International Journal of Oil, Gas and Coal Engineering
2024; 12(1): 20-30
http://www.sciencepublishinggroup.com/j/ogce
doi: 10.11648/j.ogce.20241201.13
ISSN: 2376-7669 (Print); ISSN: 2376-7677 (Online)

Optimizing Strategies Employed in Natural Gas Utilization

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To cite this article:
Nnaemeka Uwaezuoke, Anene Tochi, Ugochukwu Duru. (2024). Optimizing Strategies Employed in Natural Gas Utilization. *International Journal of Oil, Gas and Coal Engineering*, *12*(1), 20-30. https://doi.org/10.11648/j.ogce.20241201.13

Received: September 19, 2023; **Accepted**: October 25, 2023; **Published**: January 23, 2024

Abstract: Natural gas which is a subcategory of petroleum is a naturally occurring, complex mixture of hydrocarbons with minor amounts of inorganic compounds. Nigeria has a proven gas reserve estimated to be 206.53 Tscf, which is worth over 803.4 trillion dollars as of April 2022. These volumes of gases could be utilized in different ways, and the strategies employed in their utilization can be optimized to yield maximum benefit. The purpose of this study is to critically analyze the strategies employed in natural gas utilization within the Niger Delta region of Nigeria, then use an optimization technique and software to determine the optimum decision strategy. The study was limited to the use of linear optimization software, LINGO. A linear transshipment model was developed based on the gas utilization options that are employed in the Niger Delta. The transshipment model consists of three nodes: source, process, and destination nodes, which represent centers of activity. An objective function enveloping all the optimization nodes considered is defined. A set of constraints was also defined to restrict the model based on some factors such as the gas composition limit, the maximum deliverability at the destination nodes, etc. The necessary data for the study include gas composition data, fixed cost data, variable cost data, and market price data. The solution to the model provided by the software shows that the optimum net income for a period of 20 years is $2.522 trillion. The volume of gas that is required to meet market demand for the gas utilization options denoted G is 41.13264 Tscf. The result also shows that all the utilization options considered in the study are profitable since they all contributed to the optimum value obtained. A sensitivity analysis was carried out to see the effect a 10 to 50% increase or decrease in the fixed cost, variable cost, and market price data will have on the optimum value obtained.

Keywords: Gas, Optimization, Model, Utilization, Node, Transshipment, Linear Programming, Sensitivity Analysis

1. Introduction

Natural gas is a subcategory of petroleum that is a naturally occurring, complex mixture of hydrocarbons, with a minor amount of inorganic compounds [1]. Natural gas is estimated to be the fastest-growing fossil fuel in the world and is projected to overtake coal by 2030, as the second-largest source of energy after oil [2].

Nigeria has a proven gas reserve estimated to be 206.53 TCF which is worth over 803.4 trillion dollars as of April 2022. This increase positions Nigeria among the countries with the highest gas reserves in the world [3].

A decree was issued by the Nigerian government to stop the flaring of natural gas in hydrocarbon exploration and production (E&P) activities by 2008, this was all in an effort to realize commercial benefits from the nation's huge gas reserves. However, due to several factors posing as an impediment to these investment ideas by the government, this deadline date has far expired, but huge volumes of gas are still been flared. In fact, sadly, Nigeria flares an estimated 216.5 Bscf of gas as of September 2022 [4]. These volumes of gases could be utilized in different ways, and the strategies employed in their utilization can be optimized to yield maximum benefit.

The major problem in utilizing natural gas worldwide has been the high transportation costs when compared to crude oil. Transportation costs could be as high as four times those of crude oil. However, the enriching benefits of natural gas utilization such as reduced greenhouse gas emissions (GHG) would further emphasize the need for the utilization of gas in Nigeria.

Natural gas utilization entails coming up with a strategy for converting natural gas from the production field to various options that would serve economic benefits in terms of money and the environment. The available gas utilization methods include: liquefied natural gas (LNG), Gas to liquid (GTL), Natural gas to methanol (GTM), Natural gas to hydrogen (GTH), Gas to wire (GTW), Compressed natural gas (CNG), Liquefied petroleum gas (LPG), Natural gas to pipeline (GTP), Gas to hydrates (NGH), Gas re-injection process (GRP). Below is a brief explanation on them.

Pipeline Transportation; The use of Pipeline as a means of transporting gas which is also considered one of the natural gas utilization option has been in existence for long and still remains a significant mechanism for gas transportation to markets. This involves laying pipes in a palatable manner to guarantee the successful transportation of natural gas from one location to another. Existing routes for pipeline transportation of natural gas in Nigeria include the West African Gas Pipeline, WAGP and the Trans Saharan Gas Network, TSGP.

Figure 1. *Typical Pipeline transportation onshore.*

HVDC Light; This is another utilization option, a Gas-to-wire project under which gas is used to generate electricity, it is then converted to High Voltage Direct Current for long distance transmission to the market [5].

