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A Comparative Study of Liquefied Natural Gas and Pipelines as Means of Transporting Natural Gas in Nigeria

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Abstract—**This paper focuses on the methods of exporting natural gas from Nigeria. The aim of this study is to make a comparison between LNG and Trans-Saharan gas pipeline (TSGP) Systems for exporting natural gas from Nigeria. This research used both primary and secondary methods of data collection. Primary data was favoured due to inadequate data from secondary method. The quantitative data was used to review the work of previous scholars and experts in the oil and gas industries while the qualitative used was in the form of questionnaires and interviews. The study has shown that the capital cost of six LNG trains is $9.348 billion while that TSGP is $13 billion and the operating costs per unit of production with LNG is $2.78 and that of TSGP is $3.10. In this study, it was projected that the construction of TSGP will commence by 2015 at the cost of $19.383 billion and to be completed by 2020 at the total cost of $31.943 billion at constant inflation rate of 10.5%. In addition, the research has shown that, from a distance of 3000km, LNG is more competitive than the TSGP. This study also highlights that LNG is more environmental friendly, secure, cheaper and increased security and diversification in supply systems of natural gas as compared to pipelines. Generally, building more LNG plants in Nigeria is more competitive to the gas market than concentrating on the proposed trans-Saharan gas pipeline.**

Keywords—Pipelines; Power generation; Gas production; Capital cost; LNG

I. INTRODUCTION

The oil and gas industry is regarded as the motivating factor of the global economy growth. Without the exploration and production of oil and gas, the global economy growth would have not reached this far; our daily usage of oil and gas products are evident in all aspect of our lives [1]. Increase in population and rise in economies are the major causes of the increase in global energy demand. The global energy is anticipated to increase by the average of 1.3 per cent per year and the natural gas consumption is predicted to account for approximately a quarter of world energy consumption by 2030, up to about 20 per cent from now [1]. Currently, about 80 per cent of the global energy demand is provided by oil, gas and coal (fossil fuels) as a result of their affordability, abundance and availability [2]. According to Li et al [3], China meets about 90 per cent of its power demand with coal, will see its energy needs for power generation increase above double by next century surpassing America's demand by more than one third. The natural gas industry is predicted to be helpful in meeting this increasing global energy demand. The stability of natural gas supply is important for the efficient operation of the gas industry.

Natural gas transportation by pipelines accounts for about 75 per cent of the total volume of gas transported globally [4]. It is economical and convenient to use pipeline for gas transportation from offshore to onshore locations for processing or to interface with the existing distribution lines [5]. However, the use of pipelines for gas supplies have some shortcomings; it is not viable to use a pipeline at a depth of more than 100m below sea level, pipelines are permanent fixtures from production fields to consuming areas, gas supplies via pipelines are affected by pressure differential [6]. Similarly the use of pipeline is not feasible as a result of distance, security, environmental impacts or geopolitical differences. According to Pifer [7], the geopolitical differences between Russia and Ukraine disrupted the supply of gas from Russia to Europe. Thus, in these situations the transportation is best done by LNG.

In Nigeria natural gas are also supplied through pipelines and LNG transportation within and outside the country. The country has about 187TCF of proven natural gas reserves and is regarded as the seventh largest holder of natural gas proven reserve globally [2]. The exploration and production of natural gas in Nigeria is done under oil mining leases (OMLs) which are mostly operated under the term of Joint Venture (JV) with Nigerian National Petroleum Corporation (NNPC) or production sharing contracts (PSCs) granted by NNPC on a basis of sole risk by indigenous companies [8]. In year 2008, Nigeria exported 1400BCF of natural gas to global consuming market and this include: Spain, France, Portugal and USA through LNG. It also exports 170MMCFD of natural gas to Togo, Benin and Ghana through the West African Gas Pipeline [2].

The largest exporter of natural gas in Nigeria is the Nigerian Liquefied Natural Gas Company, a joint venture established by NNPC, Shell Petroleum Development Company (SPDC), Agip and Total EP. The company operates six trains with total production capacity of 22MTPY. In 2008 the country exported about 1400BCF of gas into global consuming market such as Spain, France, Portugal and USA. Other proposed LNG projects in the country are OK LNG, Brass LNG and Progress LNG [2]. The country's major domestic gas player is the Nigerian Gas Company owned and operates about 1100km of pipelines transmission systems ranging from 4 to 36 inches in diameter, with total design capacity of greater than 2 billion standard cubic feet per day, 14 compressor stations and 13 metering stations. This equipment represents the current assets base of more than 2 billion naira [9].

