International Journal of Science Academic Research
Vol. 03, Issue 06, pp.4016-4021, June, 2022
Available online at http://www.scienceijsar.com
ISSN: 2582-6425

Research Article

THE VALUE CHAIN OF GHANA'S MAJOR OFFSHORE OIL AND GAS PRODUCTION FROM 2010 – 2021

[1,] *Richard Amorin, [2]Kofi Dabo and [3]Stephen Fokuo

[1]Department of Petroleum and Natural Gas Engineering, University of Mines and Technology, Ghana
[2]Department of Petroleum Engineering, Montana Technological University, USA
[3]Ghana National Gas Company Limited, Ghana

Received 25th April 2022; **Accepted** 14th May 2022; **Published online** 30th June 2022

Abstract

The use of fossil fuels has played and continue to play a major role in industralisation. It has and continue to contribute to over 80% of the world's total primary energy production for the last three decades. Continues reliance on natural gas utilisation is deemed to support the transition to low-carbon energy system of the future compared to oil and coal. With the use of secondary data, this paper reviewed the value chain of Ghana's oil and gas operations considering the upstream, midstream and the downstream sectors from 2010 to 2021. From 2010 to 2021, Ghana has contributed over half a trillion barrels (510 MMbbl) of crude oil and over 1 Tscf of gas to the overall world's energy mix of the world from its offshore oil and gas operations. All the crude oil produced have been exported while for the gas produced, about 48.3% have been used for re-injection, 6.2% used as fuel gas offshore, 8.3% flared and 32.5% exported as sales gas. Out of the sales gas, about 54.7% was received by Ghana National Gas Company from Jubilee (49.8%) and Tweneboa-Enyenra-Ntomme (4.95%) and the remaining 45.3% was from Sankofa-Gye Nyame going to the onshore receiving facility for direct thermal power generation. About 90.34% of the raw gas received at Ghana National Gas Company was processed into lean gas for power generation. Condensates accounted for 0.65% while LPG accounted for 9.00%. Ghana now sources more than 60% of gas locally as feedstock for its thermal power generation. Out of the total gas produced from the three major fields, about 11,042,036 tonnes of CO_2 is estimated to have been emitted with the use which is far safer and better than the use of oil or coal therefore saving the environment. It is recommended that for Ghana to make the most of its oil and gas production, more value addition will be a necessity as practiced in most advanced oil and gas sectors than sale the product in its raw state.

Keywords: Crude Oil, Natural Gas, Production, Gathering, Processing, Distribution, Value Chain.

INTRODUCTION

The use of fossil fuels has played and continue to play a major role in industralisation. According to reports by 2020 BP Statistics and United Nations in 2021 [1], Oil, coal and natural gas have accounted for over 80% of the world's total primary energy production for the last three decades [1,2]. Ritchie et al. reported 83.70% in 2020 with oil accounting for 31.42%, coal 27.39% and gas 24.89% [3]. However, due to the associated environmental impact of the fuels, natural gas is deemed to support the transition to low-carbon energy system of the future compared to oil and coal. This is because of its lower carbon content and fewer impurities which makes it burn with lower sulphur dioxide content; a primary contributor to acid rain. It burns 50% and about 30% cleaner than coal and oil respectively [4, 5,6,7].

Ghana's Offshore Oil and Gas Fields

Ghana is endowed with huge hydrocarbon potentials. It has various oil and gas discoveries such as the Saltpond, Jubilee, Tweneboa-Enyenra-Ntomme (TEN), Sankofa-Gye Nyame and Offshore Cape Three Point (SGN/OCTP; SGN), Pecan, Nyankom, Block 4, and Afina. However, is only the first three that are under production with the others yet to be put into production [7]. Oil from Saltpond is heavy with a lot of Sulphur, quite different from what is being produced from the Jubilee and TEN fields [8]. The Saltpond Field is yet to be officially abandoned [8]. For the past twelve years, Ghana has been contributing to the overall world's energy mix.

Corresponding Author:** ***Richard Amorin,
Department of Petroleum and Natural Gas Engineering, University of Mines and Technology, Ghana

Ghana is ranked 12th in Africa with its proved oil reserve capacity but 7th in terms of production [9,10]. Ghana's reserves position as at 2018 stood at 1,092 MMboe, comprising 743 MMboe and 349 MMboe of oil and gas reserves respectively [11]. In 2020, Ghana exported over 30 MMbbl of crude oil ranking it 27th largest exporter of the product in the world. Crude oil was the 2nd most exported product in Ghana [12]. This work has attempted to collate various data on the production, gathering, transportation, processing, distribution, CO_2 emission aspects of the value chain of the hydrocarbons produced from Ghana's offshore oil and gas fields together for easy analysis and evaluation.

METHODS AND MATERIALS

Secondary data was gathered from literature for the studies. These included annual reports from energy and petroleum related establishments such as Petroleum Commission (PC), Energy Commission (EC), Ghana National Petroleum Corporation (GNPC), Ghana National Gas Company (GNGC), Public Interest and Accountability Commission (PIAC), and other published literature such as BP Statistics, Energy Statistics Pocketbook from the United Nations. The review considered the upstream, midstream and downstream usage of the oil and gas products from the offshore activities from mainly 2010 to 2021. Statistical analyses were performed on the set of data gathered.

