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Optimization of Liquefied Petroleum Gas (LPG) Distribution in Nigeria

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***Abstract*— As the clamor for cleaner energy sources continues, it becomes imperative to increase the per capita consumption rate of LPG, especially in developing countries like Nigeria, where the dependency on fuelwood for cooking and heating purposes, is very high. To achieve this, efforts must be made to increase the availability of the commodity while reducing its cost. Several factors are responsible for the low per capita consumption rate of LPG in Nigeria, among which are the inadequate distribution network, which not only makes the product unavailable but also expensive when available. This study focused on optimizing the LPG distribution network in fourteen major cities across Nigeria to reduce the overall landing interstate cost of the commodity. This was achieved by the application of an optimization program on existing and two (2) new proposed distribution outlets to minimize the trucking cost using the volume of LPG, distance and time between bulk terminals and various city locations across the country, as variables. The results of the model showed that the LPG loading and distribution from the proposed outlets reduced the cost of trucking of LPG by an average of 25%. This is expected to reduce the landing cost of LPG further and consequently lead to an increase in the per capita consumption of LPG in the country.**

***Index Terms*— Clean energy, LPG distribution, optimization, trucking cost.**

I. Introduction

Liquefied Petroleum Gas (LPG) is a generic term used to describe a mixture of hydrocarbons having three or four carbon atoms. LPG is also known as LP-gas or cylinder gas. It is one of the cleanest fossil fuels available to domestic, commercial, and industrial users.

LPG is a colorless, highly flammable, and odorless gas. It is non-toxic but, if inhaled in considerable quantities over a prolonged period, can have an anesthetic effect. Its physical properties depend on its composition. LPG has a typical specific calorific value of 46.1 MJ/kg. Relative density varies between 0.50-0.52 for propane and 0.56-0.59 for butane. Liquefied petroleum gases are quite safe in comparison with other fuels. For instance, Propane has a high ignition temperature of about 850-950 ^{o}F (450-510 ^{o}C), compared to about 495 ^{o}F (257 ^{o}C) for gasoline [1], making it less likely to ignite spontaneously.

LPG, as marketed in most countries rarely, consists of pure propane or butane. It is mostly a mixture of liquefiable saturated and unsaturated hydrocarbons in the C_3 - C_4 boiling range. The actual gas mixture varies depending on whether the LPG is produced from refinery gases or associated gas, i.e., gas produced with crude oil or coming from a gas field. However, LPG is sold commercially to domestic and industrial customers in three (3) grades [2], namely:

- *LPG - butane/commercial butane* consisting mainly of n-butane, isobutane, and the butylenes.
- *LPG - propane/commercial propane* consisting mainly of propane and propylene. In colder countries such as Norway and Sweden, the LPG market is primarily confined to propane.
- *LPG mixture* consisting of a variable amount of all C_3/ C_4 hydrocarbons.

A. LPG Consumption

LPG consumption in households is increasing throughout the world, especially in the Asia Pacific region, due to the region's vast and widespread population base. Increasing gas imports and rising demand for cleaner fuels, mainly from large emerging economies such as India and China, are expected to fuel global gas consumption soon. Another critical factor for LPG consumption growth is the adverse environmental effect of using biomass and kerosene. Studies have shown that black carbon, which is mostly “soot,” formed in the combustion of wood and fuel such as diesel and kerosene, is the second most important contributor to global climate change [3]. Several other studies have shown that inefficient and traditional utilization of biomass fuel and kerosene have severe health implications such as the risk of low birth weight and pulmonary tuberculosis, productivity, and the environment. According to a report by the International Society for Environmental Epidemiology [4], the risk associated with air pollution from solid fuels accounts for 3 percent of global losses of health risk. Statistically, about 1.3 million people, mostly women, and children die prematurely every year from exposure to indoor air pollution from biomass.

As a result of the human and environmental consequences of using fuelwood and kerosene for domestic applications, there has been a significant increase in LPG demand, mainly in the domestic and commercial sectors, due to the switching of local consumers from biomass to LPG, mostly in India, Indonesia and other developing countries like Nigeria. In Nigeria, for instance, LPG consumption has witnessed a steady growth from 130,000 metric tons in the year 2011, 145,000 metric tons in 2012, 250,000 metric tons in 2013, 500,000 metric tons in 2016, and expected to rise to 2,000,000 metric tons in the coming years [5].

