NASA/CR–2014-218525

Central Africa Energy: Utilizing NASA Earth Observations to Explore Flared Gas as an Energy Source Alternative to Biomass in Central Africa

Amber Jones, Charles White, Christopher Castillo, Emmanuel Hitimana,
Kenny Nguyen, Shikher Mishra, and Walt Clark
Langley Research Center, DEVELOP National Program, Hampton, Virginia

September 2014

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

Prepared for Langley Research Center
under Contract NNX14AB604

September 2014

Available from:

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I. Abstract

Much of Central Africa's economy is centered on oil production. Oil deposits lie below vast amounts of compressed natural gas. The latter is often flared off during oil extraction due to a lack of the infrastructure needed to utilize it for productive energy generation. Though gas flaring is discouraged by many due to its contributions to greenhouse emissions, it represents a waste process and is rarely tracked or recorded in this region. In contrast to this energy waste, roughly 80% of Africa's population lacks access to electricity and in turn uses biomass such as wood for heat and light. In addition to the dangers incurred from collecting and using biomass, the practice commonly leads to ecological change through the acquisition of wood from forests surrounding urban areas.

The objective of this project was to gain insight on domestic energy usage in Central Africa, specifically Angola, Gabon, and the Republic of Congo. This was done through an analysis of deforestation, an estimation of gas flared, and a suitability study for the infrastructure needed to realize the natural gas resources. The energy from potential natural gas production was compared to the energy equivalent of the biomass being harvested. A site suitability study for natural gas pipeline routes from flare sites to populous locations was conducted to assess the feasibility of utilizing natural gas for domestic energy needs. Analyses and results were shared with project partners, as well as this project's open source approach to assessing the energy sector. Ultimately, Africa's growth demands energy for its people, and natural gas is already being produced by the flourishing petroleum industry in numerous African countries. By utilizing this gas, Africa could reduce flaring, recuperate the financial and environmental loss that flaring accounts for, and unlock a plentiful domestic energy source for its people.

II. Introduction

Background

Africa is home to numerous burgeoning economies; a significant number rely on oil production as their primary source of revenue. Relative to its size and population density, the continent has a wealth of natural resources, including oil and natural gas deposits. The exploration of these resources is not a new endeavor, but rather one that spans decades, up to a century in some places. Their resources, if realized, could provide a great means of economic and social mobility for the people of Africa. Currently, Africa represents about 12 % of the energy market, yet at the same time, consumes only 3 % of the world's energy (Kasekende 2009).

The higher energy density of oil makes it a preferred fossil fuel over gas. Furthermore, oil's natural state as a liquid requires comparatively less substantial infrastructure to transport and produce than natural gas. Despite the fact that natural gas burns comparatively cleaner, it is either re-injected to increase pressure in the oil well, vented (simply released), or flared due to economic considerations. Flaring not only represents a loss of energy production, it also adds to greenhouse gas emissions which amounts to 400×10^6 tons of carbon dioxide (CO_2) annually, or roughly 1.2 % of both natural and anthropogenic world carbon emissions (World Bank 2014).

Partner/End Users

Collectively speaking, management in Africa's energy sector is currently a fragmented and inconsistent hybrid of mostly private projects and a burdened, underdeveloped public utility. Without a clear governing organization, several independent consulting agencies have ascended to serve speculators seeking analyses on the continent's energy industries.

Meanwhile, the Planet Earth Institute (PEI) is striving for Africa's independence in scientific research and governance by training the continent's next generation of scientists and leaders through locally-led and technologically innovative projects. In Angola, PEI is currently establishing the Center for Excellence in Science for Sustainability in Africa (CESSAF), the country's first ever doctoral program.

Since its inception at the 2002 World Summit on Sustainable Development, the World Bank Group's Global Gas Flaring Reduction (WBG-GGFR) public-private partnership has supported the efforts of oil producing countries and companies to increase the use of associated natural gas and thus mitigate climate change through the reduction of flaring and venting. This is accomplished in two main ways. First, the WBG-GGFR partnership currently relies on National Oceanic and Atmospheric Administration (NOAA) to perform satellite imagery analysis utilizing the Visible Infrared Imaging Radiometer Suite (VIIRS) to provide flaring calculations. U.S. government sequestration has put a delay in the processing of that information, and methodologies comparable to NOAA's for calculating flared energy volumes were established by DEVELOP during the 2013 spring and summer climate and air quality projects at Stennis Space Center. Second, the GGFR team facilitates demonstrative projects for associated gas utilization. GGFR also provides advice to governments, oil companies, and potential gas customers.

Goals and Objectives

The objective of this project was to assist the WBG-GGFR by applying NASA Earth observations in order to gain insight on domestic energy usage in Central Africa, specifically Angola, Gabon, and the Republic of Congo. This was done through an analysis of deforestation, an estimation of gas flared, and a suitability study for the infrastructure needed to realize the natural gas resources. The study attempted to answer the questions (1) how much natural gas is being flared? And (2) can the gas currently being flared replace a significant portion of the biomass being burned for fuel?

The results and methodologies were presented to PEI and the WBG-GGFR in order to help them achieve their goals. Additionally, the project provided PEI with curriculum materials for using open-source geographic information system software and public domain data from NASA Earth observations.

Study Area
The countries of Angola, Gabon, and the Republic of Congo are all located in Central Africa. In addition to being areas of interest for PEI and WBG-GGFR, these countries were chosen for study because they simultaneously experienced poor domestic energy options and a high rate of gas flaring. Angola had the second largest proven oil and gas reserve in sub-Saharan Africa (EIA 2014), but biomass represented 60% of the energy supply (IRENA 2014). Approximately 75% of the natural gas produced in Angola was flared, contributing extensively to greenhouse gas emissions and wasting billions of dollars in viable energy (EIA 2014). In Gabon, oil production declined by a third since 1997 leading to a renewed interest in natural gas. Despite this interest, 90% of natural gas produced was re-injected, flared or vented (EIA 2014). Oil production in the Republic of Congo was also declining. Similar to Gabon, 85% of associated natural gas was re-injected, flared or vented while 81% of the population relied on biomass for domestic energy (EIA 2014). Together these countries were home to 26.8 million people of which 18.75 million did not have access to electricity (World Bank 2014).