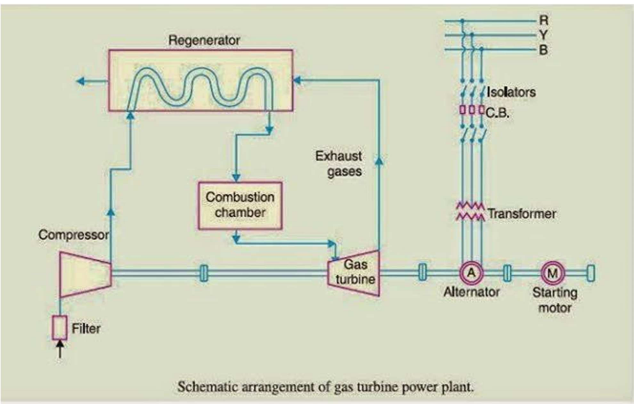

Figure 2. *Schematic arrangement of gas turbine power plant.*

Enhanced Oil Recovery, EOR; EOR is the third stage of hydrocarbon production proceeding primary and secondary recovery, at this stage sophisticated techniques that alter the original properties of the oil are used. Enhanced oil recovery can begin after a secondary recovery process or at any time during the productive life of an oil reservoir. Its purpose is not only to restore formation pressure, but also to improve oil displacement or fluid flow in the reservoir. Some EOR processes utilize natural gas for enhanced recovery of oil, e.g. miscible gas injection.

Liquefied Petroleum Gas, LPG; This particular gas has long been confused with propane. But it is in fact predominantly a mixture of propane and butane in a liquid state at room temperatures when under moderate pressures of less than 200 psig.

Figure 3. *A Liquefied Petroleum Gas storage tank.*

Natural Gas liquids, NGL; Generally, these liquids consist of propane and heavier hydrocarbons and are usually referred to as lease condensate, natural gasoline, and liquefied petroleum gases. When a wet gas gets to the surface, it forms a liquid which constitute the NGL [6].

Gas to Liquid, GTL; GTL is a refinery process whereby natural gas or other gaseous hydrocarbons are converted into longer-chain hydrocarbons such as gasoline or diesel fuel. GTL technology generally refers to the chemical conversion of natural gas into readily transportable liquids such as methanol or conventional petroleum refinery type distillate fuels [7].

Compressed Natural Gas, CNG; CNG can be formed by compressing natural gas (which is mainly composed of methane), to less than 1% of the volume it occupies at standard atmospheric pressure. It is stored and distributed in hard containers at a pressure of 200- 248 bar, usually in cylindrical or spherical containers.

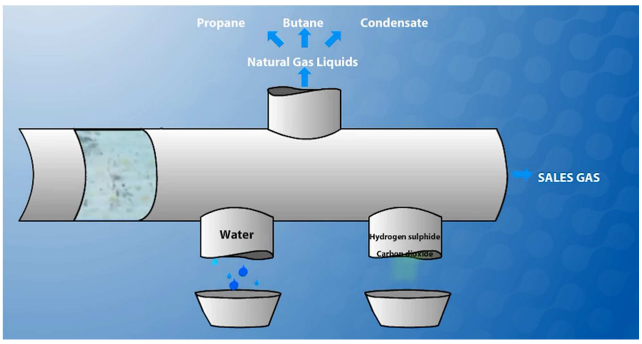

Figure 4. *Simple NGL formation process.*

With the advancement in time, there is a measure of the increase in the need for natural gas in various aspects, it could be in domestic use, industrial use, or in terms of exportation. New Hawilti report shows increased demand for domestic gas within Africa's biggest economy, driven by diesel-togas switching plans from factories and the manufacturing sector. As Europe seeks new supplies of gas to replace imports from Russia, Nigeria is frequently referenced as a key partner with the ability to help the Old Continent meet its shortage of gas.

In response, several export projects conceived decades ago have recently been put back on the table, including multi-billion dollars pipelines that would carry gas from the Niger Delta all the way to Europe via the West African coastal (offshore) and via Niger and Algeria (onshore) [8].

The need for natural gas implies demand. An increase in demand requires a reciprocating increase in production and supply toward the various utilization strategies available. Without proper evaluation or assessment of this entire system, it would result in poor decision-making. It could be in terms of transportation, cost, product quality/quantity, etc. Over the years, optimization approaches have been employed in making optimal decisions in terms of making the best selection and cost-effectiveness. The concept is applied in this study for optimizing the gas utilization strategies that were investigated. The concept of optimization could be considered an important tool in natural gas transportation problems. Optimization is the act of achieving the best result under some given circumstances. The aim of solving optimization problems is to minimize or maximize some function called the objective function [9]. The major goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables, optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function [10].

In dealing with the strategies for natural gas utilization in Nigeria a linear transshipment model was formulated. It is based on the gas utilization options that are available in the Niger Delta. This model is divided into three parts, a source, process, and destination which represent centers of activity. An objective function enveloping all the nodes considered is defined. A set of constraints were also defined. This is to restrict the model based on some factors such as the gas composition limit, the maximum deliverability at the destination nodes, etc. The solution to this model is obtained using an optimization tool, a software called LINGO. This is because of the large number of variables and equations. The solution to the model provides the maximum revenue that is realized from the utilization study over an average period of 20 years. The 20-year period was chosen because a typical gas contract agreement period ranges between 15 to 25 years. So an average was taken.

2. Materials and Methods

2.1. Model Formulation Scheme

The development of a model for the use of natural gas in the Niger Delta region of Nigeria from the source, through a process, to destination is based on the utilization paths and options applied in the country. The approach consists of a source of Natural gas which is represented as the source node (Niger Delta fields in this case), the path through which it goes, which includes the processing facilities represented as the intermediate nodes, and a final destination represented as the terminal node. A summary of the utilization process path is represented in the figure below.

