British Journal of Economics, Management & Trade
17(2): 1-8, 2017; Article no.BJEMT.32140
ISSN: 2278-098X

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Probabilistic Estimation of Potential Gas Reserves for the Emerging Nigerian Gas Market

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Authors' contributions

This work was carried out in collaboration between both authors. Author LOA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author YAO managed the analyses of the study. Author YAO also managed the literature searches. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJEMT/2017/32140
Editor(s):
(1) Chiang-Ming Chen, Department of Economics, National Chi Nan University, Taiwan.
Reviewers:
(1) Hesham A. M. Abdou, Egypt.
(2) Oluwoyo Temidayo, Kogi State University, Anyigba, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history/18788

Original Research Article

Received 9th February 2017
Accepted 18th March 2017
Published 25th April 2017

ABSTRACT

Proved reserves for the Emerging Nigerian Gas Market is estimated to be around 186 trillion cubic feet (Tcf). In the short to medium term, only 54% or approximately 100 Tcf will be available for utilisation, the remaining locked up as Gas Cap Gas, only available on the long term (constrained by OPEC production quota and lack of Gas Utilisation Infrastructure). The objective of this study was to estimate the growth potential of Associated Gas (AG) reserves and more importantly determine probabilistic estimates for potential reserves additions from the extensive Non-associated Gas (NAG) accumulations in the Niger Delta.

The Niger Delta potential AG reserves growth (deterministic) was investigated using historical reserves figures and the probabilistic potential reserves additions from NAG were explored using simple triangular distributions. The Society of Petroleum Engineers (SPE) Reserves classification framework was employed to categorize the Proved reserves (1P or P_1) as AG Reserves and Reserves additions from NAG as P_2 for Probable reserves (2P or P_1+P_2) generated as a cumulative distribution till 2050.

The results obtained indicated NAG reserves addition to the proved reserves has a 90% confidence limit of reaching between 78.39 and 89.80 Tcf, and a Standard deviation of 3.42 Tcf in 2050. The

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2P reserves estimate in 2050 is expected to lie between 267.06 Tcf and 278.49 Tcf within a confidence interval of 90%. Standard deviation from these values was also estimated as 3.42 Tcf. About total reserves of 275 Tcf would lie below the 75th percentile.
The distribution of reserves obtained would significantly improve future gas reserves availability estimates and plausible production profiles for prospective investors planning to participate in gas to power and other gas utilisation projects in the emerging Nigerian gas market.

Keywords: Gas reserves; gas market; probable reserves; proved reserves; reserves growth.

ABBREVIATIONS

AG	*: Associated Gas*
AGF	*: Annual Growth Factors*
DPR	*: Department of Petroleum Resources*
Gp	*: Gas Reserves, Tcf (Tcm)*
NAG	*: Non-associated Gas*
NGMP	*: Nigeria Gas Master Plan*
Tcf	*: Trillion Cubic Feet*
Tcm	*: Trillion Cubic Metres*
USGS	*: US Geological survey*
1P or P_1	*: Proved Reserves*
2P or P_1+P_2	*: Probable Reserves*
3P or P_1+P_2+P_3	*: Possible Reserves*

1. INTRODUCTION

Estimated size of oil and gas fields' reserves generally increases with time as fields are discovered, developed and produced. This phenomenon is referred to as reserves growth or field growth. Reserve growth models vary from field to field and from basin to basin. Indeed, some fields may show reserves reduction or negative growth. However, for a basin or a region, collective reserves growth is usually positive. International oil & gas fields also show clear evidence of reserves growth. Worldwide reserves growth will become important in future, particularly for gas, as economies demand higher levels of cleaner forms of energy for their expansion. Projections for future growth of reserves thus become vital in resource assessments and economic planning.

Many factors may contribute to reserves appreciation. These include:

- Delineation of additional oil and gas in-place, through areal extensions of fields and development of new pools and reservoirs within fields
- Higher recovery percentages of the oil and gas in-place, resulting from infill drilling and the application of improved technology and advanced engineering methods
- Revisions of reserve calculations (commonly upward), based on experience gained in the course of developing and operating a field.

Many schemes for estimating future reserve growth are based on the following assumptions:

- Age of fields (since discovery) is considered a realistic surrogate for the degree or intensity of developmental activity in the Basin generating the growth.
- Reserve growth is proportional to field size.
- Past reserve growth patterns provide a realistic basis for predicting the future.