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Despite these improvements in LPG consumption over the years, the consumption capacity still stands at about 15% of the total LPG produced per annum. Consequently, despite the country being rich in Natural gas and also a leading exporter of LPG in Africa, it still has one of the lowest per capita LPG consumption rates in Africa (South Africa, 5.5kg and Morocco, 44kg) with its per capita consumption rate put at 1.8kg, compared to the West African average of 3.5kg [5]. This low consumption rate can be attributed to reports that over 80% of the Nigerian population relies on the use of biomass fuels for cooking [6]. Fuelwood and charcoal have primarily been known to be the significant sources of energy for cooking and heating needs purposes, especially for people in rural areas. At the same time, kerosene is mostly used in urban areas. The preference for biomass fuel and kerosene among primarily poor people in Nigeria is mainly due to factors such as:

- Affordability,
- Availability
- Awareness and Safety.

If these factors can be eliminated, up to 69% of non-users in the country can be converted to using LPG [7]. Other factors, such as cultural beliefs, price, and insufficient infrastructure and logistics challenges [8], have also been identified as some of the factors influencing demand for LPG. The LPG market responds to market changes in the international oil and LNG prices; hence an increase in the global price of LPG affects domestic consumptions as consumers tend to move down the energy chain towards other energy alternatives. However, there are arguments that consumers might continue to make purchases based on the habit, even if prices reduce [9].

B. LPG Domestic Production and Supply

LPG was first produced at the Kaduna refinery and subsequently to all the four refineries in Nigeria. However, with the operational bottlenecks of the refineries and the subsequent establishment of Nigerian Liquefied Natural Gas (NLNG} in 1999, the company was tasked with the production of LPG both for domestic and exportation. Hence it is the major supplier of LPG to the Nigerian domestic market. Manufacture and supply of LPG are basically from Gas processing, importation, and oil refineries. The bulk of this production comes from gas processing from major international oil companies and the NLNG, which has been able to stabilize domestic supply in recent times [5]. Production from refineries has been reported to be very low and insignificant compared to other sources [10]. Various other studies have been published for possible and viable sources of LPG production in Nigeria. LPG production from flare gas outlets across the country is both technically and economically feasible [11] – [13].

C. LPG Safety

There is usually a great feeling of insecurity concerning LPG safety issues. A fear about explosions is a concern raised by many people about hazards and indoor air pollution effects. This perception has also contributed to the low consumption rate of LPG within the country as most people see the LPG as a highly risky source of energy; hence, they do not use it even when it is readily available. These assertions are not far from the truth as there have been several fire incidents resulting from the use of LPG. Amongst the factors responsible for these fire incidents associated with the use of LPG include:

- Use of sub-standard LPG accessories
- Over pressurizing of gas cylinders
- Lack of adequate and regular inspection and maintenance of containment devices and accessories.

To prevent these fire accidents, there is a need for more enlightenment of the citizens, especially in the rural areas. This, along with all the stakeholders, resolve to stamp out substandard LPG accessories that will help in improving safety.

LPG leak detection devices have been developed to reduce the occurrence of fire outbreak during leakages. One of such methods is a proprietary device designed by using sudden pressure drop and rise in gas concentration to set off an alarm system, which can enable a manual or automatic shutdown of the gas supply. Gas leak detection devices have also been designed to shut down the supply of gas in the event of a leak, thereby preventing the explosion [14]. The causes of explosions emanating from gas leaks as a result of structural failure – be it due to creep, fatigue, fire-induced, or other forms of accidental jeopardy, have been reported in the literature [15],[16]. The Safe handling practices of LPG storage tanks and cylinders have also been widely reported [17]-[21].

D. LPG Distribution in Nigeria

Liquefied petroleum gas exists either as a gas (vapor) or liquid when it is under a modest amount of pressure in gas bottles, cylinders, tanks, and larger LPG storage vessels. Given that gaseous LPG has a volume 270 times that of liquid LPG, it is almost always transported in its more compact liquid state. Liquefied petroleum gas can be conveyed in many ways, including by ship, rail, tanker trucks, intermodal tanks, cylinder trucks, pipelines, and local gas reticulation systems [22]. Liquefied petroleum gas pipelines are typically employed between gas fields and storage terminals. The prohibitive expense involved in building pipelines makes them rare for LPG transportation.

