,409,488.00	612,700,738.00	125,258,405.00	21,193,452.00	3,731,562,083.00
	South East	2,071,581,057.00	289,074,284.00	86,290,094.00	1,441,957.00	2,448,387,392.00
	South South	2,738,641,818.00	793,176,812.00	291,474,858.00	23,401,815.00	3,846,695,303.00
	South West	5,605,445,252.00	2,161,772,453.00	271,553,849.00	452,676,080.00	8,491,447,634.00
2018	North Central	5,549,484,793.00	1,820,975,392.00	112,661,763.00	598,841,434.00	8,081,963,382.00
	North East	2,027,655,990.00	315,947,617.00	49,520,480.00	105,199,066.00	2,498,323,153.00
	North West	3,762,393,346.00	816,413,507.00	183,179,931.00	48,794,805.00	4,810,781,589.00
	South East	2,110,507,203.00	257,537,423.00	74,640,731.00	6,223,456.00	2,448,908,813.00
	South South	2,683,737,109.00	556,090,394.00	145,635,694.00	9,337,956.00	3,394,801,153.00
	South West	3,333,667,598.00	816,326,417.00	54,221,151.00	5,333,442.00	4,209,548,608.00
2019	North Central	3,679,186,315.00	789,468,110.00	42,839,755.00	131,067,628.00	4,642,561,808.00
	North East	1,400,981,849.00	222,818,588.00	5,267,391.00	8,791,534.00	1,637,859,362.00
	North West	3,657,426,578.00	703,467,601.00	22,120,623.00	47,393,553.00	4,430,408,355.00
	South East	2,304,126,397.00	342,650,788.00	42,094,973.00	22,209,171.00	2,711,081,329.00
	South South	3,294,944,574.00	987,834,262.00	73,670,756.00	53,562,214.00	4,410,011,806.00
	South West	6,248,298,823.00	2,112,621,926.00	84,222,091.00	785,247,012.00	9,230,389,852.00

Source: E-library, National Bureau of Statistics (nigerianstat.gov.ng).

The analysis of petroleum product distribution by road in Nigeria from 2017-2019 reveals significant zonal disparities in transportation volumes, which serve as a proxy for environmental impact through associated emissions. Using Python's pandas for data analysis, key patterns emerge in terms of zonal distribution trends. South West dominated transportation volumes with 8.89 billion liters in 2017, accounting for 34.4% of the national total. The differential in 2019 was not quite high with the same region having a volume of 9.23 billion liters, which is 38.2 % of the national share. North Central showed volatile patterns with a 58% increase from 2017-2018 followed by a 42% drop in 2019. However, the South East region exhibited the strongest growth trend with a 0.87 correlation coefficient between year and volume which happened to be the highest among zones.

Table 7. Cumulative Zonal Product Consumption Distribution from 2017-2019

ZONES	PMS	AGO	HHK	ATK	TOTAL VOL. (LTRS)
North Central	12,920,079,041	3,353,143,905	302,326,771	789,693,919	17,365,243,636
North East	4,707,675,974	688,155,869	77,182,263	118,190,600	5,590,698,706
North West	10,393,228,412	2,132,581,846	330,658,959	117,881,810	12,974,350,027
South East	6,486,217,657	889,262,495	203,625,798	29,055,584	7,608,378,534
South- South	8,719,323,501	2,337,101,468	510,781,308	86,763,985	11,651,511,262
South West	15,187,411,673	5,093,723,796	409,997,091	1,232,267,534	21,923,400,094

Source: Authors.

Applying the transportation volume as an emissions proxy, Table 8 shows that the emission trend from 2017 to 2019 was highest along the South West corridors, while that of the North Central was -42% after the 2018 peak. However, the North West region has the lowest mean annual volume of 4.32 billion liters, contributing to 19% of the emission trend within the same period under study. The effect of the terrorist activities in that part of the country appears to have contributed to the low level of economic activities within that region.

