Nigeria: The Gulf of Guinea's Energy Hub – Mapping the Pathway

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Abstract

This research proposal investigates the impact of implementing a five-pillar HSSE-integrated framework known as PATHS (Protect, Advance, Trade, Harness, and Sustain) for the development of Nigeria's energy sector to ensure that the country becomes the energy hub of the Gulf of Guinea. The model involves the implementation of several developmental phases embedded within its five-pillar system, such as pipeline security and surveillance technology, community incentives for monitoring infrastructure, flare gas capture and conversion stations, and environmental protection structures through government and stakeholder investments. To model the result outcomes of the PATHS framework from 2025 to 2035, a Random Forest Regression (RFR) machine learning model was trained by studying key parameters such as project cost, amount of gas flared, oil spillage, energy revenue, electricity generation, pipeline vandalism, GDP growth rate and youth employment from historical data ranging from 2014 to 2024 with comparison data gotten from peer-resource nations such as Brazil, Qatar and Malaysia. The result obtained showed that pipeline vandalism could fall by 79%, electricity generation could rise from 15.98 GW to 63.6 GW, youth employment could grow from 68,000 to 850,000, Nigeria's energy revenue could grow by 70% and finally, the GDP growth rate was expected to be 8.81% for the year 2035. By implementing the PATHS framework, Nigeria not only stands to gain from being an energy hub, but other Gulf countries also gain a lot in terms of new investments as a result of regional stability. The PATHS framework represents a scalable pathway for the development of the energy sector in Nigeria and the Gulf of Guinea, reducing reliance on external sources of energy.

Keywords: *Nigeria, PATHS Framework, Gulf of Guinea, energy hub, oil and gas, HSSE, gas flaring, Oil spillage, pipeline vandalism, Random Forest Regression model*

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I. INTRODUCTION

In the Gulf of Guinea, access to energy remains a critical issue that needs to be resolved for economic prosperity. Despite the significant natural resource deposits of member nations such as Ghana, Benin, Equatorial Guinea, and Cameroon. Inadequate and unreliable infrastructure continues to plague the energy sector of these Nations, leading to frequent blackouts, high fuel import costs, and a lack of power supply to rural communities (IEA, 2022). According to a report in 2023 by AFDB, over 600 million people in Sub-Saharan Africa do not have access to electricity, and this impedes industrial and economic growth in the region. To bridge this gap, regional initiatives such as the West African Gas Pipeline (WAGP) and West African Power Pool (WAPP) aim to build transnational energy networks for their industrial energy needs; however, most member states lack the resource capacity to meet these needs. Nigeria is the only nation amongst the member states of the Gulf of Guinea that can undertake a large-scale energy revolution in the region with its huge oil and gas resource base and economic size, being the largest oil producer in Africa with 210 trillion cubic feet (TCF) of natural gas and 36.9 billion barrels of proven oil reserves (OPEC, 2023).

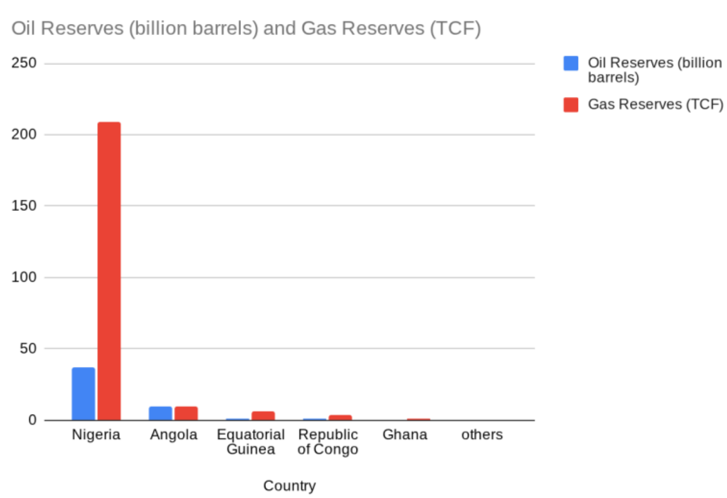


Figure 1.1. Oil and gas reserves of countries in the Gulf of Guinea (OPEC, 2023)

Adapted from the Organization of Petroleum Exporting Countries (OPEC) 2023 report in the annual statistics bulletin. The data showcases Nigeria's natural gas and crude oil reserve dominance over fellow Gulf states.

In 2023, Nigeria's economy was also the largest, with $477 billion gross domestic product (World Bank, 2024) but despite its enormous potential, the country still continues to struggle as a result of corruption and regional security crisis, preventing it from leveraging its resources to become a regional energy leader. Critical oil and gas infrastructure continues to be vandalized, and the energy industry remains underfunded (NUPRC, 2024), coupled with operational bottlenecks in the form of bureaucracy. In 2023 alone, over 6.5 billion cubic meters of gas were flared in Nigeria, unable to utilize this gas to meet local energy demands (World Bank, 2024), and pipeline insecurity as a result of piracy and militant group activity in the Niger delta has led to some operations being shut down, leading to severe revenue losses. Prior to the Dangote refinery beginning operations, Nigeria imported 90% of its refined petroleum products (OPEX, 2023). Having identified the existing gaps in the Gulf of Guinea energy sector, the research study aims to propose a practical pathway in the form of an HSSE-integrated framework (PATHS) for spearheading an energy revolution in the Gulf of Guinea with Nigeria as the strategic energy hub. By developing a Protect, Advance, Trade, Harness, and Sustain (PATHS) framework that covers all aspects of the current problems encountered in the Nigerian energy sector for its transformation, utilizing historical data (2014-2024) patterns from Nigeria, other Gulf Nations, and top-performing Oil and Gas Nations, an ML-based (Random Forest Regression model) simulation for projected outcomes of implementing the PATHS framework can be performed to investigate key performance metrics from 2025 to 2035 for addressing the current challenges facing the Gulf and reposition Nigeria as the energy hub of the Gulf of Guinea.

Figure 1.2. Map of the Gulf of Guinea Nations (PresidentistVB, 2014)

The Nations include: Nigeria, Côte d'Ivoire, Ghana, Benin, Togo, Cameroun, Equatorial Guinea, São Tomé and Príncipe, and Gabon. It is sometimes extended to include: Angola, the Republic of Congo, and the Democratic Republic of Congo.