LPG intra-state or inter-state distribution in Nigeria is mainly by road, with the use of Bridger or Bobtail trucks. The biggest challenge facing the LPG sector in Nigeria is distribution logistics [5]. The inadequate distribution facilities ranging from small low draft vessels, channel draft restrictions, scarce receiving terminals, inadequate transportation infrastructure, insufficient cylinder manufacturing plant, inadequate secondary bulk storage facilities [23] among other challenges, have hampered the smooth distribution and as a result, contributed to an increase in the landing cost of the commodity in the country.

Currently, the leading producer of LPG in Nigeria is Nigeria Liquefied Natural gas (NLNG) in its bonny plant.

After production in Bonny, the LPG is transported to Lagos, where the operational storage facilities are located. From this storage terminal, the haulage tankers from different parts of the country will load and supply to the dispensing stations across the country. This movement of the commodity from Finima, Bonny (Rivers State) to Atlas Cove in Lagos for storage before distribution to other parts of the country, creates a bottleneck, which makes LPG landing cost expensive. Also, the imported LPG volumes are discharged at the Lagos facility, from where it is distributed. Although there are LPG storage facilities in the coastal cities of Port Harcourt and Calabar, the facility in Port Harcourt was only commissioned recently. At the same time, the facility in Calabar is barely functional. It remains to be seen whether these facilities would be fully operational in the coming years. Fig.1 shows the current LPG distribution network in Nigeria, with a single functional distribution outlet in Lagos to all parts of the country. The shaded areas on the map are the locations of the three (3) refineries were very little LPG is produced.

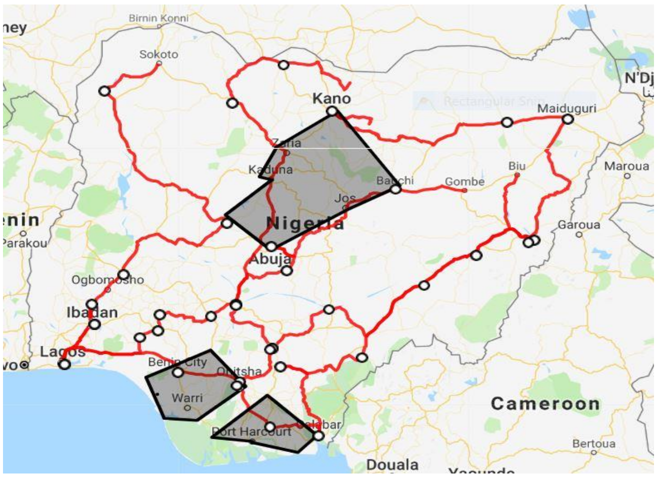

Fig.1. Current Distribution Network of LPG in Nigeria

This study aims to develop a new cost-effective distribution network for the inland distribution of LPG in Nigeria, using a minimization routine. The proposed storage facilities at Finima and Calabar will serve as distribution outlets to end-users. This study leverages the already existing platforms and jetty presently available at these proposed locations hence eliminating the cost of building new structures that would significantly increase the cost of the project. This study will also develop a model, which will be used to determine the minimum price of trucking LPG across the selected cities. This model will then be used to determine if the proposed distribution channels will be cost-effective when compared with the existing distribution channel. Emphasis is on fourteen (14) major cities across the country.

The optimization model development is aimed at reducing the landing cost of LPG across the country, thus contributing significantly to the increase in the per capita consumption of LPG. Asides making LPG readily available and at a reduced cost in Nigeria, there will also be a reduction in the environmental pollution caused by the inefficient use of biomass as a primary source of cooking energy.

II. Model Development

To fully optimize the distribution of LPG in-country, two distribution channels are proposed in Port Harcourt and Calabar, which will leverage already existing structures, thereby reducing the cost of setting up new avenues. The proposed distribution channels and the existing one in Lagos were evaluated using a non-linear optimization routine to determine the optimal distribution channel. In doing this, the following parameters were assessed:

- Time taken to transport LPG from Atlas cove to the selected States.
- Distance between Atlas cove and the selected States
- The unit cost of trucking LPG to the states
- The LPG truck volume.