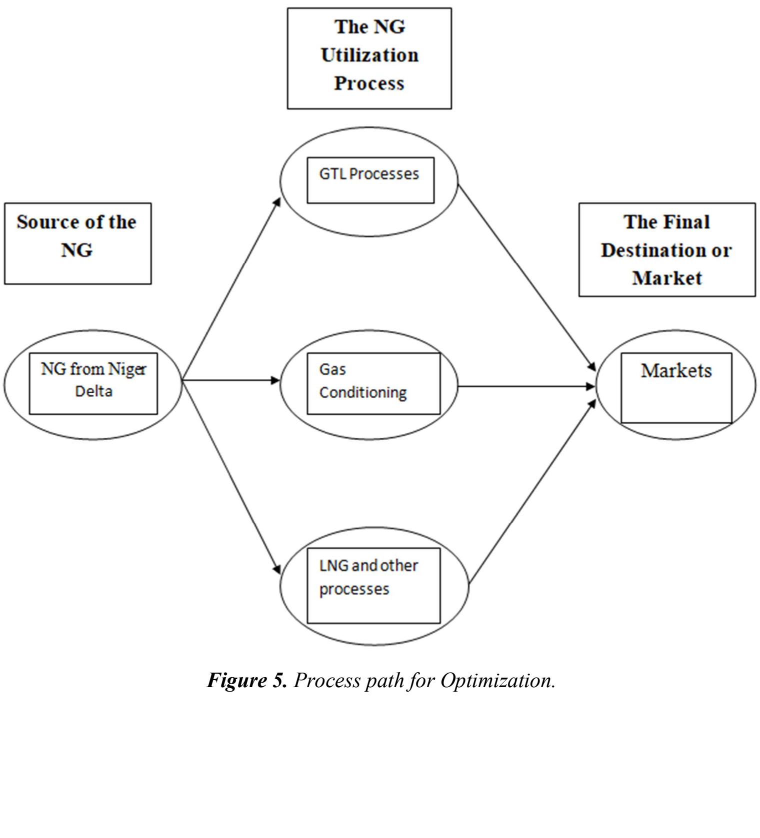

Figure 5. *Process path for Optimization.*

2.1.1. Assumptions Made in Developing the Model

Some of the assumptions which were made in deriving the model include;

1. This model is developed using basically market indices of cost and price. Things like political or social factors were not taken into consideration.
2. The model is a transshipment model. It has a single source node which satisfies a couple of destination nodes following some path called the process node. The source node in this case has no inflow while the destination has no outflow. However, the process node has both inflow and outflow.
3. The solution to the model is obtained using linear programming. Thus all the assumptions in linear programming are employed.
4. There are no time lags at each of the nodes. The gas that is transshipped from a particular node just moves immediately to the next node.

2.1.2. Proposed Natural Gas Optimization Scheme

There is a total of 13 nodes for the model. As stated earlier, this includes a source node, a process node and a destination node. The utilization scheme is presented diagrammatically in Figure 6.

