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DEVELOPMENT OF A FRAMEWORK FOR REDUCTION OF FLARE GAS IN AN OIL AND GAS PROCESSING ENVIRONMENT

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Abstract

Gas flaring is a major contribution to global greenhouse gas burden with a total volume of 100 billion cubic meters (BCM) flared annually. Russia is responsible for 35.5 BCM annually while Nigeria burns 18.27 BCM, equated to approximately $2 billion yearly. There is urgent need to therefore conduct research aimed at management of gas flaring with large economic and environmental benefits. This study has developed a sustainable framework to manage flare gas, incorporating inputs from government, legislation, industrial partners that generate energy, and environmental monitoring and enforcement agencies towards achieving significant reduction in gas flaring. The research method used semi-structured interview of key practitioners in an oil and gas industry (GASPROC) to obtain useful data on gas produced and flared; as well as gas utilised in two case companies – (ELECPROC 1 and ELECPROC 2). Data obtained were analysed using NVIVO software, and the data highlighted details of volume of gas utilised to generate electricity, the amount of electricity generated, and the volume of flared gas. Overall, the case company (GASPROC) flared about 8.33% of its total annual gas production (6.6 million cubic meters). Study recommends that 50 units of gas turbine with gas consumption and electricity generation capacities of 0.93 MCM and 150 MW each would be sufficient to utilise the flare gas and produce 7500 MW of electricity daily. A capital investment of £1.64b will generate a net profit of £1.26b/year, with a rate of return of investment on 16.3%. It is anticipated that adoption and utilisation of the framework will significantly reduce the volume of flare gas with considerable economic and environmental benefits.

Keywords: Gas Flare Reduction Framework; Gas-to-wire Technology; Gas Utilisation; Power Generation.

1. Introduction

From the inception of oil exploration, gas flaring has been continually practiced as a means of disposal of associated gas, basically for operational and safety reasons. However, the environmental concerns and natural gas sustainability have just become a global awareness in the past 30 – 50 years. Over 100 billion cubic meters (BCM) of natural gas is annually flared worldwide [1], as clearly shown in Figure 1, Russia is top on the list with 35.2 BCM, followed by Nigeria with 15.2 BCM. About 47% of the total gas produced in Nigeria is practically flared [2], which clearly signifies that the volume of flared gas in Nigeria is high.

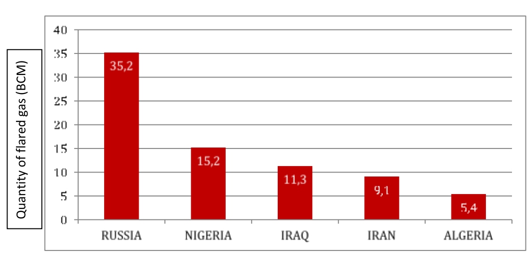

Figure 1. Representation of quantity of gas flared by top five flaring countries [1]

Nigeria has an estimated reserve of natural gas of 5.3 trillion cubic meters (187 trillion cubic feet) [3-4]. Its annual production of gas is 33.21 BCM, annual gas utilized is 14.94 BCM and the annual flared gas is 18.27 BCM [5]. Gas flare is associated with environmental, economic and health impacts and it is responsible for the release of about 300 million tons of of CO_2 per year into the environment [6], as well as pollution of the environment by Sulphur oxides [7]. It also destabilizes the ecology, and according to British Petroleum [8] Nigeria losses $2.5 billion annually due to gas flare during oil and gas processing.

There is urgent need to minimise and if possible eradicate gas flaring to help reduce the impacts that are associated with it. Thomas and Dawe [9], and Odumugbo [10] have recommended technologies for reduction of flared gas; yet huge volume of gas flaring still persists, especially in developing countries. There is a need, therefore to develop a methodology that should significantly minimise the current volume of flared gas. This study is structured to develop a framework, which should guide governments, lawmakers and practitioners on how to convert gas that should have been flared into energy, while minimising environmental pollution.