LNG is a liquid combination of lighter hydrocarbons in which methane constitute the larger proportion of about 95% [10]. The other smaller constituents of LNG are: ethane, propane, and nitrogen with little of n-pentane, n-butane, i-pentane and i-butane [10] . LNG is cleaner than oil and coal and it offers an opportunity for diversification of energy supply and characterized with a unique advantage whereby, after the liquefaction their volume is reduced about 630 times. LNG is non-toxic, non-corrosive and non-explosive and its fast vaporization properties make it safe and convenient means of transportation via vessels for long distances [11].

II. NATURAL GAS SUPPLY AND PRODUCTION

Natural gas is becoming an increasingly valuable resource for global energy market; its importance cannot be overemphasized. According to Cabalu [12], many countries around the world depend on natural gas for power generation. In 2008 natural gas supplied more than 24% of the total primary energy demand [13]. According to Cabalu [12] the global demand for natural gas is expected to rise in the future due to increase in the number of natural gas fired power plants, increase in petrochemical and agro-allied industries, its low environmental impact and ease of use. The efficient means of transporting natural gas is either by liquefaction or pipelines [14]. According to IEA [15] natural gas transportation through pipelines is not economically viable for a distance more than 3800km onshore and a distance more than 2000km for offshore pipelines. To some certain extent, pipeline transport is considered not friendly to the security of supply due to geopolitical differences vandalism and terrorism. Despite the challenges, pipeline transport dominates international traded gas, notable among them are Russia to Western Europe, supply from Canada to USA, North Africa and Norway [2]. However, as a result of its environmental impact, improved technological advancement and reduction in liquefaction costs led to rapid increase in LNG transportation [14]. According to Dahan [16], the liquefaction costs was reduced by 30 per cent which led to rise in LNG production in many countries around the globe in other to meet the growing demand of natural gas. In 2008 the global production of natural gas was about 108TCFPY mostly produced from Eurasia and North America [17]. Fig. 1 below shows global natural gas production share by regions [13]. However, in 2009 the production increased to 2,987BCMPY.

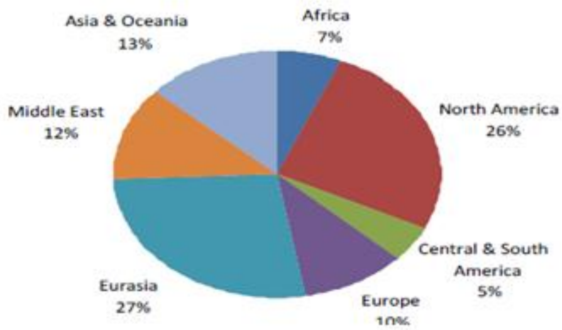

Fig. 1 Global gas production [13]

The natural gas production in Africa was 17BCF in 2005 and rose to 20.7BCF in 2008; it fell to 19.7BCF in 2009. In spite of huge production capacity, Algeria is the leading producer of natural gas in Africa representing 2.7 per cent of the global share in 2009 followed by Egypt 2.1 per cent and Nigeria 0.8 per cent [18]. Fig. 2 below shows the natural gas production in billion cubic feet per day in some African countries. `

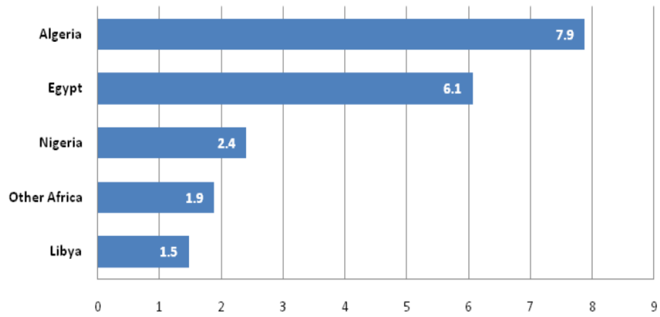

Fig. 2 African natural gas production [13]

A. *LNG Market*

Spaulding et al [19] projected that the global LNG trading will rise to about 35 per cent due to the increasing demand of natural gas and lower production cost of LNG. The gas trade in the Asian Pacific region are mostly in the form of LNG, in fact Asia Pacific dominates the global LNG market (Kumar et al [14]. The major importers of LNG in Asian Pacific are Japan Korea and Taiwan while the major importers in the region are Indonesia, Malaysia, Australia and Brunei [20]. In 2008 Japan imports about 67.25MTPA, South Korea

