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Nigeria's Natural Gas Utilization and Sustainability of Supply

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Abstract:

The overall aim of this research is to investigate whether Nigeria has enough gas to meet her domestic and export commitments in the next 30 or more years. This study is significant to the Department of Petroleum Resources, DPR, as custodian of oil and gas data and would help the DPR develop a policy plan that will ensure sustainable supply. In this study, Hubbert and Gaussian curve fitting models were used for predicting natural gas production while Logistic and Linear curve fitting models were used for predicting natural gas utilization. The case 2 Hubbert Logistic model predicted that a gap between production and utilization would occur in 2027 and natural gas reserves will become exhausted by the year 2150. Result showed that Nigeria may fail to meet its gas commitment without the discovery of new reserves and the development of gas infrastructure

Keywords: Gas utilization, Gas production rate prediction, Gas Utilization rate prediction, Model for gas production forecast, Model for gas utilization forecast

1. Introduction

1.1. Background to the Study

The Nigeria's natural gas reserves was estimated at 187 TCF, but 40% of the reserves will not be available in the short term because they are stranded in the gas caps and therefore not accessible until after the production of oil (DPR, 2008). The available reserves may not meet the outline demand growth. OPEC has already reported about 180 TCF reserves for Nigeria as at January 2015, which indicated that the gas resource to underpin the projected power generation capacity has declined. Meanwhile, the sector is now confronted with unprecedented utilization growth from about 5 bcf/d to about 20 bcf/day in 2012 (NGMP, 2014). More growth is envisaged in the next decade. The only challenge is how to maintain current portfolio with available and affordable supply. Since there is no evidence of gas exploration currently in Nigeria, it is necessary to determine how long the current reserves would last based on projected utilization.

The overall aim of this research is to ensure that Nigeria as a nation has enough gas to meet her domestic and export commitments in the next 30 or more years. The research has the following objectives:

- Develop scenarios for gas production rate till exhaustion of present gas reserve using Hubbert logistic and Gaussian models and compare and contrast the models' forecasts
- Develop scenarios for gas utilization up to 2050 using logistic and linear models and compare and contrast the models' forecasts
- Compare gas utilization forecasts from the logistic and linear models with gas production forecasts from Hubbert logistic and Gaussian model
- Highlight and discuss critical points like the year of peak production, the year of intersection of the gas production and utilization curves, and the time when projected gas utilization will exceed production rates

This study used gas production, utilization and Nigerian population data from 1957 to 2004 for the modeling of natural gas production and utilization. Gas utilization represents gas demand while gas production represents gas supply. We assumed that the entire reserves will be recovered through production. The assumption is better because it is easier to apply recovery factor on the total calculation to get the recoverable values. There are different methods for natural gas production and utilization forecasting but this study is limited to curve fitting approach.

Literatures were reviewed on the efforts Nigerian government has so far made in achieving its aspirations for domestic economy as an offshoot of national gas supply and pricing policy 2008. Also reviewed were the previous research and studies on natural gas production forecast and utilization.

This study is important for the following reasons:

- The gas business is different from oil because the gas contract is bound by long time strictly defined obligations that guarantees the producer minimum revenue inflows and security of supply to the off takers. Nigeria needs to be sure that there is enough gas for their domestic and export commitments.
- It would offer Nigeria opportunity to invite more investors to the gas sector if there are extra uncommitted gas reserves or proffer timely solution if the study identifies a gap.
- The DPR as the regulatory arm of the Nigerian oil and gas industry will find this study useful. DPR as the custodian of national gas reserves is expected to confirm gas availability in Nigeria.
- This study would be useful for National planning as Nigeria strives to establish itself as a hub for regional and international energy markets.

Investment opportunities are abundant in Nigerian gas sector. Articulated aspirations of government for the sector comprise of creation of new industries, retention of economic value and generation of revenue from gas that will equate that of oil as well as domestic gas market development and, stopping of gas flaring.

Considerable progress was recorded to ensure that these objectives of government are realized. Figure 1 below shows Nigeria's historical gas production and utilization since inception of crude oil production in 1958. Nigeria's gas production has grown from 7.1 Bcf/d in 2008 to 8.4 Bcf/d at the end of 2014 (NNPC, 2014).

It was observed that gas flaring reduced from 26% in 2008 to 12% in 2014. It is expected that gas flaring will be significantly reduced when some of the on-going gas utilization projects are completed

