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Floating Gas to Power (FGTP): A Screening Study for Stranded Gas Fields Offshore Nigeria

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ABSTRACT: *Floating Gas to Power (FGTP) has been identified as a frontier concept for stranded gas field development. Instead of converting dry gas to LNG (FLNG Concept), the gas is used offshore for generating electricity as an end product. Offshore to Onshore electric power transmission is usually by marine or subsea cabling. The electricity is eventually distributed into a large utility power grid. As an emerging economy with a population expected to keep growing, the question of how to bridge Nigeria's continuously increasing power deficit has become topical. Furthermore, offshore Nigeria, stranded gas reserves are found in difficult locations and in such quantities as to render their exploitation through conventional means economically unfeasible. The main objective of the study was to perform a Niger delta basin-wide screening: identify and rank Nigeria's most prospective stranded offshore gas fields and perform a first-order evaluation of the scale of FGTP possible contribution to alleviating the country's power deficit. A conventional exploration risking approach was used to evaluate, rank and risk offshore Niger Delta stranded gas fields for hydrocarbon fluid type, location, water depths, and distance from shore, terrain, accumulation size, and average reservoir properties. All relevant data public domain data have been analyzed. 765 fields in the Niger Delta basin have been evaluated and ranked. 79 of these fields were revealed to possess good to very good FGTP Project potential. A shortlist of the most prospective fields was then enumerated and ranked. Based on the results of this study, we believe we have localized some of the more interesting "sweet-spots" for FGTP Offshore Nigeria, from an industry perspective. Technological developments, the gas price and the continued increase in demand for energy will define if and when these resources will be exploited on a large scale. Furthermore, the study shows that the FGTP option in the Offshore Nigeria space deserves thorough scrutiny and further studies to evaluate its techno-economic feasibility. It could prove an economical and environmentally friendly option for energy generation. If properly harnessed, it could resolve the epileptic power supply problem in Nigeria, generate huge potential revenue for the government, and create numerous employment opportunities.*

KEYWORDS - *Gas to Power, Electricity, Floating, Nigeria, Offshore, FGTP*

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I. INTRODUCTION

Stranded natural gas are essentially gas that is wasted or unused either because conventional means of development face logistical and economic barriers, and/or the local market for gas is too small, and/or the gas field is too far from the industrialized markets. There are several ways to utilize stranded natural gas ranging from pipelines to power as shown in Fig. 1.

As shown in Fig. 2, most of Nigeria's gas utilization is via pipelines and reinjection, domestically and LNG as exports. Despite the country's poor power situation, about 11% of it's the gas produced is flared. Yet, almost two-thirds of the Nigerian population do not have access to electricity. It was estimated that Nigeria needs about 13GW of electricity daily in 2013 [1]. However, the current installed capacity is only about 50% of that. When one takes into consideration the transmission and distribution efficiency, this capacity falls to about 35%. Taking into consideration the population and economic growth between 2013 and 2020, one will realize that the situation is quite grim. For a nation with one of the largest gas reserves in the world, it is ironic that the country should has such serious power problems.

A significant amount of Nigeria's gas reserves is considered stranded. While there are plans to bring more pipelines on board, a critical analysis of the situation shows that this would be insufficient in solving Nigeria's power problems quickly [2][3][4][5][6][7][8][9].

Floating Gas to Power (FGTP) has been identified as a frontier concept for stranded gas field development. Instead of converting dry gas to LNG (FLNG Concept), the gas is used offshore for generating electricity as an end product. Offshore to Onshore electric power transmission is usually by marine or subsea cabling. The electricity is eventually distributed into a large utility power grid. Gas to power (or electricity or wire) refers to the utilization of gas in a turbine, subsequently creating energy. The essential standard of the energy cycle requires consuming gas in a gas turbine (GT) and delivering power which can be changed over to electric force by a coupled generator. This sort of energy plant is introduced in expanding numbers the world over where significant amounts of natural gas are bounteous. [10]

The main objective of the study was to perform a Niger delta basin wide screening: identify and rank the Nigeria's most prospective stranded offshore gas fields and perform a first order evaluation of the scale of FGTP possible contribution to alleviating the country's power deficit.

II. MATERIALS AND METHODS

2.1 Approach

A conventional exploration risking approach was used to evaluate, rank and risk offshore Niger Delta stranded gas fields for hydrocarbon fluid type, location, water depths, and distance from shore, terrain, accumulation size, and average reservoir properties. All relevant data public domain data have been analyzed. 765 offshore fields in the Niger Delta basin have been evaluated and ranked. Several of these fields were revealed to possess good to very good FGTP Project potential. A shortlist of the most prospective fields is then enumerated and risked. Based on an extensive literature review, the following key driving factors influencing the screening study were identified namely hydrocarbon fluid type, location, water depths, distance from shore, terrain, accumulation size and average reservoir properties. Using these key driving factors, a public domain database of Oil and Gas reserves in Nigeria was analyzed and then screened appropriately.

2.2 Data Source

The data is derived from access to IHS Energy Database. IHS Markit is a global leader in information, analytics, and solutions for the major industries and markets that drive economies worldwide. Our company partners with clients in business, finance, and government to help them see the big picture with unrivaled insights that lead to well-informed, confident decisions. IHS Markit serves more than 50,000 key customers in over 140 countries, including 85 percent of the Fortune Global 500. Headquartered in London, IHS Markit (Nasdaq: INFO) is committed to sustainable, profitable growth.