26.68MTPA, and Taiwan 8.81MTPA. The same year Malaysia export was about 21.6MPTA, Indonesia 19.6MTPA and Australia 14.77MTPA [13]. The other emerging LNG markets in Asia are India, China and Mexico. It was projected the LNG use will rise to 12 per cent in India and 45 per cent in China by 2011[14] . The Asia Pacific region imports about 10 to 15 per cent of its LNG from Alaska and Middle East including Abu Dhabi, Qatar and Oman [14]. The demand for LNG in Asian Pacific is very robust and is expected to rise by double in 2015 [2]. The increase in LNG in Asian Pacific is attributed to established market of Japan, Korea and Taiwan. The gas consumption in Europe increased from 324BCM in 1990 to 555BCM in 2004 which corresponds to 2.2 per cent annual growth rate [15]. The increase in gas trading in the region is attributed to the rise in gas powered plants. Pipeline accounts for 85.53 per cent of total gas import to the region. In 2003 Russia imported 107.56BCM of gas to Europe which is equivalent to 44.50 per cent of the total gas imported followed by Norway and Algeria imported 68.37BCM and 30.79BCM respectively [20]. LNG accounts for 14.47 per cent imports to the region [20]. In 2007 Algeria imported 15.97MPTY which made it the largest importer of LNG in the region followed by Nigeria 14.99MPTY while the region major consumers of LNG are Spain, France, Turkey and Belgium [20]. Fig. 3 below shows the gas exported to Europe in 2003 and Fig. 4 shows gas traded by countries.

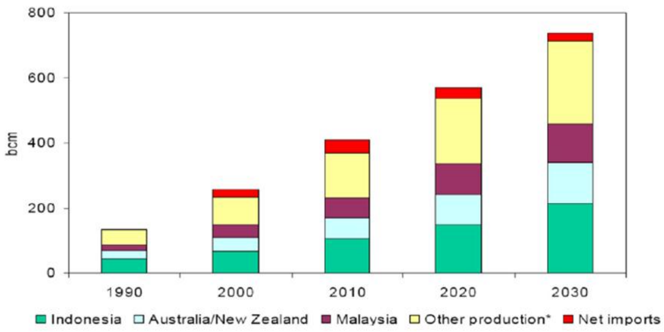

Fig. 3 Europe gas import [21]

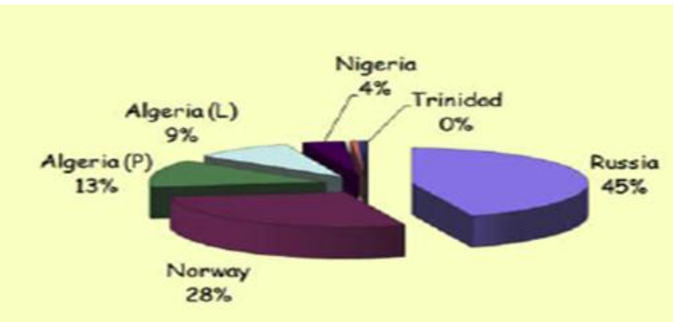

Fig. 4 Gas traded by some countries [20]

1) Nigerian LNG Market

Nigeria is the ninth largest holder of natural gas proven reserves with about 187TCF [2]. The country's main liquefaction project is the Nigeria Liquefied Natural Gas (NLNG) on Bonny Island completed in 1999. Currently, NLNG operates about six trains with production capacity of 22MTPA. In 2009 Nigeria exported about 500BCF of LNG and most of the country's exports go to Europe with Spain 31 per cent, France 15per cent, Portugal 13per cent[2]. Other export destinations include Asia 15 per cent, Mexico 16 per cent and America 13 per cent. In 2010, Nigeria exported about 41BCF of LNG to U.S which is equivalent to 10 per cent of the country's total exports and representing about 1 per cent of U.S total imports [2]. There is expected additional start-ups of seven additional LNG train from the country in 2012 but postponed till 2016. The OK LNG has 4 trains, Brass LNG 2 trains and Progress LNG 1 train [2].

2) LNG Technologies

LNG technology refers to as a process in which natural gas is converted to liquefied natural gas by lowering its temperature to -162°C [11]. These technologies are selected based on technical and economic consideration. The production of LNG may involve; liquid and gas reception, purification of gas, liquefaction, liquid and LNG storage, LNG and liquid transfer systems. The global first liquefaction plant was constructed in Ohio in 1941 with production capacity of about 2000TPY. These brought about development of more improved technologies to fast tract the liquefaction, re-gasification and storage of LNG. The LNG technologies are as follows C3-MR, Dual mixed refrigerant, Cascade, Single mixed, refrigerant and AP-X.

Cascade technology is regarded as early technology built by Conoco Philips to modify a process used in Alaska in 1960s. This technology functions with the help of three pure refrigerant components namely methane, propane and ethylene in a close loop [22]. For this technology, the feed gas is generally cooled at -35°C in the propane cycle and it further cooled to -90°C at the ethylene cycle, and lastly the natural gas liquefies to -155°C at the methane cycle. However, in 1990s the Conoco Phillips modified the close cycle loop to open cycle loop [23]. In the open cycle loop, the natural gas is sub-cooled, chilled and condensed with methane, propane and ethylene at different stages in heat exchangers with the refrigerants having multistage expansion and compression at different temperatures. This liquefaction technology was developed to meet the increasing challenges of the arctic and cold regions. This technology requires less power than any other technology to drive it [24].