II. THE PATHS FRAMEWORK

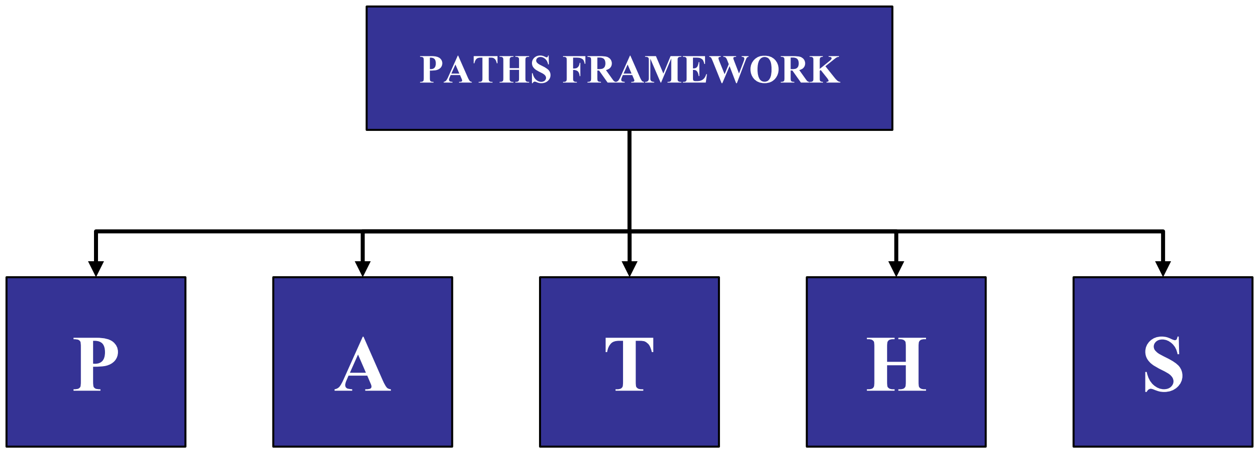
The PATHS framework is an HSSE-driven model for reforming Nigeria's Oil and Gas sector, which comprises five pillars: Protect, Advance, Trade, Harness, and Sustain. Each pillar is designed to address critical areas within the energy sector to help Nigeria in its quest to become an energy hub for the Gulf of Guinea.

- **Protect:** To ensure energy infrastructure security by seeking the support of communities through incentives. Also, incorporating AI and advanced detection systems for surveillance.
- **Advance:** This is focused on modernizing existing infrastructure, such as pipelines, LNG terminals, surveillance systems, and oil and gas crime-fighting services.
- **Trade:** This promotes cooperation between member states, policy harmonization, and transnational energy trading networks.

- **Harness:** To capture flared gas and convert it into CNG, LNG and also to build mini-power stations for electrification to meet local needs and for export opportunities
- **Sustain:** Regular environmental impact assessments and emissions monitoring to ensure the region's climate obligations are maintained.

Implementation Strategy

The successful implementation of the PATHS framework depends on collaboration between the government of Nigeria, stakeholders, and the willingness of the Gulf member states to partake in the energy reform process. Each pillar comprises key interventions coupled with HSSE-Integrated strategies for deployment. The PATHS framework is simplified in the diagram below.


PATHS FRAMEWORK
P
A
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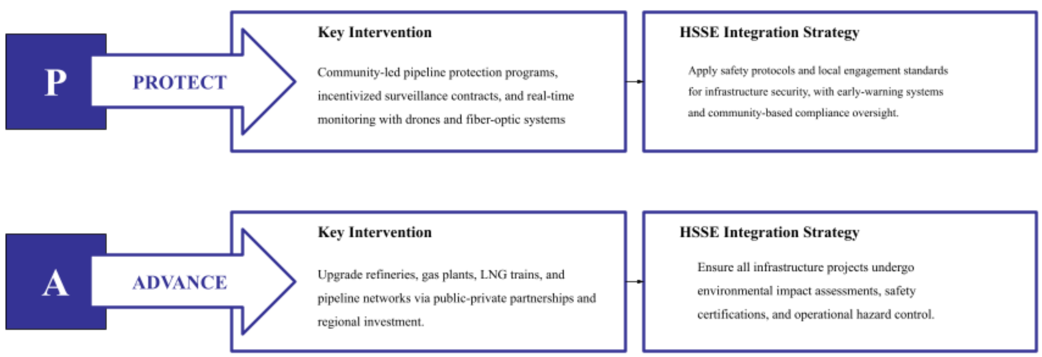

P
PROTECT
Key Intervention
Community-led pipeline protection programs, incentivized surveillance contracts, and real-time monitoring with drones and fiber-optic systems
HSSE Integration Strategy
Apply safety protocols and local engagement standards for infrastructure security, with early-warning systems and community-based compliance oversight.
A
ADVANCE
Key Intervention
Upgrade refineries, gas plants, LNG trains, and pipeline networks via public-private partnerships and regional investment.
HSSE Integration Strategy
Ensure all infrastructure projects undergo environmental impact assessments, safety certifications, and operational hazard control.

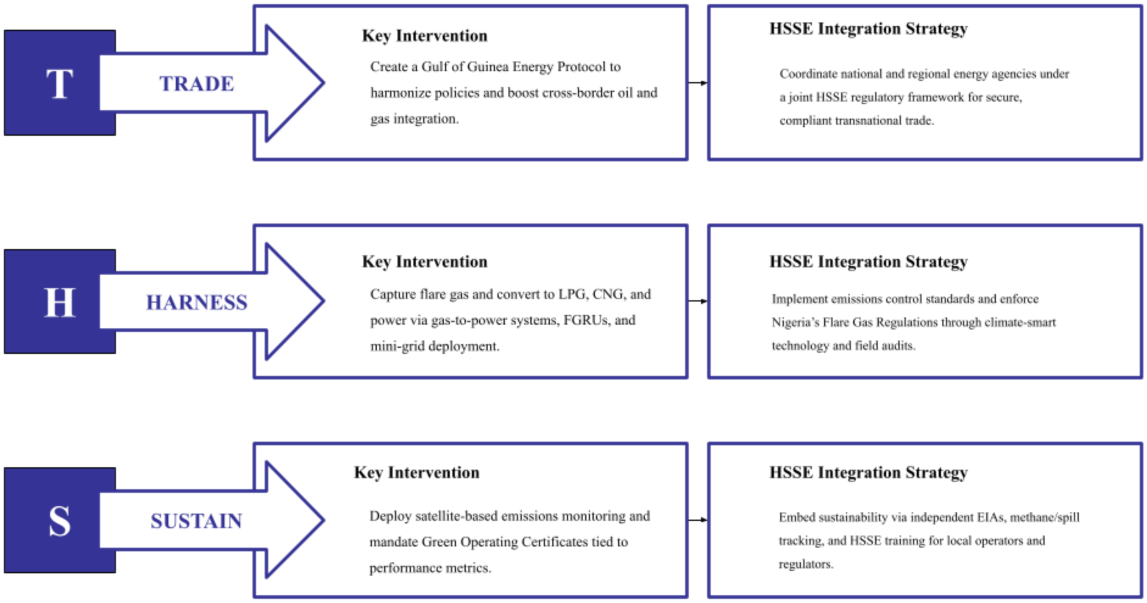


Figure 2.1. PATHS framework diagrammatic representation

key performance metrics and indicators

The various metrics used for determining how successful the framework is in improving the energy sector in Nigeria and across the region are outlined below:

- Youth employment (in thousands per year)
- Pipeline vandalism (cases per year)
- Gas flaring (bcm per year)
- Oil spillage (cases per year)
- Energy revenue (in USD)
- Electricity generation (in GW)

- GDP growth rate (in %)
- Pipeline infrastructure growth (in km)

Methodological Basis for Projections

To predict the outcomes of the PATH framework implementation, a Random Forest Regression model was selected. This section covers the model formulation, type of data used for training the model, and the timeline for the predicted results of the model.

Regression Model Formulation

The Random Forest Regression (RFR) model is expressed in ensemble form below.

$y = \frac{1}{N}\sum_{i=1}^{N} \quad Ti(x)$...equation (2.1)

Where:

y = The predicted output of the model (e.g., Oil spillage and gas flaring volume)

N = The number of trees in the ensemble system (100 was used)

$T_i(x)$ = Output from the i-th decision tree for input

Predictor variables were used to minimize overfitting and maximize the diversity of the trend with the trees built on the subsets of the regression model training data.

Out-of-Bag (OOB) Error: This was used to measure the performance of the model, showcasing an average root mean square error value within a 5% margin for all variables investigated.

Additional testing was done using **k-fold cross-validation (k=5)** to ensure consistent predictive power across folds.

k-fold cross-validation with k=5 was employed as an additional metric for ensuring the consistency of the predictions made.

The model assumes

- A continuous flow of funds for the implementation of the PATHS framework initiatives
- Collaboration between the nations in the Gulf of Guinea
- Strict adherence to policies across administrations.

Mapping of Dependent and Independent Variables

The predicted outputs of the regression model is dependent on several influencing variables shown in the table below.

Table 2.1

Dependent and Independent variables in ML model training

Dependent Variable (Y)	Independent Variables (X)
Pipeline vandalism (incidents/year)	Surveillance technology adoption rate, Local youth employment level, Community security investments
Gas flaring (bcm/year)	Number of flare capture facilities, Volume of associated gas produced, HSSE enforcement level
Oil spill incidents (cases/year)	Pipeline age and integrity, Regulatory compliance score, Worker safety training index
Electricity generation (GW)	Number of gas power plants operational, National grid expansion budget, Gas supply reliability
Youth employment in energy (thousands)	New infrastructure projects initiated, Skill acquisition programs funded, Private-sector hiring incentives
Pipeline infrastructure (km)	Federal investment in pipeline development, Regional/transnational agreements signed, Construction capacity per annum

Energy revenue (USD billion)	Hydrocarbon export volume, Global energy prices (Brent crude/gas), Trading partner diversification
Gulf of Guinea GDP growth (%)	Energy access index per country, Regional power exports, Number of energy-linked industrial projects

Each of the above influencing variables was investigated using data from 2014-2024 for a robust training of the model used for the PATHS framework projection.

Baseline Trend and Comparative Case Modeling

The historical data used were compiled from the following sources:

- Nigerian Extractive Industries Transparency Initiative (NEITI, 2024)
- Nigerian Electricity Regulatory Commission (NERC)
- Nigerian Upstream Petroleum Regulatory Commission (NUPRC, 2024)
- National Oil Spill Detection and Response Agency (NOSDRA, 2023)
- National Bureau of Statistics (NBS)
- World Bank Global Gas Flaring Reduction (GGFR) Platform
- World Bank Open Data Platform
- Organization of Petroleum Exporting Countries (OPEC)

To improve the accuracy of the model, a comparative approach was also implemented to observe infrastructural and policy reform trends by fellow resource-rich nations such as Brazil, Mexico, Indonesia, and Qatar. The data obtained from these comparative analyses was used to improve the projections of the regression model for proper simulation of the expected PATHS framework implementation outcomes.

Projection Time Frame

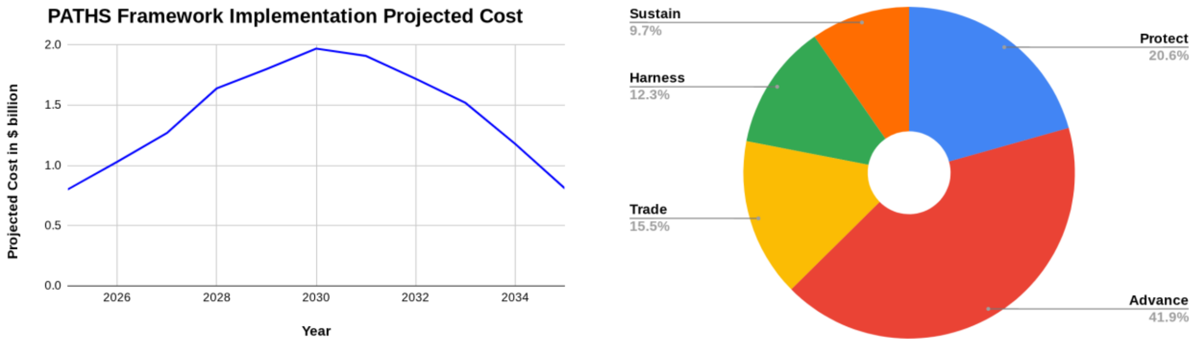
This study adopts a time frame of 2025 to 2035 for the implementation of the PATHS framework and the projected outcome. It assesses Nigeria's potential gains and also the benefits of other Gulf states using a Random Forest Regression model trained with historical and comparative data from reputable open-access data sources. The study highlights key parameters such as pipeline infrastructure growth, gas flaring, oil spillage reduction, electricity generation, energy revenue, youth employment, and GDP growth rate.

Note: Sao Tome and Principe were excluded from the study due to a lack of data for projections and their relatively small economic size

III. RESULTS AND DISCUSSION

The Result and discussion section of this research work gives a detailed insight into the benefits of implementing the PATHS framework for the nations of the Gulf of Guinea, with Nigeria serving as the focal point. The Machine learning projection data, which is based on the Random Forest Regression (RFR) model and trained using historic data from sources such as world bank, NOSDRA, OPEC and NEITI, covering the years 2014 to 2024. The ML projection data obtained served as the result for this research with eight (8) key performance indicators used for determining success, and monitored for a project time period stretching from 2025 to 2035. These KPI's are; Youth employment (in thousands per year), Pipeline vandalism (cases per year), Gas flaring (bcm per year), Oil spillage (cases per year), Energy revenue (in USD), Electricity generation (in GW), GDP growth rate (in %), Pipeline infrastructure growth (in km). The total investment required for the implementation of the paths framework was also considered.