Nigeria is expected to contribute tremendously to the projection of future World gas reserves growth because of its vast gas reserves whose *possible* value has been estimated to be as high as 600 Tcf. It has been described chiefly as a gas province as against oil that it was previously renowned for, with proved gas reserves estimates at 186 Tcf [1]. Proved reserves by definition, are reserves estimated with reasonable certainty to be recoverable under current economic conditions which include prices and costs prevailing at the time of the estimate. Proved reserves may be developed or under developed. It must have facilities to process and transport those reserves to markets that are operational at the time of the estimate or there is commitment or reasonable expectation to install such facilities in the future. On the other hand, unproved reserves are less certain to be recovered than proved reserves and may be sub-classified as probable or possible to denote increasing uncertainty [2].

Nigerian gas is of high quality grade because of its low sulphur content and richness in Natural Gas Liquids (NGLs). In spite of being the largest in terms of gas reserves in Africa, Nigeria is ranked third in gas production after Algeria and Egypt. Currently, Nigeria still flares some of its AG but this activity is gradually trimming down (an average of 24% reduction [3] was recorded between 2015 and 2016). This sharp fall in volume of gas flared obviously resulted from the continuous diversion of gas into domestic power generation although factors such as shutting down of oil and gas activities due to incessant pipeline vandalism might have also contributed to the drastic reduction.

As part of Nigeria's resolve to become a major international player in the international gas market as well as to lay a solid framework gas infrastructure expansion within the domestic market, the Nigerian Gas Master Plan (NGMP) was approved on February 13, 2008. The NGMP is a guide for commercial exploitation and management of Nigeria's gas sector. It aims at growing the Nigerian economy with gas pursuing three key strategies:

1. Stimulate the multiplier effect of gas in the domestic economy
2. Position Nigeria competitively in high value export markets
3. Guarantee the long term energy security of Nigeria [4].

The above strategies are expected to be deployed through these three approaches initiated by the Federal of Nigeria; Gas-to-power, Gas–based Industrialization (fertilizer, methanol and petrochemicals) and a robust gas export market.

Understanding reserves growth is an important input to national planning, more so because Nigeria's economy is extensively energy dependent. Consequently, the trend of additions to Nigeria gas reserves is a key factor of interest to current and prospective players (Government and private sectors) in the Nigeria Gas sector.

2. LITERATURE REVIEW

The process of estimating oil and gas reserves for a producing field continues throughout the life of a hydrocarbon field or a basin (aggregation of fields). There is always uncertainty in making such estimates. The level of uncertainty is affected by the following factors: Reservoir type, source of reservoir energy, quantity and quality of the geological, engineering, and geophysical data, assumptions adopted when making the estimate, available technology, and experience and knowledge of the evaluator [5].

Arrington [6] pioneered the use of reserves growth models to estimate trends in Ultimate Recoveries (UR) in mature petroleum provinces. By careful study of historical data and using the three year moving average of such data, he developed estimates of Annual Growth Factors (AGF) that can be used for individual fields or regions. While largely empirical and statistics based, his method gained wide acceptance because of its simplicity and the fact that estimates generated can be used as a "first pass" for Regional or Basin studies before the development of more precise and costly field level estimates. Till date, many US Geological Survey (USGS) Assessments of Oil & Gas Reserves are based on the original Arrington method or a variant of it. Over the years, several authors have sought to incorporate improvements in the original Arrington method. Schmoker and Crovelli [7] presented a deterministic Reserve Growth model for the Continental US based on Growth factors calculated based on year since discovery or age of the field. The growth factors are multiplicative constants, applied directly to a known field volume data to estimate Reserves size in future. The important contribution of Schmoker and Crovelli was the extension of the Arrington Method to include probabilities – a range of Reserves sizes could be estimated using their scheme rather than the single point estimate of Arrington.

Verma and Ulmishek [8] presented a modified form of the Arrington method in which he showed cumulative growth factor smoothing produces a better match with known volume data than annual growth factors. Forbes and Zampelli [9] challenged the premise of the original Arrington method which is based only on geologic factors, independent of the economic environment. They submitted that, given the implicit assumption that growth is systematically affected only by age, the contribution of reserve growth to supply will invariably diminish as fields become more mature. Using data from over 500 fields in the US Gulf of Mexico, they developed an empirical model based on age of the field (as measured by the number of years since first production), the field's reserve size in the year of first production, the real price of natural gas, water depth, and a set of unobserved field-specific factors. They concluded that estimating oil and gas reserve growth using an Arrington based approach may underestimate the response of reserve growth to changes in economic fundamentals.