Earth Observations and National Application Area
The paradox of gas flaring in Africa is such that while the oil industry churns out 12 % of the world's energy through African resources, the majority of the continent's population still relies on inefficient (almost five times less so than natural gas) biomass for their energy needs (Partnership for Policy Integrity 2011). Despite recent advancements in producing natural gas, such as the Angola LNG project in Soyo, there is still a vast energy potential that is being wasted. The problem is further compounded by the poor record of gas flaring, particularly in developing nations. As flaring represents a waste process, it is often under reported or in some cases not reported at all. Estimating gas flaring from space was suggested as early as the 1970's using the Defense Meteorological Satellite program (DMSP), but DMSP imagery is relatively coarse, both in spatial terms as well as terms of the radiometric bands it uses to sense the Earth (Elvidge, et al. 2013). The recently launched Visible Infrared Imaging Radiometer Suite (VIIRS) provides a superior method of detecting burning activity on Earth's surface through its multitude of sensor channels.

MODIS products, predominantly MOD09, were also utilized in this study for biomass estimations owing to their versatility and the large scope of the study area. In addition to VIIRS and MODIS, the site suitability methodology utilized a digital elevation model (DEM) from the Shuttle Radar Topography Mission (SRTM).

III. Methodology

Gas Flaring Estimation
In order to estimate the amount of natural gas that was flared and its contribution to greenhouse gas emissions, VIIRS Nightfire data provided by the National Geophysical Data Center (NGDC) were acquired, aggregated, and clipped to the region of interest before being analyzed. The Nightfire algorithm works by first identifying high radiance values in the roughly 1.55-1.65 µm window of the instrument's M10 band. Pixel values are then pulled for all nine of the bands operating at night. The M10 identification is

then confirmed using the day night band (DNB), together with VIIRS' M7, M8, M12, and M13 bands. Using the values in these spectral windows, a Planck curve is fitted to the radiance retrievals. At this point, many attributes can be estimated from the combustion source such as temperature, radiant heat, size of source, and for gas flares, the volumetric flow of methane (CH_4) and carbon loading. The Nightfire system made these daily detections available as a Comma Separated Value (CSV) or as a Google Earth Keyhole Markup Language Zip (KMZ) format. For the purpose of this study, the amount of gas and energy equivalent was estimated from a year's worth of Nightfire data. To maintain consistency among the data, the Prerun version of the Nightfire product was used and the year was defined as March 2013 – February 2014.

Since Nightfire data files are very large and some of the content was not useful for the purpose of this study, eliminating unnecessary data was imperative before aggregating daily data into a single file for the entire year. Using C-sharp syntax, a script was written in order to extract the applicable data and merge files.

Using the Quantum Geographic Information Systems (QGIS) software, shape files for the areas of interest (Angola, Gabon, and the Republic of Congo) were created. QGIS was preferred for this particular research, because it is an open source software that is easily accessed by end users. Merged data files were imported into QGIS and clipped to each country of the study area.

Combustion sources detected within the study area had temperatures ranging from 300-16,000 degrees Kelvin (K). However, biomass primarily burns in the range of 600 to 1,200 K, with a median near 1,000 K (Elvidge, et al. 2013). Gas flare temperatures tend to overlap with the high end of temperatures associated with biomass burning and have a median near 1,750 K (Elvidge, et al. 2013). For this reason, 1,400 K was taken to be the threshold, and data with temperatures less than 1,400 K were eliminated.

In order to estimate the amount of natural gas that was flared during one year, 24 hours were assumed to be the average lifetime of a flare and flare reactants were assumed to be predominantly methane. Uncontaminated natural gas is composed of 97.5 % methane (Tan 1965). For the purpose of this study, a complete combustion of uncontaminated methane was also assumed (equation 1). Average volume of flared gas was then estimated from the average volumetric rate flow rate and assumed lifetime. Then, total methane volume was then converted into energy (Q) equivalent (equation 2).

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2\,H_2O \longrightarrow Q \qquad \text{Equation 1}$$

$$Q\ (MJ) = \Delta H_{f\,CH4}\ (MJ/kg) * \rho\ (kg/m^3) * \text{Estimated volume}\ (m^3) \qquad \text{Equation 2}$$

Where,
$\Delta H_{f\,CH4}$ (54 MJ/kg) is the heating value of methane, which is the amount of thermal energy released when one mole of methane undergoes a complete combustion (Tan 1965).

Based on the stoichiometry of the balanced methane combustion equation, one mole of methane is equivalent to one mole of CO_2, which implies that the volume of methane reactant can be equated to the volume of carbon dioxide emission.

Biomass Estimation

In order to determine the amount of biomass change occurring from 2002 to 2014, above ground woody biomass and forest area change were estimated. Knowing that leaf area index (LAI) and normalized difference vegetation index (NDVI) are both correlated to biomass (Ribeiro et al. 2008), a multivariate regression analysis was implemented. LAI and NDVI were the independent variables and above ground woody biomass from 2000 provided through the Woods Hole Research Center (Baccini et al. 2008) was the dependent variable. The regression equation was then extrapolated to the future. To verify these results further, the forest area change was estimated using an unsupervised land classification using MODIS reflectance bands 1-7. This process was completed only for the country of Angola because of difficulty obtaining cloud free images over the more equatorial countries of Gabon and the Republic of the Congo. The northwest portion of Angola was removed from the study for the same reason. Normalized difference vegetation index (NDVI) change was also used to increase the accuracy of forest change and the two products were compared.

The seven bands of the Terra MODIS level three eight day surface reflectance product (MOD09A1) were acquired through the Reverb data acquisition system with 500 m resolution along with the MODIS Vegetation Indices (MOD13Q1) with 250 m resolution. The images were downloaded for each year from 2002 to 2014 for dates near the end of May. Four image tiles were required for each date to cover all of Angola. Reflectance band 1 for each of the four tiles were added into QGIS and merged together. This was repeated for the last six bands. The merged MODIS bands were then layer stacked in QGIS and clipped to the specific study area of Angola. NDVI was processed similarly. The "Unsupervised KMeans image classification" from the Orfeo toolbox was used to create 25 classes from the stacked bands. Each band was reclassified into one of three classes: water, non-forested land, or forested land. The area covered by each class was calculated using zonal statistics for comparison between the dates. The NDVI percent change between the first (May 24, 2002) and last (June 1, 2014) dates was calculated using raster calculator. All values with a change percentage under 15% were assigned a value of zero while values with a change percentage of 15% or greater were assigned the value of one. This NDVI layer was multiplied by the forest change layer in order to remove all forest change areas without significant NDVI change.