RESULTS AND DISCUSSION

Ghana's oil and gas fields are associated with light and sweet characteristics indicating its high quality. The crude oil has an

API Gravity of about 37 degrees and a sulphur content of 0.25 % (weight), with no unusual characteristics [13].

Offshore Fields

Before the discovery of Ghana's major offshore oil fields and production in 2010, it had been producing oil on a limited scale since the 1978 from its offshore shallow-depth Saltpond Field. From 2002 to 2015, the field produced a total of 1,633,000 bbl of oil (about 320 bbl/day). The field was abandoned in 2015. However, from 2010 to 2021, major crude oil output has come from Jubilee, TEN, and SGN/OCTP fields (Figure 1) [14,15]. The Jubilee Field was discovered in 2007 and it came into production in 2010. It is estimated to have 618 million barrels (MMbbls) of recoverable reserves and 505 billion standard cubic feet (Bscf) of natural gas. The TEN Field was discovered in 2016, with an estimated recoverable reserve of 240 MMbbls and 396 Bscf of gas while the SGN/OCTP Field is estimated to have 500 MMbbls of oil and about 1.4 Tscf of non-associated gas. The OCTP is an integrated development project encompassing oil and non-associated gas extraction. The block came into production in 2017 [15].

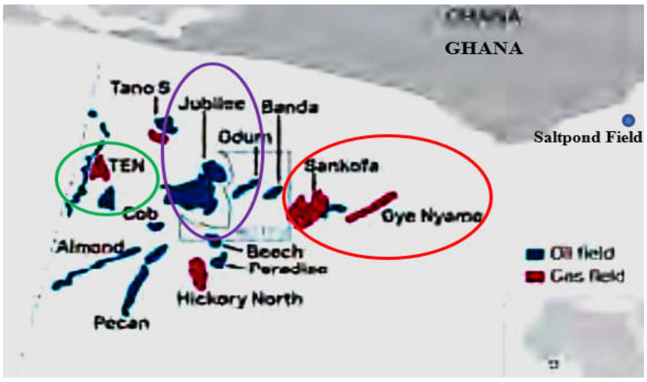
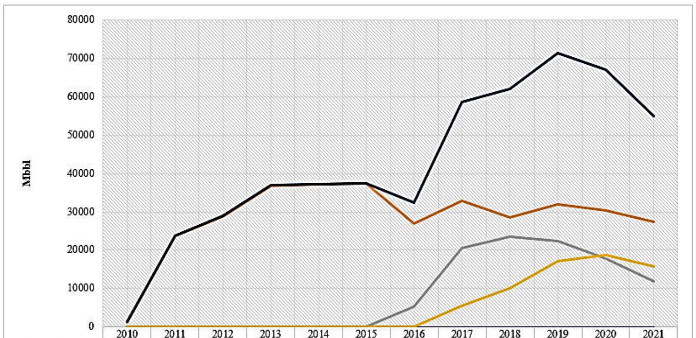


Figure 1. Offshore Oil and and Gas Fields [16]

Crude Oil Production

The three fields have produced from initial productions to end of 2021, a total of about 510 MMbbl of crude oil. Figure 2 shows the yearly production of oil from the fields [14, 15,17].



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Saltpond	98	76	105	98	97	47	0	0	0	0	0	0
Jubilee	1,268	23,758	28,831	36,760	37,202	37,412	26,982	32,750	28,462	31,915	30,425	27,335
TEN	0	0	0	0	0	0	5,316	20,453	23,557	22,319	17,803	11,978
OCTP	0	0	0	0	0	0	0	5,456	10,116	17,205	18,700	15,736
Total	1,365	23,833	28,937	36,859	37,299	37,458	32,298	58,658	62,135	71,440	66,927	55,050

Figure 2. Oil Production

Over the years, oil production has increased from 3,236 bbl/day of oil to 150,822.99 bbl/day as of December 2021. This represented an average production rate of 116,247.22 bbl/day corresponding to an average Annual Growth Rate (AGR) of 12% over the period. 2020 and 2021 recorded negative growth rates about 6% and 18% respectively [15,18,19]. By national policy directions, all these crude oils produced were exported [14,17].