2.3 Screening Criteria

2.3.1 Size of Gas Reserves vs. Distance from Shore (Market)

[11] studied how to monetize gas fields with a reserve between 10Bcf and 1Tcf by carrying out a feasibility study for gas to wire systems for small gas reserves. They conclude that gas to wire is suggested for developing small gas fields with reserves between 10Bcf and 1Tcf. (Fig. 3). Building on the work done by [11], the following screening criteria was obtained: Distance to Market ≤ 2000km and Reserves Size ≤ 5Bcf.

2.3.2 Size of Gas Reserves vs. Maximum Water Depth

[12] showed that decreasing the water depth has a great impact on the low-frequency motion of these platforms, due to a variety of complex and combined phenomena related to the different nature of waves compared to deep waters (e.g. set down effect, free and bound waves, directional spreading waves and edge waves). This requires assessing the response of the floating platform according to the offshore engineering approach of measuring the full-wave spectrum. Other studies of floating platforms for wind turbines, liquefied natural gas, compressed natural gas also arrived at similar conclusions. Based on this, a maximum water depth of 1500m was then chosen to be suitable screening cutoff.

2.3.3 Maximum Water depth vs. Distance from Shore

A data from shore of ≤ 80km was used as cutoff points based primarily on the work of [13] in 2013 on the effect of distance on gas utilization choices.

2.3.4 Transmission Cable (Wire) Cost vs. Distance from Shore

Following the work of [14] on offshore wind power integration into future power systems and the reasonable assumption that the cost of subsea cable lines for both offshore wind platforms and floating gas to power will be similar, we can see that the break-even distance for transmission cable cost is between 50 and 80 km (Fig. 4). Using these screening criteria, the resulting fields were then further ranked into anchor fields: fields large enough for stand-alone development, sweet spots – fields close enough for joint development and others. Furthermore, using the clusters identified in the database, the most promising clusters were then enumerated.

III. RESULTS AND DISCUSSION

In this study, we were interested in only offshore stranded gas or gas/condensate fields. Table 1 shows that only 12% of the fields (89 fields) in the IHIS Niger delta database satisfy this screening constraint. Using this subset as our focus dataset, we then applied the conventional exploration screening approach.

3.1 Screening Results

3.1.1 Size of Gas Reserves vs. Distance from Shore (Market)

All of the 89 selected stranded fields passed the initial screening test at this stage as shown in Fig 5. All the selected fields are within 200km of the Shoreline of Nigeria. In order to expand the illustration, the fields' reserve's sizes were further compared against the AC/DC wire criteria of 80km [14]. 20 of the fields fell into the Deepwater DC criteria at between 80km to 200km, whilst the remaining 69 fields fell into the AC wire criteria. This is illustrated in Fig 6. The results for this criterion are tabularized in the Table 2.

3.1.2 Size of Gas Reserves vs. Maximum Water Depth

Three fields were screened out based on this criterion. The criterion splits are illustrated in Fig 7. The results are illustrated in the schematic below: The results for this criterion are tabularized in the Table 3.

3.1.3 Maximum Water depth vs. Distance from Shore

Using a maximum water depth of 1500km and distance from shore of ≤ 80km as cutoff points, based primarily on the work of [13] on the effect of distance on gas utilization choices, 10 fields in the Deepwater domain were screened out. These are illustrated in Fig 8. The results for this criterion are tabularized in the Table 4

3.1.4 Transmission Cable (Wire) Cost vs. Distance from Shore

Following the work of [14] on offshore wind power integration into future power systems and the reasonable assumption that the cost of subsea cable lines for both offshore wind platforms and floating gas to power will be similar, we can see that the break-even distance is between 50 and 80 km (Fig 4). The result of this screening criteria is shown in Fig 9. The results for this criterion are tabularized in the Table 5.

3.2 Discussion of Screening Results

Based on the screening criteria listed in section 2.2, after combining the screening criteria, 10 fields were finally screened out of the 89 selected gas/gas-condensate fields that passed the initial database screening test. 79 fields are thus retained as FGTP prospects. As shown in Tables 3 and 4, most of the screened-out fields were screened out based on either their water depth or their reserves. This is consistent with literature studies that have shown that water depth and reserves sizes are the two most important criteria for successful valorization of gas reserves using floating platforms such as floating liquefied natural gas, floating compressed natural gas, and floating gas to liquids. [3][12][15][16][17] [18][19]

Table 7 and Table 10 list out the screened-out fields and retained fields with their location, maximum water depth, reserves size and distance to shore (market). As shown in Table 8, statistical analysis reveals that in general, the screened-out fields had an average water depth that is roughly 15 times those of the retained ones. Similarly, their reserves are about two times smaller than the retained ones with an average distance to shore of 157km compared to 43km for the retained fields.

3.2.1 Ranked Screening Analysis

With cumulative reserve sizes of 8425Bcf, the screened fields greatly differ in value. In the Oil and Gas industry, prospects are usually ranked in the order of potential value before deciding the order of development. We extended this conventional practice by also adding the constraint that field is either large enough to support a standalone FGTP project (which we call anchor fields) or close enough to other prospects to be developed together (which we call sweet spots). Our analysis yielded two (2) Anchor fields and several sweet spots that are enumerated in Table 9 and Table 11.

A statistical analysis of the two categories of fields as seen in Table 8 shows that these categories differ significantly from one another. In general, sweet spots have significantly smaller maximum water depth, recoverable gas and distance to shore when compared to anchor fields. Furthermore, a comparative analysis of anchor fields and screened out fields (Table 8) shows that while anchor fields were generally closer to the market and had lesser maximum water depth, the most significant difference between these two classes was that, on average, anchor fields had twenty-three times more recoverable gas than screened out fields, confirming their viability.