LAI and NDVI values for the date June 8, 2000 were used with the Woods Hole Research Center woody biomass data from 2000 to form a regression analysis. LAI data (MCD15A2) was downloaded from the Reverb data acquisition system with 1 km resolution and processed in the same fashion as the NDVI data. The "no data" values were removed from the files by setting them as null. The woody biomass dataset was downloaded from the Woods Hole Research Center (WHRC) (Baccini et al 2008) with 1 km resolution. A set of 20,000 random points were generated in ArcMap covering the study area. The values of woody biomass, LAI, and NDVI were extracted at each point.

Points with “no data” values in any variable were removed before the comparison was exported as a text file. The text file was imported into Microsoft Excel and a regression analysis was performed resulting in an R^2 value of 0.50 and a linear equation of:

$B = -102.106 + 0.022V + 2.062L$ Equation 3

Where B is estimated biomass (Mg / hectare), V is NDVI, and L is LAI. The equation was then applied to each year from 2002 to 2014 using raster calculator resulting in a 1 km resolution dataset of estimated woody biomass (Mg / hectare). To avoid values less than zero in the statistics, each pixel of the results was converted into a point and all points with pixel values less than zero were removed. The total of the pixels was summated and multiplied by 100 to calculate the total in tons of biomass. This value of tons was also estimated in energy equivalent values using conversion factors (Biomass * 0.3215 * 42) from the United Nations Economic Commission for Europe (UNECE). The trend per year was then compared to the amount of gas flared.

Site-Suitability

In order to determine a suitable pipeline route to distribute gas across Angola, a combination of spatial analysis tools was used: raster calculator, accumulated cost grid (ACG), and least cost path (LCP) analysis. ACG and LCP relied on a scoring system known as an analytical hierarchy process (AHP) which ranked an arbitrary number of variables (Cimmery 2013). The first step in the AHP was to construct a pairwise comparison table which ranked each variable in comparison to another and assigned a weighted score based on whether the variable was more or less relevant than the other (Table 1). The individual scores were then summated for each variable to acquire the final weight. Prior to actual route design, parameters that may affect a pipeline were collected using various NASA satellites and other sources. These parameters included canopy height, road network, railroad network, inland waters, population data, seismic activity data, elevation, and protected or prohibited sites. See Table 2 in the Appendix for data sources.

Least Important						Most Important
1/7 = **0.14**	1/5 = **0.20**	1/3 = **0.33**	1/1 = **1**	3/1 = **3**	5/1 = **5**	7/1 = **7**

	Slope of terrain	Primary Roads	Secondary Roads	Tertiary roads	Railway crossings	Water crossings	Seismic activity	Canopy cover
Slope of terrain	1.00	1.00	0.33	0.14	0.20	0.20	0.14	0.14
Primary Roads	1.00	1.00	0.14	0.14	0.20	0.20	0.14	0.14
Secondary Roads	3.00	7.00	1.00	0.14	1.00	0.33	0.14	0.20
Tertiary Roads	7.00	7.00	7.00	1.00	5.00	5.00	0.14	1.00
Railway crossings	5.00	5.00	1.00	0.20	1.00	0.20	0.20	0.20
Water crossings	5.00	5.00	3.00	0.20	5.00	1.00	0.14	0.20
Seismic activity	7.00	7.00	7.00	5.00	7.00	7.00	1.00	3.00
Canopy Cover	7.00	7.00	5.00	1.00	5.00	5.00	0.33	1.00
SUM OF COLUMN	**36.00**	**40.00**	**24.48**	**7.83**	**24.40**	**18.93**	**2.25**	**5.89**
							TOTAL	**159.77**

Table 1 *Pairwise comparison table*

Once the weights were assigned to each variable, they were applied to their respective rasters and combined into a single cost grid using the raster calculator. Each pixel had a value and corresponding color so that overlapping factors were apparent. Figure 1 shows the resultant cost grid with weights applied, where some variables were more relevant than others (left), and where all variables were weighted equally (right).

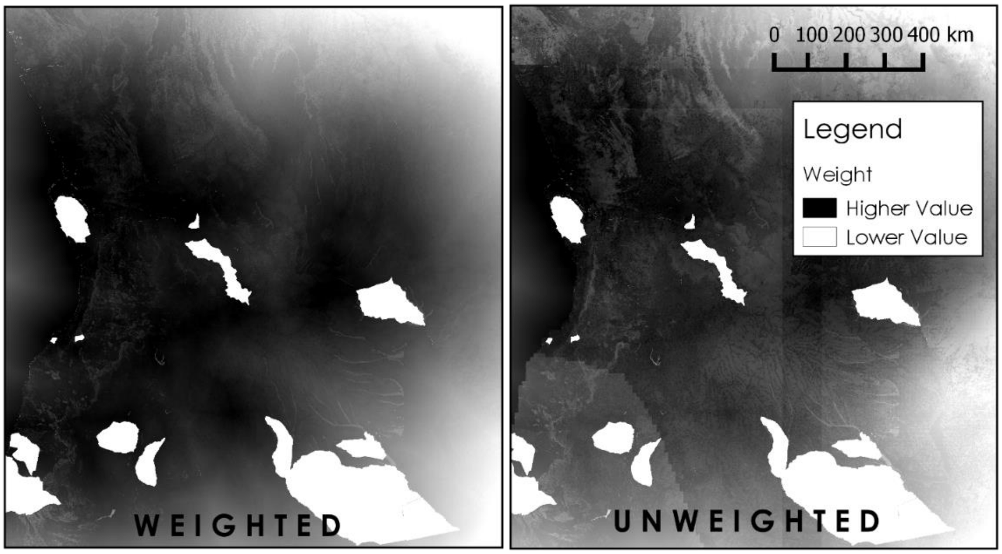


Figure 1 *Weighted and un-weighted rasters resulting from single cost grid. The whited-out features represent prohibited areas. In the weighted raster, the darker shades represent more highly ranked variables, in this case roads and slope of terrain. In the un-weighted raster, all variables were ranked equally.*

An ACG was then created by combining the raster calculator result with a destination point (or points). The twenty most populated cities in Angola were chosen as destination points for this study. With the ACG, higher cost was observed for points further from the destination, as was fluctuation due to the scores provided by the single cost grid of combined variables.