2. Literature review

2.1. Gas flare reduction through Gas-to Wire technology

Electricity generation with power cycle is one of the methods suitable for systemic reduc-tion and or elimination of gas flare. The basic principle of the power cycle requires burning gas in a gas turbine (GT) and producing power which can be converted to electric power by a coupled generator. This type of power generating plant is installed in increasing num-bers around the world where substantial quantities of natural gas is abundant [11]. It pro-duces high power outputs at high efficiencies and low emissions. Gas turbines can also be used in simple cycle mode for base load mechanical power and electricity generation in the oil and gas sector where natural gas and process gases have been used as fuel and their maintenance costs are much lower than those for liquid fuels. According to Meetham [12], the gas turbine has its advantages, which include the following:

- ✓ Fuel flexibility: the gas turbine has the capability to burn various qualities of gases than other reciprocating engines.
- ✓ Few number of moving parts: with less moving parts comes cheaper cost of maintenance.
- ✓ High availability
- ✓ Less vibration as well as noise.
- ✓ It is compact

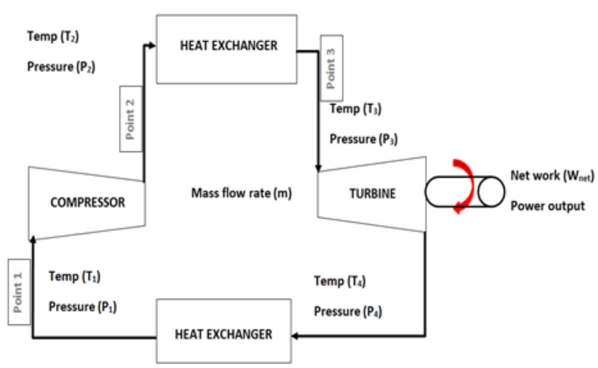

Figure 2. A Flowchart of the Brayton Cycle
(Adapted from Rahimpour et al. [11])

Figure 2 shows the Brayton cycle, which is one of the most efficient cycles for the conversion of gas fuels to electricity [13]. At entry point 1, the air which enters the plant comes from the atmosphere to the compressor where the pressure is ramped up from atmo-spheric pressure to 23 bar. At point 2, the compressed air then passes to a combustion chamber and blends with natural gas where combustion takes place. At point 3 of the cycle, hot gases are directed to the gas turbine where they expand to the atmospheric pressure and the gas energy is converted to mechanical energy which generates electricity. Exhausted gases are subsequently discharged from the gas turbine at point 4 of the cycle.

Figure 3 shows the T-S diagram, which is a conceptual thermodynamic cycle made up of a very small set of components. This cycle could either be an open gas turbine cycle or a closed gas turbine cycle; and is made up of two adiabatic and two constant processes. It is made up of four processes, with either a gas or a mixture of gases as working fluid. The first process is known as an adiabatic compression, the second process is the heat supply at constant pressure, the third process is an adiabatic expansion, and the fourth process is known as a release heat at constant pressure.

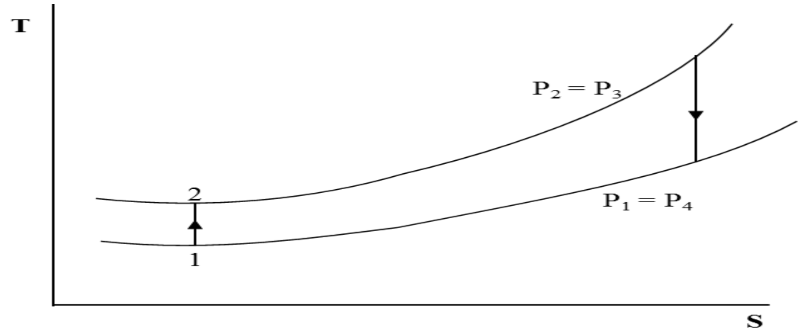

Figure 3. T – S Diagram illustrating the stages in Joule-Brayton Cycle [14]