3.2.2 Areal Clustering

Based on geographical clustering of the selected fields, the fields are then grouped into 6 different clusters for ease of combined studies and development. Appendix A3 shows a summary of the clusters and analysis of the cluster with respect to the number of anchor fields and sweet spots that fall into each. Appendix A4 below shows a schematic of the cluster method of development with a subsea to beach connection.

Based on cluster locations, mapped onto existing onshore power facilities (to act as offtake points for Gas to Power pipelines), 6 Onshore locations were identified, in 6 states in the South-South region of Nigeria that have a portion of the Atlantic coastline. Figure 11 below also shows the mapped onshore landing grid power points. The Table 12 summarizes the Anchor fields, sweet spots and proposed onshore power grid landing points.

IV. FIGURES AND TABLES

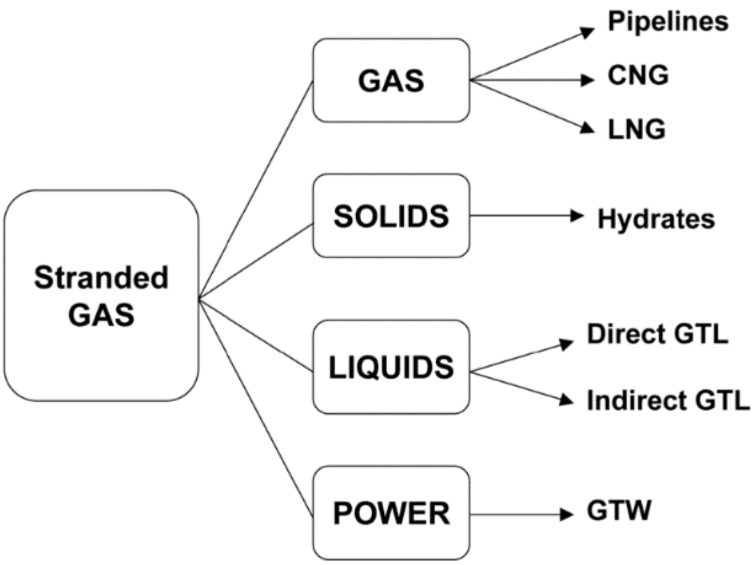

Fig 1. Stranded Gas Utilization Method. Source: Petrowiki [20]

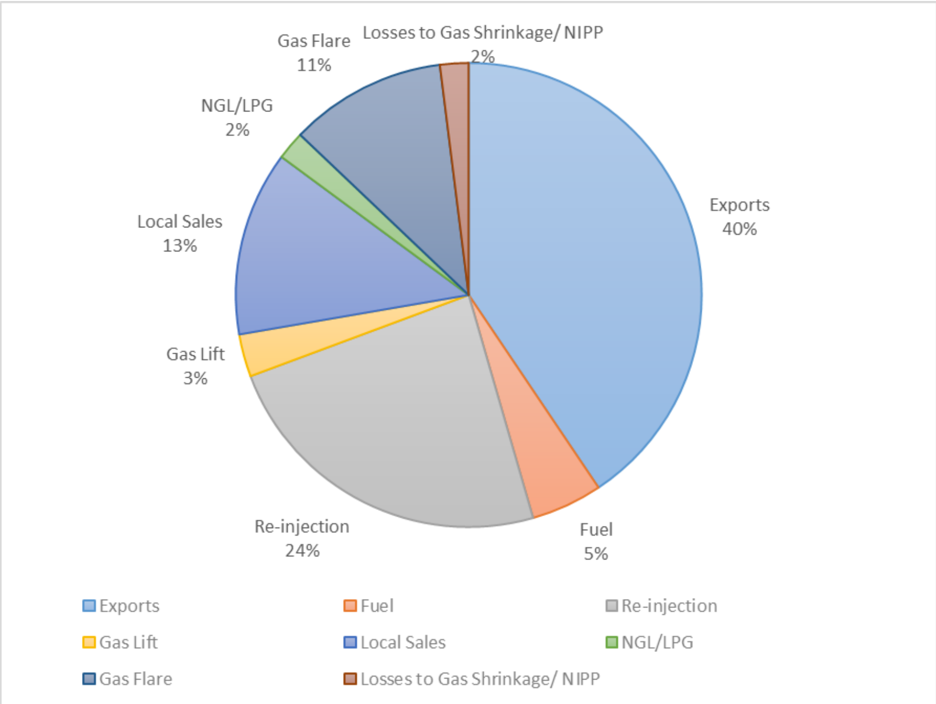

Fig 2. Nigeria Gas Utilization Breakdown in 2017. [21]