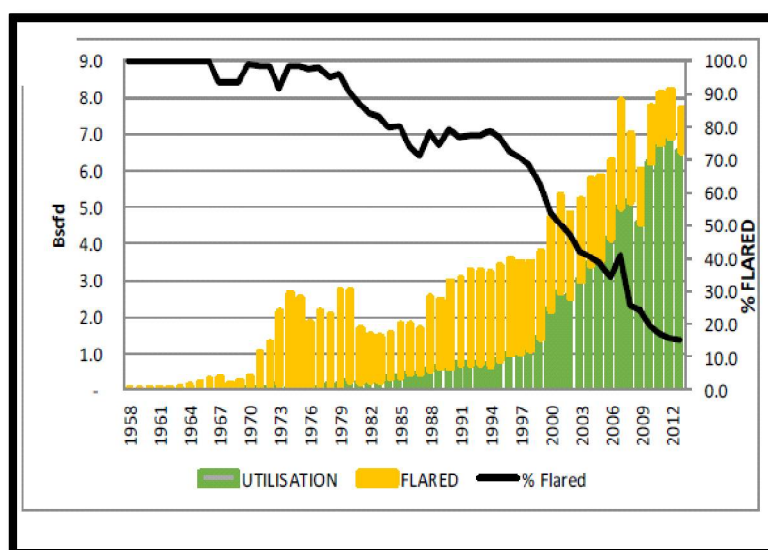


Figure 1: Nigeria's Historical Gas Utilization (NGMP, 2014)

Source: Dr. Nwaozuzu, *Energy Infrastructure 2017*

From the current yearly natural gas production of 3004 Bscf, approximately 11% was flared (DPR' 2017). This was a huge reduction from the 70% flared prior to 1999. The gases that are supposed to be flared were now being directed into gas-based projects for monetization and maximization of economic value to the nation's gas resource. Power sector reforms has also increased domestic gas consumption while gas export that was not in existent before 1999, was also granted attention.

All-inclusive gas utilization Master plan was implemented, wherein LNG and independent power projects (IPP) developments were given priority (Nwaozuzu, 2017). It is expected that LNG export earnings and sufficient domestic power provision from IPPs, will robustly sustain and enlarge economic development and urbanization, increase opportunities for employment in Nigeria, and elevate the general wellbeing. It is expected that Government's efforts towards host community integration into the mainstream of national development and growth would be reinforced.

1.2. Aspiration of Government

Abundance of gas resources in Nigeria, has prompted the Government to see the domestic gas sector development as a good policy plan for achieving 10% per annum GDP growth. Government may have achieved high earnings in LNG exports through tax receipts and equity stake dividends, but Government recognized that apart from economic rent, significant economy improvement may be achieved from the utilization of natural gas in Nigeria and natural gas value addition (NGSPP, 2008).

International markets gas price rise has motivated more export of LNG. This has created a glitch as there is now a considerable shortfall in domestic gas available for utilization (DGSO, 2015).

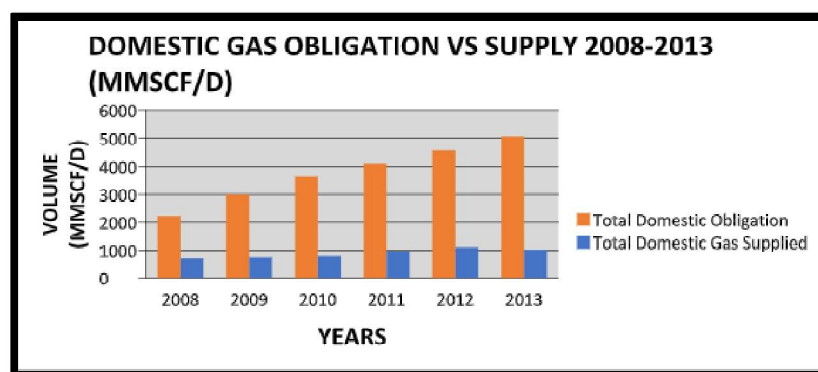


Figure 2: Domestic Gas Obligation vs. Supply 2008 – 2013
Source: (Department of Petroleum Resources (DPR, 2017)

This continuous shortfall will jeopardize the economic aspirations of the Nigeria if unchecked. The natural gas required to sustain the planned National aspiration of GDP growth is huge and far exceed supply. This is because of reform in the power sector and growing demand by the industries like fertilizer and methanol (NGSPP, 2008). The industries that could not compete in countries where the cost of gas is high, have expressed their willingness to relocate to Nigeria. But Nigeria should ensure that gas is available and affordable to avert diversion of investment to nations in competition with Nigeria. Demand growth is expected to translate to a significant reserves and production capacity development requirement. In addition, significant development activity is required to translate the reserves into the required daily production to supply the huge demand. Other challenges in matching the gas supply requirements with growing domestic demand is the price affordable and hence gas pricing. Government is keen in motivating the growth in these sectors. However, timely provision of affordable natural gas is critical to the realizing the government's aspiration for the domestic economy.

Some of the gas-based projects being undertaken in line with Governments aspiration include:

1.2.1. Independent Power Plants (IPP)

Government has encouraged investors including local and international oil companies in Nigeria to invest on IPPs as part of the Power Sector reform. The government believed that Independent Power Projects will improve electricity supply and provide necessary support for economic growth, and it is expected that participating JV/PSC companies would earn additional revenue and boost their social responsibility in the domestic economy.