Forbes and Zampelli [10] examined reserve growth based on aggregation of field data on the year of first production, in contrast to their investigation in 2009 which was based on individual field level. They claimed that the advantage of the approach is its potential to yield insights about the resource potential of a particular geologic province. The results strongly suggest that age is not the sole factor in explaining a field's annual reserve growth. In particular, they found out that the annual growth rate in the known petroleum volumes of a field is affected by the economic environment as proxied by price. They concluded that the incorporation of this effect into the modeling process has the potential to improve the accuracy of resource assessments.

The statistical approach to estimating Niger Delta hydrocarbon reserves growth was explored by Oseh et al. [11]. The study was on a field basis as against a basin. The model they developed was based on extrapolation of additional reserve due to exploratory drilling trend and the additional reserve factor which is due to revision of the existing fields. The Estimation model was used alongside with Linear Regression Analysis to estimate the constants in the equation and the results compared with the actual reserves. Kingsley-Akpara and Iledare [12] provided a descriptive analysis of Niger delta reserves growth, discussed the causes of reserves growth (primarily additional discoveries, reserves revision and reserves extension) and showed the importance of crude oil, incentives, government policy incentives and new technology on reserves growth pattern. They identified the engineering input driving oil discoveries, and upward revision of existing reserves through field appraisals, accelerated field development approvals and improved recovery schemes. Reserves discovered, developed and appraised in Niger Delta basin by three operators and reserves growth from this sample space is referenced to describe reserves growth situation in Nigeria. Reserves additions from Onshore were 2608MMbbls per field between 1954 and 1960, and 1808MMbbls per field between 1971 and 1975. The most recent additions came from the offshore fields giving 1303MMbbls per field between 1996 and 2000, and 1974MMbbls per field between 2000 and 2005.

Despite the huge gas reserves and the high tendency of reserves growth, the Nigerian gas market is faced with competitive challenges. Aimikhe et al. [13] observed the trend in Global gas development worldwide and studied its impact of Nigerian Gas market. They considered that the boom of unconventional gas development in the United States which is a major importer of Nigerian gas and the increased expansion of LNG facilities in Qatar and Australia could pose a threat to the Nigerian Gas market in 2016. Moreover, the new gas discoveries of large gas reserves in East Africa including Mozambique and Tanzania located in the Indian Ocean may negatively affect Nigeria's revenue from gas exports owing to proximity of those countries to Asian buyers. They recommended establishment and proper running of gas related industries, functioning petrochemical industries, increased investment in gas to liquid (GTL) technology and Gas to power (GTP) as gas utilisation options as means to generate more revenue for the country from gas sales in the face of an uncertain global gas market

In the course of implementing the NGMP, there is a need to envision the trend of gas reserves (1P, 2P and 3P) additions or otherwise, in order to effectively deploy the key strategies of the plan. The projected trend of these gas reserves additions, in the case of Nigeria, has not been widely discussed in Literature as of date. Where it has been discussed, only point statistical and point estimate methods such material balance, simulation and decline curve methods have received attention. Hence, there arises the need to approach such reserves reports probabilistically.

In this paper, investigation was based on the implicit assumption of the Arrington methodology. While acknowledging the importance of the economic environment (the trend in oil and gas prices due to supply and demand), it was assumed that some of the effects of the economic environment might have been accounted for in the Proved Reserves figures. Published proved reserves figures are the end product of the level of development activities in a field or basin and is reflective of the economic environment. An explicit treatment of the economic environment will be useful if the investigation is aimed at determining the relative contributions of each of the factors contributing to Reserves Growth. However, the main interest of this research was the magnitude of Reserves Growth and the implications for Gas availability for the emerging Gas Business as envisaged in the NGMP.

3. METHODOLOGY

3.1 Deterministic Evaluation

The published Country Reserves Data from *2015 BP Statistical Review of World Energy* was used.

Historical Proved Reserves data for Nigeria Gas from 1980 was adopted, so about 35 years of published data was employed. Nigeria Proved Reserves is currently estimated as 186 Trillion cubic feet (Tcf).

Fig. 1 shows the actual Nigeria proved gas reserves and 3-year moving average estimates for the published data while Fig. 2 shows the calculated Annual Growth factors.