Result



(a) **(b)**

Figure 3.1. PATHS framework implementation cost

Figure 3.1 above shows the PATHS framework investment plan with (a) being the total project implementation cost per year stretching from 2025 to 2035, while (b) is the investment share of each pillar within the PATHS framework. In chart (a), there is a continuous rise in investment cost (in billion USD) which peaks around year 2030 and then falls back considerably to the initial investment in year 2035, which means that larger investments are needed in the middle of the project implementation years mainly due to the set-up of critical infrastructure, which should have been almost fully implemented before the year 2035. The chart (b), the advanced pillar of the PATHS framework, requires the largest investment share of 41.9% due to the need for infrastructural upgrades and construction of new energy facilities, which the pillar is centered on.

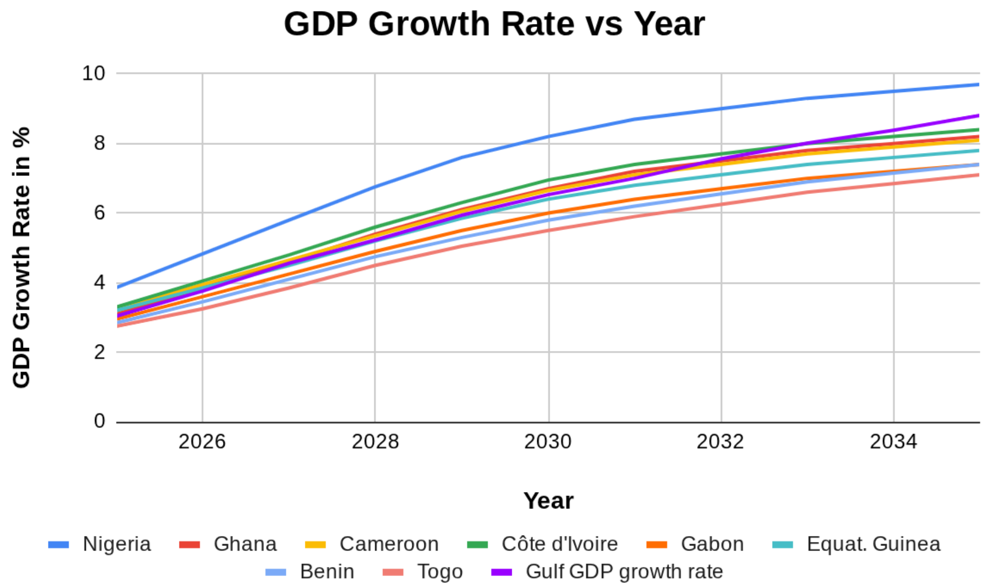


Figure 3.2. Projected GDP Growth Rate of the Gulf of Guinea Nations

Figure 3.2 above shows the annual GDP growth rate of eight (8) countries within the Gulf, with Nigeria leading the way with a GDP of just under 4% in 2025 to over 9% in 2035, Benin (2.85 to 7.4%), Togo (2.75 to 7.1%), Equatorial Guinea (3.2 to 7.8%), Gabon (2.95 to 7.4%), Cote d'ivoire (3.3 to 8.4), Cameroon (3.25 to 8.1%), and Ghana (3.1 to 8.2%). In essence, the plot shows that implementing the PATHS framework is highly beneficial to all nations within the Gulf.

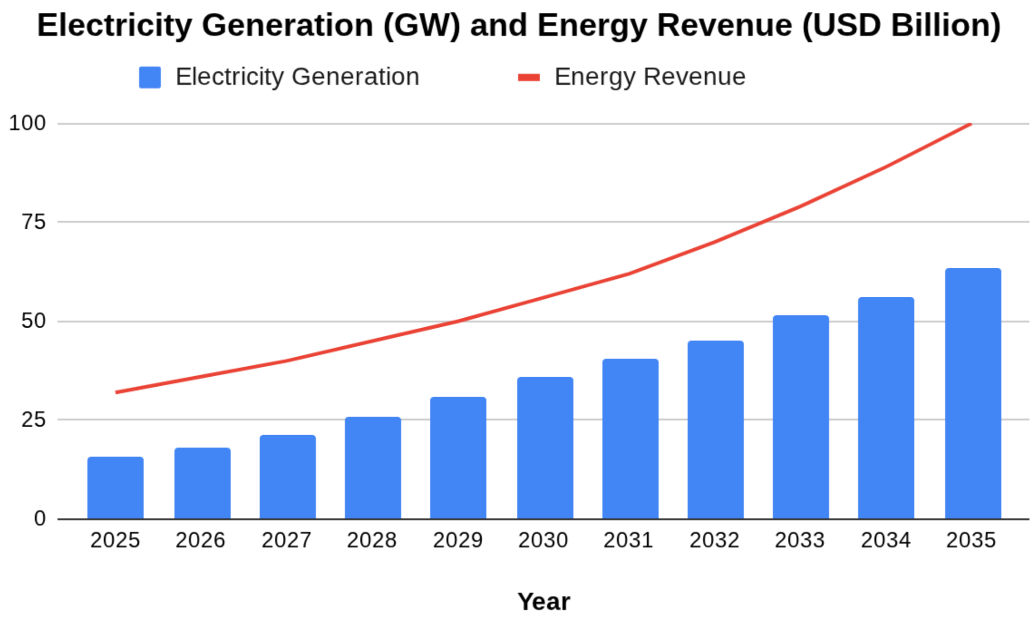


Figure 3.3. Comparison between Projected Values of Electricity Generated in the Region and Energy Revenue

From Figure 3.3 above, it is observed that the energy generation and revenue from Oil and Gas trading increases rapidly within the 10 year period from around 15.98 GW (total output from all Gulf countries) in 2025 to 63.6 GW in 2035 and $32 billion (USD) from 2025 to over $100 billion respectively. The impliaction of this growth in energy generation and revenue means less dependence on external funding for major infrastructural projects and a rapid economic growth rate (already shown in figure 3.2). Gulf nations would become truly independent economically.