Under the National Integrated power Project (NIPP), there are ten federal government of Nigeria owned intervention power projects conceived with the aim of improving power generation output so as to close the gap between power demand and supply. The combined capacity is about 5.46GW (Nwaozuzu, 2017). Under the Independent Power project (IPP), these are private sector power stations which are connected to the National Grid. More than sixty (60) licenses were granted to private investors for building of power stations within the country. The combined capacity of the IPPs constructed is about 1.39GW (Nwaozuzu, 2017).

1.2.2. The Liquefied Natural Gas Projects

Nigeria LNG Limited (NLNG) started production from trains 1 & 2 in 1999. Six trains are currently operational. NLNG's plant, in Bonny Island Rivers State, with a production capacity of 22 Million Tonnes Per Annum (MTPA) of LNG, and 5 MTPA of NGLs (LPG and Condensate) from 3.5 Billion cubic feet per day (Bcf/d) of natural gas intake. The NLNG is currently planning to construct the seventh train which will increase the company's capacity to produce 30 MTPA of LNG.

According to NNPC, NLNG's operations had significantly reduced the flaring gas in Nigeria. The company is also currently supplying approximately 40% of the annual domestic consumption of liquefied petroleum gas.

1.2.3. Other LNG Projects

In addition, a 2 train Brass LNG plant and a 4 train Olokola (OK) LNG plant with expected output of 10 and 20 MTPA respectively are at their different stages of development. Brass LNG's shareholding was NNPC with 49%, Eni, Total and ConocoPhillips with 17%. The Brass LNG Front End Engineering and Design (FEED) has suffered several postponements. The project was re-cycled back to pre-front end engineering and design (FEED) in 2014, as a result of ConocoPhillips' divestment from the project and withdrawal of its optimized cascade process, which is the technology planned for use in the construction of the plant. Apart from ConocoPhillips' exit, other issues remain unresolved such as:

- The misalignment between concession expiry dates for the leases and the 20-year gas supply agreement (GSA)
- Upstream funding for gas supply
- Gas supply plan
- GSA issues and impact of PIB

The OK LNG Limited was formed in 2007. The shareholders are NNPC, Shell, Chevron and BG. In 2012, BG Group Plc. withdrew from the project. The other partners, Shell and Chevron pulled out in 2013 due to lack of progress. The OK LNG

project is currently in 'preservation' mode and may be resuscitated at a later date, subject to gas resource availability, project funding and markets for LNG.

1.2.4. The West Africa Gas Pipeline

The West African Gas Pipeline (WAGP) is expected to export gas to Ghana in a 421-mile pipeline from Niger Delta through Lagos Beach terminal in Nigeria. The WAGP is the first of its kind in sub-Saharan Africa. The originally planned pipeline utilization capacity was 200 MMscf/d and projected to steadily increase to approximately 460 MMscf/d by 2026 (Nwaozuzu, 2017). This project is planned to boost the cooperation and economic development in the sub-region in agreement with New Partnership for African Development (NEPAD) (Nwaozuzu, 2017). Presently, the WAGP infrastructure is grossly underutilized, with open access, but not enough gas. However, stakeholders are discussing how the pipeline can be fully utilized to improve the project economics (Nwaozuzu, 2017).

1.2.5. The Tran Saharan Gas Pipeline (TSGP)

The TSGP is a 4401 km pipeline which is expected to export Nigerian gas to Spain through Niger and Algeria. Estimated to have a capacity of thirty billion cubic meter of natural gas, the TSGP will link the Trans-Mediterranean, Maghreb-Europe, Galsi and Medgaz and pipelines. The TSGP is a partnership between Algeria's Sonatrach, the Nigerian National Petroleum Corporation (NNPC), and the Niger National Oil Company. Sonatrach and the NNPC together holds 90% of the shares, while the Niger National Oil Company holds 10%. The TSGP will promote economic co-operation between neighboring countries, and will in due course, will help diversify Nigeria's gas export route. A Tran Saharan gas pipeline is still under consideration. The technical and commercial viability of this project is still being studied by a consultant on behalf of NNPC and Sonatrach.

2. Research Methodology

The research methodology covers research intention, description, sources of data and definition of the methodology used, assumptions and limitation of the research study.

Empirical methods were used to analyze qualitative data for this research. The data collected were secondary data and their sources include: the production and utilization of natural gas data from 1958 to 2004, the domestic gas supply obligation and sectorial gas demand from the DPR, the population of Nigeria from 1967 to 2004 from the World Bank databank, the gas master plan data from the NNPC and gas policies from the Ministry of Petroleum Resources.