The use of GTW technology for gas flare reduction has been simulated in a refinery in Iran by Rahimpour *et al.* [11]. It showed that the estimated capital investment is high; however, it also showed that the rate of return of investment is high. The simulation was carried out using gas flow rate of 356.5 million standard cubic feet of gas per day (MMSCFD) into the turbine. This process produced 2130 MW of electricity daily. Subsequently, a study by Ojijiagwo *et al.* [15], using Nigeria as a case study, showed that GTW technology is economically viable in flare gas management. It highlighted an estimated annual net profit of £1.64b from an estimated capital investment of £1.26b, as well as a generation of about 7,500 MW of electricity. Therefore, GTW could be a way forward for gas flare minimization, which also comes along with financial incentives from sales of electricity.

3. Methodology

Semi-structured interview survey was used to collect information for this study. Five key personnel from three companies (one gas producing and flaring company, and two electricity generation and distribution companies) were interviewed. The choice for the case companies and interviewees was based on the fact that results from the interview will guide development of a framework for gas flare management, which should be beneficial to the case companies. Table 1 shows key members of staff and levels of experience of the interviews.

Table 1. Demographics of key personnel from the interviews

Case Company	Key Personnel	Year of experience
GASPROC	Production Manager	20
	Health and Safety Manager	23
	Operations Supervisor	15
	Field Operator 1	22
	Field Operator 2	10
ELECPROC 1	Power Plant Operator	11
	Operations and Maintenance Manager Electrical	18
	Maintenance Repairer	12
	Technical Manager	6
	Shift Supervisor.	22
ELECPROC 2	Power Plant Operator	10
	Operations and Maintenance Manager	5
	Electrical Maintenance Repairer	16
	Technical Manager	2
	Shift Supervisor.	7

Apart from interviews, official company documents such as memoranda, agendas, minutes of meetings, progress reports, administrative documents and newspaper articles from the case companies were also used to confirm volumes of gas produced, utilised and flared in Nigeria. They also provided the reports for plant inspection, equipment status, workflow, and staff strength within these case companies.

Gas to wire (GTW) economics data from Ojijiagwo *et al.* [15] using ALSTOM GT13E2 turbines, whose primary parameter are shown in Table 2 was integrated into this study. In total, this study provided an estimate of 50 units of gas turbine of 150 MW capacity each, and generating a total of 7,500 MW of electricity in Nigeria. A unit of ALSTOM GT13E2 consumes a total of 0.93 million cubic meters (mcm) of gas per day and generates 150 MW of electricity; therefore this process established the utilization of 16.97 BCM of gas per year (930,000 x 50 x 365) and generation of 7,500 MW of electricity. This highlights that with GTW technique, gas flaring could be reduced from an annual flare rate of 18.27 BCM to 1.3 BCM in Nigeria (see Ojijiagwo *et al.* [15]).

Table 2. Primary performance parameters for GT13E2 Turbine [16]

Fuel	Natural Gas	Fuel	Natural Gas
Frequency	50 Hz	Thermal Efficiency	36%
Gross Electricity Output	150 MW	Turbine Speed	3000 rpm
Gross Electricity Efficiency	36.4%	Fuel Gas Temperature	31°C

These data was analysed and systematically used for the development of a gas flare reduction framework, which provides a methodical process for management of flare gas in oil and gas processing environment. Using the NVIVO software, the collected data were coded into nodes and put into categories which covered major areas of concerned such as gas production, utilisation, and flaring. Categories were further grouped into themes such as gas flare management and gas production and utilisation themes as seen in Figures 4 and 5 respectively. Some of the main categories forming the gas flare management theme are causes of gas flaring; issues with flared gas; and funding issues. While for gas production and utilisation, some major categories are demand by users, daily production, availability of customers, electricity generation companies.