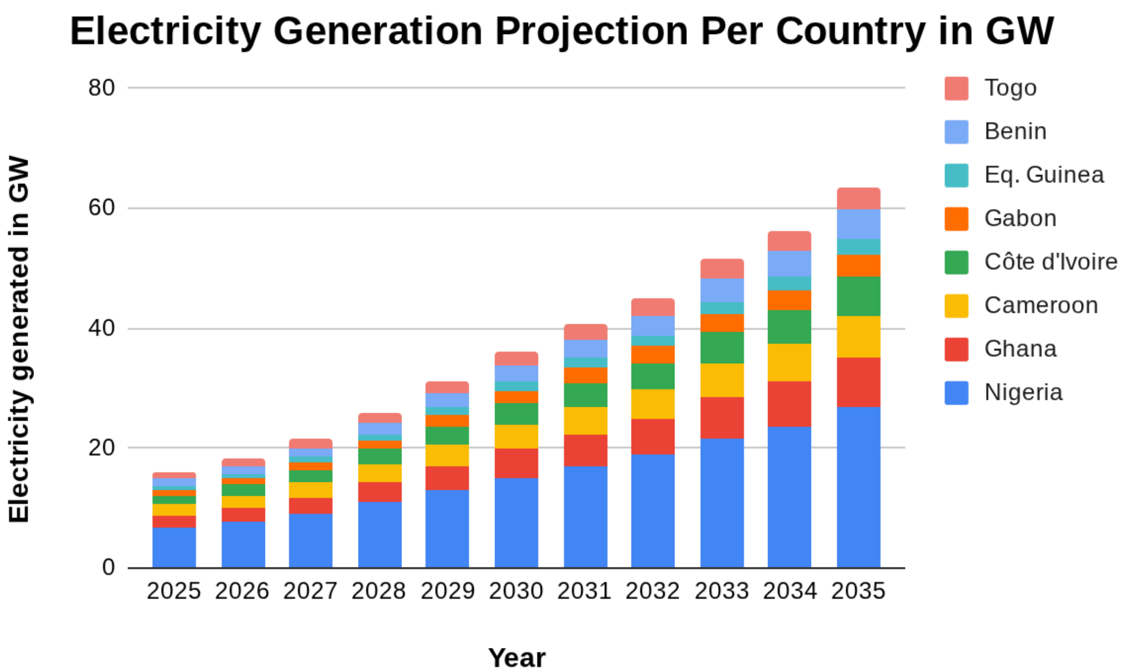


Figure 3.4. Stacked Electricity Generation for Eight Gulf Countries

Figure 3.4 represenrs the individual electrical generation per country within the Gulf. Nigeria has the largest share (20.3 GW) of the 63.6 GW of power generated in 2035 with the others being Ghana (7.60 GW), Cameroon (7.50 GW), Cote d'ivoire (7.49 GW), Gabon (7.44 GW), Equatorial Guinea (7.59 GW), Benin (2.85 GW) and Togo (2.75 GW). This increase in energy generation across all the Gulf nations would ensure the growth of the manufacturing sector hence improving the economies and providing indirect sources of employment for locals.

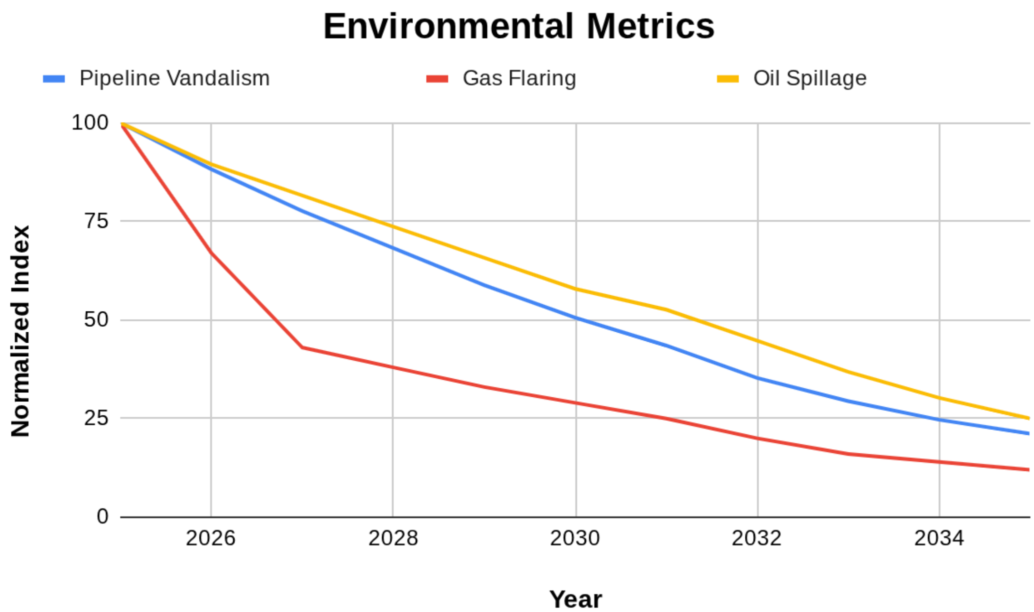


Figure 3.5. Environmental Impact for the Projected PATHS Implementation Period

Figure 3.5 above shows the reduction in environmental concerns related to the Oil and Gas industry; gas flaring, pipeline vandalism and oil spillage. With the implementation of the PATHS framework, Nigeria would see a 79% decrease in pipeline vandalism from 85 cases recorded in 2025 to under 18 cases in 2035, 88% decrease in gas flaring in the Niger delta from 10 billion cubic meters (bcm) to 1.2 bcm, and a 75% decrease in oil spillage cases from 380 in 2025 to under 95 cases in 2035. This means the environment (water-bodies and soil) would be better protected from pollution due to oil and gas operations that often lead to losses of other sources of livelihood particularly crop farming and fishing, which form a major part of the local economy in the Niger delta.