Table 8. Emission Trend of Petroleum Products Distribution by Road

Zone	Mean Annual Volume	Emission Trend (2017-2019)
South West	7.31 billion liters	+38%
North Central	5.79 billion liters	-42% (after 2018 peak)
North West	4.32 billion liters	+19%

Source: Authors.

In a nutshell, the following corridor represents key environmental hotspots occasioned by the following reasons: Lagos-Ibadan corridor (South West) with sustained high volumes, Abuja-Lokoja axis (North Central) due to volatile but large transports and Port Harcourt-Aba route (South-South) arising from the

441 million liter increase. In addition, in terms of variability, South West showed the highest standard deviation (2.71 billion liters) indicating unstable transportation patterns. Concerning consumption growth, 4/6 zones showed positive volume-year correlations, namely: South East: +0.87, South-South: +0.5, North West: +0.64, and North East: +0.16. This analysis suggests road transportation of petroleum products creates spatially uneven environmental pressures, with the South West remaining the primary emissions hotspot despite improvements in North Central regions after 2018. The methodology used volume as a direct emissions proxy, which could be refined with actual vehicle emission factors in future studies. Further analytical computations using COPERT estimate emissions based on fuel type and volume, vehicle type (tanker trucks, distance traveled, and emission factors (kg CO_2/litre, etc.) are shown in Table 9. From computational assumptions, each liter of diesel (AGO) combusted emits approximately 2.7 kg CO_2 and the tanker trucks in Nigeria are typically diesel-powered, the following statistics in Table 9 gives the zone-by-zone CO_2 emissions from tanker fuel consumption alone. The South West's highest distribution volume of 21.9 billion liters has the highest emissions, spill risk, accident probability, and infrastructure stress. Major urban centers (e.g., Lagos) face compounded air quality and congestion issues. The North Central, North West, and South-South have high volumes ranging from 11.6 to 17.4 billion liters and by implication significant emissions and environmental risks, especially along major transport corridors. South-South faces additional risk due to proximity to oil production and sensitive ecosystems. However, the South East and the North East experienced lower volumes (5.6–7.6 billion liters) and thus lower emissions and risk frequency, but potentially higher impact per incident due to less robust emergency response and infrastructure.

Table 9. Estimated Truck CO_2 (tonnes) and Environmental Implications

Zone	Total Volume (Litres)	Estimated Truck CO_2 (tonnes)	Environmental Risks
South West	21,923,400,094	13,753,073	Highest emissions, spills, accidents, air/road stress
North Central	17,365,243,636	9,064,489	High emissions, spill/accident risk, road degradation
North West	12,974,350,027	5,758,071	High emissions, spill/accident risk
South- South	11,651,511,262	6,309,174	High emissions, sensitive ecosystems, compounded pollution
South East	7,608,378,534	2,400,988	Moderate emissions, less frequent but potentially severe
North East	5,590,698,706	3,507,179	Relatively high emissions, spills, accidents, air/road stress

Source: Authors. CO_2 Estimations are done using COPERT

In addition, other environmental risks associated with the petroleum products distribution by road include: spill risk: higher volume and frequency of transport which translate to a higher probability of spills/leaks, and road accidents as a result of more tanker movements with corresponding increased accident/fire risk, air pollution rising from more truck trips and more Nitrous Oxide, Particulate Matter, and Volatile Organic Carbon emissions in addition to road degradation such as road wear and increasing maintenance needs. To boost agility in petroleum distribution in Nigeria, emphasis should shift to Pipelines and Rail transportation which would reduce road tanker dependency in high-volume zones. There should be stricter safety/spill regulations, especially in high-risk corridors. Emission control policies should be introduced and enforced in Nigeria to encourage cleaner vehicle fleets and enforce emission standards. Emergency preparedness must be beefed up to improve response capacity in lower-volume and infrastructure-poor zones.