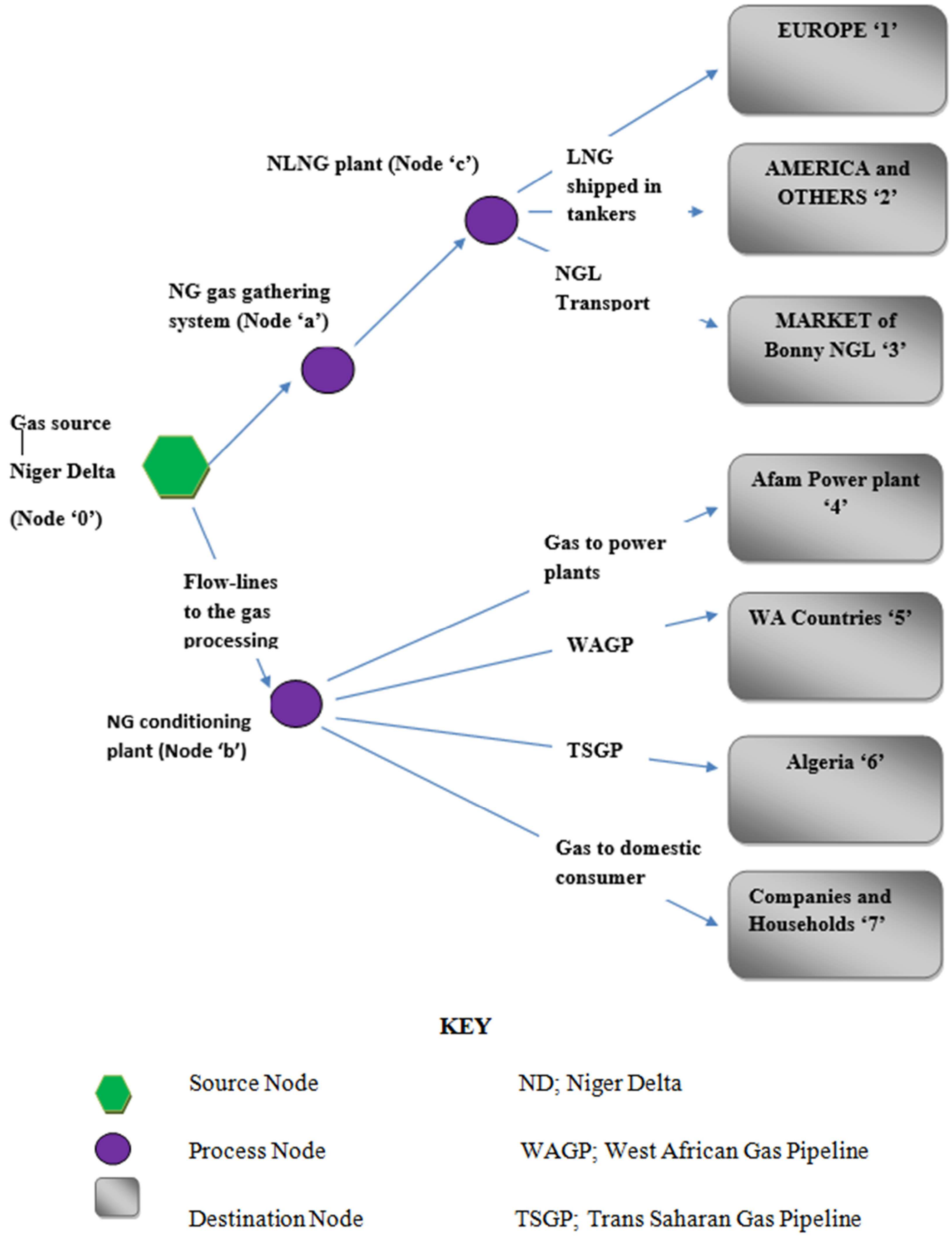

Figure 6. *Optimization Scheme consisting of 11 Nodes.*

Table 1. *A Summary of the Process Node.*

Path For The Destination Node	Process
0-a-c-1	Natural Gas coming from the source, moving through the gas gathering system, NLNG plant to Europe
0-a-c-2	Natural Gas coming from the source moving through the gas gathering system, NLNG plant (in form of LNG) to America
0-a-c-3	Natural Gas from the source moving through the gas gathering system, NLNG plant (in form of NGL) to market
0-b-4	Natural gas from the source moving through the gas conditioning plant for use in power generation
0-b-5	Natural gas from the source moving through the gas conditioning plant for export using WAGP
0-b-6	Natural gas from the source moving through the gas conditioning plant for export using TSGP
0-b-7	Natural gas from the source moving through the gas conditioning plant for local consumption

2.2. Developing the Optimization Model for the Niger Delta

A linear transshipment approach was used in developing the model. It is still under linear programming. This involves having an objective function and a set of constraints.

2.2.1. The Objective Function

This is a profit or net income function. It is to be maximized in other to obtain the optimum revenue generated over a period of time taking into consideration all the assumptions to the model which was stated earlier. Below is the equation.

$$J = [\text{Benefits}] – [\text{Fixed Costs}] – [\text{Variable Costs}] \quad (1)$$

Representing this in terms of nodes we have;

$$\sum_i \sum_j (B_{ij}x_{ij} - FC_{ij}y_{ij} - VC_{ij}x_{ij}) \quad (2)$$

where;

i, j = This indicates the flow-through path i j as shown in Figure 6

x_{ij} = This represents the amount of gas processed/transported from node i to j in Tscf.

y_{ij} = It is a coefficient switch to determine whether a fixed cost should be applied (y_{ij} = 0 or 1)

B_{ij} = The revenue (Benefits) that is generated at a destination node in $/Mscf, j is strictly 1, 2, 3, 4, 5, 6 and 7

VC_{ij} = The variable cost associated with transportation/processing of a given quantity of natural gas at the j-th node in $/Mscf

FC_{ij} = The fixed cost associated with transportation/processing of a given quantity of natural gas at the j-th node in $ billion.

2.2.2. The Constraints

The set of constraints include the following;

Node storage constraints: This ensures no gas is left at any node. $\sum_i x_{ij} - \sum_k x_{jk} = 0$ (3)

where;

x_{ij} = amount of gas entering the j-th node from other nodes, i, (i = source or process nodes)

x_{jk} = amount of gas leaving the j-th node to other nodes, k (k= process or destination nodes).

Fixed cost Constraints: It is applied to any node that involves conversion, processing, or transportation of natural gas and/or its by-products. These constraints take the following form:

$$y_{ij} - \frac{x_{ij}}{M} \geq 0 \quad (4)$$

where;

x_{ij} = The amount of gas entering the j-th node from other nodes, i, (i = source or process nodes)

y_{ij} = It is a coefficient switch to determine whether a fixed cost should be applied (y_{ij} = 0 or 1)

Gas Volume Constraints: It takes the form;

$$\sum_i xoi \leq G; \quad (5)$$

And

$$\sum_j x_{jt} - \sum_i x_{0i} = 0; \quad (6)$$

where;

G = The amount of gas available at source node, "0", for processing, conversion and transportation.

xoi = The amount of gas leaving the source node,"0", to nodes "a" through "c"

Gas Deliverability Constraints; The constraint is given by;

$$x_{jt} \leq 365 Q_{jt} t \quad (7)$$

X_{jt} = The amount of gas exiting node j and entering node "t" in Trillion cubic feet, Tscf.

$Q_{jt,}$ is the gas deliverability at the destination node in units of MMscf/d.

t, is the time for the contract time (20 years in this case)

2.3. Summary of the Natural Gas Optimization Model

The model contains a total of 30 variables. Below is the representation of these equations in the form of a code for the optimization software LINGO.