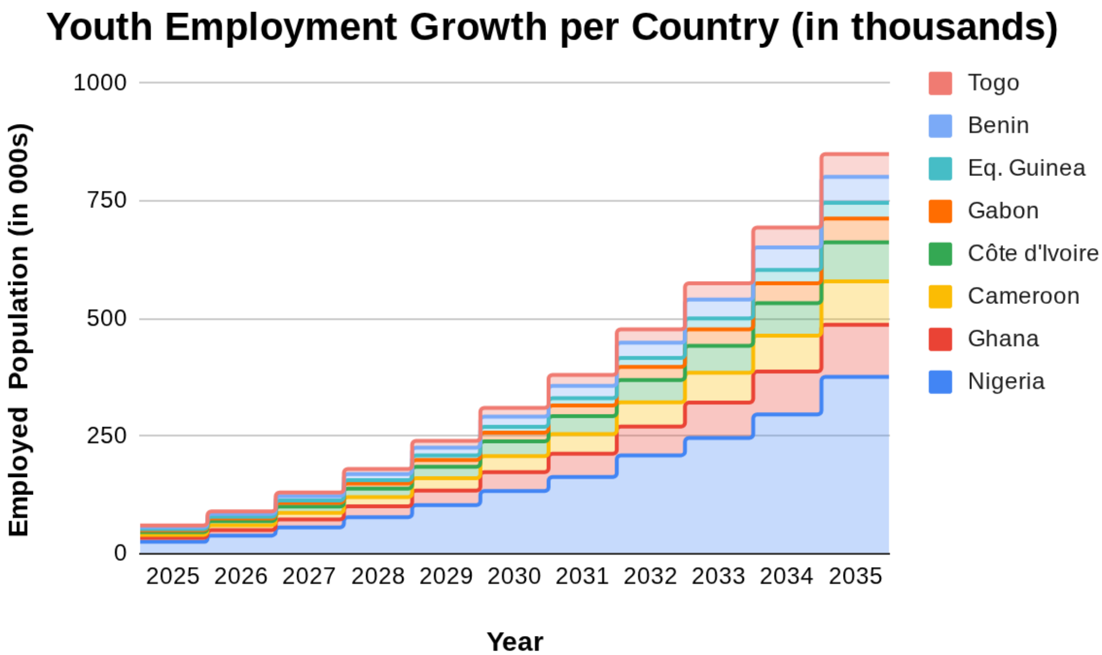


Figure 3.6. Youth Employment Projections Per Year within the Gulf region

Figure 3.6 above shows the ability of the PATHS framework to reduce youth unemployment in the subregion, with direct employment of over 297,000 youths in Nigeria. Ghana, Cameroon, Cote d'ivoire, Gabon, and Equatorial Guinea having 110,000 youths directly employed, with Benin and Togo both with 50,000 youths employed, bringing the total sum to 850,000 youths for the year 2035. The total number of youths projected to be employed directly through the implementation of the framework from 2025 to 2035 is 4.02 million. With more youths being employed in the oil and gas sector, there would be a significant drop in illegal oil bunkering and pipeline vandlism (as shown in figure 3.5).

Table 3.1

PATHS Framework Implementation Projections from 2025 to 2035

Year	Pipeline Vandalism (cases/year)	Gas Flaring (bcm/year)	Oil Spillage (cases/year)	Electricity Generation (GW)	Youth Employment (000s)	Pipeline Infrastructure (km)	Energy Revenue (USD Billion)	GDP Growth (GoG Nations, %)
2025	1479	10	380	15.98	68	3,164	32	3.04
2026	1263	6.7	340	18.2	102	3,350	36	3.76
2027	1092	4.3	310	21.5	140	3,600	40	4.56
2028	981	3.8	280	26	182	3,998	45	5.23
2029	870	3.3	250	30.99	240	4,550	50	5.94
2030	748	2.9	220	35.99	310	5250	56	6.53
2031	643	2.5	200	40.6	380	5900	62	7
2032	522	2	170	44.97	490	6,250	70	7.56
2033	435	1.6	140	51.5	576	6,420	79	8.01
2034	365	1.4	115	56.24	684	6,500	89	8.38
2035	310	1.2	95	63.6	850	6,550	100	8.81

Note. Table 3.1 above shows the breakdown of the projected results of PATHS implementation in the Gulf of Guinea, with Nigeria as the focal point. The GDP Growth is based on the predicted average growth rate for the region.

Discussion

Based on the data obtained from the projected result, the cost required for implementation of the PATHS framework has an estimated average value of 1.4 billion USD per year. This amount covers the modernization of existing infrastructure, building of modular flare gas capture and conversion stations, pipeline security, and surveillance technology. The pipeline vandalism dropped significantly from 1479 cases in 2025 to 310 cases in 2035, highlighting the impact of not just pipeline surveillance technology but also youth employment in the form of community pipeline defense corps and training programs implemented. Gas flaring and Oil Spillage also saw large reductions from 10 to 1.2 bcm per year and 380 cases per year to 95 cases, respectively. The drop in these two parameters is mostly attributed to the building of flare gas capture and conversion systems and the improved compliance with environmental policies.

Electricity generation in the region increased from 15 GW in 2025 to 63.6 GW in 2035, while for energy revenue, Nigeria, as the energy hub, was projected to make 90% of the 100 billion dollars revenue in the year 2035, making a similar percentage as revenue also for the other years. Pipeline infrastructure was predicted to stretch from 3164 km (currently based on WAGP, Niger-Benin, and WAPP infrastructure) to 6550, even though the model was not equipped to map the structural pathway of the piping infrastructure. The predicted GDP growth for the Gulf countries saw a rapid rise from an average of 3.04% in 2025 to a combined growth rate of 8.81% with Nigeria having a significant amount of the GDP in the region (about 80%). The results showcased the influence of several variables on each key parameter and their effect on expected outcomes.

IV. CONCLUSION

This research was carried out to map a pathway for the development of Nigeria's energy sector in its quest to become the Gulf of Guinea’s energy hub by implementing the PATHS framework. The results obtained from the regression model projections showed that with continuous investment into the various parameters specified by the framework (Oil and gas infrastructure, Gas flaring capture and conversion stations, Pipeline security and surveillance, etc), Nigeria and the rest of the Gulf Nations can achieve significant economic growth. Nigeria, being the energy hub of the region, also stands to gain a lot from energy sales and investment in petrochemicals for export to its neighbors. Future studies can consider the use of hybrid models, such as non-linear scenario-based models, for performing sensitivity analysis on projected outcomes. More research can also be carried out on designing a framework for the funding of the PATHS project while modeling its cost-to-benefit ratio.