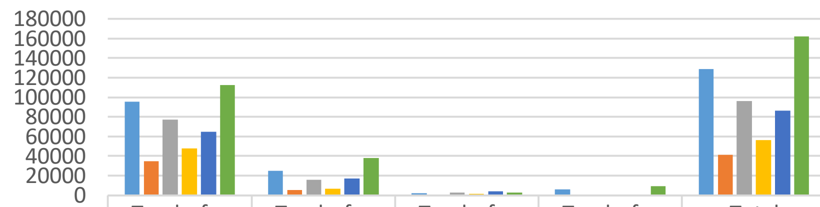
4.6 Environmental Implications of Vehicular Traffic by Zone Using COPERT Computations

As shown in Table 10 and Figure 2, South West has the largest share of total trucks in the country (28.42%), followed by North Central (22.52%) and North West (16.82%). PMS trucks dominate across all zones, accounting for 69–85% of trucks in each zone. The highest proportion is in South East (85.25%), while the lowest is in South West (69.27%). AGO trucks are most prevalent in South West (23.24%) and South-South (20.06%), but less so in South East (11.69%) and North East (12.31%). HHK and ATK trucks make up a small fraction in all zones, with HHK peaking in South-South (4.38%) and ATK in South West (5.62%). North East has the smallest share of total trucks (7.25%), indicating lower distribution activity there. The distribution is highly uneven, with the South West zone accounting for over a quarter of all tanker trucks, and PMS trucks forming the bulk of the fleet in every zone. Other fuel types (AGO, HHK, ATK) represent much smaller shares, and their proportions vary by region.

Table 10. Percentage Distribution of Road Tanker Trucks across Zones

Zone	PMS Trucks %	AGO Trucks %	HHK Trucks %	ATK Trucks %	Total Trucks % of All Zones
North Central	74.40%	19.31%	1.74%	4.55%	22.52%
North East	84.21%	12.31%	1.38%	2.11%	7.25%
North West	80.11%	16.44%	2.55%	0.91%	16.82%
South East	85.25%	11.69%	2.68%	0.38%	9.87%
South-South	74.84%	20.06%	4.38%	0.75%	15.11%
South West	69.27%	23.24%	1.87%	5.62%	28.42%

Source: Authors.



	Trucks for PMS/year	Trucks for AGO/year	Trucks for HHK/year	Trucks for ATK/year	Total Trucks/year
North Central	95704	24838	2239	5850	128631
North East	34872	5097	572	875	41413
North West	76987	15797	2449	873	96106
South East	48046	6587	1508	215	56358
South- South	64588	17312	3784	643	86307
South West	112499	37731	3037	9128	162396

North Central North East North West South East South- South South West

Figure 2. Estimated Number of Road Tanker Vehicles for Petroleum Products Distribution

Computer Programme to Calculate Emissions from Road Transport (COPERT) is a widely used European tool for estimating air pollutant and greenhouse gas emissions from road transport. It calculates emissions based on vehicle numbers, types, fuel consumed, and average activity (e.g., distance driven). For a basic estimation of this study, we use typical COPERT emission factors for heavy-duty diesel trucks (as most Nigerian tankers are diesel-powered). Approximate emission factors per kilometer (from COPERT 5 and literature) are CO_2 (carbon dioxide)-900 g/km, NO_x (nitrogen oxides)-8 g/km, and PM_{10} (particulate matter)-0.25 g/km. Although the actual values depend on truck age, fuel quality, and driving conditions, these are reasonable averages for Africa. Estimating Annual Emissions per Zone assuming that each truck travels 50,000 km/year (typical for fuel distribution trucks in Nigeria). Table 11 summarizes the calculated emissions per geopolitical zone.