Gaussian and Logistic Hubbert curves were generated for the gas production rate and these curves were fitted to the rate of gas production data iteratively. The rate of natural gas production versus time (in year) curve and the cumulative natural gas production versus time (in years) plots were observed as the iterations were being carried out. The optimal points are those points where the curve of rate of natural gas production versus time and the cumulative natural gas production versus time curve generated from the Gaussian and Hubbert equations match those from the actual data. How both curves forecasted the production of natural gas are then compared and contrasted. Logistics and linear models were used to generate utilization of gas curves and these curves were fitted with actual gas utilization data and how both curves modeled the utilization of natural gas data were then compared and contrasted. This is the same approach adopted by Melikoglu (2013). In addition, the rate of production of natural gas and the rate of its utilization were compared and contrasted using the best models

2.1. Application of Curve-Fitting Models

Curve-fitting models are either predictive or descriptive (Höök et al., 2011). According to Brandt (2010), application of curve-fitting models is describable in three main steps as follows:

- Select a mathematical function that can fit the data set
- Fit the curve and improve fit quality by adjusting constraint parameters
- Forecast production trends by extrapolation of the model

With modern software, data are easily fitted with curves and this software rely on numerical methods such as maximum likelihood, least squares and regression to estimate the curve path. How well, the model fits the historical data is usually describable by the goodness-of-fit (This is the R-squared values calculated. R-squared is called Coefficient of Determination and it tells goodness of fit). A high goodness-of-fit indicates that a certain model is suitable for descriptive purposes while for predictive purposes, a high goodness-of-fit entail that the model performs well, but the outcome is not necessarily guaranteed (Anderson and Conder, 2011).

The Goodness-of-fit is calculated as the actual data deviation from the corresponding points on the curve, i.e., the magnitude of error. This value can also be expressed as a coefficient of determination (R^2) in regression analysis whose parameter ranges from 0 to 1, with R^2 values near 1 indicating good fit, while values nearer to 0 shows poor fit to the historical data.

2.2. Identification of Key Factors

It has been established in the literature that the URR affects the performance of curve-fitting models. According to Brandt (2010) earlier studies have also shown that the assumed URR significantly influenced production forecasts that is derived from curve-fitting models.

Another obvious key factor is the shape of the curve which must create a reasonable fit to the underlying time series (Sorrell et al., 2010a). In the study of U.S. oil production, Hubbert observed that the logistic curve fitted the cumulative production data with amazing reliability, and he concluded that the annual production is the first derivative of the curve. Many other curves were later studied and deemed useful for both descriptive and predictive purposes on the topic of fossil fuels (Höök et al., 2011).

The third key factor is the number of production cycles. Initially, most studies used single-cycle models; however, it was observed that due to political, economic and technological causes production curves could undergo several phases, and such phase changes are not captured by only one production cycle (Al-Fattah and Startzman, 1999; Nashawi et al., 2010). Extra production cycles were therefore added to several subsequent studies to improve fitting using multi-cyclic models (Maggio and Cacciola, 2012; Al-Fattah and Startzman, 1999). Anderson and Conder (2011) found out that the number of cycles used for the models influences the results, especially in the event of over-fitting, but only very few studies presented investigated the impact of this factor.

Consequently, the implications of the four different key factors on curve-fitting modeling of fossil fuel production were analyzed namely, URR assumptions, curve shapes used, number of cycles and depletion rate constraints.

This study used Hubert and Gaussian curve fitting models for predicting natural gas production while Logistic and Linear curve fitting models were used for predicting natural gas utilization.

Due to the inherent weaknesses in the curve fitting models and in accordance with the studies such as Laherrere (2000), and Mohr et al.(2011), it is very importance to perform a more comprehensive analysis using several models and curve-fittings instead of relying on just one curve shape; thus the use of multiple scenarios in this study. The key factors discussed above was also very useful for obtaining more consistent forecast results.

Model	Equation for production $q(t)$ or cumulative production $Q(t)$	Fitting parameters	Point of inflection
Hubbert			0.5
Gaussian	$\exp [-]$		0.5
Logistic			0.5
Linear			

Table 1: Selected Common Functions Used In Curve-Fitting Models

2.3. Gas Production Rates Forecasting

Gas production rates were forecasted using Gaussian and Hubbert models.

2.3.1. The Gaussian Curve Forecast

The Gaussian function describes physical events that are very large. The function is continuous and approximates the exact binomial distribution of events. It is represented mathematically below.

Where Q_a is the Ultimate Recovery Resource, which is 187 tcf in this case since we are assuming that all the Nigeria gas resources can be produced in the long term and, s and t_m are the standard deviation and mean of the time. The important curve fitting parameters of the Gaussian model are the mean and standard deviation

2.3.2. The Hubbert Logistic Forecast

The Hubbert Logistic function is used to forecast the growth and decay of fossil fuels. The natural gas production is represented mathematically as The natural gas cumulative production is also represented mathematically as and are the fitting parameter for the Hubbert logistic function

The values of and The Hubbert Logistic function is linearized into the equation shown below When we make plots of versus we hope to get a straight line but this is not the case all the time, like the plot in figure 3.