OBJECTIVE FUNCTION

MAXIMIZE

$$(B_{0a}–VC_{0a})*X_{0a}+(B_{ob}–VC_{0b})*X_{0b}+(B_{ac}–VC_{ac})*Xac+(B_{c1}–VC_{c1})*X_{c1}+(B_{c2}-VC_{c2})*X_{c2}+(B_{c3}-VC_{d3})*X_{c3}+(B_{b4}–VC_{b4})*X_{b4}+(B_{b5}–VC_{b5})*X_{b5}+(B_{b6}–VC_{b6})*X_{b6}+(B_{b7}–VC_{b7})*X_{b7}–FC_{0a}*Y_{0a}–FC_{0b}*Y_{0b}–FC_{ac}*Yac–FC_{c1}*Y_{c1}–FC_{c2}*Y_{c2}–FC_{c3}*Y_{c3}–FC_{b4}*Y_{b4}–FC_{b5}*Y_{b5}–FC_{b6}*Y_{b6}–FC_{b7}*Y_{b7} \quad (8)$$

Constraints

Gas Volume Constraint

$$X_{0a} + X_{0b} <= 30 \quad (9)$$

$$X_{c1}+X_{c2}+X_{c3}+X_{b4}+X_{b5}+X_{b6}+X_{b7}-X_{0a}-X_{0b}=0 \quad (10)$$

Node Storage Constraints

$$X_{0a} - X_{ac} = 0 \quad (11)$$

$$X_{ac} - X_{c1} - X_{c2} - X_{c3} = 0 \quad (12)$$

$$X_{0b} - X_{b4} - X_{b5} - X_{b6} - X_{b7} = 0 \quad (13)$$

Fixed Cost Constraints

$$1000\, y_{0a} - X_{0a} >= 0 \quad (14)$$

$$1000\, y_{0b} - X_{0b} >= 0 \quad (15)$$

$$1000\, y_{ac} - X_{ac} >= 0 \quad (16)$$

$$1000\, y_{c1} - X_{c1} >= 0 \quad (17)$$

$$1000\, y_{c2} - X_{c2} >= 0 \quad (18)$$

$$1000\, y_{c3} - X_{c3} >= 0 \quad (19)$$

$$1000\, y_{b4} - X_{b4} >= 0 \quad (20)$$

$$1000\, y_{b5} - X_{b5} >= 0 \quad (21)$$

$$1000\, y_{b6} - X_{b6} >= 0 \quad (22)$$

$$1000\, y_{b7} - X_{b7} >= 0 \quad (23)$$

Gas Composition Constraints

$$X_{c1} <= (Y_{c1}/100)*G \quad (24)$$

$$X_{c2} <= (Y_{c2}/100)*G \quad (25)$$

$$X_{c3} <= (Y_{c3}/100)*G \quad (26)$$

$$X_{b4} <= (Y_{b4}/100)*G \quad (27)$$

$$X_{b5} <= (Y_{b5}/100)*G \quad (28)$$

$$X_{b6} <= (Y_{b6}/100)*G \quad (29)$$

$$X_{b7} <= (Y_{b7}/100)*G \quad (30)$$

Gas Deliverability constraint

$$X_{c1} <= Q_{c1}t \quad (31)$$

$$X_{c2} <= Q_{c2}t \quad (32)$$

$$X_{c3} <= Q_{c3}t \quad (33)$$

$$X_{b4} <= Q_{b4}t \quad (34)$$

$$X_{b5} <= Q_{b5}t \quad (35)$$

$$X_{b6} <= Q_{b6}t \quad (36)$$

$$X_{b7} <= Q_{b7}t \quad (37)$$

2.4. The Relevant Data for the Study

The tables below gives a summary of the relevant data required in the study.

Table 2. *Gas Composition Data.*

Process	Component used	Mole %
Pipeline	C1, C2, C3	96.5%
NGL Conversion	C3, C4, C5+	3.5%
LNG Conversion	C1, C2	94.4%
Methanol Conversion	C1	88.1%

Table 3. *Fixed Cost data.*

NODE	Process/Destination	Price in billion $	Info source
A	NG gathering system	1.0	[11]
B	NG conditioning plant	0.75	[12]
C	NLNG Plant	10	[13]
1	Sales of LNG to Europe	0.051	[14]
2	Sales of LNG to America	0.094	[15]
3	Sales of NGL to Market	0.83	[15]
4	Gas to wire at Afam	0	Proximity to producing fields
5	Natural Gas to WA countries through Pipelines	0.924	[16]
6	Natural Gas to Algeria through Pipelines	20	[17]
7	Natural Gas for local use	2.8	[22]

Table 4. *Summary of the variable cost data.*

NODE	Process/Destination	Price ($/Mscf)	Info source
A	NG gathering system	0.2	[18]
B	NG conditioning plant	0.2	[12]
C	NLNG Plant	3	[19]
1	Sales of LNG to Europe	3.5	[20]
2	Sales of LNG to America	4.5	[20]
3	Sales of NGL to Market	1.4	[21]
4	Gas to wire at Afam	0.5	[21]
5	Natural Gas to WA countries through Pipelines	0.15	[22]

NODE	Process/Destination	Price ($/Mscf)	Info source
6	Natural Gas to Algeria through Pipelines	0.2	[22]
7	Natural Gas for local use	0.5	[21]

Table 5. *Summary of Market Price.*

COMMODITY	PRICE	INFO SOURCE
LNG	$27.5/Mscf	[23]
Natural Gas	$85/Mscf	[23]
NGL (Butane)	$157.5/bbl	[23]

3. Result

The solution to the optimization model provided by LINGO for the Niger Delta will be presented and discussed here. The result enlightens us on the optimum value of the maximized objective function (in trillion dollars) and the volume of Gas which is necessary to satisfy market demand for the gas utilization projects (in trillion standard cubic feet, Tscf). This volume of Gas which is the Gas from the source node, was initially not assigned any value but left as a variable denoted “G’.