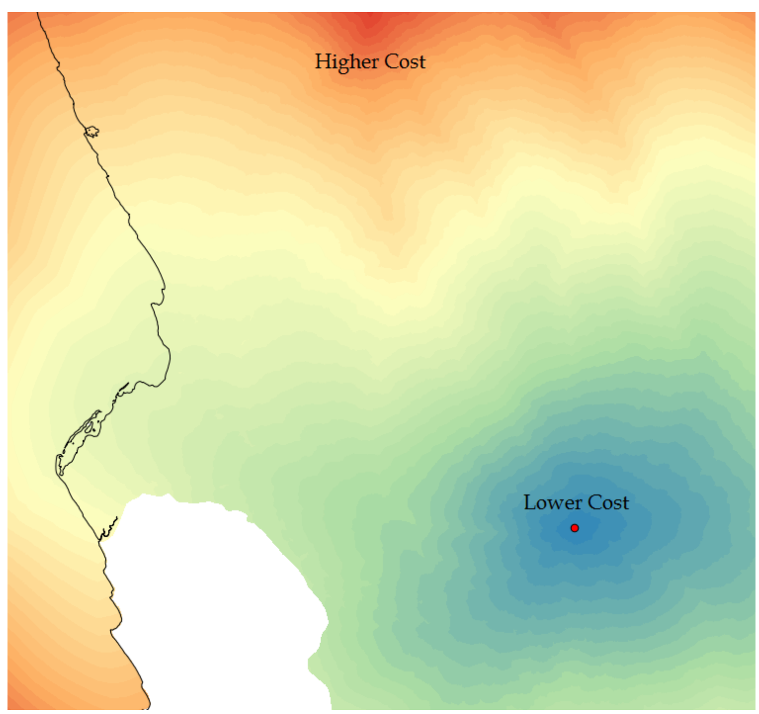


Figure 2. *Accumulated cost grid for a single destination. The further from the destination point, the more economic and environmental cost is accumulated. The white space represents a prohibited area through which a pipeline may not be routed.*

Finally, a LCP was calculated by inputting a source point and the ACG. When multiple destination points were used during creation of the ACG, the LCP was observed, more often than not, to favor the destination nearer to the source. In this study, the LCP did forfeit route length, but was ultimately more favorable than an unweighted approach since it avoided many areas where a pipeline route may be more costly to implement, for example, areas of more sloped terrain, or of dense vegetation. Accurate, efficient AHP application would require expert or client input, as well as a consideration for all possible variables.

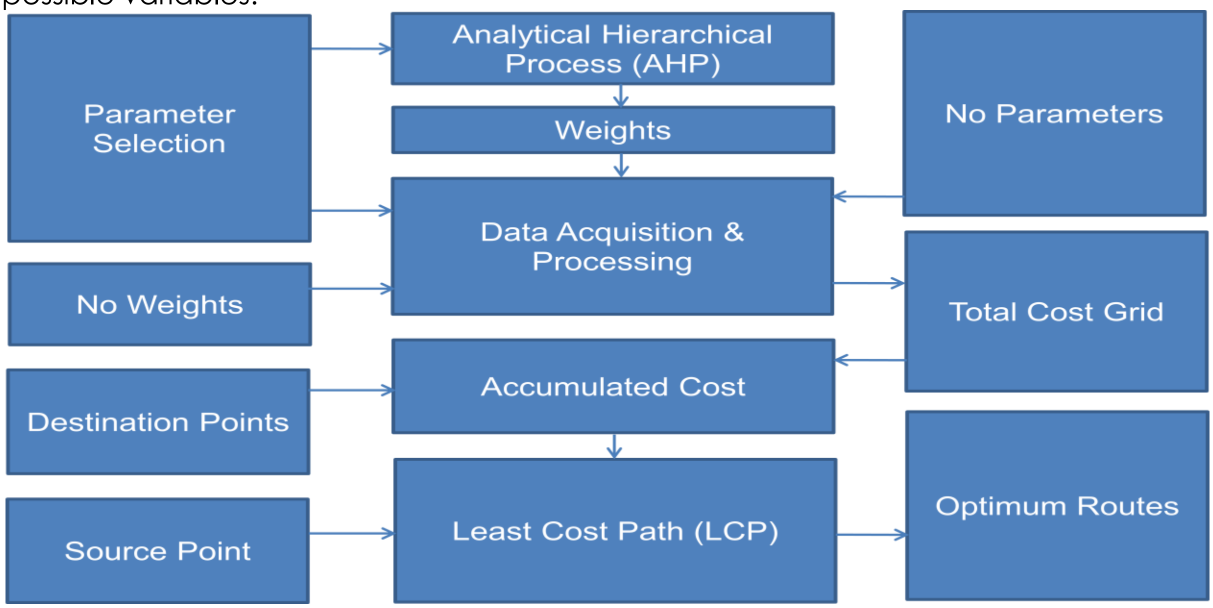


Figure 3 *Methods summary for the satellite based gas pipeline site suitability study*

IV. Results & Discussion

Biomass Estimation

The biomass estimations using NDVI and LAI showed similar results to the forest area change using MODIS reflectance. The areas along the coastline and in the southwestern portion of Angola near the Namib Desert had the highest levels of biomass change over the 12 year period. These results can be seen in figure 4 showing biomass and figure 5 showing forest area changes.