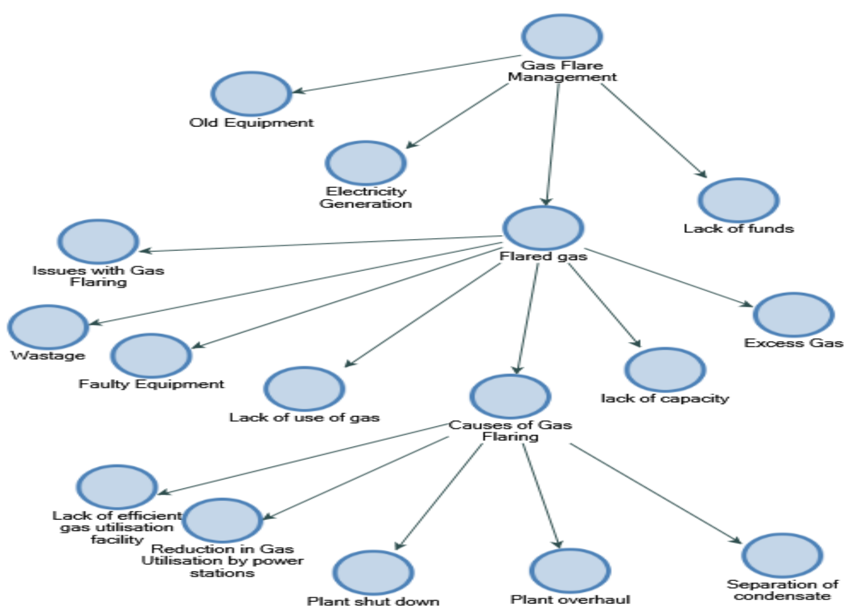

Figure 4. Gas flare management theme

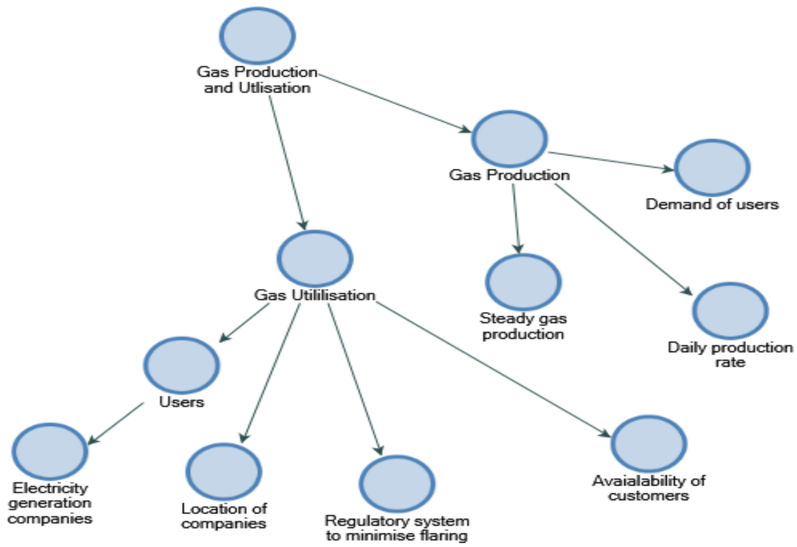

Figure 5. Gas production and utilisation theme

4. Discussion

4.1. Gas production, utilization and flaring

GASPROC produces 240 million standard cubic feet per day (mmscfd). Of this capacity, ELECPROC 1 receives 50 mmscfd; while ELECPROC 2 is directly supplied with and utilizes 120 mmscfd. Furthermore, 50 mmscfd is supplied to a third organisation, through existing manifold and pipeline. The remaining 20 mmscfd is subjected to constant flaring. However, in a situation whereby the demand is less, there is a regulatory system which sends signal to the gas production plant to minimise production to reduce waste (flaring).

4.2. Gas utilization and electricity generation

Data retrieved from the three case companies highlights the impact of GTW on flare gas reduction using ALSTOM GT13E2 gas turbine. A reduction in volume of gas flare as well as potential amount of electricity generated with specified units of gas turbine are presented in Table 3.