Using data from Table A1 of Appendix A, an optimization model was proposed. The model is of the form:

Minimize

$$C = k_1x_1 + k_2x_2 + k_3x_3 \tag{1}$$

Where C is the trucking cost, x_1, x_2, *and* x_3 are the independent variable (distance (km), time (hour), and volume tons).

In the first instance, a non-linear optimization program was used to model the data, but it failed to converge, and as such, no solution was obtained. This non-convergence is because the dependent and independent variables are linearly related. Hence a linear program of the form in Eq. 2 was developed.

Minimize

$$C = k_1x_1 + k_2x_2 + k_3x_3 + \cdots + k_nx_n + 0s_1 + 0s_2 + 0s_3 + \cdots + 0s_n \tag{2}$$

Subject to:

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \cdots + a_{1n}x_n + s_1 &= b_1 \\ a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \cdots + a_{2n}x_n + s_2 &= b_2 \\ a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + \cdots + a_{3n}x_n + s_3 &= b_3 \\ \\ a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 + \cdots + a_{mn}x_n + s_n &= b_n \end{aligned} \tag{3}$$

For

$$k_i, x_i > 0, where\ i = 1, 2, 3,$$

Where ki is the coefficient of the variables, xi. Si is slack variables with coefficient zero (0). bi are constants. Reducing Eq 2 to Eq.3, the model becomes:

Minimize

$$C = k_1x_1 + k_2x_2 + k_3x_3 + 0s_1 + 0s_2 + 0s_3 \tag{4}$$

Subject to

$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + s_1 = b_1$$
$$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + s_2 = b_2$$
$$a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + s_3 = b_3$$

for

$$k_i, x_i > 0, where\ i = 1, 2, 3, \dots, n$$

where

k is the k_i (i = 1,2,3)

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$$

and

$$b = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}, s$$

Assuming a typical LPG truck carries 21 metric tons of LPG, and using the data in Table A1, of Appendix A, then;

$$A = \begin{bmatrix} 1782 & 29.0 & 21 \\ 1144 & 16.08 & 21 \\ 1609 & 22.1 & 21 \end{bmatrix}$$

and

$$b = \begin{bmatrix} 750000 \\ 700000 \\ 720000 \end{bmatrix}$$

A MATLAB program was used to solve the linear programming model of Eq.3 using the Simplex Method. The solution to the model was obtained as:

$$C = 30698x_3 + 4841x_2 - 19.66x_1 \qquad (5)$$

Where

x_3 is the volume of LPG (metric tons) transported, the unit of the coefficient is cost per metric ton transported

x_2 is the time (hour) traveled, the unit of the coefficient is cost per hour traveled

x_1 is the distance (km) from source to destination, the unit of the coefficient is cost per km traveled.

For this study, some factors which can affect the time of travel were kept constant during the optimization process. These factors are:

- The conditions of the road.
- The Nature and condition of the trucks.
- Stoppages along the road due to gridlocks and other factors

III. Results and Discussion

The result of the optimization routine is presented in Table 1. From the results, the minimization routine has reduced the trucking costs of LPG using specific distribution outlets, as against the current trend of using only the Lagos distribution outlet. For example, the current trucking cost for moving LPG from Lagos to Akure is one hundred and thirty-five thousand naira (₦135,000). However, the result from the model showed that this could be reduced to ninety-three thousand, one hundred and three-naira forty-five kobo (₦93,103.45). Also, the proposed distribution routes were subjected to the optimization model. The results from the model showed that distributing LPG from the proposed Port Harcourt channel to Kano and Sokoto is more cost-effective with a cost reduction of 24%, respectively, than transporting LPG from Lagos as is currently the case. Also, it is more profitable to distribute LPG from Calabar to Gombe and Maiduguri, with an average cost reduction of 28% and 25%, respectively, than from Lagos.

The results also showed the most cost-effective distribution outlets for LPG transportation to specific cities across the country. For instance, Figs 2 and 3 show the preferred cities for LPG distribution from the proposed Calabar and Port Harcourt distribution outlets, respectively. It should be noted that LPG distribution to the town of Enugu, can either be from the Port Harcourt or the Calabar outlets, due to the similarity in cost of trucking.