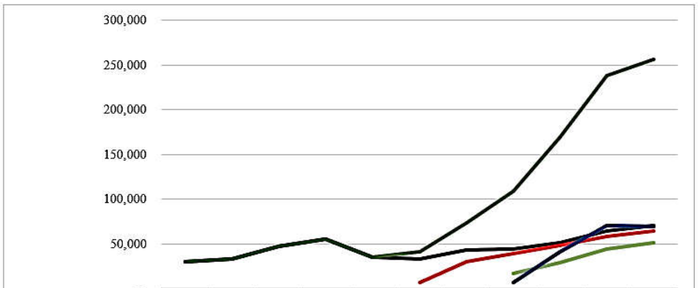
Natural Gas Production

Gas exports commenced from the Jubilee Field in 2014 after the completion of the Atuabo Gas Processing Plant (AGPP) or GNGC. Until the construction of the gas processing facility, most of the gas produced from the field were injected back into the reservoirs with a minor fraction flared [14, 17]. Since 2014, total gas production, comprising Associated Gas (AG) and Non-Associated Gas (NAG), has grown by 25% CAGR from 95 MMscf/d in 2011 to 702 MMscf/d in 2021. The Jubilee Field associated gas accounted for about 58% of all gas produced with an AGR of about 9%. The TEN Field on the other hand accounted for about 27% of all gas produced with an AGR of about 79% and lastly, the SGN Field accounted for the remaining 15% with an AGR of 182% [15, 17]. Though gas production from the SGN started in 2017, it was not until the NAG facilities on the FPSO was commissioned in 2018 that gas exports to the Onshore Receiving Facility (ORF) at Sanzule in the Western Region could commence [15]. The three fields have produced over 1 Tscf of both AG and NAG as at the end of 2021. Table 1 and Figures 3 to 5 show the production and primary utilisation of oil and gas from the fields [15, 17, 18]. The Jubilee field accounted for about 57% of all gas produced while the TEN field accounted for 27% with SGN accounting for the remaining 16%. Associated gas accounted for about 83% (923,753.10 MMscf) and non-associated gas accounted for the remaining 17% (188,621 MMscf). Out of this, about 48.3% have been used for re-injection, 6.2% used as fuel gas offshore, 8.3% flared and 32.5% exported as sales gas [15, 17, 18].

Table 1. Gas Production

Field (2014-2021)	Associated Gas Production (MMscf)	Non - Associated Gas Production (MMscf)	Gas Re-injected (MMscf)	Fuel Gas (MMscf)	Flared Gas (MMscf)	Sales Gas (MMscf)	%
Jubilee	511,031	-	211,645	33,959	67,416	176,728	56.7
TEN	247,895	-	168,852	15,301	19,699	17,394	27.5
SGN	142,162	188,621	145,848	18,277	3,183	160,492	15.8
Total	**901,088**	**188,621**	**526,345**	**67,537**	**90,297**	**354,614**	**100**
%	82.7	17.3	48.3	6.2	8.3	32.5	4.7*

* Unaccounted for.

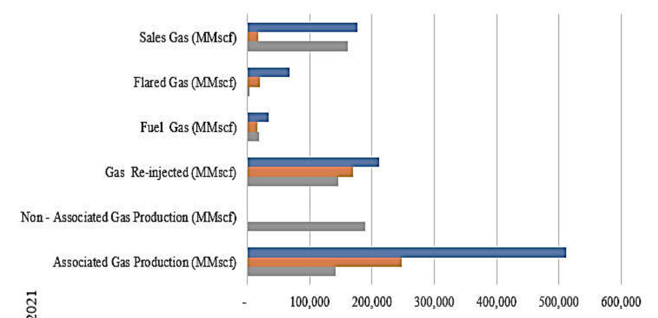


	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
JUBILEE AG	30,295	33,580	47,450	55,758	35,372	33,664	43,800	44,842	51,280	64,462	70,527
TEN AG						7,300	29,930	39,473	48,387	58,675	64,130
SGN AG								17,275	28,758	44,470	51,659
SGN NAG								7,136	41,184	70,356	69,946
Total NAG								7,136	41,184	70,356	69,946
Total (AG/NAG)	30,295	33,580	47,450	55,758	35,372	40,964	73,730	108,726	169,609	237,963	256,262

Figure 3. Associated and Non-Associated Gas Production

Total gas production has been increasing over the years. An increase of about 7.7% was recorded in 2021 relative to that of 2020. A total of 256,262.04 MMscf of AG and NAG was produced in 2021 from the fields compared to the 2020 volume of 237,962.82 MMscf which was also an increase of 40.3%

over 2019 production [14,22]. The SGN Field, relatively gas-concentrated, produced the highest volume of combined AG and NAG of 121,604.96 MMscf while the Jubilee and TEN Fields produced 70,527.21 MMscf and 64,129.87 MMscf respectively. A volume of 30,997.95 MMscf (about 44%) of raw gas produced was exported from the Jubilee Field to the GNGC. The gas exported in 2021, was approximately 17.4% more than the volume of 26,414.88 MMscf recorded in 2020 [17, 19].