Single Mixed Refrigerant is a technology in which the refrigerant is compressed and circulated using a single compression train [22]. The technology is made of one unit of liquefaction exchanger, compressor, compressor driver and a refrigerant. The technology is generally used in a base load liquefaction and it is associated with very low efficiency of performance as compared to other liquefaction technologies [23]. The technology is often used in offshore liquefaction and it requires the LPG storage refrigerant to increase the safety issues in confined areas.

C3MR is a technology that consist of two refrigerating cycles which includes: the pre-cooling cycle which has propane refrigerant and sub-cooling cycle which is made up of mixed refrigerants ethane, methane and nitrogen which are used for partial separation of liquefied gas into vapour and liquid [22]. The feed gas is pre-cooled to about 238K by propane while the mixed refrigerant in the sub-cooling further reduces the temperature to about 123K [25]. The cooling in this process is done by Kettle type heat exchangers. The C3MR technology was developed to prevent flaring by using the high shell side pressure application and it is characterised with high thermal efficiency as compared to single mixed refrigerant technology.

Dual Mixed Refrigerant is a technology invented by SHELL Petroleum to conquer C3MR limitations. The techniques consist of two wound heat exchangers, one for pre-cooling and the other for liquefaction. The cooling is done by two refrigerants thus propane and methane which are usually done by wound heat exchangers at difference temperatures instead of the kettles [25]. The technology has advantage that the pre-cooling refrigerant combination can be adjusted to different temperatures on a regular basis. It is driven by gas and can be found in operation in many places including the Sakhalin Island project of 4.8MTPY capacity for each train [23]. This technology has an excellent liquefaction capacity if the hydrocarbon inventory is being reduced.

AP-X is regarded as improved C3MR technology because of additional pure nitrogen sub-cooling loop after the spiral wound heat exchanger. The aim of the modification is to increase the efficiency of the technology. The added pure nitrogen loop is driven by a compressor.

Mixed Fluid Cascade is a technique that uses three mixed refrigerants which are selected from ethane, nitrogen, propane and methane. These mixed refrigerants are used both in the liquefaction and cooling process. This technology is driven by electric refrigeration compressors. This technology has advantage of operating in arctic climate and it was selected in SnQhvit LNG project in Norway.

Dual Nitrogen Expander is a technology that is regarded as safer compared to other technologies due to the inert characteristics of nitrogen refrigerant in the process which has low thermal efficiency. This technology uses two different cycles which are independent of themselves. The initial cycle usually utilizes methane while the second one utilizes nitrogen [23].

Kryopak Expansion is an LNG technology that functions through isentropic expansion that utilizes the gas as inlet refrigerant instead of mixed refrigerant. This process is alike with single mixed refrigerant. Table I below shows a comparison of some offshore LNG technologies.

Table I: Comparison of offshore LNG technologies [26]

	C3-MR	Cascade	SMR	DMR	MFC	N2 Expander	Krypak Expander
Thermal Efficiency	High	High	Medium	High	High	Low	Low
Equipment Count	Medium	High	Low	Medium	Medium	Medium	Low
Precooling Exchanger	Kettle	Core-in Kettle	Plate-fin	Spiral Wound	Plate-fin	Kettle	Plate-fin
Liquefaction Exchanger	Spiral Wound	Core-in Kettle Plate-fin	Plate-fin	Spiral Wound	Spiral Wound	Plate-fin	Plate-fin
Hydrocarbon Refrigerant Storage	Large	Large	Medium	Medium	Medium	None	None
Capital Investment	Medium	Medium	Low	Medium	Medium	None	None
Offshore Suitability	Medium	Medium	High	High	High	High	High
Compactness	Low	Low	Medium	Medium	Low	High	Medium
Motion Impacts	High	Medium	Medium	Medium	Medium	Low	Low

3) LNG Costs

The cost of investment in the entire value chain of LNG from exploration and production, liquefaction, transportation and re-gasification differs from one another [27]. According to energy information agency [27], about 15 to 20 per cent of the total LNG investment cost goes to exploration and production. Liquefaction accounts for about 30 to 45 per cent of the total investment. Shipping accounts for 10 to 30 per cent while storage and re-gasification accounts for about 15 to 25 per cent of the total investment. Fig. 5 below shows the total per centage cost of the LNG value chain.