For the various utilization options incorporated in the model which are represented by nodes or routes. The optimal utilization is that where there is gas to meet the demand, that is $X_{ij} > 0$. This means that the path is a profitable one. But if $X_{ij} = 0$ (note, the value of X_{ij} cannot be less than 0) for a particular node, then it is not a profitable one.

An interesting part of this project work is the sensitivity analysis carried out on the result gotten. This involves varying the variables which includes the fixed cost, variable cost and the market prices in terms of a certain percentage increase or decrease to observe the effect it has on the optimal solution. But we will start with a discussion of the result gotten from the base case.

3.1. Base Case

The result gotten from the base case shows that the volume of Gas which is necessary to satisfy market demand for the gas utilization projects denoted G is 41.13264 Tscf. And the optimum revenue gotten from the solution of the base case is $2.522 trillion. Also, from the result gotten, since all the variables which represent node/utilization option all have non zero values, they are all profitable and contributed to the optimum value obtained from the solution.

```
LINGO/WIN64 20.0.10 (20 Dec 2022), LINDO API 14.0.5099.197

Licensee info: Eval Use Only
License expires: 29 JAN 2024

Global optimal solution found.
Objective value:                              2521.977
Infeasibilities:                              0.000000
Total solver iterations:                             2
Elapsed runtime seconds:                          0.81

Model Class:                                        LP

Total variables:                    21
Nonlinear variables:                 0
Integer variables:                   0

Total constraints:                  30
Nonlinear constraints:               0

Total nonzeros:                     83
Nonlinear nonzeros:                  0
```

Variable	Value	Reduced Cost
X0A	17.79164	0.000000
X0B	23.34100	0.000000
XAC	17.79164	0.000000
XC1	10.79200	0.000000
XC2	5.560000	0.000000
XC3	1.439642	0.000000
XB4	1.752000	0.000000
XB5	1.460000	0.000000
XB6	14.60000	0.000000
XB7	5.529000	0.000000
Y0A	0.1779164	0.000000
Y0B	0.2334100	0.000000
YAC	0.1779164	0.000000
YC1	0.1079200	0.000000
YC2	0.5560000E-01	0.000000
YC3	0.1439642E-01	0.000000
YB4	0.1752000E-01	0.000000
YB5	0.1460000E-01	0.000000
YB6	0.1460000	0.000000
YB7	0.5529000E-01	0.000000
G	41.13264	0.000000

Figure 7. *Lingo Result for the Base Case.*

3.2 Sensitivity Analysis

It would be interesting to see the effect of variable changes based on a certain percentage increase or decrease in the optimal value. The variables to be varied includes the fixed cost, variable cost, and market price, using the following increment ±10%, ±20%, ±30%, ±40%, and ±50% in parameters from the base case.

3.2.1. Fixed Cost Sensitivity Analysis Results

The optimal income for the 10%, 20%, 30%, 40% and 50% increase in the fixed cost are $2.521, $2.521, $2.520, $2.519, and $2.512 trillion respectively. The optimal income for the 10%, 20%, 30%, 40%, and 50% decrease in the fixed cost are $2.522, $2.523, $2.524, $2.525, and $2.526 trillion respectively.

3.2.2. Variable Cost Sensitivity Analysis Results

The optimal income for the 10%, 20%, 30%, 40%, and 50% increase in the variable cost are $2.509, $2.495, $2.482, $2.469, and $2.455 trillion respectively. The optimal income for the 10%, 20%, 30%, 40%, and 50% decrease in the variable cost are $2.535, $2.549, $2.562, $2.575, and $2.589 trillion respectively.

3.2.3. Market Price Sensitivity Analysis Results

The optimal income for the 10%, 20%, 30%, 40%, and 50% increase in the market price are $2.788, $3.054, $3.320, $3.586, and $3.852 trillion respectively. While The optimal income for the 10%, 20%, 30%, 40%, and 50% decrease in the market price are $2.256, $1.990, $1.724, $1.458, and $1.192 trillion respectively.