2010-2021	Associated Gas Production (MMscf)	Non - Associated Gas Production (MMscf)	Gas Re-injected (MMscf)	Fuel Gas (MMscf)	Flared Gas (MMscf)	Sales Gas (MMscf)
Jubilee	511,031	-	211,645	33,959	67,416	176,728
TEN	247,895	-	168,852	15,301	19,699	17,394
SGN	142,162	188,621	145,848	18,277	3,183	160,492

Figure 4. Various Gas Usage

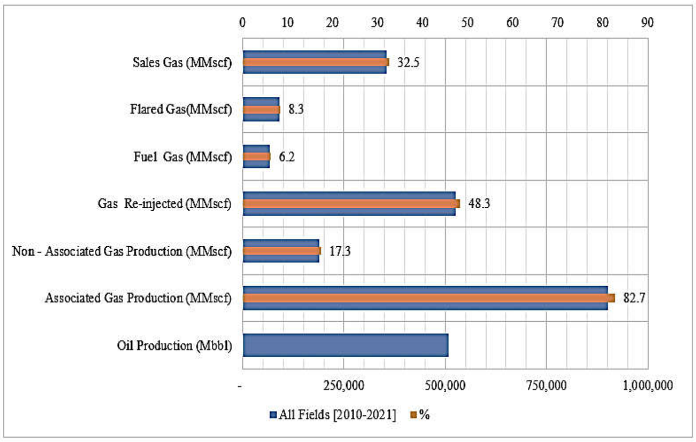


Figure 5. Oil and Gas Production and Utilisation

Midstream and Downstream

There are four basic roles of the gas value chain at the midstream and downstream in Ghana. These are [15, 16, 20]:

a. Gas aggregation: the gathering of both domestic and international gas. Currently, GNGC is the gas aggregator;
b. Gas processing: the processing of raw gas into lean gas and other derivatives for downstream use. Some of these derivatives are condensates, LPG and isopentanes. GNGC currently processes raw gas from the Jubilee and TEN Fields;
c. Gas shipping: the sale of processed gas to downstream customers. Currently, GNPC and GNGC perform this role (delivers power and non-power customers); and
d. Gas transportation: the transportation of lean gas and other derivatives through gas pipelines to downstream customers. Currently, GNGC, WAP Coand Genser Energy are the most recognised transporters.

Data from 2014 to 2021 revealed that about a total of 354,614 MMscf of gas was exported to the onshore facilities for further use. Out of this, about 54.7% was received by GNGC from Jubilee (49.8%) and TEN (4.95%) for both power and nom-power users while the remaining 45.3% was from SGN going to the ORF at Sanzule for direct thermal power generation (Figure 6) [15,17,18]. Jubilee raw gas produces about 75% – 80% lean gas while TEN raw gas produces about 90% – 95% lean gas. However, if the two gases are commingled, 80% - 85% lean gas is produced. The rest are liquids percentages. Over the period (2014 to 2021), about 90.34% of the raw gas received at GNGC was processed into lean gas and other derivatives for downstream use. The lean gas is exported to various power facilities for power generation (Figure 6; detailed diagram is shown in Figure A under Appendix). Condensates accounted for 0.65% while LPG accounted for 9.00%. Ghana contributes about 50% of the total LPG consumed in the country [21]. In 2020, Tema Oil Refinery accounted for 1.4% of domestic LPG while GNGC accounted for the remaining 98.6% [22]. This gas is used by about 90% by locals for cooking fuel and other domestic purposes [21]. The produced condensates are offloaded to Tema Oil Refinery for gasoline blending purposes. The remaining gas (about 0.01%) is used for site power production and to flare/vent stacks for safe operations (Figures 7 and 8) [15, 17,18].

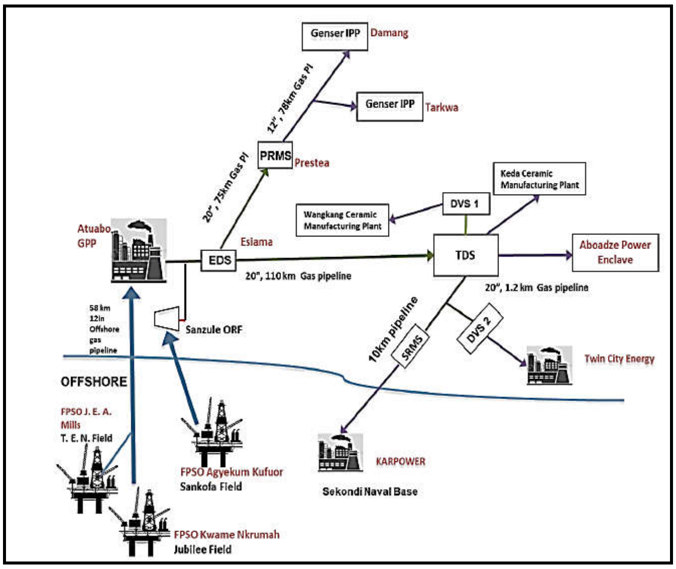


Figure 6a. Gas Gathering, Processing and Distribution [23]

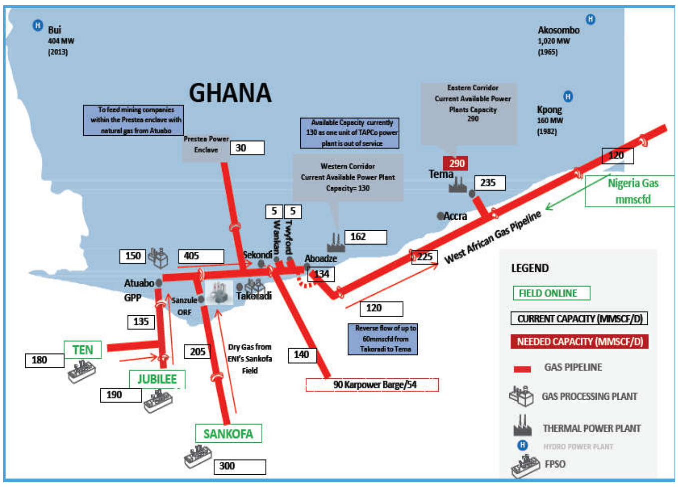


Figure 6b. Gas Gathering, Processing and Distribution [16]