The annual growth factors show a haphazard trend in the early years and a constant trend towards the tail of the graph. This is indicative of a maturing petroleum environment and lack of field activities towards discovery of additional reserves. In the case of Nigeria, Proved Gas Reserves comprises mainly AG; NAG is ignored due to lack of Gas infrastructure and an undeveloped Gas market. The trend in Fig. 2 reflects that the situation for 2010 to 2015 proved Gas Reserves was at 186.1 Tcf, showing no growth whatsoever. Regression of the Proved Reserves data using polynomial, power, logarithmic and exponential forms shows the power function having the best fit and may be represented by the following relationship:

$$Gp = -0.101Y^2+8.4417Y+20.943 \quad (1)$$

$R^2 = 0.955$

Where *Gp* is reserves in Trillion cubic feet and Y is the elapsed year since the reference year (1980) Using eq. 1, projected Proved Reserves is expected to reach 190.54 Tcf in 2030—an increase of about 4 Tcf over 15 years. This is expected due to current lack of significant investment in AG infrastructure, gas gathering and processing in Nigeria, a consequence of the current uneconomic domestic gas price and also the current global depression in the prices of oil and gas. Fig. 3 shows the future projection of Nigeria AG reserves using the model in eq. 1.

3.2 Probabilistic Evaluation

In this study, probabilistic evaluation was adopted for the projection of NAG reserves and NAG reserves growth. The triangular distribution was employed in the probability analysis of NAG reserves. A 2015 base NAG Reserves of 18.8 Tcf or 10% of AG Reserves was used as the initial level to capture independent initiatives to augment reserves availability for the NLNG and the Independent Power Projects that are yet to be captured rigorously in Total Reserves. In addition, minimum NAG Reserves growth rate of 2.5%, most likely growth rate of 5% and optimistic NAG growth rate of 7.5% were assumed. The optimistic growth rate of 7.5% was chosen to reflect aggressive development of NAG fields to support the current drive to realize the objectives of the Nigeria Gas Master Plan. Simulation runs with @Risk Software generated reserves profile additions from NAG fields as well as total reserves (AG and NAG) for each of the years, i.e., 2016 through 2050.

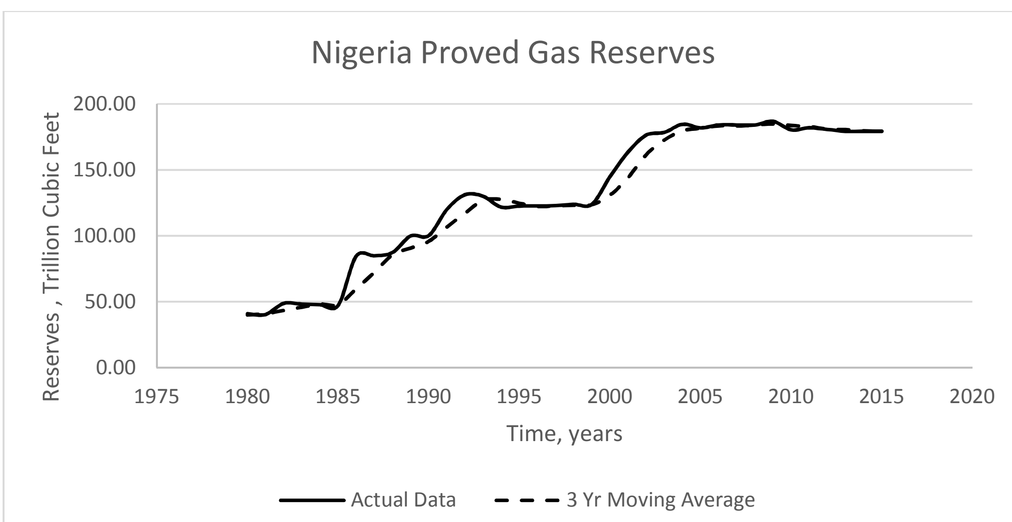

Fig. 1. Nigeria proved gas reserves (Actual Data and 3-year Moving Average Estimates)