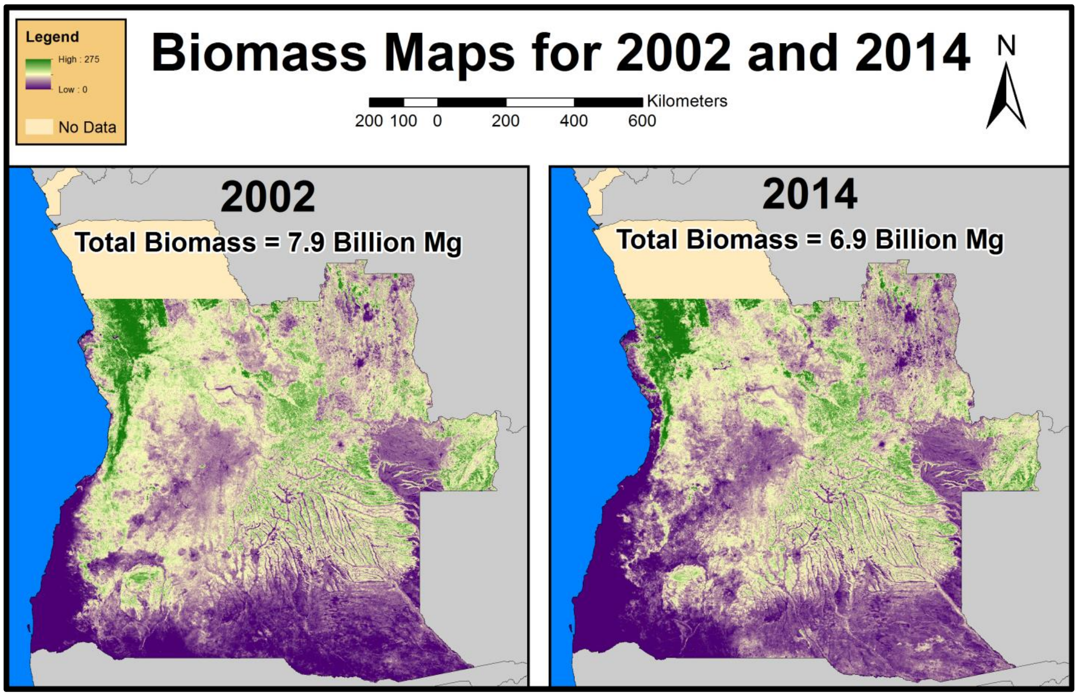


Figure 4 *Biomass maps in Mg / hectare for 2002 and 2014*

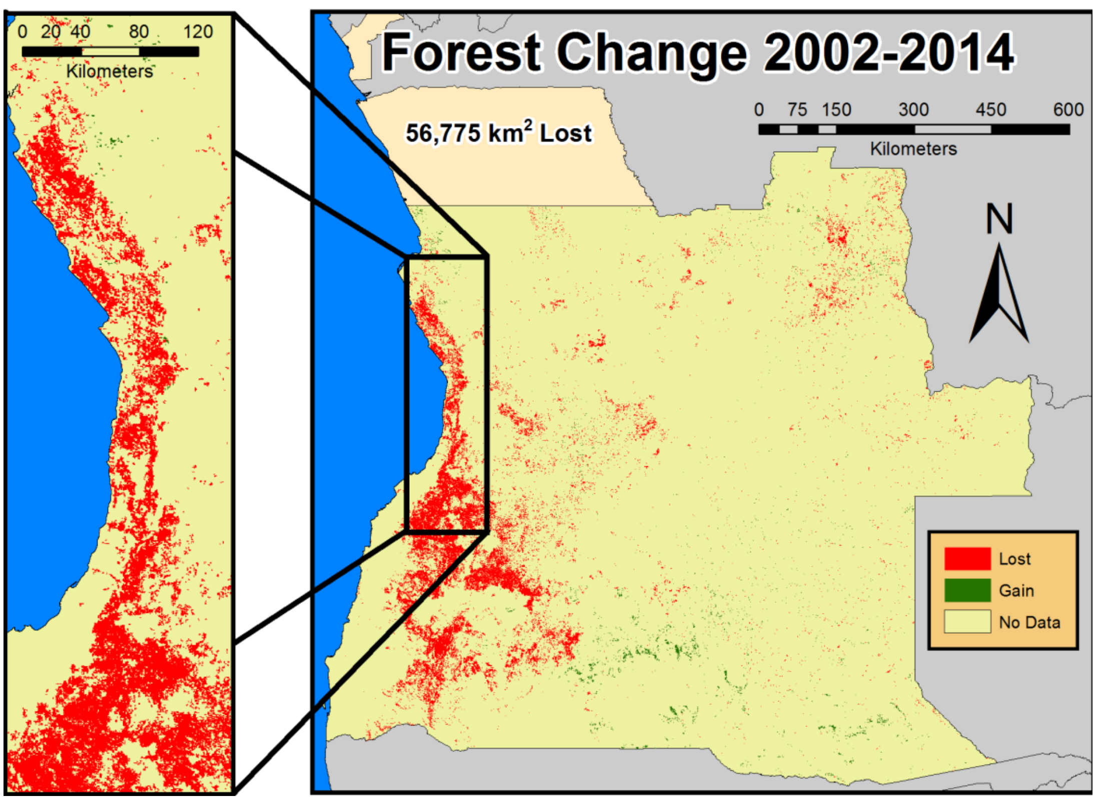


Figure 5 *Forest area change from 2002 to 2014*

Over the study period, approximately 996.3 billon metric tonnes of biomass were removed from the study area. The amount of biomass present using the methods presented produces some variability on an annual basis (Figure 6).