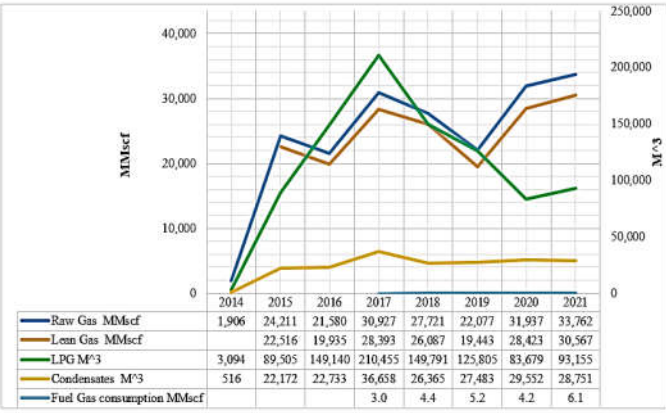


Figure 7. 2014-2021 GNGC Gas Processing

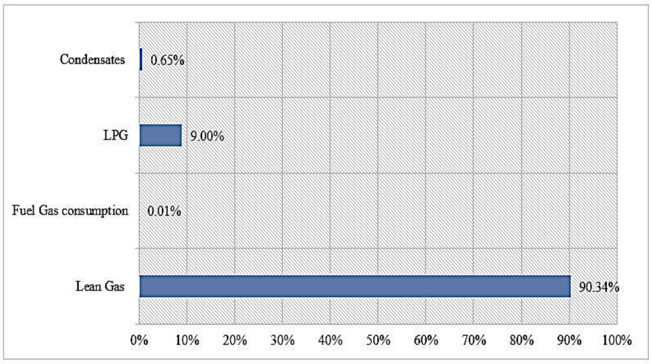


Figure 8. 2014-2021 GNGC Percentages of Gas Processed Products

Power Generation

According to the Energy Commission of Ghana 2021 report on 2021 National Energy Statistics, in 2010, hydro plants generated the highest proportion (about 92%) of electricity requirement whereas thermal plants generated the remaining 8%. However, in 2020, out of a total of 20,170 GWh of electricity generated, about 36.2% was from hydro while 63.6% was from thermal and 0.3% from renewables [14,22]. Since 2015, thermal has been the dominant source of electricity generation. The main fuels sources for the thermal plants are natural gas, Light Crude Oil (LCO) and Heavy Fuel Oil (HFO). Up to 89% of installed thermal plants depend on natural gas as the primary fuel source due to its comparative advantage over oil in terms of indigeneity, cost and environmental friendliness [22,24]. In 2019, Ghana procured about 63% of gas from its own offshore fields and another 37% via the West African Gas Pipeline. Renewable energy made up less than 1% of the the electricity mix excluding hydro [25]. Figure 9 shows estimated projection of the various energy mix from 2011 to 2020 [3]. Gas from the SGN Field provides more than 50% of the feedstock for thermal power generation in Ghana [15].

Green House Gas (GHG)

Typical pipeline-quality natural gas is about 95% CH_4, 3% NGLs, and 2% non-hydrocarbon gases, of which approximately half is CO_2. However, there remains a range of gas compositions that are consistent with pipeline specifications.

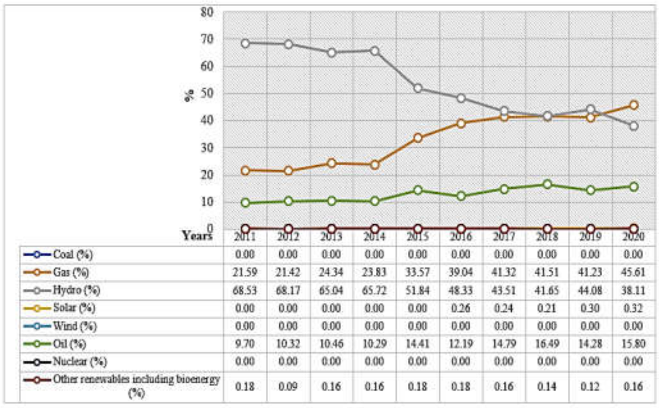


Figure 9. Energy Mix [3]