Table 3: Data on Electricity Generation from Gas Turbines

No. of Gas Turbine (150 MW capacity)	Vol. of gas used daily (M^3)	Electricity produced daily (MW)	Vol. of gas used yearly (M^3)	Electricity produced yearly (MW)
1	930,000	150	339,450,000	54,750
2	1,860,000	300	678,900,000	109,500
5	4,650,000	750	1,697,250,000	273,750
10	9,300,000	1,500	3,394,500,000	547,500
15	13,950,000	2,250	5,091,750,000	821,250
20	18,600,000	3000	6,789,000,000	1,095,000
25	23,250,000	3,750	8,486,250,000	1,368,750
30	27,900,000	4,500	10,183,500,000	1,642,500
35	32,550,000	5,250	11,880,750,000	1,916,250
40	37,200,000	6,000	13,578,000,000	2,190,000
45	41,850,000	6,750	15,275,250,000	2,463,750
50	16,972,500,000	7,500	16,972,500,000	2,737,500

It shows that one unit of gas turbine with a capacity of 150 MW can utilise 930,000 m^3 of gas on a daily basis, and this amounts to 339,450,000 m^3 of gas over a period of one year. 930,000 m^3 of gas produces 150 MW of electricity daily; while in one year, 339,450,000 m^3 of gas produces 54,750 MW of electricity. These figures double when the number of gas turbine is increased to two. The amount of electricity generated is directly proportional to the volume of gas utilised, while the volume of gas utilised is directly proportional to the number of turbines.

Figures 6 and 7 have been used to describe the effect of number of gas turbines on gas flaring and electricity production respectively. The graph in figure 6 is in relation to Table 3 and based on ALSTOM GT-13E2 with capacity of 150 MW. It clearly shows a proportional increase in gas used with increase in the number of gas turbines.

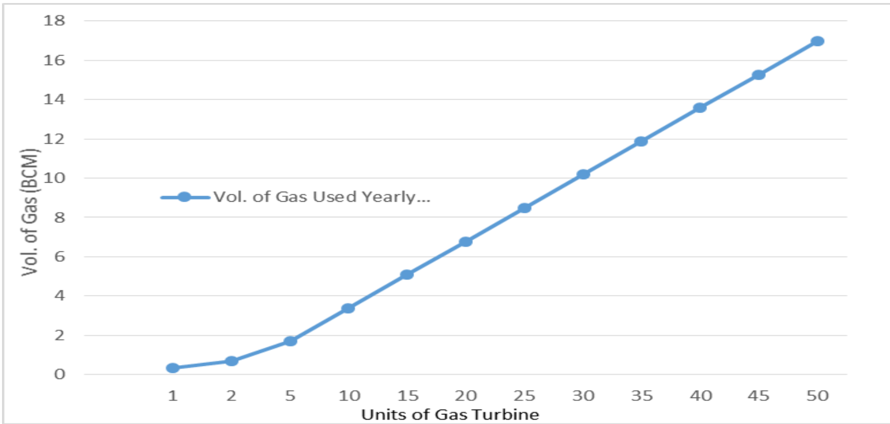

Figure 6. Graph showing units of gas turbine used versus volume of gas reduced

Figure 7 shows a plot of gas turbine units against electricity produced. For example, 50 units of gas turbine generate 7,500 and 2,737,500 MW of electricity daily and yearly respectively. Subsequently, 10 units of gas turbine generate 1,500 and 547,500 MW of electricity daily and yearly respectively.