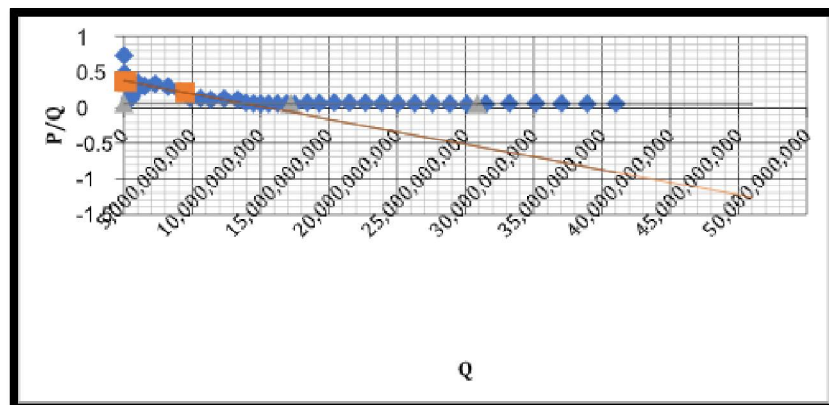


Figure 3: Hubbert Linearization Plot

The plot fits two different straight lines. When the t_0 of the Hubbert Linearization plot is set to zero, we obtain U_0 as the intercept on the U axis. This is shown mathematically below:

The Hubbert linearization plot gave two U_0 . The brown line intercept was 0.3753 and is discussed in this work as Case 1. The green line intercept was 0.06211 and is discussed in this work as Case 2. A third case was assumed, which is the average of the Cases 1 and 2. The two U_0 were averaged to give 0.21873, which is discussed as Case 3.

To get t_{max} which is the year that production of natural peaks, we make t_{max} the subject of the Hubbert logistic function as shown below: is the cumulative production at any year t .

2.4. Gas Utilization Rates Forecasting

Gas Utilization was forecasted using the Logistic and Linear models and this approach adopted was that of Melikoglu (2013). The different approaches were used to forecast natural gas utilization rates up to year 2050.

2.4.1. The Logistic Function Forecast

The logistic function is used to forecast the natural gas utilization and is shown below $U(t)$ is the natural gas utilisation at year t , U_{max} is the maximum attainable natural gas demand per capita in cubic metres, which is estimated to be at 990m^3 for Italy, South Korea and Spain. Turkey aims to achieve this U_{max} in 2023. The same value of 990m^3 was assumed for Nigeria. Further details on U_{max} can be found in the work of (Melikoglu, 2013). Furthermore t_0 and t_{max} are the population in time t and the time where one-half the U_{max} is reached.

The coefficient k of the equation is obtained from the plot below:

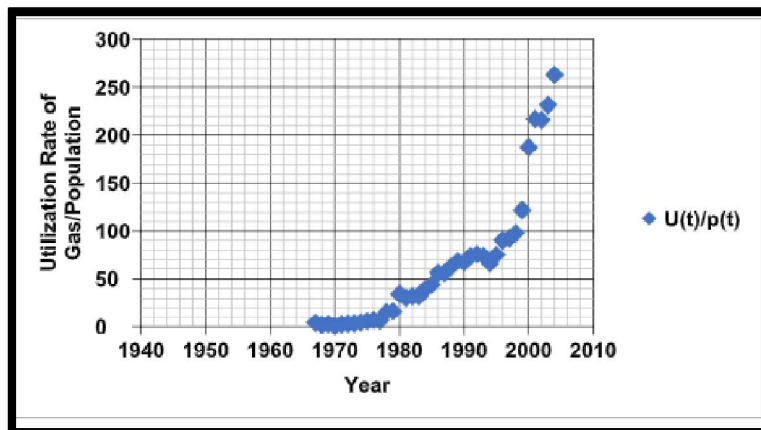


Figure 4: Plot to Obtain Constant for the Logistic Function

A straight line is fitted through the trends in the data. Two trends are observed from Fig 4. The trend line that best fit plot, similarly to the Hubbert Linearization plot to obtain, is the trend line from 1994 to 2004. The values of k and t_{max} were calculated as 0.09232 and year 2015 respectively.

2.4.2. The Linear Model Forecast

The linear model is represented mathematically below is the reference year and it is 1967 for this work, when gas utilisation data was first recorded and U_0 is natural gas demand per capita at the reference year, and b is an unknown coefficient, which was calculated to be 7000 m^3 per capita per year. The meaning of other variables in the equation does not change.

3. Results and Discussion

This chapter reviewed the data collected and presents analysis of the data in line with the objectives of the dissertation.

3.1. Natural Gas Production Forecast

The natural gas production forecasts using the Gaussian and Hubbert Logistic models are discussed below

3.1.1. Gaussian Model

The optimal Gaussian model as shown mathematically below:

The mean and standard deviation for the model is 2035 and 45.5 respectively and the rate of production and cumulative production curves are shown below.