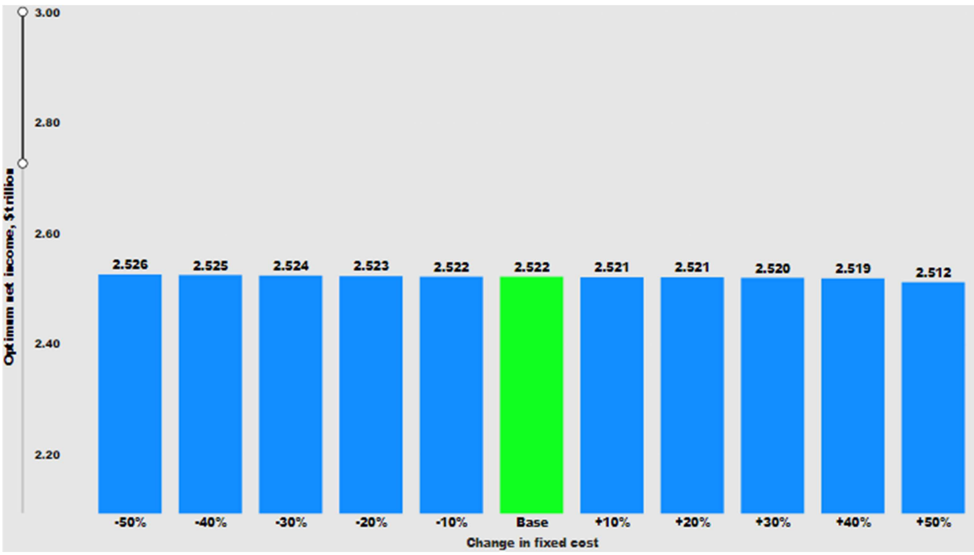

Figure 8. *Fixed cost sensitivity.*

4. Discussion

This model is quite similar to that found in the work published by Ogbe Emmanuel. However, the significant difference is the software used in finding the solution to the objective function. In his work, he used LINDO, while LINGO is employed here. LINGO is a more user-friendly software and provides a more accurate solution to a linear programming problem. It can handle numerous variables more efficiently. Another significant difference is the objective function itself as well as the set of constraints within which the objective function is bound. The objective function contains the different utilization options currently employed in Nigeria using current data which makes the model more efficient. Below are further discussions on the results provided by the software.

4.1. Fixed Cost Analysis

It is quite notable that the change in the fixed cost does not cause a significant change in the optimum income. As can be seen from the result, a percentage increase in the fixed cost reduces the optimal income, while the percentage decrease does the opposite. Also, throughout these increase and decrease in the fixed cost, it had no effect at all either on the optimal gas reserve required from the source (G remains 41.13264 Tscf) or on the optimal decision (all the utilization options maintained their non-zero value).

4.2. Variable Cost Analysis

Unlike the changes in the fixed cost, the change in the variable cost had a measure of significant effect on the optimal income. As can be seen from the result, a percentage increase in the fixed cost reduces the optimal income, while the percentage decrease does the opposite. Also, throughout these increase and decrease in the fixed cost, it had no effect at all either on the optimal gas reserve required from the source (G remains 41.13264 Tscf) or on the optimal decision (all the utilization options maintained their non-zero value).

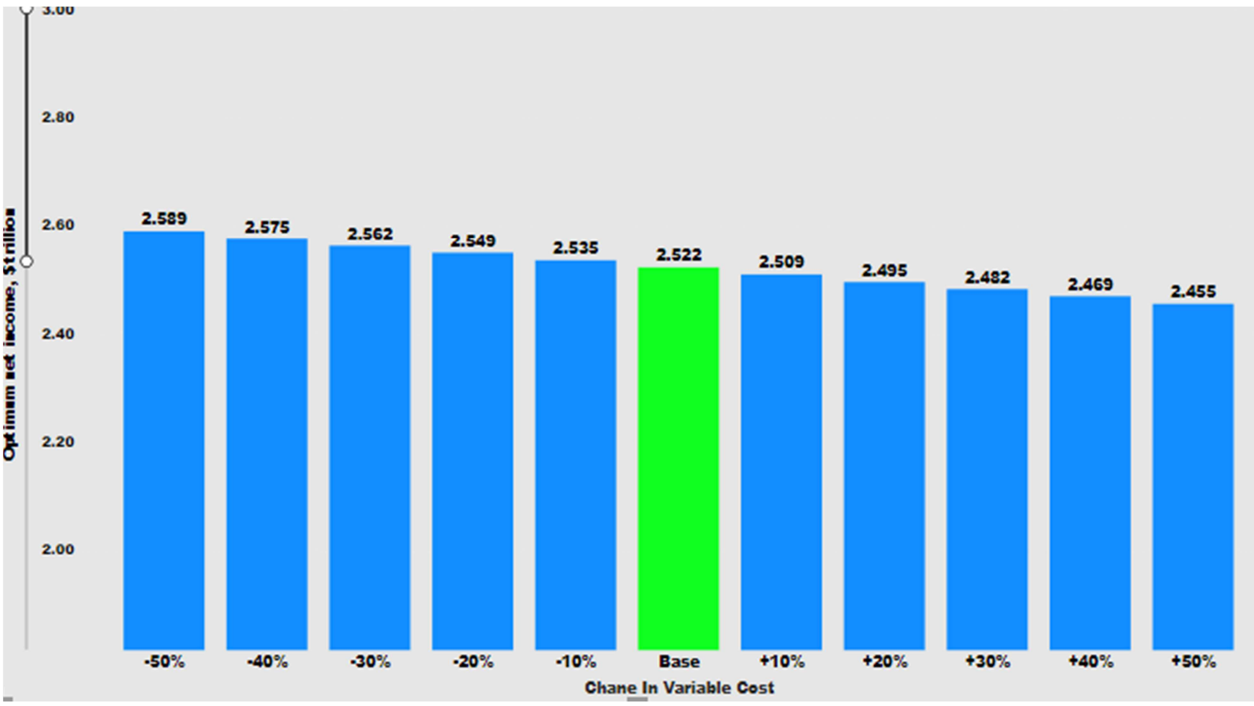

Figure 9. *Variable cost sensitivity.*

4.3. Market Price Analysis

Now unlike the optimal income seen with the change in fixed and variable cost, the optimal income with change in market price is very significant. And this time the percentage increase causes a significant increase in the value of the optimal net income. While the percentage decrease causes a significant decrease in the value of the optimal net income. These significant changes are due to the larger fluctuation in oil and commodity prices caused by factors ranging from environmental, political, etc. Also, throughout these increase and decrease in the fixed cost, it had no effect at all either on the optimal gas reserve required from the source (G remains 41.13264 Tscf) or on the optimal decision (all the utilization options maintained their non-zero value).