Fig. 5 Cost of LNG value chain [28]

The LNG liquefaction plant generally consists of one or more liquefying trains with an average liquefying capacity of 3 to 3.5MMTPY and usually cost between $1billion to $2 billion [29]. The costs variation is a result of different locations. The LNG transportation cost is the function of distance between the liquefaction plants to re-gasification terminals and the quantity of LNG transported [29]. The capacity of LNG carriers ranges from 135000 m^3 to 138000m^3 and can cost approximately $170 million [2]. According to Gendolohe et al [30] the re-gasification terminal construction largely depends on the cost of labour, capacity and the nature of the site. In Nigeria the liquefaction plants for trains 1 and 2 was constructed at the cost of $3.6 billion, train 3 was constructed at the cost of $1.8 billion, trains 4 and 5 costs $2.2 billion and train 6 cost $1.748 billion [31].

B. Pipelines

Pipelines are regarded as the effective means of natural gas transportation. According to Chang et al [25], natural gas transportation by pipeline are cheaper and convenient at a distance of 2000km at a depth of 100m offshore and 3800km onshore. The pipeline transports are used as substitute to tankers and LNG for natural gas transportation and they are characterized with high costs on investment with low operating costs. The global dominance of natural gas transportation by pipeline is Russia, USA, part of European countries and part of Africa. The success of the pipeline transport depends on the design criteria and operations.

1) *Pipeline Design*

The design of pipeline is usually based on stress related principles which serves as a guide to material selection and welding requirement [32]. The internal pressure from the contained gas and external pressure from the water column in the case of offshore transport and the sand nature in the case of onshore are important considerations for pipeline design [33]. In addition, other design considerations are concentrated loads, impact and excessive plastic strain as a result of too much bending construction [33]. According to Barrette [32] the pipeline diameter is the major design consideration, it has to be big enough to avoid pressure drops ends, and small enough for the deployment scheme to be cost effective. The pipeline wall thickness is chosen based on the internal pressure of the gas, corrosion allowance and fabrication tolerance[16]

2) Pipeline Operations

The operational life span of a pipeline is over 40 years and. prior to pipeline commissioning the following testing are required: gauging, cleaning, flooding, pressure and leak testing. In other to control the deposition of many products such as gas hydrates, paraffin and asphalt, a flow assurance test is required. Flow assurance test is a complex operation designed to control and prevents deposition of many products. Robotic system is used for the purpose of flow assurance as well as for leak detection and these devices are called pigs [32].

3) Economics of pipeline

Pipelines of long distance with huge diameter have very high capital cost on investment. According to Gandolphe et al [30], the major determinant cost factors for pipeline transmission systems are: distance, diameter, nature of the terrain and the operating pressure. Other factors to be considered include: climate, labour cost, competition among the contractors, right of ways, population density and safety regulations [2]. All the above mentioned factors differ from one place to another. The cost of operating pipeline transmission systems is proportional to the number of compressor stations, which entails the quantity of fuel consumed, the labour costs and turn around maintenance [2]. In pipeline design, the compression capacity and diameter depend largely on the load factor expected. The per unit construction of pipeline transmission systems depends on the rate of utilization capacity. The higher the loads factor of utilization, the serious viability of the project [30]. According to Gandolphe et al [30], the global pipeline construction standard for large diameters ranges from 46 to 60 inches with total operating capacity between 15 to 30 109MTPY with a distance of about 1000km will cost between $1 billion to $2 billion. Gas pipeline that supplied gas to USA from Canada has about 36 inch diameter with a distance of 3686km and operating pressure of 120 bars and cost about $ 3 billion [30]. Table II below shows the cost of some long distance pipeline transmission systems around the world.

Table II. Cost of some long distance pipeline [34].

Pipeline/Route	Capacity (10^3M^3/year)	Length (km)	Budgeted cost ($b)
Africa to Europe			
Nigeria-Niger- Algeria- Europe	30	4128	13.00
Algeria to Spain	8	767	0.90
Middle-East to Asia			
Iran-India to Pakistan	18-20	3300	5.00
Qatar-Pakistan	16.50	1600	3.50

4) Nigerian Gas Pipeline

The Nigerian gas company is vested with responsibility of developing of an efficient gas industry to fully serve Nigeria's energy and industrial feedstock needs through integrated gas pipeline network and also to export natural gas and its derivatives to the West African Sub region [35]. The company operates eight supply systems namely: the Sapele gas supply systems, the Alada systems, Imo river-Aba system, Obigbo North-Afam systems, Alakiri-Afam-Ikot Abasi system, Alakiri-Onne system, Escravos-Lagos system and Sapele-Oben-Ajaokuta. All these facilities comprise 1,100km of pipelines between 4 to 36 inches in diameter with total design capacity of more than 2BCF of gas per day, 14 compressor stations and 13 metering stations [35]. The only gas pipeline export from the country is the West African Gas Pipeline that carries gas from Nigeria to Ghana and is about 678km distance and 20 inches diameter for the main pipeline with compressor station at Lagos with total design capacity of 170 million standard cubic feet per day [36].