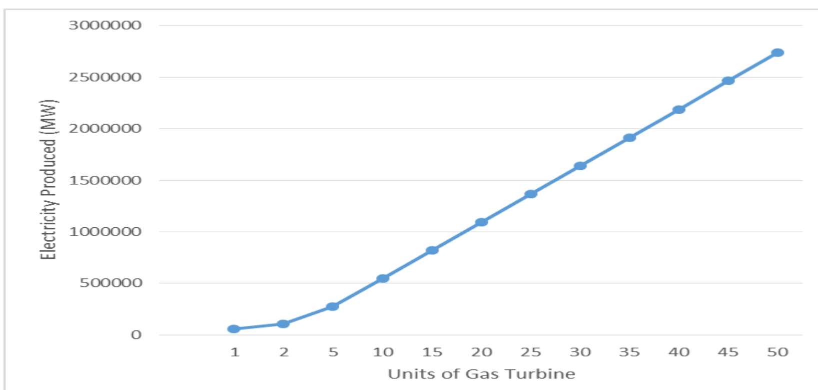

Figure 7. Graph showing units of gas turbine used versus electricity generated

5. Development of gas flare management framework

To develop the gas flaring management framework, eight (8) variables were considered and used as guides to show process flow and identify trend of reduction level of gas with the help of the gas flare reduction framework.

<u>Variables and Mathematical Structure for the Framework:</u>

These variables are explained as follows:

i. T: Total gas produced on an annual basis. This is measured in billion cubic meters (BCM).
ii. Y: Quantity of gas current utilized. Volume of gas that is currently consumed through different technologies after production.
iii. X: Estimate of potential flare gas. Total volume of gas that could be flared after production.

iv. Q_1: Quantity of gas saved from flaring, which could be diverted to GTW, GTL, LNG, and Re-injection processes.
v. Q_2: Additional quantity of gas recovered from flare stack (converted only as a result of huge volume of gas still remaining for flare after Q_1).
vi. Q_3: Residual quantity of flare gas. This is the final volume of flared gas.
vii. Y_f: Final estimated utilized gas. Total volume of gas consumed after certain volume has been converted from the initial potential flare gas.
viii. Z: Finished product converted from the potential flared gas. With respect to GTW, this is electricity (measured in MW), and this is dependent on some variables such as prime quantity of gas converted; secondary quantity of gas converted; units of turbine; thermal efficiency.

This is mathematically stated as:

$Z = f(Q_1, Q_2, \text{units of turbine, thermal efficiency})$.

The equations (1)-(6) are useful for the determination of the variables used in the framework for management of gas flaring:

$$Y = T - X \ldots \quad (1)$$
$$X = T - Y \ldots \quad (2)$$
$$Q_1 = X - (Q_2 + Q_3) \quad (3)$$
$$Q_2 = X - (Q_1 + Q_3) \quad (4)$$
$$Q_3 = X - (Q_1 + Q_2) \quad (5)$$
$$Y_f = Y + (Q_1 + Q_2) \quad (6)$$
$$Z = f\,(Q_1, Q_2, \text{units of turbine, thermal efficiency}) \quad (7)$$

Also, prior to developing the gas flare management framework, the following factors were considered:

i. Volume of gas produced: involves the total volume of gas that is produced annually either from associated gas or non-associated gas deposits
ii. Volume of gas utilized: includes the annual gas utilization after production for various needs, through different technological approaches like Gas Re-injection, Gas to Liquid, Gas to Electricity, Liquefied Natural Gas, Gas to Methanol, as well as through other technologies.
iii. Volume of gas flared: during the production of crude oil, most of the associated gas is flared. Therefore this section is responsible for any part of the gas that is produced, but not utilized. In a simple statement, any gas that is not utilized after production is subjected to flaring. This volume is measured per annum.
iv. Reason for gas flaring: it is common knowledge that gas flaring is wasteful and contributes to greenhouse gas in the environment among other negative impacts; yet, it is a common practice in the oil and gas sector. Therefore, this study reviewed the reasons for continuous gas flaring in the oil and gas industry, particularly in Nigeria.
v. Agreement among stakeholders: this study also demonstrated the link between gas production/flaring organizations and the electricity power stations.
vi. Positive contribution from the government: government laws and bills play roles in encouraging and supporting the reduction of gas flaring. For instance, promulgation of incentives like of tax holiday or tax could encourage investment towards gas reduction technological. Rather than wasteful flaring, money meant for taxation could be channelled towards gas reduction technologies. Also the government could have a joint business venture with these oil and gas firms to support and encourage investment towards gas flare reduction technologies.