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APPENDIX A: Machine Learning Model Implementation

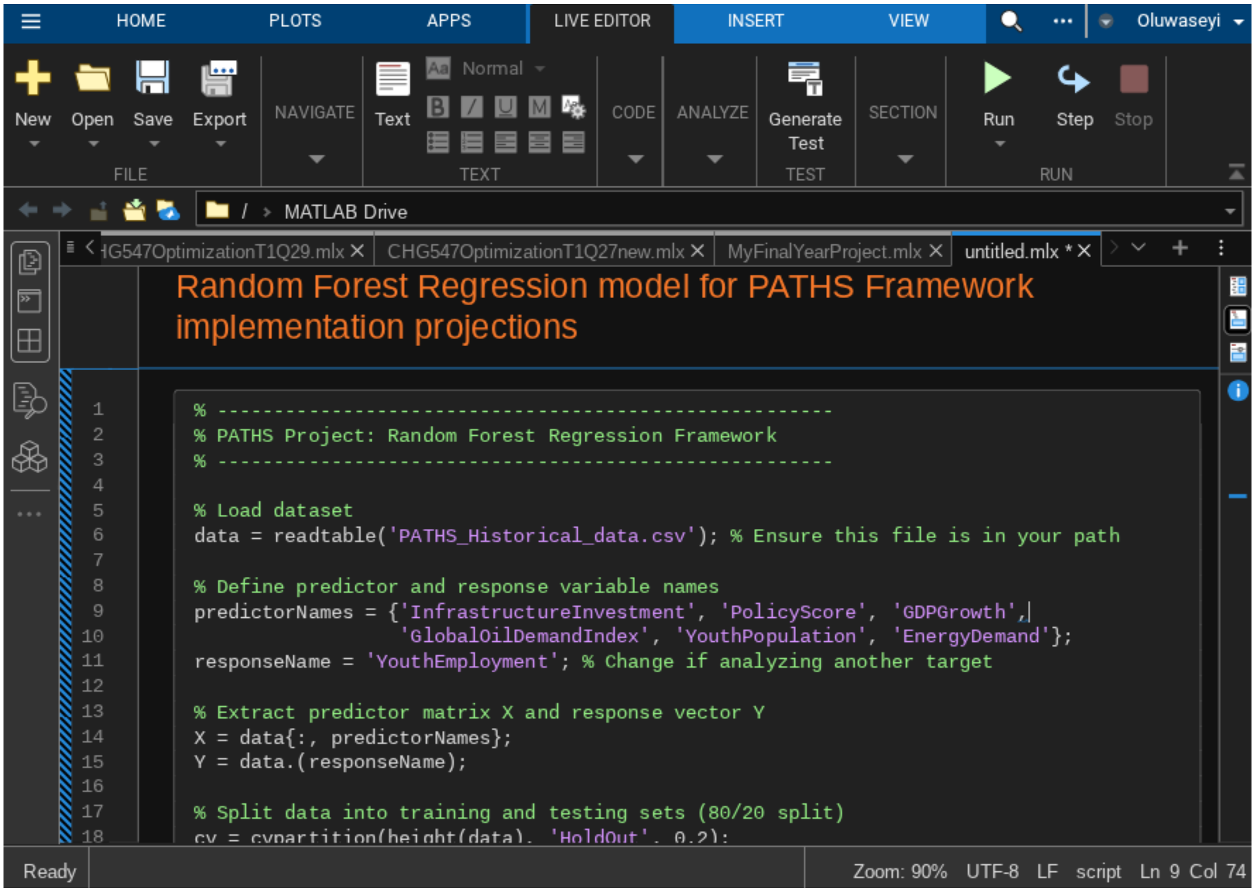


Figure A1. RFR model training in MATLAB

[The full model training code can be viewed on my GitHub page here:]