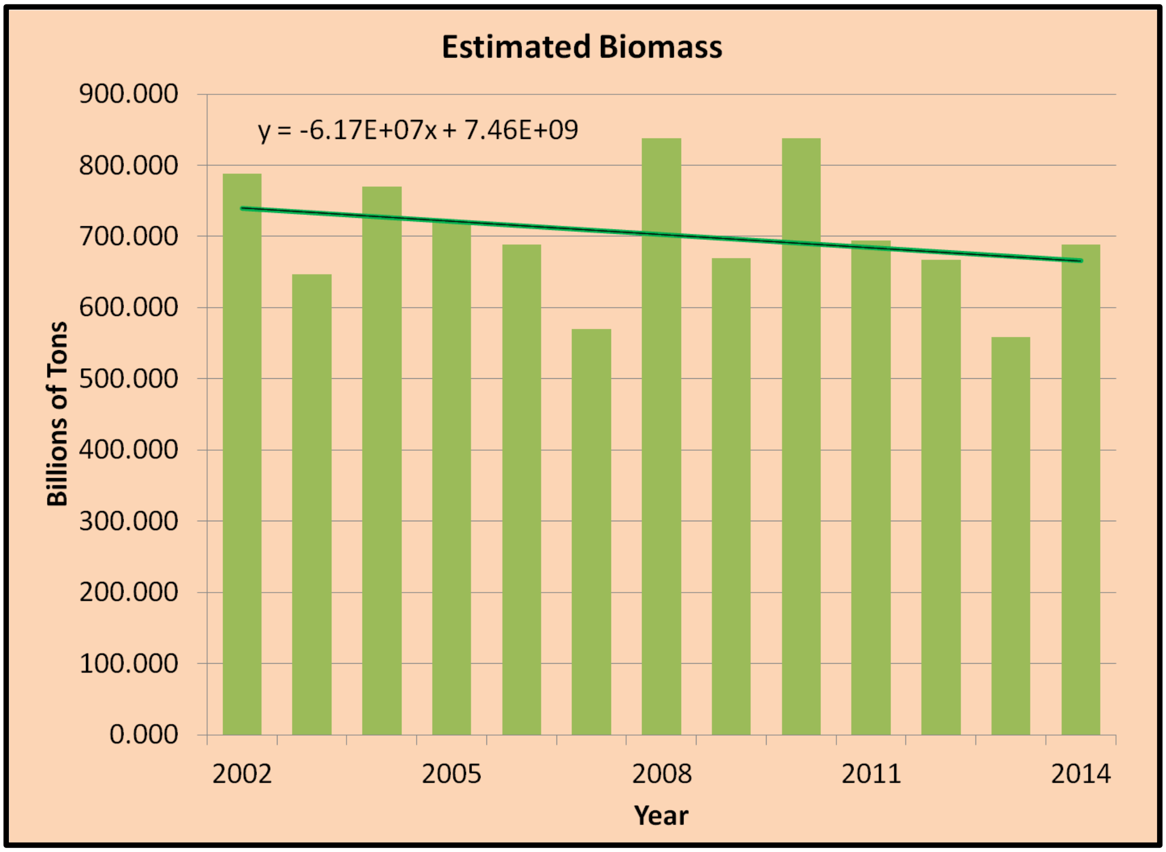


Figure 6 *Estimated biomass using LAI and NDVI from 2002 to 2014*

This variability made it difficult to analyze annual changes so a trend line was used to determine the average annual change over the time period. This trend line estimated that an average of 61.7 million metric tonnes of biomass were lost each of years studied which equates to approximately 833 billion MJ of energy.

For the same time period, it was estimated that 56,775 km^2 of forested area had been lost within the study area. This value was significantly higher than the Global Forest Change (GFC) product from the University of Maryland which estimated forest area lost at 18,668 km^2 (Hansen et al. 2013). The large estimation of forest cover lost is likely due to the methods used in this study. When determining the classes, areas that were borderline forest on a course MODIS reflectance image were added to the forest area. These same areas tended to have the most change in reflectance during the study period. For this reason, the forest area change from this study overestimated, but it was successful at identifying the areas of high biomass change.

The annual biomass loss estimations were significantly higher than the Food and Agriculture Organization of the United Nations (FAO) at 16.15 million metric tonnes (FAO

2010). This difference was likely due to the exclusive use of course remotely sensed reflectance data and its products. The woody biomass data from the WHRC was obtained using in situ, MODIS reflectance, and LiDAR data (Baccini et al. 2008). The FAO used similar methods to estimate biomass. This study used only coarse NDVI and LAI to data to estimate biomass resulting in variation from year to year. NDVI and LAI are both dependent on seasonal and climatic changes that may not have significant influence on the biomass present.

Gas Flaring

Preliminary results show that an estimated 109 million cubic meters (m^3) of natural gas were flared in Angola, 46.2 million m^3 in the Republic of Congo, and 20.3 million m^3 in Gabon for a period of one year. This equates to about 4 billion MJ of energy equivalent, 1.65 billion MJ, and 0.725 billion MJ in Angola, Republic of Congo, and Gabon respectively. However these estimates were obtained without taking into consideration various uncertainty factors. For instance, due to a U.S. government shutdown in October 2013, 24 out of 365 days of the study period did not have any reported data.

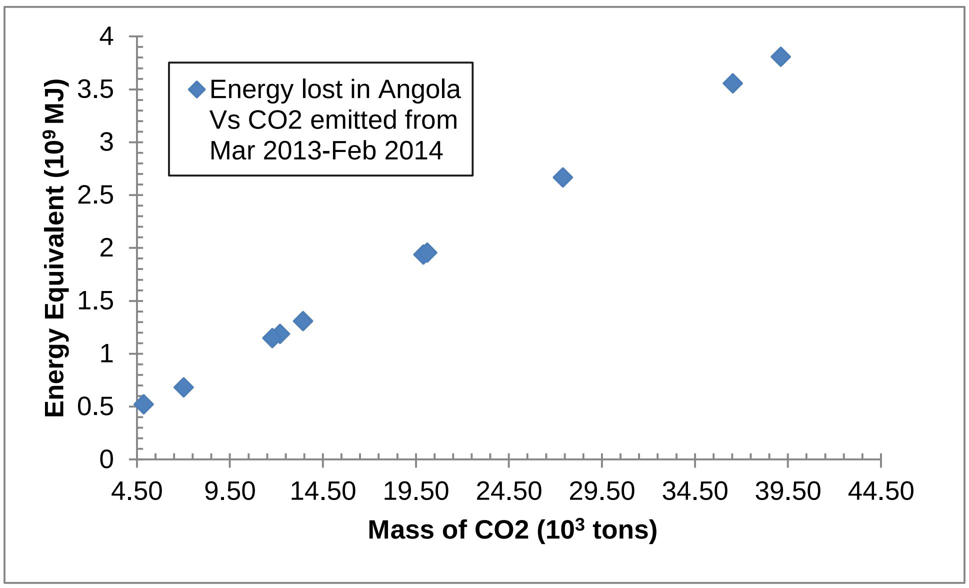


Figure 7 *The plot showing the non scaled amount of energy that could have been harvested from gas flaring in Angola from Mar 2013 to Feb 2014 versus the amount of carbon dioxide that was emitted into atmosphere*

Furthermore, a comparative study of biomass and natural gas is necessary. One of the useful factors to compare these two fuels is by combustion efficiency. The combustion efficiency of natural gas is approximately five times higher than combustion efficiency of woody biomass. Moreover, if it is assumed that harvested natural gas will be used for cooking, then heat transfer efficiency of biomass stove and natural gas stove should be taken into consideration. In developing countries such as Angola, woody biomass stoves are often inefficiently built. This renders a considerable amount of energy to be lost to the atmosphere as heat.