DATA FOR THE FRAMEWORK:

i. The figures below are based on an annual statistics from Nigeria regarding gas production, utilization, and flaring.
ii. Total gas production: 33.21 BCM per year
iii. Currently utilized gas: 14.94 BCM per year
iv. Potential flare gas: 18.27 BCM per year

v. Estimated units of turbines required to utilize potential flare gas: 50 Unit of 150 MW capacity each
vi. Potential extra gas usage (from potential flare gas): 16.97 BCM per year. As seen from the framework, this figure is realized by subtracting the final potential flare gas from the current potential flare gas. This could be mathematically stated as: $X - Q_3$
vii. Expected amount of electricity generation: 7,500 MW per day (150 MW per turbine)
viii. Estimated capital investment: Table 4 is an extract from Ojijiagwo *et al.* [15], and gives a breakdown of the capital investment on GTW in Nigeria
ix. Expected net profit per year: Table 5 highlights the expected net profit per year (£1.26b) in the estimated income and return statement for a typical Nigerian power plant.

Table 5. Estimated income and return cost statement [15]

Caption	Value
(a): Cost of sale of electricity	£0.07/kwh
(b): Total cost of electricity sale/year	£4,599,000,000
(c): Product Cost for turbines operation	£0.007/kWh
(d): Total product cost for turbines/year	£459,900,000
(e): Fixed Charges	£689,850,000/Year
(f): Break-even Point Capacity	10,950,000,000 kWh
(g): Yearly income in B.E.P Capacity	£766,500,000
(h): Capacity of turbines Per Year	65,700,000,000 kWh
(i): Total Cost	£2,792,935,000
(j): Total Yearly Income	£4,599,000,000
(k): Gross Profit	£1,806,065,000/year
(l): Net Profit	**£1,264,245,500/year**
(m): ROI	16.3%/year