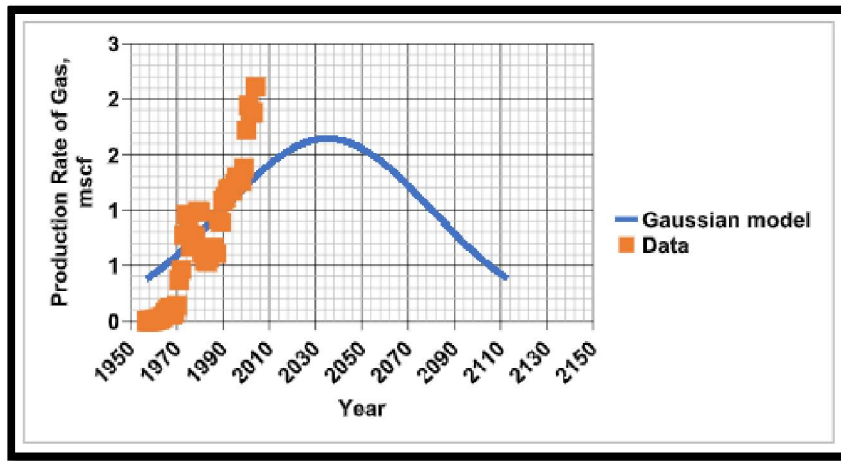


Figure 5: Optimal Gaussian Model for Forecasting Natural Gas Production

The optimal model forecast that production of natural gas will peak in the year 2035 and will be completely exhausted by the year 2113. The coefficient of determination for the production of natural gas production curve in Figure 5 is 65%, while the coefficient of determination of the cumulative gas production is Figure 6 is 72%.

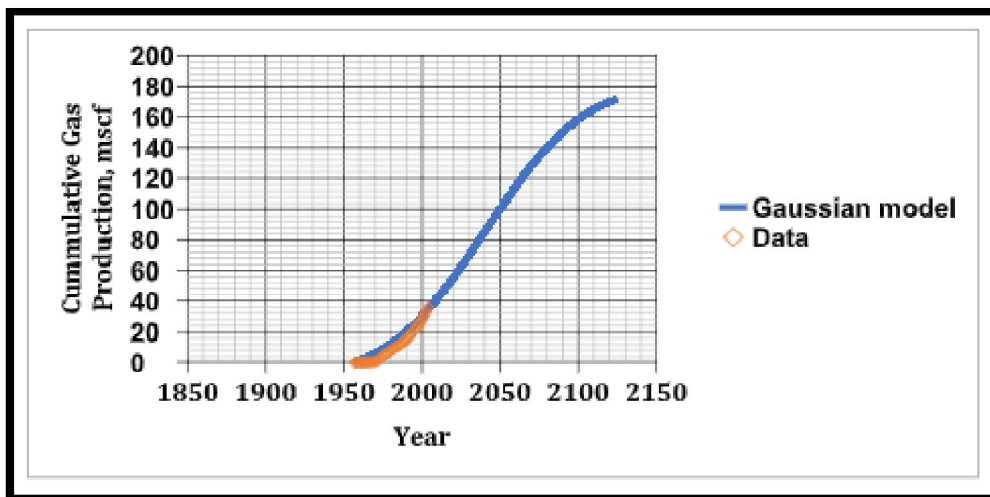


Figure 6: Optimal Gaussian Model for Forecasting Cumulative Natural Gas Production

This model is referred to as the optimal because it has the highest coefficient of determination for the natural gas production curve and it has a reasonable high value of coefficient of determination for cumulative gas production.

3.1.2. The Hubbert Logistic Model

The year that production of natural gas will peak, , for Case 1, Case 2, and Case 3 is 2007, 2027 and 2010 respectively.

The Case 2 predicts that production of natural gas will peak in the year 2027 and that natural gas reserve will be exhausted in 2150.

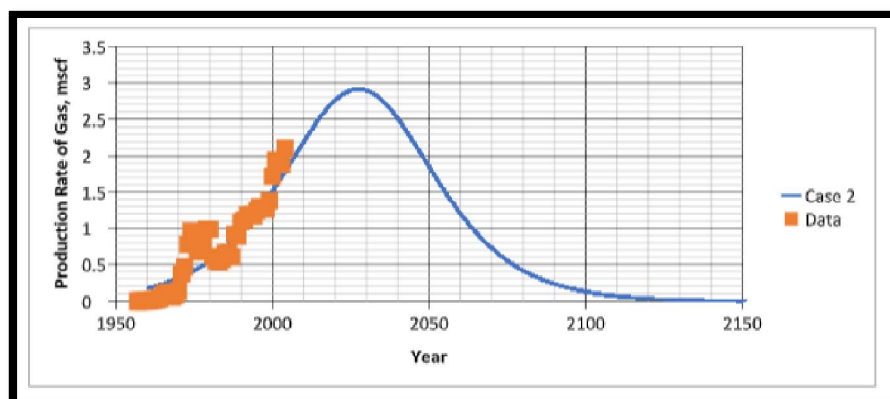


Figure 7: Case 2 Production Rate of Natural Gas

The coefficient of determination for production rate curve is 99.9995% and the cumulative production curve match the actual data. Case 2 is the optimal Hubbert Logistic model

The Hubbert Logistic Production rate model is show below

The cumulative production model is show below

The cumulative production for Cases 1, 2, and 3 are shown in Fig 8 below. Case 2 models the actual natural cumulative production data most accurately and Case 2 will be used in further discussion in this work.