The minimum Carbon (C) content coefficient for natural gas to match that for pure CH_4, has an energy content of 1,005 Btu per standard cubic foot. Gas compositions with higher or lower Btu content tend to have higher C emission factors, because the "low" Btu gas has a higher content of inert gases (including CO_2 offset with more NGLs), while "high" Btu gas tends to have more NGLs. Flare gas may have an even higher energy content as 1,300 to 1,400 Btu per cubic foot. An average pipeline-quality gas heat content with an average C content in a cubic foot of gas is 14.48 MMT C/QBtu [26]. Gas flare may be a hot or cold process emitting often toxic or corrosive products such as Carbon Dioxide (CO_2), methane (CH_4), and nitrous oxide which contribute to global warming. Depending on operating conditions, waste gas composition, and other factors, the emissions of pollutants from flares may consist of incomplete or unburned fuel such as methane, volatile organic compounds, and by-products of the combustion process (e.g., Soot, CO_2, CO, NO, NO_2, and SO_2) which are of health and environmental concerns. [25, 26]. Noticeable, the operations of cold vents are more harmful to the environment than hot flares. Methane is far a more potent greenhouse gas, about 20 times higher than CO_2 even though it only lasts about a decade in the atmosphere whereas CO_2 persists for a couple of centuries [29]. In the US, it is estimated that the social cost for releasing a metric tonne of CO_2 is $51 while that of methane is $1,500, and nitrous oxide is $18,000 [30].

For a linear alkane with n carbon atoms, the stoichiometry equation for complete combustion is shown in Equation 1[31]:

$$C_nH_{2n+2} + {}_{(3n+1)/2}\,O_2 > {}_{n}CO_2 + {}_{(n+1)}H_2O + \text{Energy} \quad (1)$$

Table 2 shows the amount of CO_2 generated for using both gas and crude oil to generate 1000 MW of power in the Takoradi Enclave in Ghana. The use of the local gas produces about 6.3 times CO_2 compared to the use of crude oil to produce the same power [15,17,18,31].

Table 2. Estimated CO_2 Emissions

Fuel Source	Fuel Quantity	Tonnes of CO_2 Produced	Purpose	Total Tonnes of CO_2 Produced
Gas MMscf	168	3,620	Burnt to generate 1000 MW of power	
Oil (Equivalent Oil Rate) bbl	38,960	22,834		
Fuel Gas (MMscf)	67,537	1,455,272	Burnt to generate power	**11,042,036**
Flared Gas (MMscf)	90,297	1,945,682	Burnt for safety	
Sales Gas (MMscf)	354,614	7,641,083	Burnt to generate energy	

Out of the total gas produced from the three major fields, about 11,042,036 tonnes of CO_2 have been emitted far better than the use of oil or coal therefore saving the environment from GHG. With the less GHG impact, gas will therefore continue to remain the most sustainable and relatively cost-competitive fuel supply to produce affordable power in the country [22].

Legal and regulatory framework

Ghana's institutional framework for the upstream oil and gas sector over the past ten years to improve governance outcomes, promote transparency and accountability, and reduce bureaucratic red tape. This has been done with a view towards [15]:

i. Managing the technical, environmental and social risks within the sector;
ii. Maximising the direct (fiscal revenues), indirect and induced (local content, supply chain and wider industrial development) benefits to the country; and
iii. building the capacity to engage effectively with investors (IOCs) and the supply chain.

The institutional capacity to oversee and manage the upstream oil and gas sector rests with various government ministries, commissions and other departments. A few key ones are highlighted:

i. Ministry of Energy: The Ministry has mainly policy and oversight functions, and the Minister is in charge of myriad matters, including licensing of acreage.
ii. Ghana National Petroleum Corporation: The national oil company performs a commercial role and is a party to every petroleum agreement.
iii. Ghana Petroleum Commission: This is the mandated regulator of the industry and performs managerial, technocratic, and regulatory functions, as well as an advisory role to the Minister.
iv. Ghana National Gas Company: This is the national gas company and from 2020, per a directive from the Presidency, became the mandated aggregator of the gas in the industry.
v. Environmental Protection Agency: It is responsible, in conjunction with the Commission, for matters dealing with Health, Safety and Environment (HSE) and works in conjunction with other bodies.
vi. Public Interest and Accountability Committee (PIAC): It is a statutory body charged with the monitoring and compliance by the government of the Act that governs petroleum revenue management in Ghana. Its objects are stated as to monitor and evaluate compliance with the Petroleum Revenue Management Act, 2011 (Act 815) by government and other relevant institutions, to provide space and platform for public debate, and to provide independent assessments on the management and use of petroleum revenue.

Conclusion

This work has attempted to collate various data on the production, gathering, transportation, processing, distribution, all the crude oil produced from the three major offshore fields from 2010 to 2021 (510 MMbbl) was exported. The three fields have also produced over 1 Tscf of both AG and NAG; Jubilee accounting for about 57%, TEN Field accounting for 27% with SGN accounting for the remaining 16%. AG accounted for about 83% (923,753.10 MMscf) and NAG accounted for the remaining 17% (188,621 MMscf). Out of this, about 48.3% have been used for re-injection, 6.2% used as fuel gas offshore, 8.3% flared and 32.5% exported as sales gas. GNGC received about 54.7% of the sales gas from Jubilee (49.8%) and TEN (4.95%) and the remaining 45.3% was from SGN going to the onshore receiving facility for direct thermal power generation. About 90.34% of the raw gas received by GNGC was processed into lean gas for power generation. Condensates accounted for 0.65% while LPG accounted for 9.00%. Aside the amount of gas re-injected, all other gas produced from the three major fields, have accounted for about 11,042,036 tonnes of CO_2 generation. However, this is far safer and better source of fuel than the use of oil or coal. It is recommended that for Ghana to make the most of its oil and gas production, more value addition will be a necessity as practiced in most advanced oil and gas sectors than sale the product in its raw state.