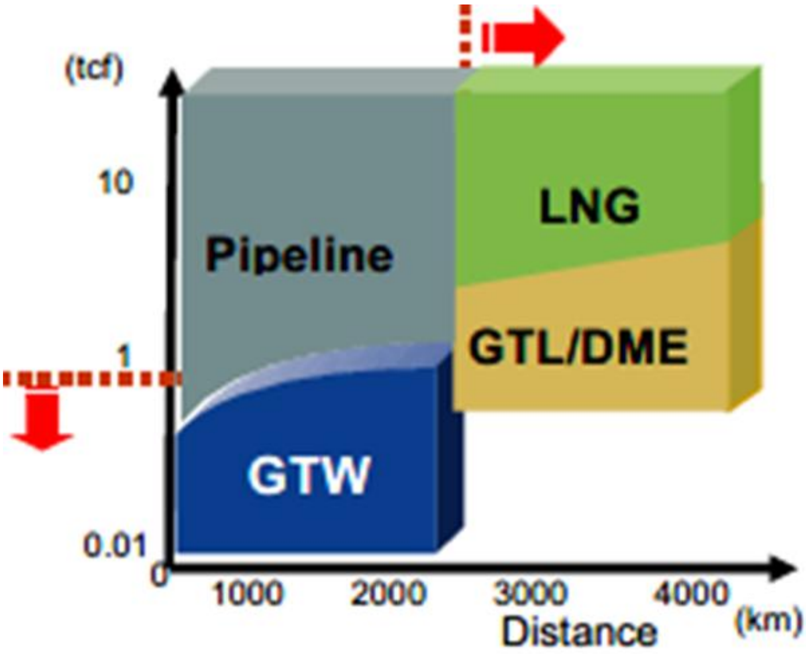

Fig. 3. Solutions for Gas Transmission as a function of Reserves volume and distance to Market. [11]

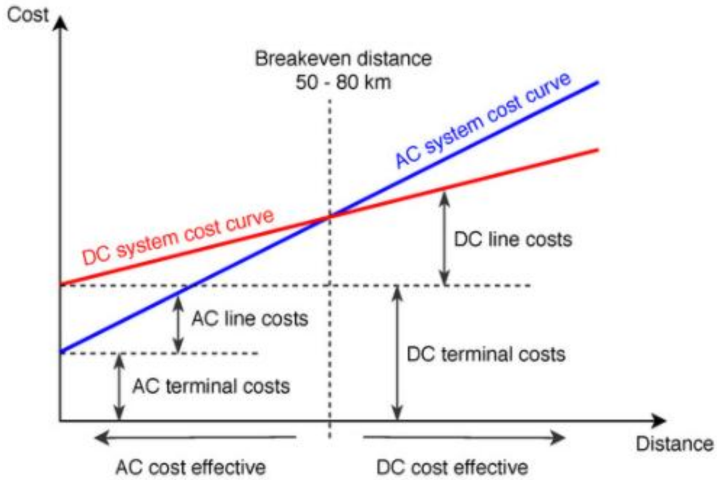

Fig 4. AC and DC system costs based on transmission distances for submerged cables. [11]

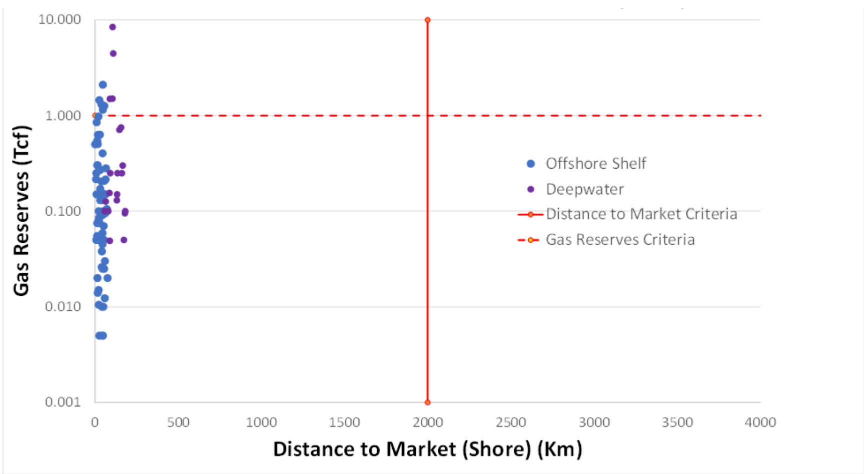

Fig 5. Reserves Size vs Distance from Shore.

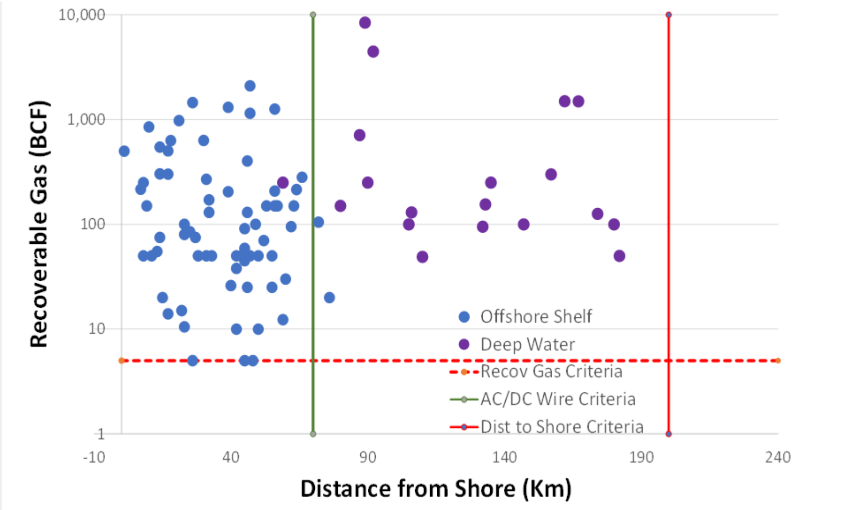

Fig 6. Recoverable Gas vs Distance from Shore (AC/DC Wire Criteria)