After taking into consideration major uncertainty factors, preliminary results were scaled by the factor of five. This means that approximately 20 billion MJ of natural gas energy equivalent were flared in Angola per year, 8.25 MJ in the Republic of Congo, and 2.9 MJ in Gabon. These results were derived from intermediary results provided in table 3 (appendix).

In figure 8, the monthly results show that July and August 2013 topped other months in gas flaring and the flares volume trend is the same for all three countries. This may be partially attributed to seasonal and climatic conditions. Generally in a tropical region, July and August are drier months with fewer clouds, and therefore data capture accuracy is higher.

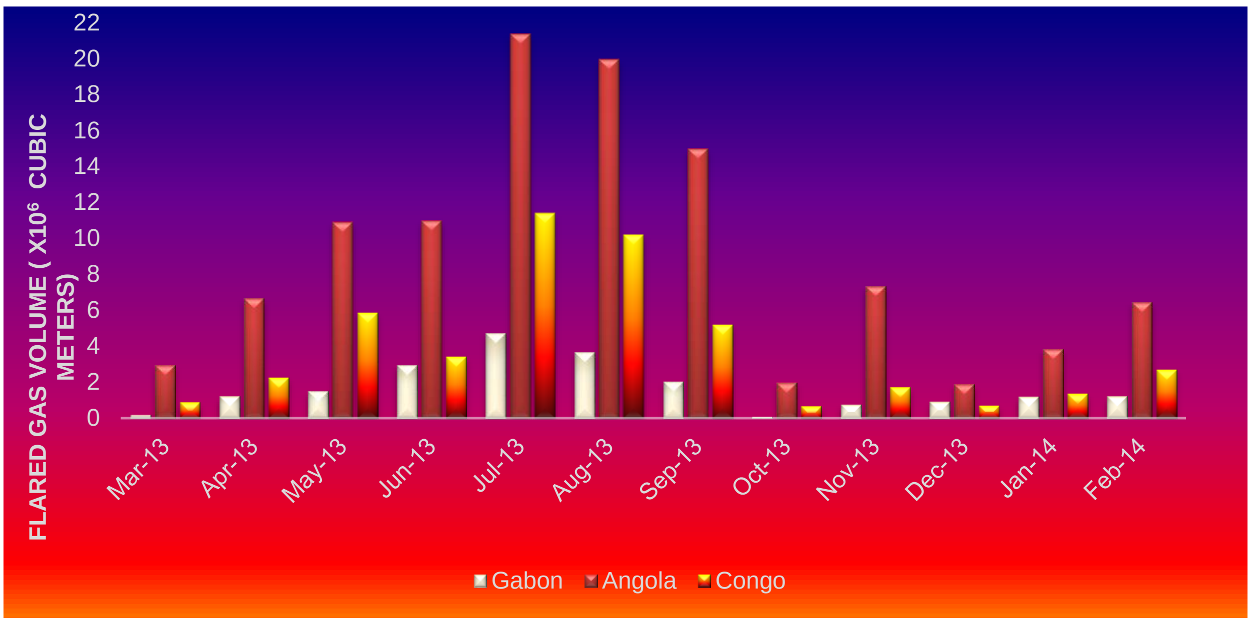
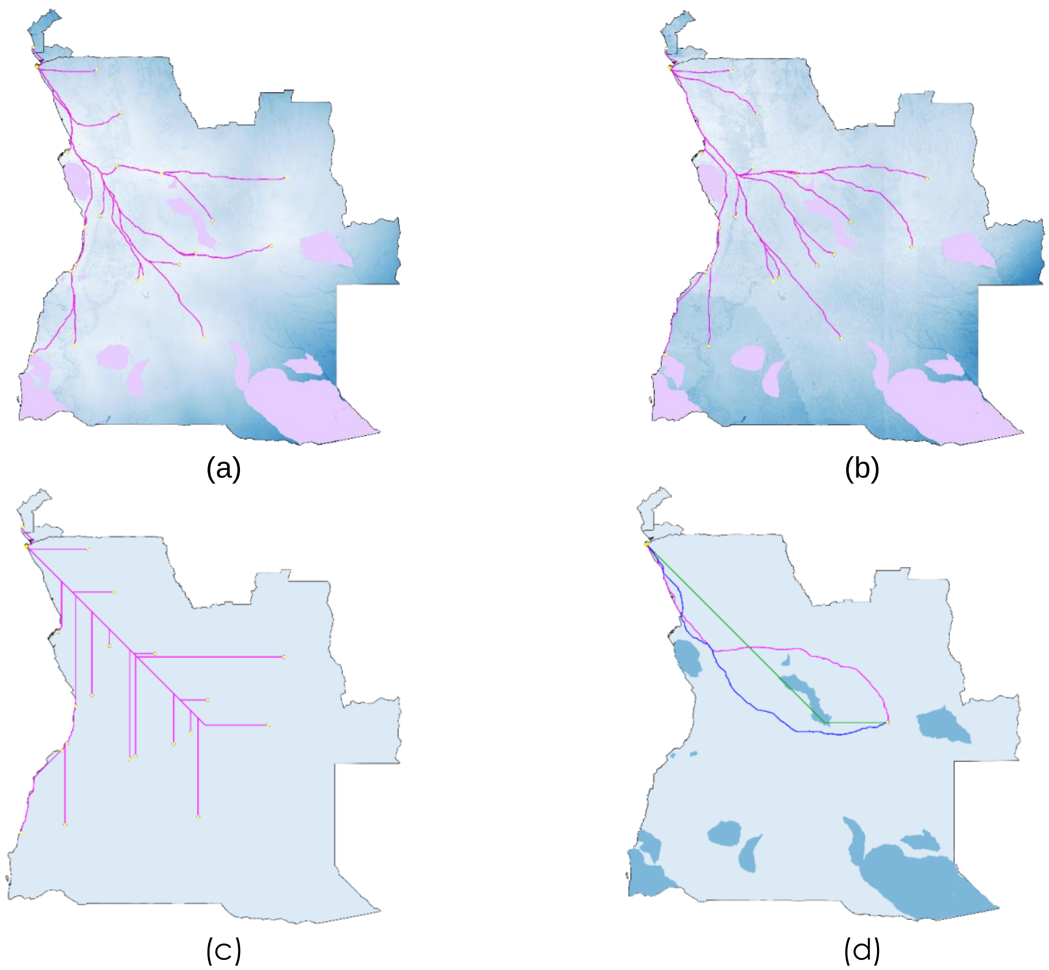


Figure 8 *Graphical representation of rough estimation of monthly gas flaring volumes for each country from the study area*



(a) (b) (c) (d)

a) Least Cost Path (LCP) derived with weighted parameters. Total route length is ~15816.44 KM.
b) LCP derived without weighted parameters. Total route length is ~15400.45 KM.
c) LCP derived without parameters. Total route length is 14465.35 KM.
d) Comparison between three types of LCP for one destination.
    - Total route length with weighted parameters: ~1238.44 KM.
    - Total route length without weighted parameters: ~1210.82 KM.
    - Total route length without parameters: ~1052.96 KM.

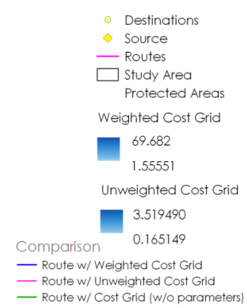


Figure 9 *Final site suitability results*

It was observed that the optimal route for natural gas pipelines sacrificed route length, but studies have shown that it is ultimately much more cost efficient than an un-weighted and no parameter approach.

V. Conclusions

The gas flared in Central Africa represented a significant amount of energy that could potentially be harvested. Estimations show that approximately 20 billion MJ of equivalent energy were flared in Angola over the study period when adjusted for combustion and heat transfer efficiency of natural gas compared to biomass. The amount of flared gas could replace 10% of the consumed biomass in 2011 as reported by the International Energy Agency (IEA).

Although it was possible to create a methodology to estimate biomass loss, the values of biomass loss were not comparable to the amount of potential energy lost through gas flaring.

AHP derived cost grid makes considerable amount of difference in LCP by giving due consideration to relative importance of parameters but it comes at the cost of route length. Desirable result depends on the selection of parameters & AHP implementation.

VI. Acknowledgments

The team would like to extend gratitude toward the following people:

The science team at the NOAA National Geophysical Data Center behind the VIIRS Nightfire product, particularly those that extended their help to us, Drs. Feng Hsu and Mikhail Zhizhin

The science advisors and mentors who took time out of their workloads to respond to our survey on pairwise comparisons for pipeline routing

VII. References

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VIII. Appendix

Table 2: Site Suitability Study Data Source

S.No	Parameter	Source
	Angola Administrative Boundaries, Roads, Rail-Roads and Inland Waters	http://www.diva-gis.org/gdata
	Angola SRTM Data	http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

	Global Seismic Hazard Map	http://gmo.gfz-potsdam.de/pub/gshap_data/gshap_data_frame.html
	Protected Areas	http://www.globalforestwatch.org/
	Global Canopy Heights	http://www.nasa.gov/topics/earth/features/forest20120217.html
	Protected Areas	http://www.protectedplanet.net/
	Population Count	http://sedac.ciesin.columbia.edu/data/set/grump-v1-population-count/data-download

Table 3: Results of Gas Flaring Rough Estimations from March 2013 to February 2014

	Angola	**Gabon**	**Republic of Congo**
Flared Gas (m^3 / year)	109,145,882	20,333,304	46,218,154
* Energy Equivalent (MJ)	3,889,959,241	724,678,955	1,647,215,014
Carbon Dioxide (tons / year)	201,047	37,454	85,134
Temperature Range (K)	1400-9946	1400-13506	1400-7483

* Non scaled results

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
01- 09 - 2014	Contractor Report	

4. TITLE AND SUBTITLE	
Central Africa Energy: Utilizing NASA Earth Observations to Explore Flared Gas as an Energy Source Alternative to Biomass in Central Africa	**5a. CONTRACT NUMBER** NNX14AB604
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
Jones, Amber; White, Charles; Castillo, Christopher; Hitimana, Emmanuel; Nguyen, Kenny' Mishra, Shikher; Clark, Walt	**5e. TASK NUMBER**
	5f. WORK UNIT NUMBER 389018.02.14.01.05

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
NASA Langley Research Center Hampton, Virginia 23681	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
National Aeronautics and Space Administration Washington, DC 20546-0001	NASA
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)
	NASA/CR-2014-218525

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category 43
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

Langley Technical Monitor: Lindsay M. Rogers

14. ABSTRACT

Much of Central Africa's economy is centered on oil production. Oil deposits lie below vast amounts of compressed natural gas. The latter is often flared off during oil extraction due to a lack of the infrastructure needed to utilize it for productive energy generation. The objective of this project was to gain insight on domestic energy usage in Central Africa, specifically Angola, Gabon, and the Republic of Congo. This was done through an analysis of deforestation, an estimation of gas flared, and a suitability study for the infrastructure needed to realize the natural gas resources. The energy from potential natural gas production was compared to the energy equivalent of the biomass being harvested. A site suitability study for natural gas pipeline routes from flare sites to populous locations was conducted to assess the feasibility of utilizing natural gas for domestic energy needs. Analyses and results were shared with project partners, as well as this project's open source approach to assessing the energy sector. Ultimately, Africa's growth demands energy for its people, and natural gas is already being produced by the flourishing petroleum industry in numerous African countries.

15. SUBJECT TERMS

Biomass; Deforestation; GIS; Gas flaring; Greenhouse emission; Remote sensing

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			STI Help Desk (email: help@sti.nasa.gov)
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Prescribed by ANSI Std. Z39.18