Table 11. Calculated Emissions by Geopolitical Zone in Nigeria

Zone	Trucks	CO_2 (tonnes/year)	NO_x (tonnes/year)	PM_{10} (tonnes/year)
North Central	128,631	5,788,395	51,452	1,608
North East	41,413	1,863,585	16,565	518
North West	96,106	4,324,770	38,442	1,202
South East	56,358	2,536,110	22,543	705
South-South	86,307	3,883,815	34,523	1,081
South West	162,396	7,307,820	64,958	2,030

Source: Authors.

Analysing the environmental implications according to greenhouse gas emissions (CO_2), the South West is the largest emitter (>7.3 million tonnes CO_2/year), reflecting its high truck activity and economic role. North East emits the least, correlating with its lower truck numbers and activity. High CO_2 emissions contribute to climate change and global warming. In terms of air quality (NO_x and PM_{10}), NO_x emissions are highest in South West, North Central, and North West. These gases contribute to smog, acid rain, and respiratory issues. PM_{10} emissions (particulate matter) are also highest in South West, posing risks for lung health, especially in urban areas. Zones with more trucks face greater risks of air pollution and related health problems. In terms of zonal disparities, South West and North Central face the greatest environmental burdens from tanker traffic. North East and South East have much lower impacts but may still experience localized pollution near major depots or highways. Therefore, zones with high emissions may need stricter vehicle emission standards, investment in cleaner vehicles, or improved logistics to reduce environmental impact. Monitoring and mitigation (e.g., tree planting, and air quality monitoring) are especially important in high-traffic zones. The environmental burden from tanker trucks is highest in the South West and North Central zones. Air pollution (NO_x, PM_{10}) and greenhouse gas emissions are directly proportional to the number of trucks in each zone. Targeted interventions in high-traffic zones can help mitigate environmental and public health impacts.

5. SUMMARY OF FINDINGS

This study investigated the logistics agility of petroleum product distribution in Nigeria, highlighting the structural and systemic barriers that hinder effective fuel supply and affordability. Despite Nigeria's status as a leading crude oil producer, the country continues to experience persistent fuel supply challenges, largely due to its overwhelming reliance on imported refined products and a failing domestic infrastructure. One of the key observations from the analysis is the chronic underperformance of local refineries. The lack of functional refining capacity has made the country heavily dependent on imported petroleum products, exposing it to FX volatility and fluctuations in global oil prices. Moreover, strategic national refineries remain largely dormant, while private sector initiatives—such as modular refineries—have been slow to materialize due to inadequate investment support and adverse policy environments. In parallel, the nation's distribution infrastructure has deteriorated significantly. Pipelines, which are crucial for cost-effective and secure distribution, have suffered from neglect, vandalism, and sabotage. This has led to overdependence on road-based haulage, which is inefficient for long-distance bulk transport due to high operational costs, logistical delays, and security risks. Between 2017 and 2024, pump prices for both AGO and PMS have experienced steep increases, rising by 542% and 386% respectively. These surges align closely with the progressive elimination of fuel subsidies and worsening exchange rate conditions. Regression analysis confirms that fluctuations in the FX market, more than global crude oil prices, have been the primary driver of pump price increases. A 100% rise in the exchange rate results in an estimated 136.7% increase in fuel prices, highlighting the elasticity of this relationship. The study further reveals that these price increases have had a measurable impact on the cost of living. A statistically significant relationship exists between the prices of PMS and AGO and the Composite Consumer Price Index (CCPI), which reflects inflation and household economic pressure. Fuel price increases have directly contributed to rising costs across sectors reliant on transportation and energy, including logistics, manufacturing, retail, and services. Additionally, several operational inefficiencies and governance issues plague the downstream sector. Corruption, product diversion, smuggling, and subsidy fraud remain pervasive, often orchestrated by powerful interest groups within the fuel supply chain. These practices not only destabilize market operations but also prevent the realization of a transparent, responsive, and equitable fuel distribution system. The North Central, North West, and South-South regions, with distribution volumes ranging from 11.6 to 17.4 billion liters, exhibit correspondingly significant emissions and environmental risks. These risks are spatially concentrated along major transport corridors, highlighting the vulnerability associated with fuel transportation networks. Furthermore, the South-South's proximity to oil production activities and ecologically sensitive areas introduces an additional layer of complexity, potentially amplifying the severity of environmental incidents. Conversely, the South East and North East, with lower distribution volumes (5.6-7.6 billion liters), ostensibly experience reduced emissions and incident frequency. However, the potential for a disproportionately higher impact per incident remains a critical concern, linked to comparatively less developed emergency response capabilities and infrastructural limitations within these regions. In summary, the study underscores the critical need for a logistics framework that prioritizes agility, sustainability, and resilience. Without substantial reform and infrastructure investment, the country will continue to experience fuel crises, economic inefficiencies, and diminished consumer welfare.