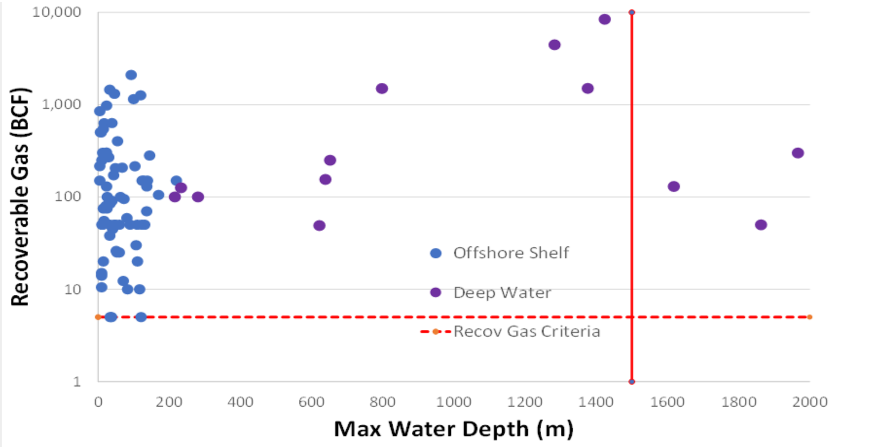

Fig 7. Recoverable Gas vs. Maximum Water Depth.

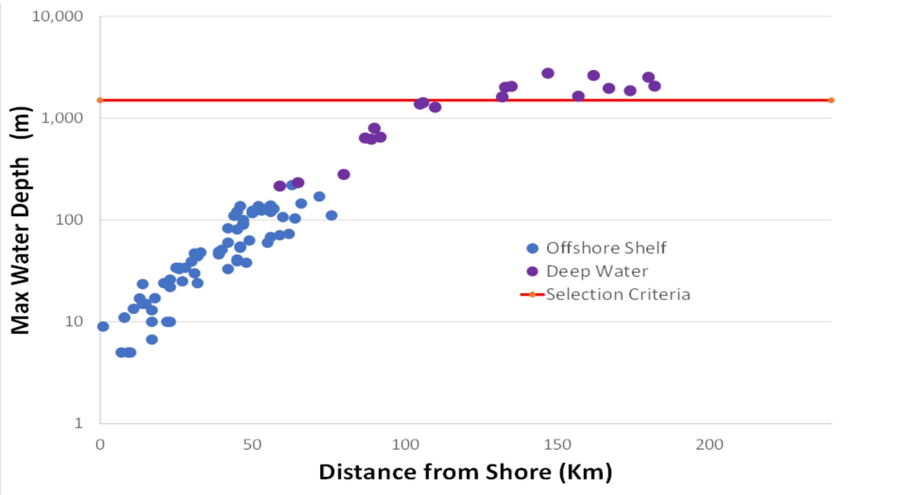

Fig 8. Max Water Depth vs Distance from Shore.

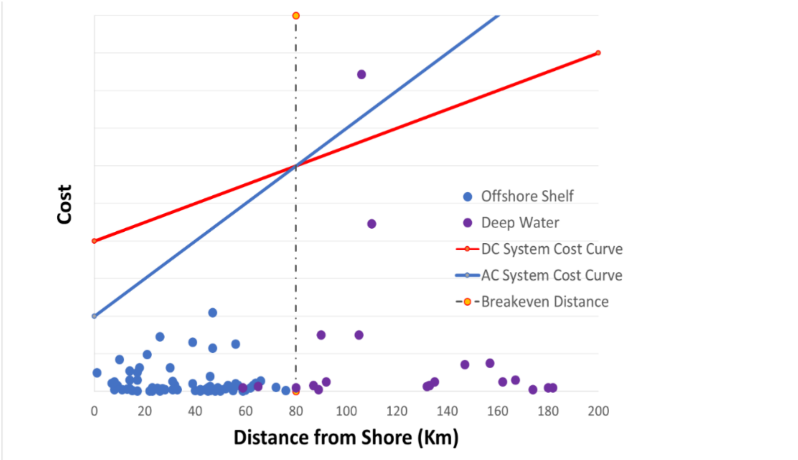

Fig 9. Cost vs Distance from Shore

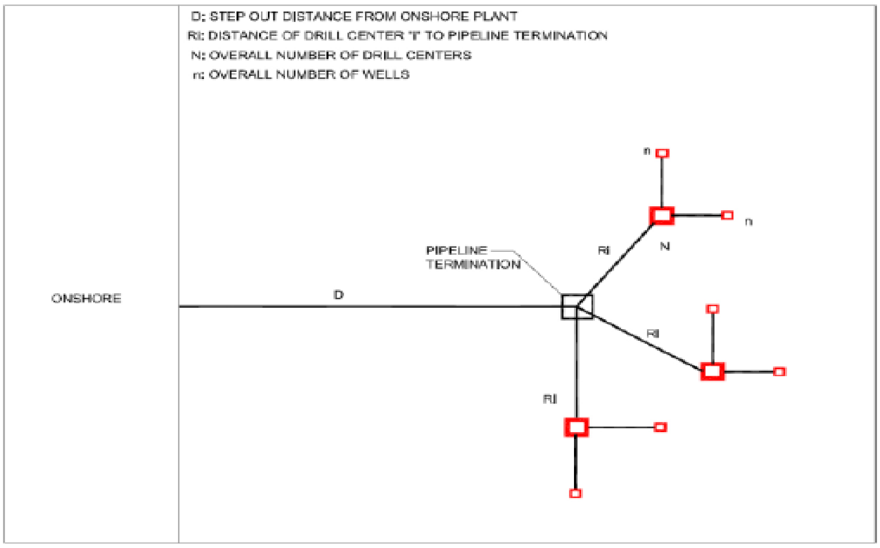

Fig 10. Cluster Method of Development [22]