REFERENCES

1. Leonardo, S. (2021), Energy Statistics Pocketbook 2021, United Nations Publications, *https://unstats.un.org/unsd/energystats/pubs/documents/2021pb-web.pdf.* Accessed: May, 2022.
2. Primary Energy, BP Official website, *https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/primary-energy.html.* Accessed: April, 2022.
3. Ritchie, Hannah, Roser Max and Rosado Pablo (2020) - "Energy". Published online at Our World in Data.org. Retrieved from: *'https://ourworldindata.org/energy'.* Accessed: April, 2022.
4. The Advantages of Natural Gas, *https://www.snelsonco.com/advantages-of-natural-gas/.* Accessed: May, 2022.
5. Economic Impact, https://www.ngsa.org/economic-impact/. Accessed: February, 2022.
6. Amorin, R, and Dabo, K. (Jnr), (2022), Assessment of the Safety Handling of Domestic Liquified Petroleum Gas (LPG) Cylinders using a Suburb of Afienya Township as a Case Study, *European Journal of Technology*, Vol. 6, Issue 2, pp. 16 – 31, https://doi.org/10.47672/ejt.1033.
7. Dale, S. (2022), BP Energy Outlook 2022 Edition, *https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/energy-outlook/bp-energy-outlook-2022.pdf,* Accessed: May, 2022.
8. Aidoo, I, (2018), Saltpond Oil Field: No Decision Yet, Public Interest and Accountability, *https://www.piacghana.org/portal/12/13/168/saltpond-oil-field-no-decision-yet.* Accessed: June, 2022.
9. Proved Crude Oil Reserves in Africa in 2021, by Country, https://www.statista.com/statistics/1178147/crude-oil-reserves-in-africa-by-country/. Accessed: May, 2022.
10. Goodrich, G. (2022), Top 10: Africa's Leading Oil Producers in 2021, *https://energycapitalpower.com/top-10-africas-leading-oil-producers-in-2021/.* Accessed: March, 2022.
11. Ghana National Petroleum Cooperation 2018 Annual Report, *https://www.gnpcghana.com/speeches/annual_report2018.pdf.* 105 pp.
12. Crude Petroleum in Ghana, *https://oec.world/en/profile/bilateral-product/crude-petroleum/reporter/gha.* Accessed: March, 2022.