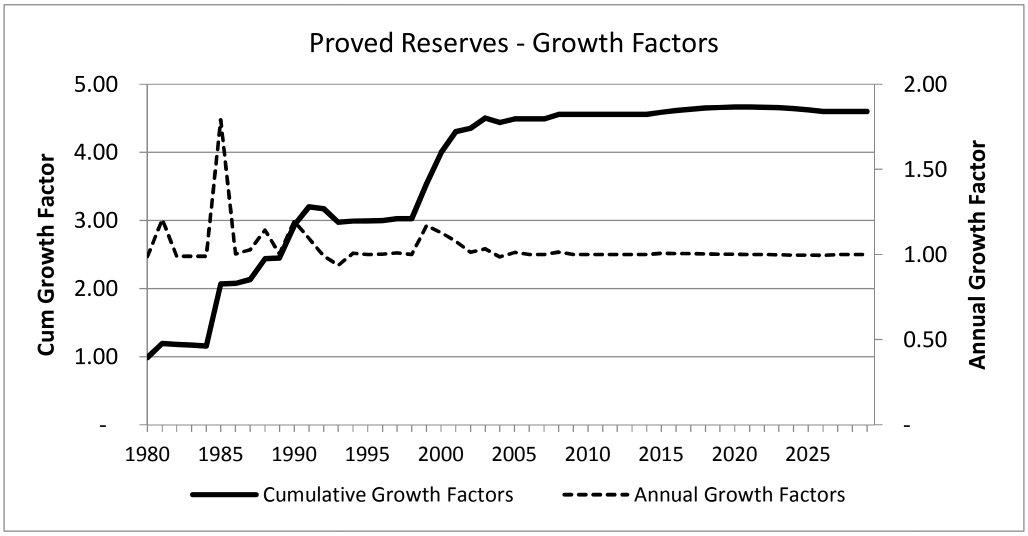

Fig. 2. Annual and cumulative proved reserves growth factors

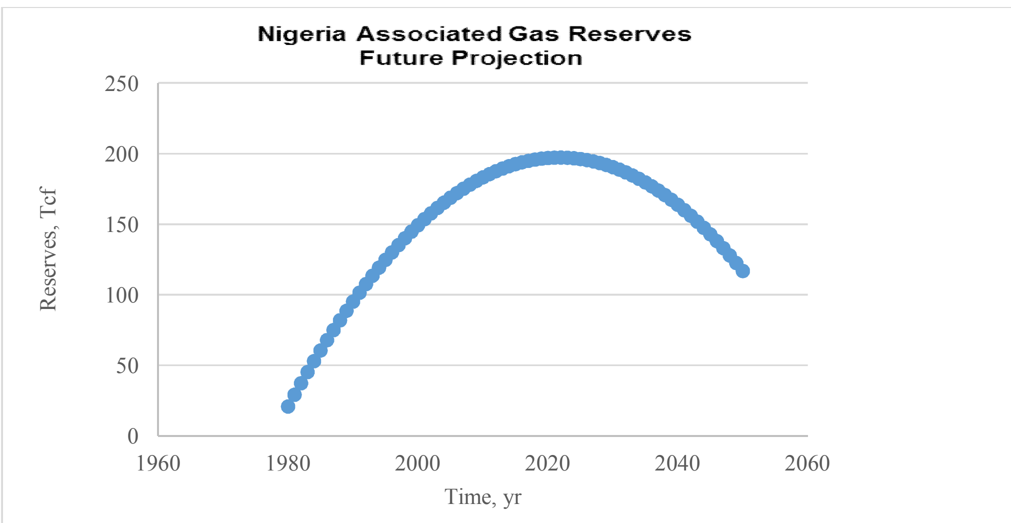

Fig. 3. Nigeria AG reserves future projection using equation 1

4. RESULTS AND DISCUSSION

Fig. 4 indicates that the NAG reserves addition to the proved reserves has a 90% confidence limit of reaching between 78.39 and 89.80 Tcf, and a Standard deviation of 3.42 Tcf in 2050. The range gives a picture of the NAG reserves estimate (probabilistic) which would depend upon improvement of gas infrastructure and development of NAG fields.

Fig. 5 gives a probabilistic distribution of the total reserves estimate in 2050; a combination of the deterministic power law model for proved (AG) reserves estimate and that obtained from the Probabilistic NAG additions. The 2P reserves estimate in 2050 is expected to lie between 267.06 Tcf and 278.49 Tcf within a confidence interval of 90%. Standard deviation from these values was also estimated to be 3.42 Tcf.

Fig. 6 is a representation of the simulation results obtained in Fig. 5 as a cumulative probability distribution. About a total reserves of 275 Tcf would lie below the 75th percentile in the year 2050.