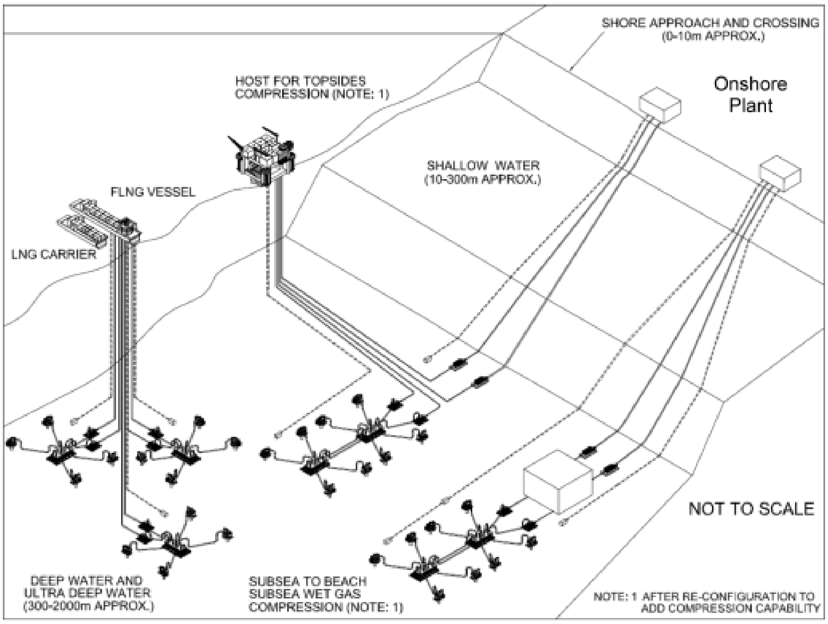

Fig 11. Subsea-to-Beach with either Topsides or Subsea Compression vs FLNG [22]

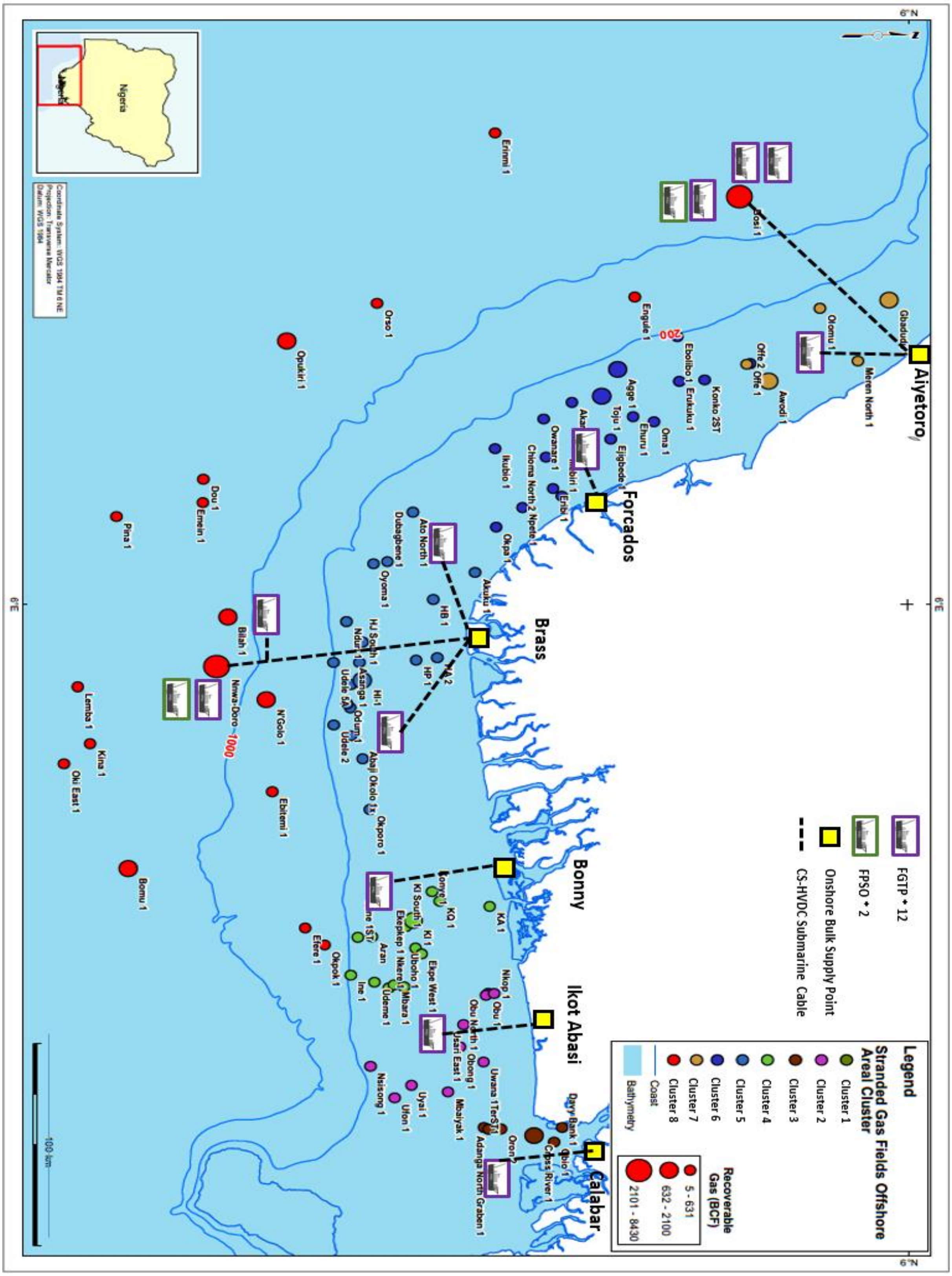

Fig 11. Selected Stranded gas fields with FGTP Potential

Table 1: Selection of Stranded Gas fields from offshore Nigeria from IHIS Database.