Fig. 6 below shows domestic gas pipeline network systems in Nigeria.

Fig. 6 Nigeria's domestic pipeline routes [35]

III. Methodology

This section provides a through explanation of the Methodological approach and process of data collection applied in order to achieve objectives of this study.

A. Data Collection

Generally, there are two major methods of data collection, this include: primary method of data collection and secondary method of data collection. This study used both the primary and secondary methods of data collections. The primary data was favored because there is no adequate data on the trans-Saharan gas pipeline and also, the researcher want to know the view of Nigerians on the importance or otherwise about the proposed TSGP. But, there have been much information on liquefied natural gas.

The primary method of data collection used in this study include questionnaire and telephone interview. The Questionnaires were distributed to some selected oil and gas industries in Nigeria which include Gazprom, NNPC and NGC. Some of the questionnaires were also distributed to Nigerian students studying oil and gas management in Coventry, University, UK. The choice of the oil and Gas companies in Nigeria was to get first-hand information about the oil and gas industry in Nigeria. Thirty questionnaires were sent to Nigeria, ten to each of the companies mentioned above and fifty questionnaires were also distributed to Nigerian students in Coventry University. However, to ensure validity and reliability of this research telephone interview was conducted with officials of Gazprom Nigeria and a senior official of the NNPC who has worked for about 20 years with the NNPC.

The secondary method of data collection include published articles and journals on LNG and pipeline, academic journals on LNG and pipeline, journals of science and engineering, textbooks, internets and sources from government companies NNPC, NGC and NLNG. The purpose of using the secondary data is to review and recognize the previous work done by the experts which have great impacts on the literature of this research. Much attention was given to the government company sources because they are the major players both in LNG and pipeline in Nigeria.

B. Types of Data

Generally, there are two major types of data the quantitative and qualitative. Quantitative data deals with figures while qualitative deals with words. Quantitative is a type of data collection that is associated with the scientific and experimental approach while qualitative is a type of data collection that is concerned with describing meaning instead of drawing statistical inferences. This study used both qualitative and quantitative types of data collection.

In order to provide the vast understanding and excellent description of LNG and pipeline process a qualitative process was used. The qualitative type of data provides the means of gathering and clear description of the data and studies from the site for proper critical analysis[14]. The reason for this type of data is to provide neutrality as it takes into consideration of the view of respondents. The methods used in this type of data collections are questionnaires, observation and interviews.

C. Data Analysis

The data analyzed using charts, graphs and tables are regarded as quantitative while data that provide vast description is regarded as qualitative. The qualitative data approach is divided into the following categories: enthrography, historical grounded theory and phenomenology approaches.

In this study, the collected data were analyzed technically in other to get an in-depth knowledge and wider understanding of LNG and pipeline. In order to satisfactorily meet the set aim and objectives of this study and also the challenges raised, a critical evaluation and comparison for both the qualitative and quantitative data used in this section.

IV. Results And Discussions

In other to perform the result and discussion analysis on this topic the following factors were considered in drafting the questionnaire: capital cost, operating cost, choice of method, security threats, environmental friendliness, long distance viability, and economic importance as well as technical aspects.

In Nigeria, the LNG plants for trains 1 and 2 were constructed at the cost of \$3.6 billion, train 3 was constructed at the cost of \$1.8 billion, trains 4 and 5 cost \$2.2 billion and train 6 cost \$1.748 billion. Therefore, the total construction cost of the six LNG liquefaction trains in Nigeria was \$9.348 billion. The trans-Saharan gas pipeline is about 4128km long with 56 inches diameter pipeline delivering about 30BCMA at a cost of \$10 billion for the pipeline construction and \$3 billion for the compressor stations, totaling \$13 billion. Table II shows the comparison in terms of capital costs on investment between LNG production trains in Nigeria and the proposed TSGP. The capital cost of proposed TSGP is higher that LNG trains despite the fact the total production capacity of the NLNG Plants is greater than the TSGP.

Fig. 8 below shows the comparison on the projected capital cost of TSGP. In this study it is assumed that the TSGP project would commence by January 2015. It is also assumed that Nigerian inflation rate will be maintained at a constant rate of 10.5 per cent per annum. The discount rates can be calculated using the formular F=P(1+i)n.
Where: F=future price; P=present price; 1=constant; i=inflation rate; n=number of years.