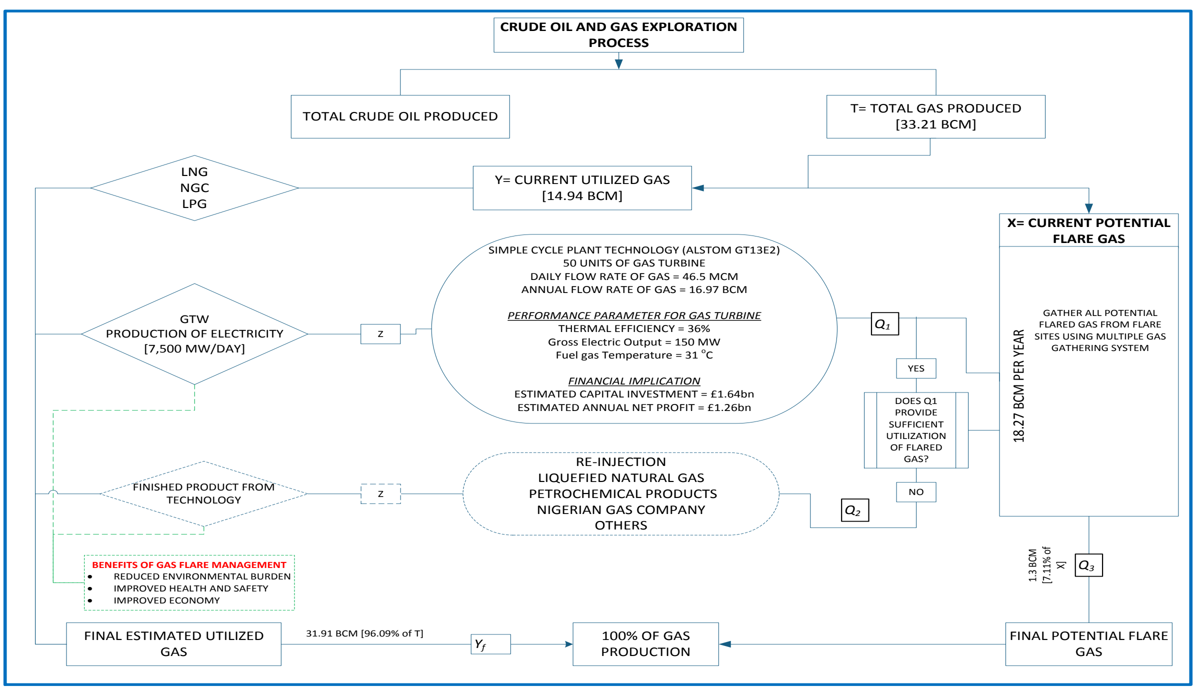

Figure 8. Framework for gas flare minimization in an oil and gas processing environment in Nigeria

The framework for gas flare minimisation demonstrates a guide for gas flare reduction. First, it highlights the total volume of gas produced annually in Nigeria (33.21 BCM), shows the volume of gas currently used (14.94 BCM), and the volume of gas wasted through flaring (18.27 BCM). To significantly minimise the amount of flared gas, Q_1 (gathered through pipelines) is converted to GTW. This serves as fuel for simple cycle gas turbines of 150 MW capacity each, with thermal efficiency of 36%. A single gas turbine of this capacity utilises 0.93 million cubic meters (MCM) per day, equivalent to 46.5 MCM per day for 50 units of gas turbine. The cost breakdown includes an estimated capital investment of £1.64b for the purchase of gas turbines, which generate an annual estimated income of £1.26b from annual sales of 7500 MW of electricity generated from 50 units of gas turbine.

The framework for gas flare minimisation also accommodates other technologies by providing an option to combine other gas flare management technologies. This is beneficial when GTW technology is not capable of utilising all the potential flared gas. Therefore, Q_2 (secondary quantity of gas) is converted for use as an alternative technology like LNG, re-injection or GTL.

The adoption and accurate application of this framework will significantly reduce gas flaring in Nigeria by 92.89%. The framework also has other benefits aside gas flare reduction, such as reduced environmental impact, improved environment, and improved health and safety.

6. Conclusions

Data from literature and case study companies carried out in this study showed that Nigeria has an estimated reserve of natural gas to the tune of 5.3 trillion cubic meters (187 trillion cubic feet) [3-4]. Giwa *et al.* [5] also state that the annual production of gas in Nigeria is 33.21 BCM; annual gas utilized through liquefied natural gas, Nigerian gas company (for electricity generation), and liquefied petroleum gas is 14.94 BCM; while the annual flared gas is 18.27 BCM. The gas flare reduction framework developed by this study is technically not expected to totally stop gas flaring; rather it is aimed at proposing to develop viable measures to minimize gas flaring to a significant level.

The GTW technology was chosen as the preferred technology for gas reduction in Nigeria, firstly because it is a sustainable means of gas utilization. This is because according to Ahmed, Bello and Idris [3], electricity is accessible to less than 40% of the Nigerian population; while Iwayemi [17] highlighted that the electricity production and supply in Nigeria is faced with a huge challenge of inadequacy; also, Ojijiagwo *et al.* [15] showed in a separate study that GTW is economically viable for gas flare management. Overall, GTW technology ensures constant use of gas by gas turbines, and could also guarantee improved electricity generation and supply in Nigeria.

This research also took into cognizance the fact that Nigeria is a huge country and potentially one of the leading global economies. However, such potential will rarely be achieved with the epileptic or poor nature of electricity production and supply in Nigeria. Therefore apart from the fact that this framework will minimize waste, improve financial input to the country, reduce environmental hazards, as well as minimize other negative impacts associated with gas flaring, it will also alleviate erratic the electricity supply scenario of Nigeria, and thereby help to achieve Nigeria's potential as a leading global economy.

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