Category	Fields Reviewed	% Total	Comments
Oil / Gas Fields	589	77%	Discovery/Appraisal/Development/Producing
Gas / Condensate Fields	24	3%	Gas fields, Producing, Temporarily Shut-in
Gas / Condensate Fields	63	8%	Onshore Gas Fields Appraisal / Discovery
Gas / Condensate Fields	89	12%	Offshore Gas Fields Appraisal / Discovery
Total	765	100%	

Table 2: Max Water Depth vs Distance from Shore

Category	Depth <= 1500m	% of Total	Comments
Retained Fields	86	97%	
Screened Out Fields	3	3%	Ultra-Deep Offshore Terrain
Total	89	100%	

Table 3: Size of Gas Reserves vs. Maximum Water Depth

Category	Depth ≤ 1500m	% of Total	Comments
Retained Fields	86	97%	
Screened-Out Fields	3	3%	Ultra-Deep Offshore Terrain
Total	89	100%	

Table 4: Max Water Depth vs Distance from Shore

Category	Depth ≤ 1500m	% of Total	Comments
Retained Fields	79	89%	
Screened Out Fields	10	11%	Ultra-Deep Offshore Terrain
Total	89	100%	

Table 5: Wire Cost vs Distance from Shore

Category	Distance ≤ 80 Km	% of Total	Comments
Retained Fields	71	80%	Mostly Offshore Shelf Terrain
Screened-Out Fields	18	20%	Mostly Deep Offshore Terrain
Total	89	100%	

Table 6: Table of final Screening Results

Category		% of Total	Comments
Retained Fields	79	89%	Deep Offshore / Offshore Shelf Terrain
Screened Out Fields	10	11%	>1500m depth, <500 Bcf / < 10BCF Reserves
Total	89	100%	

Table 7: Screened Out Fields

Longitude	Latitude	Field Name	W.Depth (m)	Rec Gas (BCF)	Shore (Km)
2.954444	7.176667	Bomu 1	1646	750	157
3.573594	4.825315	Opukiri 1	2766	710	147
2.80489	6.620488	Kina 1	1967	300	167
3.247729	5.442447	Dou 1	2059	250	135
2.908836	5.608638	Pina 1	2632	250	162
3.245868	5.546223	Emein 1	2019	150	133
3.925724	4.657802	Orso 1	1618	130	132
2.703386	6.710471	Oki East 1	2067	100	182
4.385124	3.896524	Erinmi 1	2525	95	180
2.75648	6.36658	Lemba 1	1863	50	174

Table 8: Table of final Screening Results

	Screened Out Fields			Retained Fields		
	Max W.Depth (m)	Rec.Gas(Bcf) (BCF)	Shore (Km)	W.Depth (m)	Rec.Gas (BCF)	Shore(Km)
Mean	2116.2	278.5	156.9	146	433	43.2
Median	2039	200	159.5	53	100	45
S.Deviation	398.1	251	19.3	283.9	1110.5	25
Minimum	1618	50	132	5	5	1
Maximum	2766	750	182	1424	8430	110

Table 9: FGTP Sweet Spot Fields

Longitude	Latitude	Field Name	Cluster	D. (m)	Rec.Gas.BCF	Shore (Km)
5.925095	4.638885	Gbadudu 1	6	33	1450	26
5.455661	5.001711	Awodi 1	6	24	978	21
4.865917	4.951083	Agge 1	5	120	1260	56
4.803973	5.070394	Toju 1	5	100	1148	47
4.586416	5.342281	Chioma North 2	5	39	631	30
3.868623	6.339123	HI-1	4	93	2100	47
3.343461	6.05609	Bilah 1	4	1376	1500	105
3.493415	6.424797	N'Golo 1	4	798	1495	90
4.146836	5.977917	HB 1	4	17	629	18
4.16275	6.238083	HA 2	4	15	546	14
4.067	7.410583	KI 1	3	46	1310	39
4.038375	7.436422	KI South 1	3	55	402	46
3.850625	7.483953	Utine 1ST	3	145	281	66
4.535989	8.370471	Cross River 1	2	5	850	10
4.4076	8.339989	Oron 2	2	7	502	17
4.6463	8.335392	Davy Bank 1	2	9	500	1
4.074639	7.532378	Ekepkep 1	3	41	45	45
3.644488	7.443484	Efere 1	3	639	155	87
3.821917	7.654333	Ine 1	3	170	105	72
4.382417	7.73725	Nkop 1	1	23	303	14
4.349803	7.743467	Obu 1	1	13	301	17
4.26227	7.875224	Usari East 1	1	30	269	31

Table 10: Retained Fields

Longitude	Latitude	Field Name	W.Depth (m)	Rec.Gas (BCF)	Shore (Km)
5.33957	4.17773	Bosi 1	1424	8430	106
5.925095	4.638885	Gbadudu 1	33	1450	26
5.455661	5.001711	Awodi 1	24	978	21
5.804875	4.911375	Meren North 1	13	50	11
5.369828	4.927467	Offe 1	48	50	33
4.932475	4.627397	Engule 1	622	49	89
5.65625	4.676528	Olomu 1	83	10	42
4.865917	4.951083	Agge 1	120	1260	56
4.803973	5.070394	Toju 1	100	1148	47
4.586416	5.342281	Chioma North 2	39	631	30
4.925875	5.161867	Ehuru 1	44	172	32
4.577778	5.172222	Owanare 1	137	130	46
5.098635	4.80377	Ebolibo 1	233	126	65
4.839145	5.26106	Ejigbede 1	34	85	25
4.493889	5.566944	Npete 1	15	75	14
4.614294	5.483642	Eribi 1	17	55	13
4.648619	5.516881	Ikebiri 1	11	50	8
5.384097	4.923844	Offe 2	47	50	31