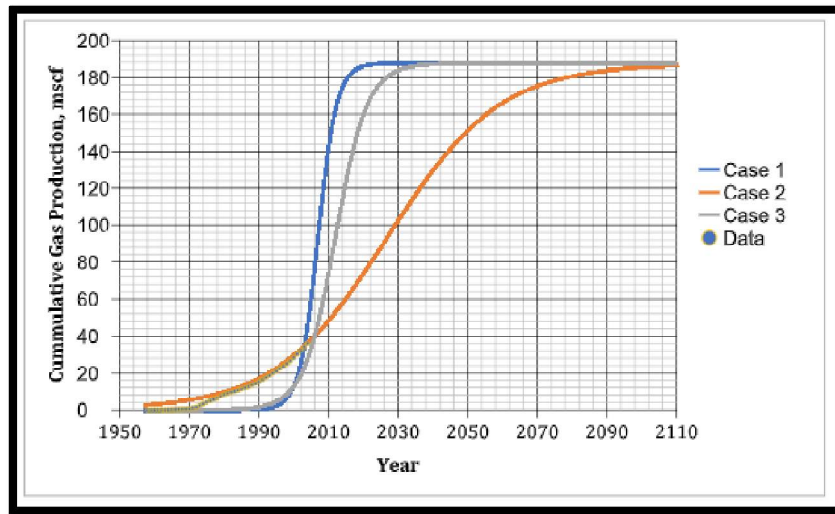


Figure 8: Natural Gas Cumulative Production Forecasts for Cases 1 - 3

3.2. Gas Utilization Rates Forecasting

Gas Utilization was forecasted using Logistic and Linear models and the approach adopted was that of (Melikoglu, 2013). The different approaches were used to forecast natural gas utilization rates up to year 2050.

3.2.1. The Logistic Function Forecast

Case 1: When it is assumed that natural gas is utilized by the entire population of Nigeria

The logistic function is dependent on population and for this case it is assumed that the entire population of Nigeria utilize natural gas. The Fig 9 shows how the logistic function model natural gas utilization data. The coefficient of determination of this plot is 88.75%, and it is a good model. However, the model seems to over predict from around 1995.

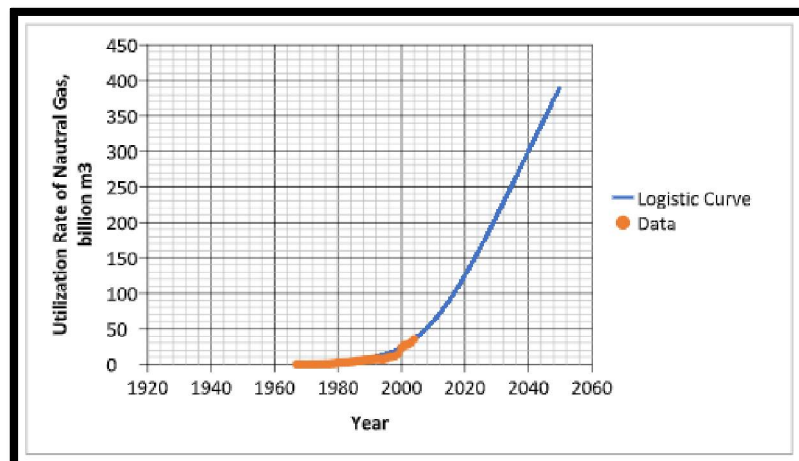


Figure 9: Logistic Model Forecast for Natural Gas Utilization with Full Population

Case 2: When Half the Population Utilize Gas is used to Model Gas Utilization

When half the population was used, the logistic model fits the data to a reasonably high level but then tends to under predict after 2000.

3.2.2. The Linear Model Forecast

Case 1: When it is assumed that natural gas is utilized by the entire population of Nigeria

The linear model only fits 39.3% of the actual utilization data and it is seen to over predict the rate of gas utilization.

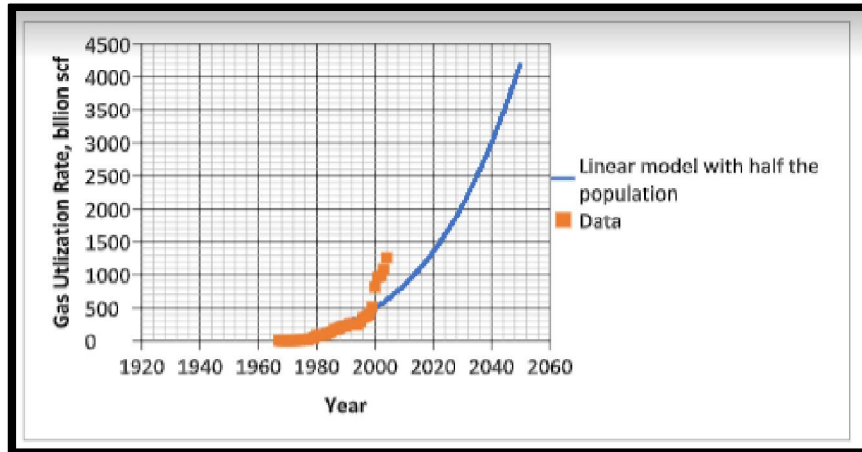
Case 2: When half the population is used to model gas utilization