The TSGP construction work is expected to last for five years, commencing by 2015 and completion by 2020. Therefore, by 2016 the projected cost will be
n=2016-2015
n=1
F=\$19.383(1+0.105)1
F=\$19.383(1.105)1
F=\$21.418b
By 2020 the projected cost will be
n=2020-2012
n=1
F=\$28.901(1+0.105)1
F=\$28.901(1.105)1
F=\$31.94b

Fig. 7 compares the capital cost between LNG and TSGP. It shows that the capital cost on investment is higher in the proposed trans-Saharan gas pipeline than the LNG liquefaction plants constructed despite the fact that the total production capacity of the liquefaction plants is about 22MTPY equivalent to 30.36BCMPY which is greater than that of trans-Saharan pipeline which is about 30BCMPY. The margin in production capacity is about 0.36BCMPY in favour of LNG, and also the margin on capital cost on investment is \$3.652 billion in favour of LNG. This amount can build another two different liquefaction trains, thereby increases the production capacity and create more job opportunities for Nigerians.
It was calculated that upon completion, the TSGP project by 2020 will cost \$31.943b which is about 146 per cent increase when compared to the original budgeted cost of \$13b in 2011. The present and projected cost is shown in fig. 8.

Table II shows the comparison in the operating cost per unit of production between LNG and the proposed TSGP. The values from the table were used to plot fig. 9.

TABLE II. Comparison per unit cost of production LNG and TSGP.

Stages Involves	LNG	Pipeline
Exploration and production cost per MMBtu ($)	0.70	0.70
Liquefaction cost per MMBtu ($)	1.00	-
Transportation cost per MMBtu ($)	0.70	0.50
Compression cost per MMBtu ($)	-	0.10
,Tariff cost per MMBtu ($)	-	0.20
Treatment cost ($)	0.10	0.10
Total operating cost per MMBtu ($)	**2.50**	**1.60**

Fig. 10 shows the total operating cost of MMBtu of gas from Nigeria to Spain between LNG and TSGP. The operating cost per MMBtu of gas increases as the delivery distance increases. For every 1000km, the transportation cost for LNG experiences a negligible increase by 10 per cent of its original transportation cost while that of pipeline increases by 50 per cent of the original cost for both the transportation and compression. This is because there is no significant impact on distance and compression, compared to pipeline. The main aim of the TSGP is to link the pipeline in Algeria through to Spain. However, considering the distance of Maghreb gas pipeline that convey natural gas from Hassi R'mile in Algeria through Morocco to Spain which is about 1,609km, the total distance from Niger Delta in Nigeria to Spain would be about 5,737 km. The total operating costs for LNG from Nigeria to Spain is $2.78 per MMBtu and pipeline is $3.10 per MMBtu.

Fig. 11 shows that up to distance of 2000km, pipeline is most competitive than LNG in gas transportation in Nigeria. As the distance approaches 3000km LNG is becoming more competitive than the pipeline for gas export. Therefore, the transportation cost per MMBtu of gas is cheaper for LNG than the proposed trans-Saharan gas pipeline for exporting natural gas from Nigeria because the proposed pipeline is about 4128km distance.