13. Kastning, T. (2012), Basic Overview of Ghana's, Emerging Oil Industry, FES Ghana, *https://library.fes.de/pdf-files/bueros/ghana/10490.pdf.*Accessed: June, 2022.
14. Amonoo-Neizer, O. (2021), 2021 National Energy Statistics, *Energy Commission of Ghana* 64 pp. Accessed: May, 2022.
15. Assessment of the Management and Use of Ghana's Petroleum Revenues (2011-2020), *Public Interest and Accountability Committee Report*, 226 pp.
16. Ampofo D. (2021), An Overview of Ghana's Gas Sector, A Position Paper on Supply, Demand and the Way Forward, Ghana Upstream Petroleum Chamber, 23 pp, *https://www.ghanaupstream.com/wp-content/uploads/2019/05/GUPC_PositionPaper_Gas_FORSAMPLEPRINT_16April2021_1.pdf.* Accessed: June, 2022.
17. Petroleum Commission of Ghana, Production and Lifting Archive, *https://www.petrocom.gov.gh/archive/.* Accessed: April, 2022.
18. Assessment of the Management and Use of Ghana's Petroleum Revenues Annual Reports for 2011, 2012, 2013, 2014, 2014, 2015, 2016, 2017, 2018, 2019, 2020. *https://www.piacghana.org/portal/5/25/piac-reports.* Accessed: May, 2022.
19. Adom-Frimpong, K. (2021), Assessment of the Management and Use of Ghana's Petroleum Revenues 2021 Annual Report, *Public Interest and Accountability Committee Report*, 203 pp.
20. Ghana National Gas Company, Our Impact on Ghana's Industrialization, *http://www.ghanagas.com.gh/ghana.* Accessed: January, 2022.
21. Natural Gas Pipeline Network, Genser Energy, *https://www.genserenergy.com/operations/ghana/natural-gas-pipeline-network/.* Accessed: June, 2022.
22. Amonoo-Neizer, O. (2021), 2021 Energy Outlook for Ghana, Energy Commission, *http://www.energycom.gov.gh/.*Accessed: March, 2022.
23. The 2021 Gas Challenge, *Study Guide for Tertiary Institutions' Edition,* Ghana National Gas Company, 161 pp.
24. Osei-Tutu, P., Boadi, S. andKusi-Kyei, V. Electrical energy transition in the context of Ghana. Energy Sustain Soc 11, 47 (2021). *https://doi.org/10.1186/s13705-021-00322-4.*
25. Acheampong, T. and Menyeh, B. O., (2021), Ghana's Electricity Supply Mix Has Improved, But Reliability and Cost is Still a Challenge, *https://theconversation.com/ghanas-electricity-supply-mix-has-improved-but-reliability-and-cost-is-still-a-challenge-161762.* Accessed: May, 2022.
26. ANNEX 2 Methodology and Data for Estimating CO_2 Emissions from Fossil Fuel Combustion, *https://www.epa.gov/sites/default/files/2020-04/documents/us-ghg-inventory-2020-annex-2-emissions-fossil-fuel-combustion.pdf.* Accessed: June, 2022.
27. Denham, P. and Donnelly, A., (2015), Managing the Hazards of Flare Disposal Systems, *https://www.icheme.org/media/8462/xxv-paper-15.pdf. Accessed:* February, 2022.
28. Ismail, O. S. and Umukoro, G. E., (2016), Modelling Combustion Reactions for Gas Flaring and Its Resulting Emissions, *Journal of King Saud University - Engineering Sciences*, Vol. 28, Issue 2, ISSN 1018-3639, pp. 130-140.
29. Buchanan, M., (2020), Why Methane Is a Far More Dangerous Greenhouse Gas Than Carbon Dioxide, *https://theprint.in/environment/why-methane-is-a-far-more-dangerous-greenhouse-gas-than-carbon-dioxide/378858/.* Accessed: February, 2022.
30. Clifford, C., (2021), Here's What You Need to Know About 'The Social Cost of Greenhouse Gases' — A Key Climate Metric, *https://www.cnbc.com/2021/03/09/heres-everything-you-need-to-know-about-the-social-cost-of-greenhouse-gases.html.* Accessed: February, 2022.
31. Asante, K B. (2022), Balancing Energy Poverty and Energy Transition in Africa; the Role of Gas *https://www.youtube.com/watch?v=abGh6zAzzZc&t=24s.* Accessed: June, 2022.

APPENDIX

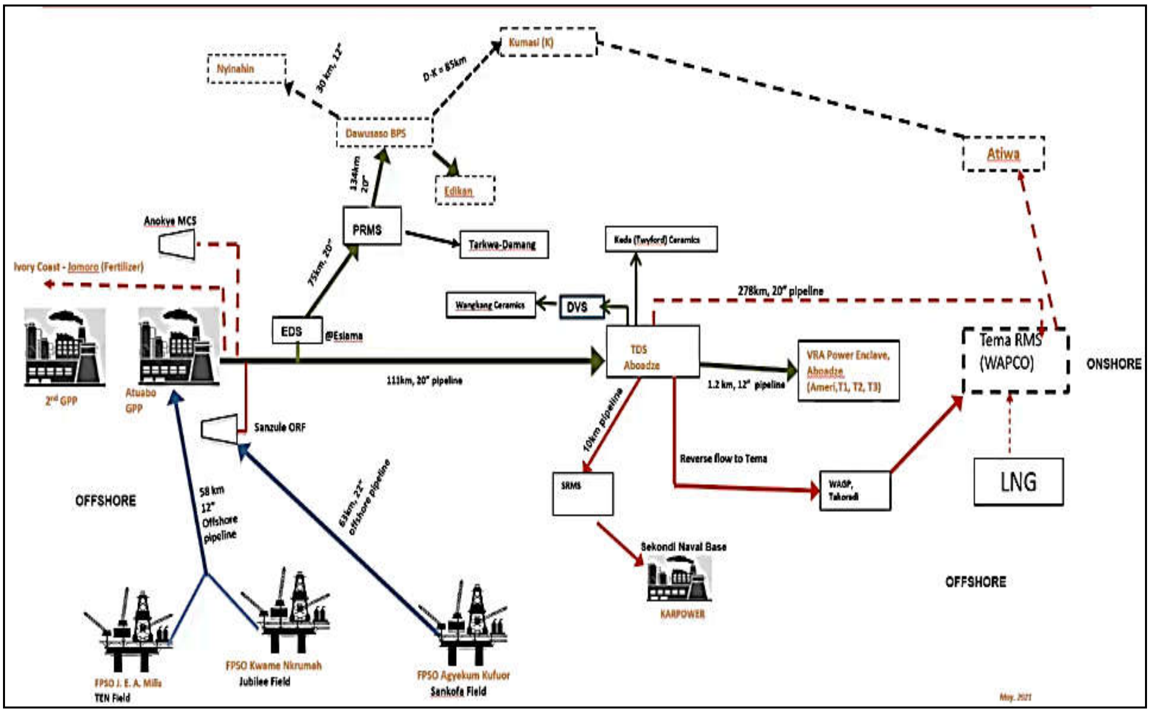


Figure A. Existing and Proposed Lines for Gas Transportation Network [31]

****