Figure 10: Linear Model Forecast for Natural Gas Utilization with Half Population

When half the population was used for linear model forecast, the model gave a better fit compared to when the full population was used in Case 1. The Case 2 linear model is therefore better than the Case 1 linear model. The linear model in Case 2 tends to under predict the natural gas utilization rate after 2000, similar trend was observed with Case 2 for logistic model.

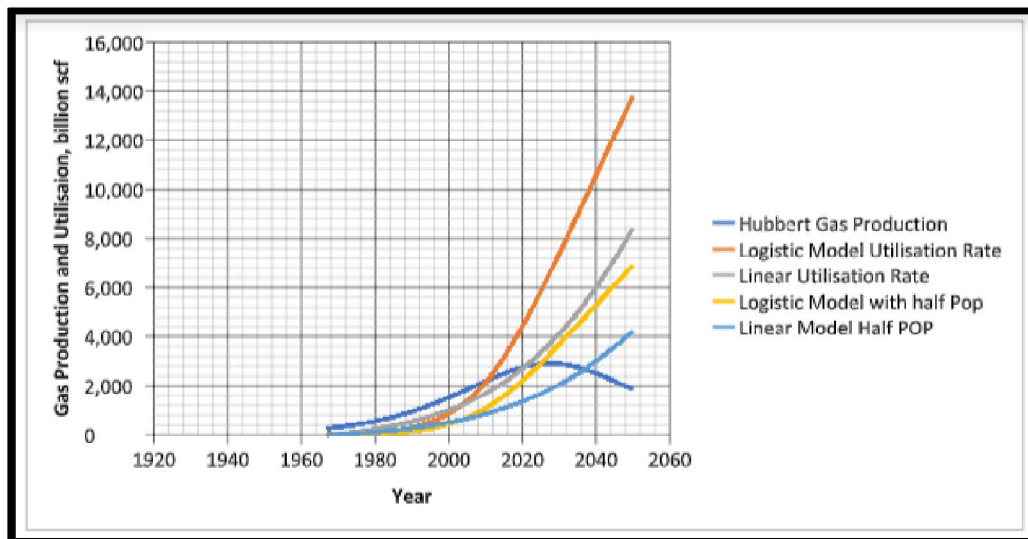


Figure 11: Hubbert Natural Gas Production and Utilization Curves

There will be a gap between natural gas utilization and production rate after the point of intersection of the production and utilization curve. When natural gas utilization need exceed the rate of natural gas production, Nigeria will have to import natural gas to satisfy the growing rate of utilization.

The year at which the natural utilization and production rates curve intersect depend on the utilization rate model that is being considered. The utilization models we have considered has shown that, by at most year 2037, forecasted natural gas utilization would exceed forecasted rate of production. Therefore, extensive exploration of new natural gas reserve should be embarked upon in Nigeria; otherwise, Nigeria will become a net importer of natural gas by that year.

4. Conclusions

4.1. Forecasting the Rate of Natural Gas Productions

The Gaussian model did not give accurate prediction of the natural gas production in Nigeria. The optimal Gaussian model gives the best values of coefficient of determination for both the rate of production and cumulative production curve. The optimal model forecast that production of natural gas will reach its maximum in the year 2035 and will be exhausted in the year 2113.

The Case 2 Hubbert Logistic model is the most accurate model for predicting the production rate of Nigeria's gas reserve. This model most accurately fit the natural gas production and natural gas cumulative production data. This model predicts that production will peak in the year 2027 and that the natural gas reserves will become exhausted by year 2150.

4.2. Forecasting the Rate of Natural Gas Utilization

The natural gas utilization model prediction is a function of the fraction of the population used in the forecast. When it was assumed that the entire population use gas, the logistic model forecast was more accurate than when half the population was used, while the linear model forecast gave better results when half the population was used in the model.

4.3. The Gas Production and Utilization Gap

The year in which there would be a gap between gas production and gas utilization would depend on the gas utilization model used. The earliest time when there would be a gap in production and utilization is 2011, when the logistic model was used with full population and the latest time would be 2037 when linear model with half the population was used. The best natural gas utilization model was the logistic model with half the population and this model predicted that the gas utilization and production gap would start in 2027.

4.4. Policy Recommendations

- Government should develop policy incentives that would ginger aggressive gas exploration in Nigeria in the likes of Reserves Addition Bonus
- Government should also develop incentives that would encourage Gas exploration in Nigerian frontier and Inland basins
- Government should develop incentives that would encourage exploration in deeper horizons in Nigerian green and brown fields.

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