Also, the Lagos distribution outlet was more cost-effective for LPG distribution to cities in the southwest region like Lagos (where the current distribution outlet is located), Akure and Ibadan, due to the proximity to the Lagos distribution outlet. The LPG distribution network from the Lagos distribution outlet remains strategic and essential for the distribution of the commodity to cities closer to the Lagos distribution outlet, as shown in Fig 1. Similarly, the delivery from the refineries to cities around them is also vital. Also, two (2) new proposed distribution networks form the Port Harcourt and Calabar outlets, obtained from the optimization model, has been developed. These proposed distribution outlets, together with the Lagos outlet and refineries, will help drive down the delivery cost of LPG across the country. Fig.4 shows the new distribution networks.

Table 1. Optimized and current trucking cost of the selected routes.

Cities	Distance from Lagos (Km)	Current Trucking Cost (₦)	Minimized Cost using Lagos Route (₦)	Distance from Port Harcourt (Km)	Minimized Cost using Port Harcourt Route (₦)	Distance from Calabar (Km)	Minimized Cost using Calabar Route (₦)
Akure	314	135,000	93,103	473	243,000	625	256,500
Awka	501	300,000	285,714	213	214,285	289	240,000
Bauchi	1284	710,000	676,190	915	514,493	829	489,655
Enugu	560	280,000	266,667	226	202,899	259	200,000
Gombe	1291	700,000	666,667	1070	507,246	984	482,758
Ibadan	139	106,000	73,103	594	125,080	625	132,500
Kano	1063	700,000	666,667	1004	507,246	1022	608,695
Maiduguri	1589	720,000	685,714	1363	580,645	1148	514,285
Makurdi	744	550,000	523,809	488	482,456	415	440,000
Owerri	534	350,000	333,333	95	250,000	206	280,000
Port Harcourt	616	400,000	380,952	N/A	N/A	N/A	N/A
Sokoto	1782	750,000	714,285	1233	543,478	1305	652,173
Umuahia	577	360,000	342,857	115	255,319	155	288,000
Uyo	656	500,000	476,190	141	403,225	88	344,827