6. CONCLUSION

The petroleum sector remains a fundamental pillar of Nigeria's economy, underpinning energy provision, transportation systems, industrial production, and broader developmental objectives. Despite this central role, the distribution of refined petroleum products within the country is plagued by inefficiencies that manifest in frequent supply shortages, elevated pump prices, compromised product quality, and weak infrastructure. These systemic challenges are largely rooted in the failure to build and maintain a robust domestic refining and distribution capacity. Nigeria's prolonged dependence on imported fuel has entrenched vulnerabilities within the supply chain, making it susceptible to external market shocks and FX instability. Furthermore, structural corruption and entrenched vested interests have obstructed reform efforts and undermined policy initiatives intended to revitalize the downstream sector. Consequently, the petroleum value chain remains riddled with inefficiencies that inflate consumer prices and restrict equitable access to fuel. Given that petroleum products account for over 70% of Nigeria's energy consumption, price volatility and supply constraints have had widespread economic repercussions. These include rising inflation, declining purchasing power, increased cost of living, and reduced business competitiveness. Many enterprises, especially small and medium-sized businesses, struggle to absorb the escalating cost of fuel, which in turn dampens production, erodes profit margins, and threatens long-term viability. Households, too, face mounting pressures as energy costs consume a growing share of disposable income, thereby affecting living standards and social well-being. Logistics agility is critical in addressing these challenges. An agile distribution system can deliver refined products to consumers in a timely, cost-effective, and uninterrupted manner, regardless of fluctuations in demand or supply chain disruptions. Agility in this context is driven by logistics processes that are lean, responsive, adaptable, and cost-efficient. Attaining such a system requires a multidimensional approach involving institutional reforms, infrastructure upgrades, and the integration of digital technologies. To achieve a sustainable and resilient petroleum distribution framework, the government must act decisively. This includes revitalizing the country's existing refineries, encouraging private sector investment in local refining projects, and investing in the rehabilitation and expansion of pipeline infrastructure. A shift toward multimodal transportation—incorporating rail and marine logistics—should also be explored to reduce overreliance on road haulage and its associated risks. The environmental hotspots occasioned by the following distribution network were uncovered: Lagos-Ibadan corridor (South West) with sustained high volumes, Abuja-Lokoja axis (North Central) due to volatile but large transports, and Port Harcourt-Aba route (South-South) arising from the 441million liter increase. In addition, in terms of variability, South West showed the highest standard deviation (2.71B liters) indicating unstable transportation patterns. Importantly, transparency and accountability must be restored across the petroleum supply chain. Eradicating corruption, enforcing compliance, and promoting market competition are essential to ensuring that the distribution of fuel supports, rather than undermines, national development goals. Ultimately, aligning petroleum logistics with the principles of agility and sustainability is not merely a technical or operational necessity, it is a strategic imperative. It is central to achieving Nigeria's broader development priorities, including the United Nations Sustainable Development Goals (SDGs), notably SDG 7 (affordable and clean energy), SDG 9 (industry, innovation, and infrastructure), and SDG 13 (climate action). Without this alignment, the country risks prolonged economic stagnation and social hardship in the face of growing energy demands.

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