5.107072	5.003328	Erukuku 1	60	50	42
4.388122	5.305778	Ikubio 1	110	50	44
5.206449	4.99689	Konko 2ST	51	26	40
4.391133	5.655844	Okpa 1	15	20	15
4.359222	7.735028	Obu North 1	10	14	17
5.008386	5.183708	Oma 1	34	5	26
4.687661	5.098286	Akarino 1	121	5	45
3.300167	6.277	Nnwa-Doro	1283	4460	110
3.868623	6.339123	HI-1	93	2100	47
3.343461	6.05609	Bilah 1	1376	1500	105
3.493415	6.424797	N'Golo 1	798	1495	90
4.146836	5.977917	HB 1	17	629	18
4.16275	6.238083	HA 2	15	546	14
3.516857	6.835493	Ebitemi 1	652	250	92
4.309291	5.858039	Akuku 1	11	250	8
3.825828	6.357503	Asanga 1	124	150	53
3.823373	6.586788	Toriye 1	129	150	57
3.809894	6.442853	Odum 1	139	150	56
3.756944	6.538056	Udele 2	220	150	63
4.078844	6.249047	HP 1	26	100	23
3.757018	6.25907	Udele 5A	216	100	59
3.966881	5.809444	Dubagbene 1	39	91	45
3.807175	6.076878	Nduri 1	137	70	52
3.869781	6.167556	HJ South 1	81	59	45
3.857458	6.258731	Ofrima South West 1	90	50	47
3.869371	6.687967	Abaji Okolo 1x	123	50	50
3.821219	6.461698	Asanga 3A	131	50	55
3.912381	5.819647	Oyoma 1	53	25	46
3.897914	6.914245	Okporo 1	117	10	50
4.066356	5.588694	Ato North 1	38	5	48
4.067	7.410583	KI 1	46	1310	39
4.038375	7.436422	KI South 1	55	402	46
3.850625	7.483953	Utine 1ST	145	281	66
4.365328	7.3485	KA 1	5	216	7
3.914345	7.685829	Udeme 1	104	215	64
3.991456	7.697561	Mbara 1	68	208	56
4.098819	7.558883	Ekpe West 1	49	205	39
3.644488	7.443484	Efere 1	639	155	87
3.821917	7.654333	Ine 1	170	105	72
3.720206	7.518897	Okpok 1	281	100	80
4.029722	7.705614	Uboho 1	63	100	49
4.171323	7.323559	KQ 1	25	75	27
4.140128	7.281843	Konye 1	34	50	28
4.074639	7.532378	Ekepkep 1	41	45	45
3.905208	7.482564	Aran	107	30	60
3.970863	7.71028	Nkere 1	71	12	59
4.535989	8.370471	Cross River 1	5	850	10
4.4076	8.339989	Oron 2	7	502	17
4.6463	8.335392	Davy Bank 1	9	500	1
4.614596	8.400221	Obio 1	5	150	9
4.358611	8.341111	Adanga North	10	15	22
4.339322	8.333996	Adanga North Horst	10	10	23
4.382417	7.73725	Nkop 1	23	303	14
4.349803	7.743467	Obu 1	13	301	17

4.26227	7.875224	Usari East 1	30	269	31
4.248183	7.974564	Obong 1	24	130	32
3.992583	8.20125	Ufon 1	73	95	62
4.339314	8.042422	Uwana 1TerST1	22	80	23
4.200706	8.175526	Mbaiyak 1	33	38	42
4.057647	8.145108	Uyai 1	60	25	55
3.898548	8.060154	Nsisong 1	111	20	76

Table 11: FGTP Anchor Fields

Longitude	Latitude	Field Name	W.Depth(m)	Recov.Gas (BCF)	Shore (Km)
5.33957	4.17773	Bosi 1	1424	8430	106
3.300167	6.277	Nnwa-Doro	1283	4460	110

Table 12: Proposed Clusters and Land station locations

Cluster	Onshore Location	Nigerian State	Anchor Fields	S.Spots Spots	Others	Total
1	Ikot Abasi	Akwa Ibom	0	3	6	9
2	Calabar	Cross River	0	3	3	6
3	Bonny	Rivers	0	6	10	16
4	Brass	Bayelsa	1	5	17	23
5	Forcados	Delta	0	3	15	18
6	Aiyetoro	Ondo	1	2	4	7
			2	22	55	79

V. CONCLUSION

Based on the results of this study, we believe we have localized some of the more interesting anchor fields and sweet spots for FGTP Offshore Nigeria, from an industry perspective. Technological developments, the gas price and the continued increase in demand for energy will define if and when these resources will be exploited on a large scale. The study shows that the FGTP option in the Offshore Nigeria space has a limitation in that it deserves a thorough scrutiny to evaluate its techno-economic feasibility, as it could prove an economical and environmentally friendly option for future green energy generation. Possible application: If FGTP is properly harnessed, it could generate huge potential revenue for the government, resolve the epileptic power supply problem in Nigeria and create numerous employment opportunities.

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