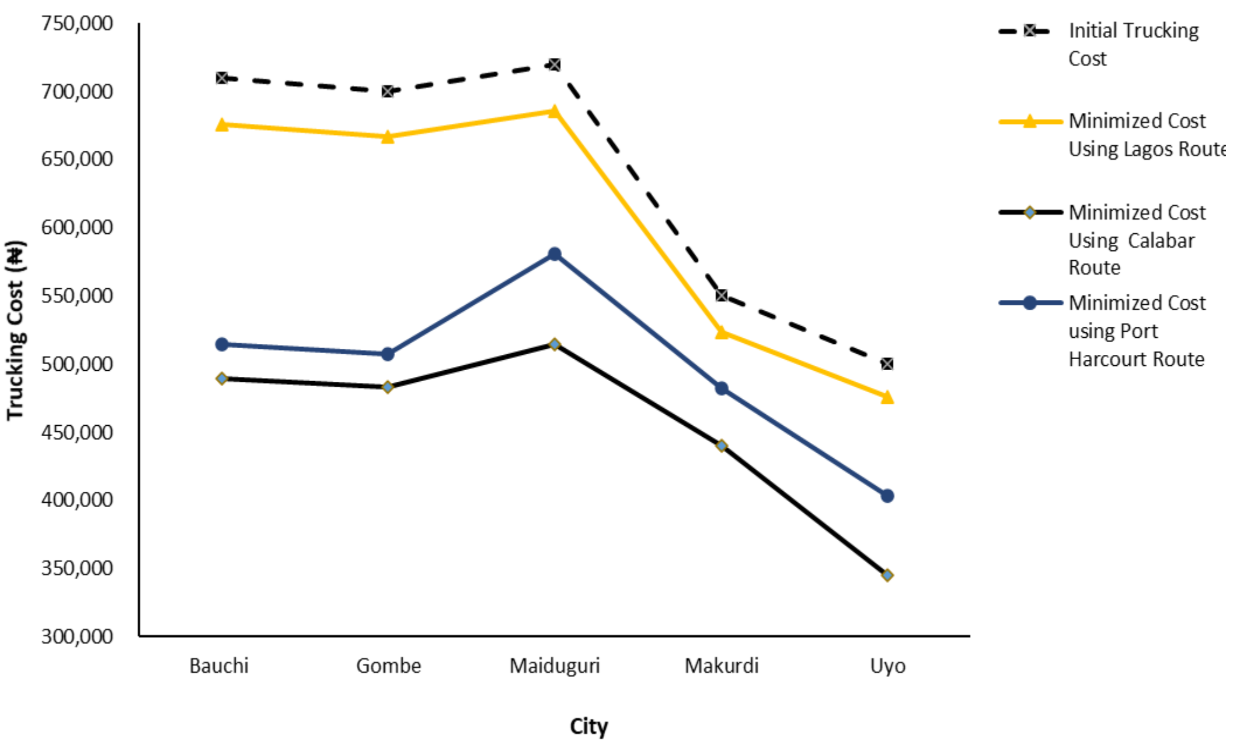

Fig.2. Preferred Cities for Calabar Distribution Outlet

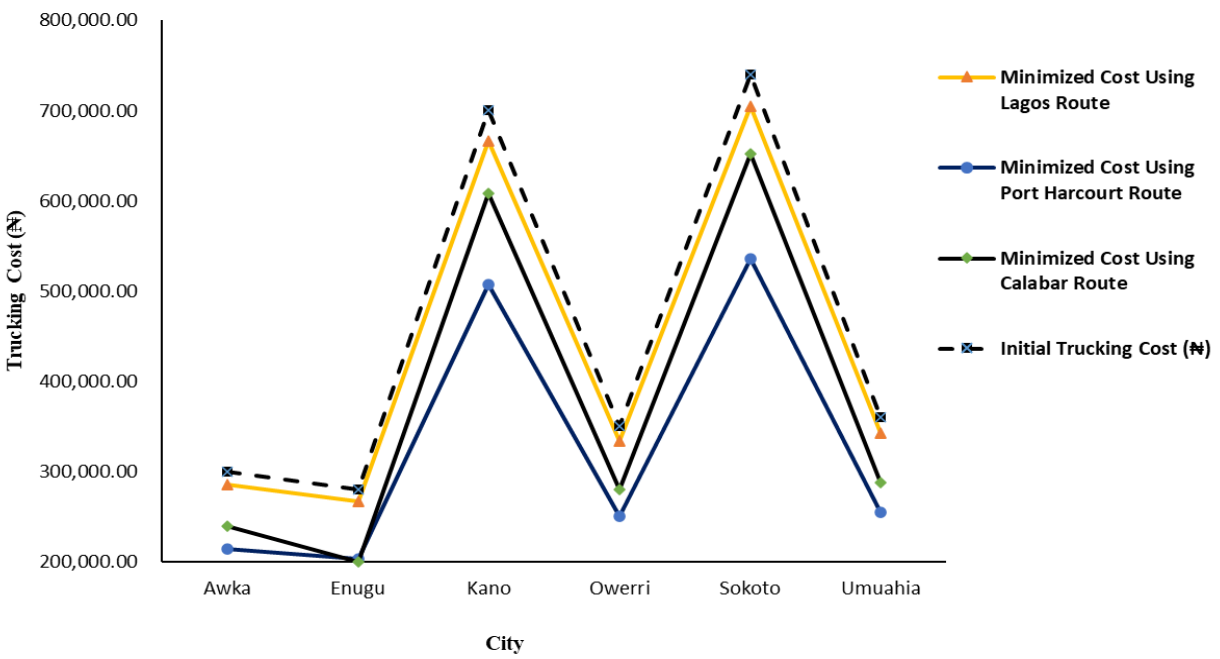

Fig. 3. Preferred Cities for Port Harcourt Distribution Outlet

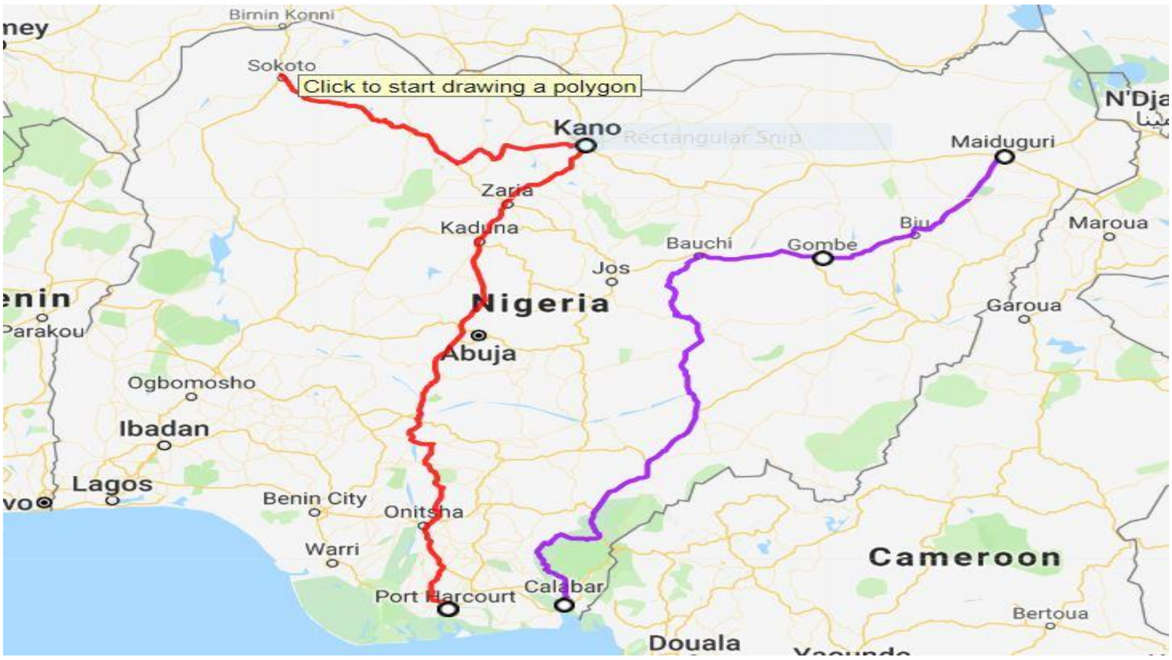

Fig. 4. Proposed distribution network using Port Harcourt and Calabar outlets

IV. Conclusion

This study has developed a new cost-effective distribution network for LPG delivery to cities across Nigeria, using the proposed Port Harcourt and Calabar outlets, in addition to the existing Lagos outlet. The study also revealed that as much as an average of 25% reduction could be made in trucking costs across cities in the country if the proposed Port Harcourt and Calabar outlets are utilized for LPG distribution.

The cost of trucking LPG from the outlets mainly in the southern part of the country, to the cities in the Northern part of the country, is almost double the amount required for trucking the commodity to the towns in the southern part of the country. Consequently, to reduce the trucking cost to cities in the Northern part of Nigeria, the LPG production capacity from the Kaduna refinery should be ramped up to meet the demand of the commodity in that region. The supply from the refinery will bring down the trucking cost and hence the landing cost of LPG in the area., thereby contributing to the increased per capita consumption of the commodity. Alternatively, the proposed distribution outlets in this study should be utilized to reduce the cost of transporting LPG from Lagos to the northern cities of Nigeria.

The cost reductions in this study are for a unit LPG truck delivery. The savings from *x* amount of trucks on a weekly, monthly, or annual delivery basis, can only be imagined.

APPENDIX A

TABLE A1: DATA FOR MODEL DEVELOPMENT.

City	Distance from Lagos (Km)	Time (hrs)	Trucking Cost (₦)
Akure	314	5.00	135,000
Awka	501	7.22	300,000
Bauchi	1284	18.67	710,000
Enugu	560	9.15	280,000
Gombe	1291	18.40	700,000
Ibadan	139	2.50	106,000
Kano	1063	16.08	700,000
Maiduguri	1589	22.10	720,000
Makurdi	744	12.67	550,000
Owerri	534	8.12	350,000
Port Harcour	616	9.32	400,000
Sokoto	1782	29.00	750,000
Umuahia	577	9.38	360,000
Uyo	656	11.18	500,000

Source: Kiakia gas [24].

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