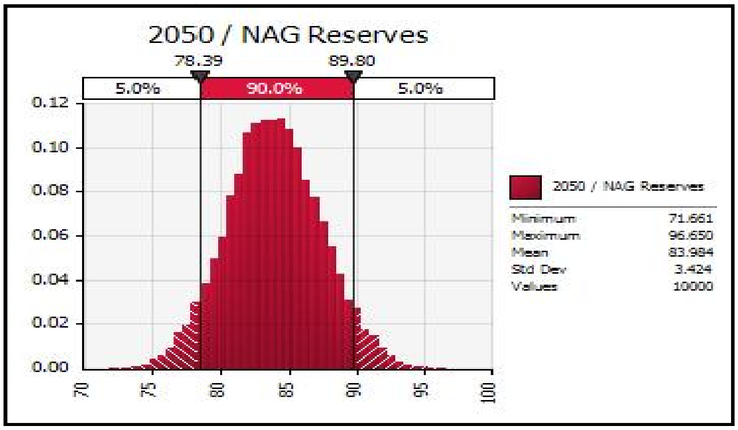

Fig. 4. Monte Carlo simulation results for NAG reserves growth in 2050

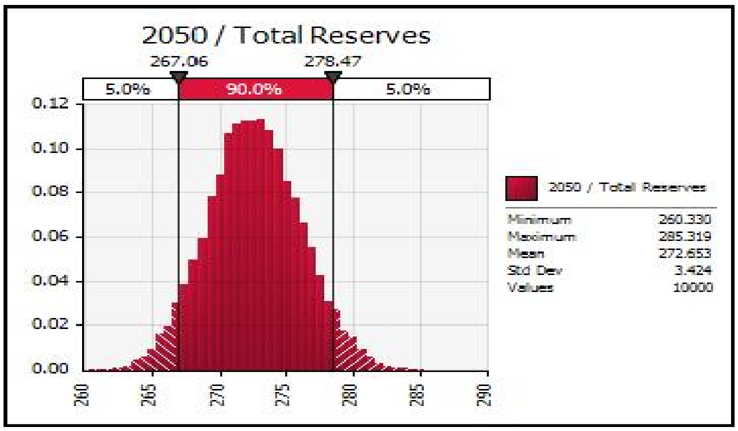

Fig. 5. Monte Carlo simulation results for total (Probable) reserves growth in 2050

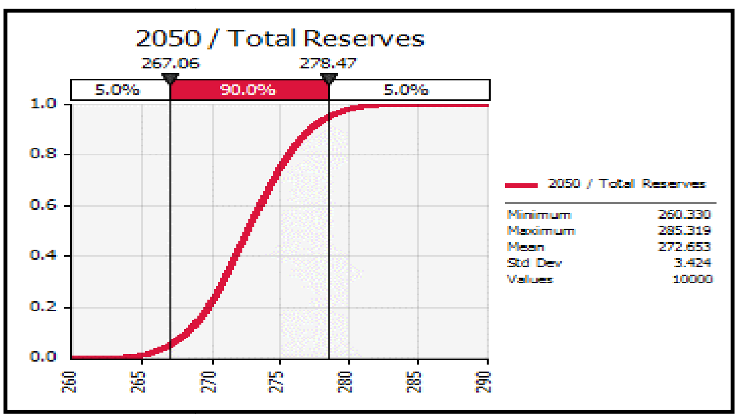

Fig. 6 . Cumulative probability distribution for total (Probable) reserves growth in 2050

5. CONCLUSION AND RECOMMENDATION

I. Nigeria in deed, is a country with high gas reserves potential. However, aggressive effort is needed to tap into the abundant gas resources.

II. In this paper, the AG reserves was assumed to be current proved gas reserves and was estimated to grow to approximately 190 Tcf in 2030 and decline to approximately 116 Tcf in 2050. However, additions from the NAG reserves would potentially increase the total reserves to approximately 267 Tcf in 2030 and 278 Tcf in 2050, both within a confidence interval of 90%. This would be subject to improved domestic gas prices compared to what currently obtains and more economically favourable global prices of gas. These fundamental factors would foster aggressive efforts to develop more NAG fields as well as improved infrastructure for gas in Nigeria.

III. In terms of SPE reserves classification [2], by 2050, 1P for Nigeria gas reserves should be approximately 116 Tcf while 2P should be a value of 285.3 Tcf, as revealed by the estimations from this study. The widely published 600 Tcf possible reserves shows that a lot more effort will be needed to tap into the huge gas reserves that Nigeria is endowed with.

IV. The probabilistic method employed in this paper relied upon published data from BP Statistical Review, 2015 and Nigeria National Petroleum Corporation (NNPC) Statistical Reports. Should these figures change for any reason, the results of this study would also have to change.

V. The study may be extended to probabilistic estimation of potential oil reserves for Nigeria as it was not covered in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/18788