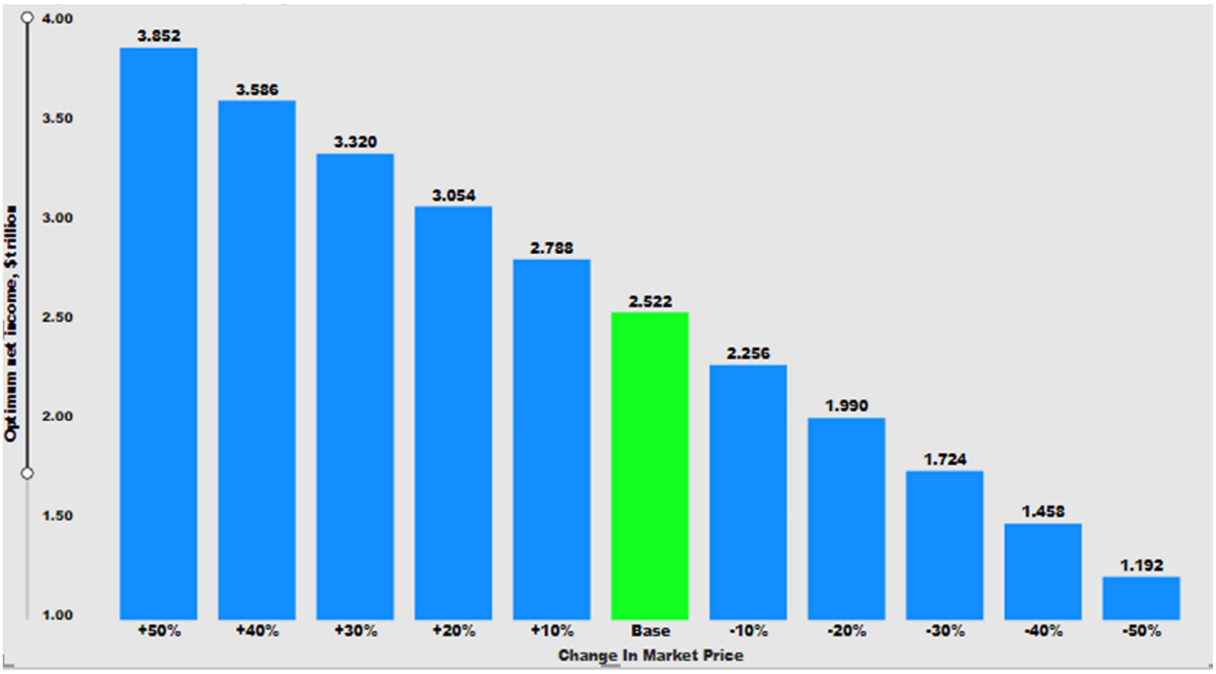

Figure 10. *Market Price sensitivity.*

5. Conclusions

Based on the model developed, for a 20-year contract period, the optimum net income generated is $2.522 trillion. It is also understood from the study that the volume of gas required to meet demand and generate that optimum net income is 41.13264 Tscf. Also based on the model developed for the Niger Delta in terms of Gas utilization, all the utilization options which are represented by nodes contribute to the maximized objective function. In other words, they are all profitable, from the base case through the sensitivity analysis keeping in mind the 20-year contract period. The utilization node/path that consumes the highest volume of gas is node "b" which is the Natural Gas Conditioning plant, about 23.341 Tscf. This volume is shared among four destination nodes, The Afam power plant, The West African Gas Pipeline, The Trans-Saharan Gas Pipeline, and domestic use by companies and households. The Trans-Saharan Gas Pipeline has the highest of this volume about 14.6 Tscf.

6. Recommendations

This model can be employed in a single field to obtain a better insight into the options for gas utilization whereby a decision can be taken on how to optimize the profit from that field, also several source nodes can be incorporated to emphasize the presence of several producing wells as well as many other utilization options.

Abbreviation

CNG: Compressed Natural Gas
LNG: Liquefied Natural Gas
LPG: Liquefied Petroleum Gas
NGL: Natural Gas Liquid
EIA: Energy Information and Administration
LINGO: Linear Interactive Numerical General Optimizer
G: Total gas volumes at the source in Tscf
MMBTU: Million British thermal unit
Q: Deliverability at the destination nodes, MMscf/d
Tscf: Trillion standard cubic feet per day
TSGP: Trans-Saharan Gas Pipeline Project
WAGP: West African Gas Pipeline Project
Y: mole fraction of gas or by-product at the destination node
MMscf/d: Million standard cubic feet per day

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