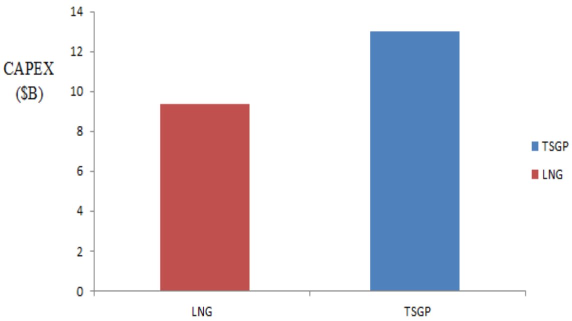

Fig. 7 Capital cost comparison

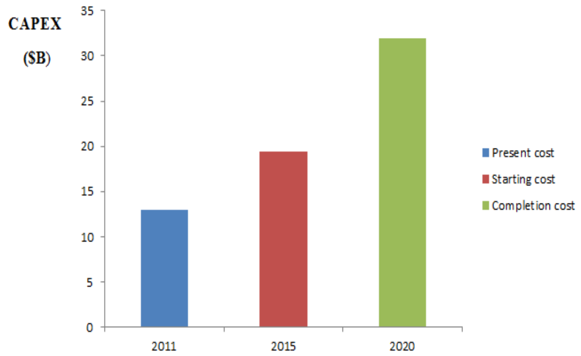

Fig. 8 Comparison of the projected capital cost of TSGP

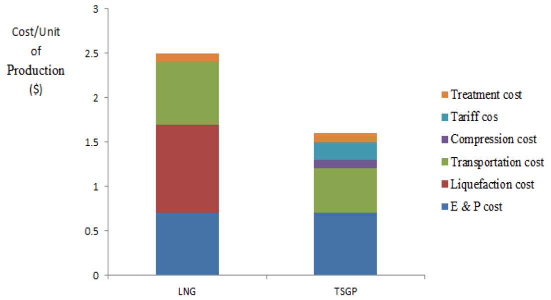

Fig. 9 Cost per unit of production between LNG and TSGP

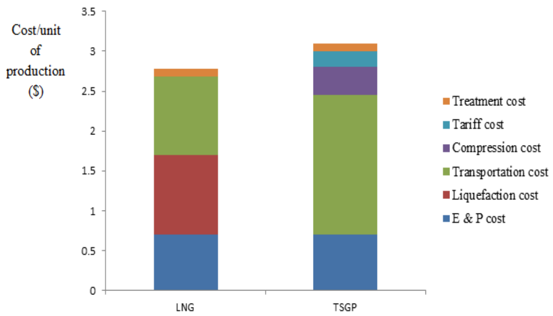

Fig. 10 Cost per unit of production from Nigeria to Spain

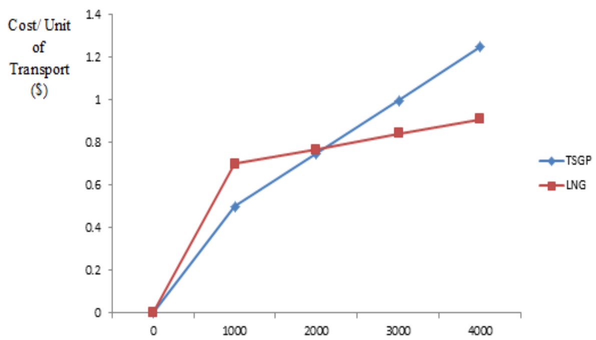

Fig. 11 Transportation cost per MMBTU at a distance of 4000km

CONCLUSIONS

The trans-Saharan gas pipeline is considered as strategic because it can alleviate poverty by opening up economic growth opportunities in the African sub-region and can boost domestic gas supply in the continent and also serves as a medium through which Nigeria's energy sources and southern Algeria's gas field can be duly exploited, reaching the European market. However, the security challenges are too important to be ignored, because it can lead to the decline of economic viability of the project. Security costs of the project are possible to be very high, as both local and foreign workers need to be protected from potential attacks. The pipeline will require expensive surveillance and constant patrolling once completed so as to protect the facilities from security threats. Putting all these factors into consideration will raise the project costs beyond profitability.

This study has found that the capital cost of six LNG trains is $9.348 billion while that TSGP is $13 billion, and the operating costs per unit of production with LNG is $2.78 and that of TSGP is $3.10. It was projected that the construction of TSGP will commence by 2015 at the cost of $19.383 billion and to be completed by 2020 at the total cost of $31.943 billion at constant inflation rate of 10.5 per cent, also the study has found that from a distance of 3000km, LNG is more competitive than the TSGP. The TSGP pipeline is regarded as one of the global longest pipeline project. The construction will take place in one of the world's difficult environments, the Sahara desert which raises the costs significantly. Once constructed is difficult to increase the production capacity and difficult to diversify, the pipeline will be in competition with other pipeline supply to Europe. The project is capital intensive which make it difficult to find private partners willing to commit to such an unpredictable enterprise.

However, developing Nigerian Liquefied Natural Gas Company would be less expensive and more efficient way of exporting the country's natural gas resources since the LNG spot market already exist. Generally, there is increase in LNG importance as substitute to clean fuel for electric power generation and industrial usage both in Europe and Asia. In Japan for instance, the demand for LNG is on the increase so as to offset it power supply deficit caused by the nuclear reactor shut downs. The increase in LNG usage is also attributed to uncertainties with shale gas, disasters associated with nuclear power plants and attempts by the developed countries to cut down their emissions rate.

This study has also found that LNG transportation has increased security and diversification in supply systems of natural gas as compared to pipelines. In general, due to the enormous benefits of LNG identified in this study, and putting into consideration that the NNPC cannot afford two projects at the same, it is therefore important for Nigerian government to develop more LNG plants than concentrating on the proposed TSGP.

Acronyms

BCF	Billion Cubic Feet
BCMPY	Billion Cubic Meter Per Year
IEA	International Energy Agency
JV	Joint Venture
KM	Kilometer
LNG	Liquefied Natural Gas
MMBtu	Million British Thermal Unit
MMTPY	Million Tons Per Year
MTPY	Million Tons Per Year
NLNG	Nigerian Liquefied Natural Gas
NNPC	Nigerian National Petroleum Corporation
SPDC	Shell Petroleum Development Company
TCF	Trillion Cubic Feet
TCFPY	Trillion Cubic Feet Per Year
TPA	Tons Per Annum
TSGP	Trans Saharan Gas Pipeline

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