APPENDIX B: Data Sources

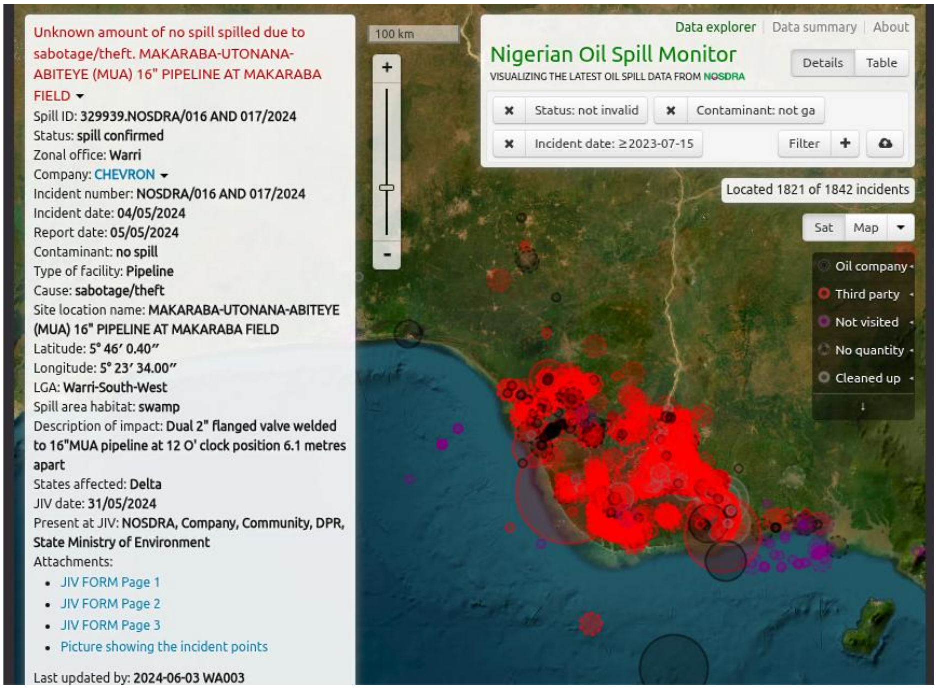


Figure B1. Oil spillage data tracker from NOSDRA

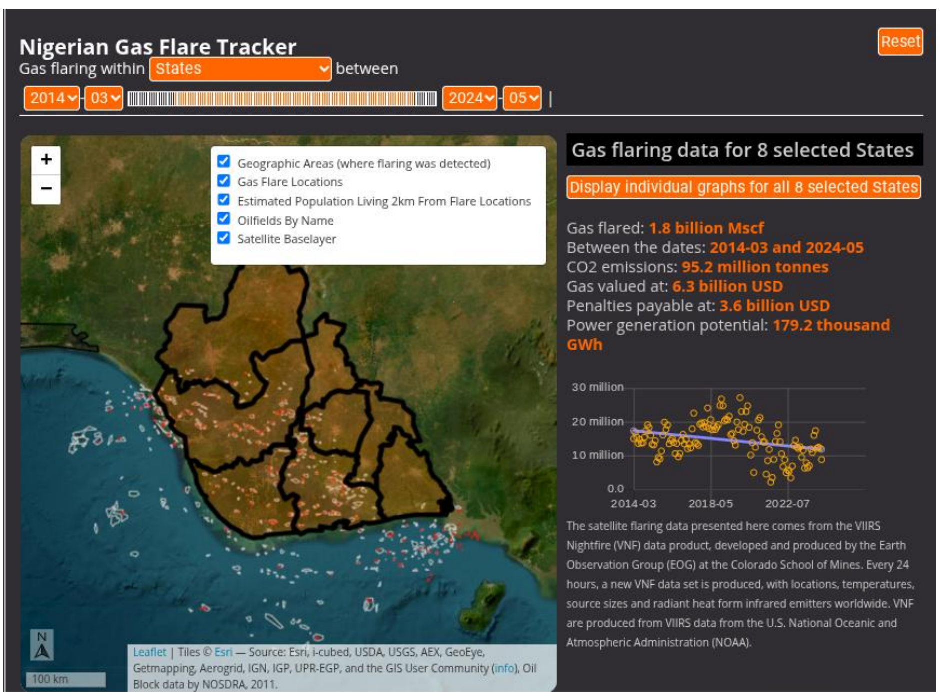
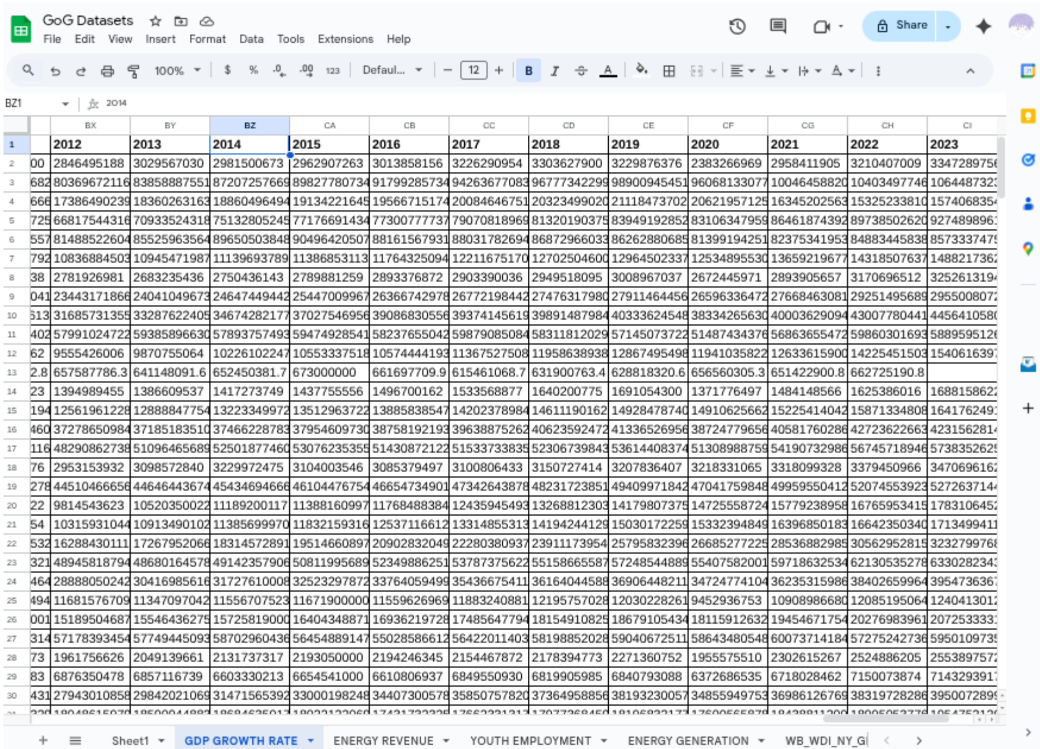


Figure B2. Gas Flare Tracker from NOSDRA



		BX	BY	BZ	CA	CB	CC	CD	CE	CF	CG	CH	CI
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10	613	31685731355	33287622405	34674282177	37027546956	39086830556	39374145619	39891487984	40333624548	38334265630	40003629094	43007780441	445641058
11	402	57991024722	59385896630	57893757493	59474928541	58237655042	59879085084	58311812029	57145073722	51487434376	56863655472	59860301693	588959512
12	62	9555426006	9870755064	10226102247	10553337518	10574444193	11367527508	11958638938	12867495498	11941035822	12633615900	14225451503	154061639
13	2.8	657587786.3	641148091.6	652450381.7	673000000	661697709.9	615461068.7	631900763.4	628818320.6	656560305.3	651422900.8	662725190.8	
14	23	1394989455	1386609537	1417273749	1437755556	1496700162	1533568877	1640200775	1691054300	1371776497	1484148566	1625386016	168815862
15	194	12561961228	12888847754	13223349972	13512963722	13885838547	14202378984	14611190162	14928478740	14910625662	15225414042	15871334808	164176249
16	460	37278650984	37185183510	37466228783	37954609730	38758192193	39638875262	40623592472	41336526956	38724779656	40581760286	42723622663	423156281
17	116	48290862738	51096465689	52501877460	53076235355	51430872122	51533733835	52306739843	53614408374	51308988759	54190732986	56745718946	573835262
18	76	2953153932	3098572840	3229972475	3104003546	3085379497	3100806433	3150727414	3207836407	3218331065	3318099328	3379450966	347069616
19	278	44510466656	44646443674	45434694666	46104476754	46654734901	47342643878	48231723851	49409971842	47041759848	49959550412	52074553923	527263714
20	22	9814543623	10520350022	11189200117	11388160997	11768488384	12435945493	13268812303	14179807375	14725558724	15779238958	16765953415	178310645
21	54	10315931044	10913490102	11385699970	11832159316	12537116612	13314855313	14194244129	15030172259	15332394849	16396850183	16642350340	1713499411
22	532	16288430111	17267952066	18314572891	19514660897	20902832049	22280380937	23911173954	25795832396	26685277225	28536882985	30562952815	323279976
23	321	48945818794	48680164578	49142357906	50811995689	52349886251	53787375622	55158665587	57248544889	55407582001	59718632534	62130535278	633028234
24	464	28888050242	30416985616	31727610008	32523297872	33764059499	35436675411	36164044588	36906448211	34724774104	36235315986	38402659964	395473636
25	494	11681576709	11347097042	11556707523	11671900000	11559626969	11883240881	12195757028	12030228261	9452936753	10908986680	12085195064	124041301
26	001	15189504687	15546436275	15725819000	16404348871	16936219728	17485647794	18154910825	18679105434	18115912632	19454671754	20276983961	207253333
27	314	57178393454	57749445093	58702960436	56454889147	55028586612	56422011403	58198852028	59040672511	58643480548	60073714184	57275242736	595010973
28	73	1961756626	2049139661	2131737317	2193050000	2194246345	2154467872	2178394773	2271360752	1955575510	2302615267	2524886205	255389757
29	83	6876350478	6857116739	6603330213	6654541000	6610806937	6849550930	6819905985	6840793088	6372686535	6718028462	7150073874	714329391
30	431	27943010858	29842021069	31471565392	33000198248	34407300578	35850757820	37364958856	38193230057	34855949753	36986126769	38319728286	395007289

Figure B3. GDP Growth Data from World Bank

The other raw data used from different organizations in this research project can be accessed here: