Carbon Footprint of the Large Scale Gold Mining Industry of Ghana

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Abstract

Mining has been an important economic activity accounting for a substantial part of foreign exchange and government revenue. The gold mining sector has undergone considerable expansion due to liberalization with more foreign mining companies investing in the sector in particular large-scale open pit gold mining. Resultant expansion in mining has led to heightened environmental concerns and significant challenges due to key activities used in the mining operations hence contributing to greenhouse gas emissions. Investigations were conducted to assess the sources and key activities in large scale gold open pit mining operations in Ghana giving rise to greenhouse gas generation. The study adopted the Intergovernmental Panel on Climate Change (IPCC) guideline for estimating greenhouse gas inventory. The operational boundary as against the organizational boundary was considered for the study. The operational boundary was drawn around the physical mining site. Within this boundary, the emissions were quantified and reported under direct emission due to company activities (Scope 1) and indirect emissions from secondary use or activity (Scope 2). The study found that activities due to land use, blasting, fuel use to power mobile equipment and stationary combustion sources, electricity use and waste management were the contributing greenhouse gas emission sources in a large scale gold mining operation with electricity use and fuel used in transportation accounting for 92.46% of the total emissions. Average contribution of the large scale gold mining industry in Ghana to the total national greenhouse gas emission inventory for the country was established to be 11.08%.

Introduction

Global warming has occurred in the past as a result of natural influences, but the term is often used to refer to the warming predicted to occur as a result of increased emissions of greenhouse gases (Van der Geest, 2002). This brings in the concept of climate change. The Intergovernmental Panel on Climate Change (IPCC) shares the view that global climate change is a rise in temperature caused by emissions of greenhouse gases (Houghton, Jenkins and Ephraums, 1990). These are gases released into the atmosphere based on energy usage. The increasing interest in 'carbon footprints' comes as a result of growing public awareness of global warming. Carbon footprint describes the amount of Greenhouse Gas (GHG) emissions caused by a particular activity or entity. The global community recognizes the need to reduce greenhouse gas emissions to mitigate climate change. Countries, organizations and individuals alike are starting to take responsibility. Businesses and services that are not currently regulated under the Kyoto protocol may wish to preempt future regulations, and may find marketing advantages in being 'green' (Kumar, Sharma, and Vashista, 2014). In the past, companies focused on their own emissions and measured their own footprint, but now they are increasingly concerned with emissions across their entire supply chain. Calculating a carbon footprint can be a valuable first step towards making quantifiable emissions reduction. Footprint analysis is a useful tool that can compare environmental performance between companies and nations and provide an indication of how these companies or nations are moving along a sustainable development pathway.

Studies on carbon footprint of mining in Ghana as a contributor to climate change is

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lacking. The Ghana National Greenhouse Gas Inventory Report for 2014 fails to capture contribution of the mining industry to emissions as part of its report although mining is one key sector that requires high energy to produce an ounce of gold. In 2016, mining consumed 10% of the electricity generated for the country (Energy Commission of Ghana, 2016).

The large scale gold mining industry in Ghana is firmly established with twelve large scale operational sites actively involved in gold mining. These are AngloGold Ashanti - Obuasi Mine, AngloGold Ashanti - Iduapriem Mine, Goldfields - Tarkwa Mine, Goldfields - Damang Mine, Golden Star - Bogoso/ Prestea Mine, Golden Star - Wassa Mine, Chirano Gold Mine, Newmont - Ahafo Mine, Newmont - Akyem Mine, Adamus Gold Mine and Perseus Gold Mine. The process of mining in Ghana is heavily reliant on three key components; water, fuel and electricity. All twelve (12) large-scale mining companies rely on hydro processes to extract gold from the ore and this makes water a most essential component of mining in Ghana. Similarly, transportation cannot be taken out of mining due to the need to move material from the mining pits to stockpiles and "waste" dumps as well as supply of goods to and from site. Electricity consumption demand for mining is high and cuts across all regions in the world where mining takes place.

Sectors within the economy contributing to greenhouse gas emission are well available in terms of literature. These main sectors are the energy sector (made up of the oil and gas industry), industrial process and product use sector (chemical industry, electronics industry, mineral industry, etc), agriculture, forestry and land use sector (livestock rearing and dung management, forest degradation and deforestation, afforestation and reforestation, wood and fuel wood harvesting, wildfire disturbance, etc) and the waste sector (solid waste disposal, biological treatment of solid waste, incineration and open burning, waste water treatment and discharge, etc). The mining industry, with contribution to deforestation of large acres of land and high energy consumption resulting in emissions from operations into the atmosphere as well as waste generation has a big role to play in contributing to greenhouse gas (GHG) emissions.

The drift towards greener processes is unachievable with the exclusion of the extractive minerals industry for which gold mining remains key. Of the twelve large scale gold mining companies in Ghana, only two of these companies (Goldfields and Newmont) report on their greenhouse gas emissions fundamentally due to no policy requirement by the regulatory authorities of Ghana compared with countries such as Australia, USA and Europe where reporting on greenhouse gas emissions form part of the basic requirement of environmental impact statement for mining. The study gives guideline to effectively estimating greenhouse gas emission for a large-scale gold mining operation with the aim to equipping both company and regulatory authorities such as the Environmental Protection Agency with the needed tool to compute, monitor and manage greenhouse gas emissions from large-scale mining operations.

Materials and Methods

This research is guided by three key reference methodologies: the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories;

World Research Institute (WRI) and World Business Council for Sustainable Development (WBCSD) Greenhouse Gas Protocol Initiative on Corporate Accounting and Reporting Standard; and ISO 14064-1 - Specification with guidance at the organizational level for the quantification and reporting of greenhouse gas emissions and removals (ISO, 2007).

To calculate the carbon footprint of a company, it is important to establish the boundaries - organizational boundaries and the operational boundaries. This guides in defining the sources and sinks to be included or left out of calculation. The operational boundary is drawn around the physical mining site. Within these boundaries the emissions associated with the following activities are quantified and reported under direct emission due to company activities (Scope 1); indirect emissions from secondary use or activity (Scope 2); and other indirect emissions from activities of contractors providing service to the company (Scope 3) (WRI/WBCSD, 2006). The study is limited to only Scope 1 and 2 of the company's operations.

Another key item in GHG estimation is the tier approach. A tier represents a level of methodological complexity. Usually three (3) tiers are provided. Tier 1 is the basic method, Tier 2 intermediate and Tier 3 most demanding in terms of complexity and data requirements. Tiers 2 and 3 are sometimes referred to as higher tier methods and are generally considered to be more accurate (IPCC, 2006).

GHG have different Global Warming Potential (GWP) and persists for a different length of time in the atmosphere (AlHashmi, Haider, Hewage and Sadiq, 2017). To compare greenhouse gases, they are indexed according to their GWP. GWP is the ability of a GHG to trap heat in the atmosphere relative to an equal amount of carbon dioxide. Greenhouse gases are expressed in carbon dioxide equivalents MMTCDE, or million metric tons of carbon dioxide equivalents (AlHashmi et al., 2017). Table 1 gives a breakdown of the three major greenhouse gases – carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) - and their relationship with carbon dioxide.

*For purpose of confidentiality, the company name is withheld and indicated as Company XYZ. Company XYZ is a large-scale gold mining company operating an open pit (surface) mine in Ghana. All computations are based on the data made available by Company XYZ as well as the Ghana Chamber of Mines. The study was carried out between the period of January, 2016 and December, 2016.

Identifying GHG Emission Sources from Company XYZ's Operation

The first step in the estimation of greenhouse gas emission is to identify the sources of emission from the company's activities. To undertake this exercise, there was the need to breakdown the gold manufacturing process into a step by step assessment of the day to

TABLE 1:
The Three Main Greenhouse Gases and their 100-Year Global Warming Potential (GWP) Compared To Carbon Dioxide

Unit of GHG	Equivalence to CO_2
1kg CO_2	1 kg CO_2
1kg CH_4	28 kg CO_2
1kg N_2O	265 kg CO_2

Source: (IPCC, 2014)

day activities of each step of the process flow. After categorizing the identified activities under the IPCC Guidelines, it was necessary to establish the primary sources for each of these sources. These were identified to be deforestation (land use), energy (electricity and mobile combustion), industrial processes (stationary combustion and blasting operations) and waste management.

GHG Emission due to Land Use

To identify GHG from land use, it was important to establish the land use activities from the operations of the company. These were identified as shown in Figure 1.

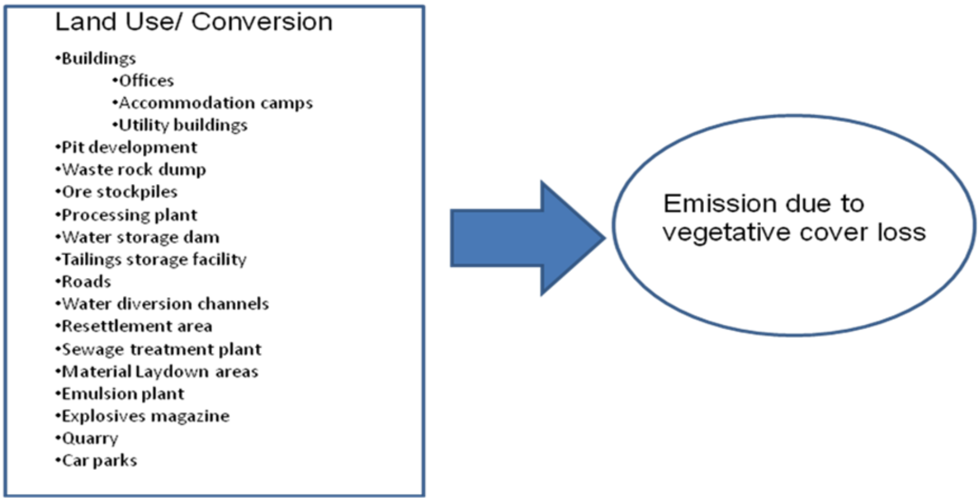

Figure 1 Land Use from Surface Gold Mining Operations

Carbon stock loss contributing to greenhouse gas emission was estimated for deforested and reclaimed areas of the mining operation. Carbon stock losses or gains were not estimated for croplands, grassland, wetlands, settlements, livestock and other land use. Carbon stock calculations were done on existing data set made available by the company.

In the estimation of the carbon emission due to deforestation; the following formula was used in line with the IPCC Guideline for GHG Inventories:

$$\text{Carbon Emission} = \text{Activity Data (AD)} * \text{Emission Factor (EF)} \quad \text{(Equation 1)}$$

Where:

AD – changes in the area of land use

EF – average amount of emissions per unit area of each type of activity

To estimate the emission from land use, it was important to identify all individual species affected by the mining operation and obtain height and diameter at breast height (dbh) measurements. This data was obtained from the company. Stand tree biomass were calculated by summing up the individual trees. Allometric equation for biomass carbon (kg/ha) estimation of trees from moist forest zone in Ghana based on diameter at breast height measurement and wood density of tree species was used to estimate carbon stock (Yeboah, Burton, Storer, and Opuni-Frimpong, 2014).

The tree allometric equation developed for measuring and reporting on forest cover and carbon stock in Ghana by the Council for Scientific and Industrial Research Institute (CSIR) - Forestry Research Institute of Ghana (2014), Kumasi was used in the computation of the carbon stock for this study. To determine the carbon stock from a tree, the mass was calculated using the equation developed by Yeboah, et al, (2014) as follows:

$$Y = (a*(\rho*(dbh)^2)^b) \quad \text{(Equation 2)}$$

Where Y = aboveground (AG) tree biomass in kilograms, a and b are constants 0.012 and 1.542 respectively and ρ is tree density and dbh is tree diameter at breast height.

Belowground biomass carbon was estimated by using the equation proposed by Yeboah, et al, (2014) as follows:

$$Y = (a^*(\rho^*(dbh)^2)^b) \quad \text{(Equation 3)}$$

Where Y = belowground (BG) tree biomass in kilograms, a and b are constants 0.052 and 1.214 respectively and ρ is tree density and dbh is tree diameter at breast height.

Carbon sequestration in kilograms per hectare is calculated by multiplying tree biomass (AG or BG) by the assumed carbon 0.4748 (or 47.48%) from moist forest zone in Ghana (Yeboah, et al., 2014).

For a company undertaking reforestation project as part of its reclamation plans, it was important to establish the carbon removals through this effort. Similar to computing for carbon emissions, the same approach was used to determine above ground and below ground biomass.

Carbon stock change was then calculated as:

$$\Delta \text{ Carbon Stock} = \text{Carbon Removals} - \text{Carbon Emissions} \quad \text{(Equation 4)}$$

GHG Emission from Blasting Operations

Blasting and exposure of rock potentially contribute to emission of GHG. Ammonium Nitrate - Fuel Oil (ANFO) is the blasting agent (explosive) type used on the Mine. In calculating greenhouse emission from blasting operation, a tier 1 approach was used. IPCC default emission factor of 0.170 was used. Data on explosive used in the year under review was summed up. The total quantity of explosives used in 2016 by Company XYZ was 11,723,767 kilogrammes. This comprised of boosters, downlines, detonators, surface delays and other accessories.

To determine the GHG emission due to blasting, the total charge of explosives used is multiplied by an emission factor.

Applying the IPCC basic formula for calculating GHG emission:

$$CO_2 \text{ emission from blasting} = \text{Activity Data X Emission Factor} \quad \text{(Equation 5)}$$

Blasting contributing to greenhouse gas emission stems from the use of explosives in fragmenting the ore so that they become mineable. Blasting is used in both open pit and underground mining operations. While traditional blasting utilized black powder and dynamite, there are many different types of explosives used today (Phifer and Hem, 2012). Common explosives used in industry now are ANFO (ammonium nitrate/fuel oil), slurries, and emulsions.

GHG Emission due to Mobile Combustion

Fossil fuel combustion is a major anthropogenic source of carbon dioxide (CO_2) emissions (IPCC, 2007). Currently, energy supply and use account for about 84% of all anthropogenic CO_2 emission and can be linked to 65% of all anthropogenic GHG emission (IEA, 2010).

The figure below shows key sources of fuel use on the Mine.

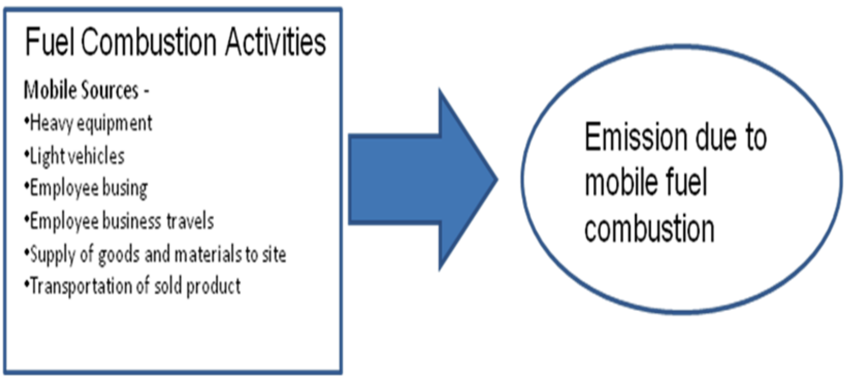

Figure 2: Mobile Fuel Use Activities Generating GHG

Mobile equipment includes heavy duty vehicle/ equipment which cover haulage trucks, excavators, motor graders, bull dozers, loaders, compactors, etc; light duty vehicles/ equipment which cover passenger vehicles such as pick-up trucks, troopers, buses, etc and the last group made up of auxiliary equipment such as mobile cranes. Most Mines use diesel fuel only.

To ensure consistency in computing, the study adopted a Tier 1 approach for mobile combustion using the fuel consumption data for all vehicles used on the Mine. This was obtained from the Supply Chain department of the company.

To account for the GHG emissions due to mobile combustion; the US EPA (2010) approach for estimating GHG for mobile sources was used and this is consistent for diesel fuels. The following assumptions are made:

1. Nearly all fuel carbon is converted to CO_2 during combustion process and conversion is relatively independent of firing configuration of vehicle
2. CO gas formation is insignificant compared to amount of CO_2 produced
3. CH_4 and N_2O are related to vehicle miles travelled rather than fuel consumption and account for 5% of diesel engine emissions in terms of CO_2 equivalent

CO_2 estimate was multiplied by 100/95 to incorporate the contribution of the other GHGs. This multiplier incorporates the global warming potential (GWP) for CH4 which is 28 and for N_2O is equal to 265 (IPCC, 2014).

An oxidation factor of 0.99 was applied to the carbon content to account for a small portion of the fuel that was not oxidized into CO_2 (US EPA, 2010).

Applying this;

To calculate the CO_2 emissions from a gallon of fuel, the carbon emissions were multiplied by the ratio of the molecular weight of CO_2 (44) to the molecular weight of carbon (12), that is 44/12.

The equation for calculating CO_2 emissions from a gallon of diesel is defined as:

$$CO_2 \text{ Emission Factor} = \text{Mass of 1 gallon of diesel} \times \text{Oxidation Factor} \times \text{Molecular Weight of Carbon} \quad \text{(Equation 6)}$$

$$CO_2 \text{ from Mobile Combustion Source} = \text{Activity Data} \times \text{Emission Factor} = \text{Total Mobile Fuel Use} \times CO_2 \text{ Emission Factor} \quad \text{(Equation 7)}$$

All activities of the company that result in GHG emission from mobile source in 2016 including bussing of employees were accounted for and reported appropriately.

GHG Emission from Stationary Combustion Sources

To determine the GHG emissions from the identified stationary combustion sources (stack emissions) a tier 3 approach was used.

There are two main methods for estimating GHG emissions from stationary combustion sources using a tier 3 approach:

- Direct measurement
- Analysis of fuel input

Direct measurement of CO_2 emissions was performed through the use of a Continuous Emissions Monitoring System (CEMS) (US EPA, 2016). The direct measurement approach was adopted for the study as against the analysis of fuel input due to its accuracy. Process gas and point source emission testing was conducted using a variety of testing methods. These included using international reference methods (notably for environmental compliance reporting) and custom methods (Nelson, 2003). The United

States Environmental Protection Agency (US EPA) has developed reference methods for the measurement of point source emissions and these form the basis of testing conducted. Gas sampling was performed isokinetically in order to take a representative sample of gas, liquid phase mists and solid phase material. To allow for non-uniformity of distribution, samples were obtained from multiple sample points across the sampling plane in order to give an overall average of the emissions.

Automatic isokinetic sampling equipment designed for the execution of the US EPA methods was used. US EPA Method 5 provided the base methodology for subsequent methods. It was necessary to execute US EPA Methods 1 to 4 in advance (Nelson, 2003). The sampling train was modified as required for other determinants. This included using different impinger solutions which reacted with target gas species. The solutions were analyzed in a laboratory to determine the species concentrations.

A Testo 350 XL flue gas analyser was used to perform dry gas composition measurements of the gas stream. The method of analysis was by means of electrochemical cells, which recorded concentrations of the various gases.

GHG Emission due to Electricity Use

Although the company has a power generating plant, it was not used during the 2016 calendar year due to constant supply of power from the national grid.

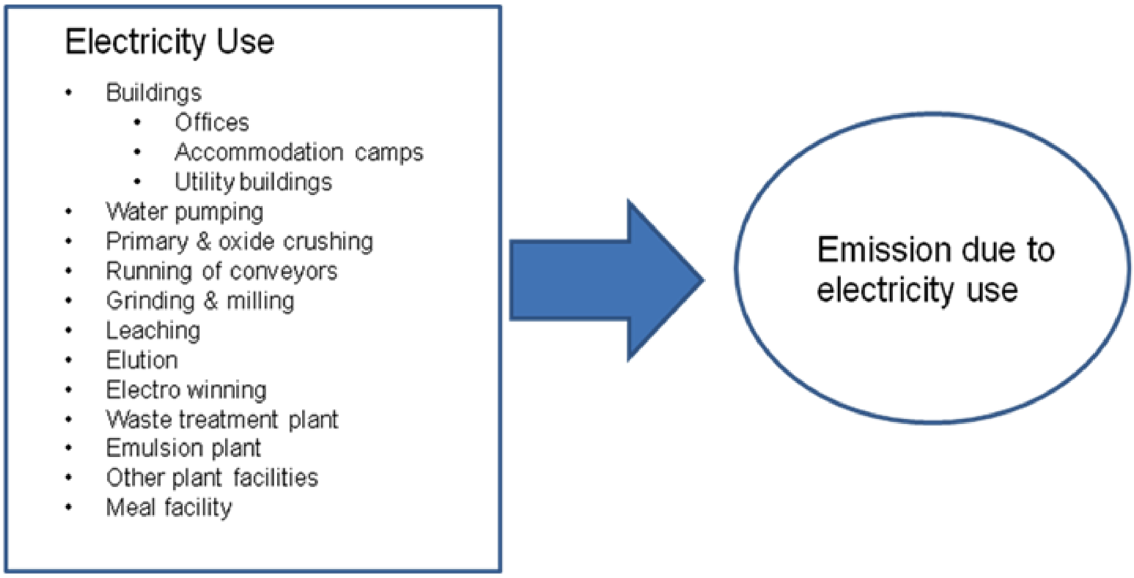

Figure 3: GHG Emission Due to Electricity Use

Electricity uses were identified for the following activities as shown in the figure below:

$$CO_2 \text{ Emissions} = \text{Electricity used X Emission factor} \quad \text{(Equation 8)}$$

In order to convert electricity consumed in kilowatt hour (kWh) to kilogram (kg) of carbon dioxide, the energy use is multiplied by a conversion factor which is known as the emission factor.

The country-specific emission factor obtained from the Energy Commission of Ghana was used in the calculation while electricity purchased and used for the year was obtained from the company.

GHG Emission due to Waste

To estimate GHG emission from waste generated on the Mine, it was important to

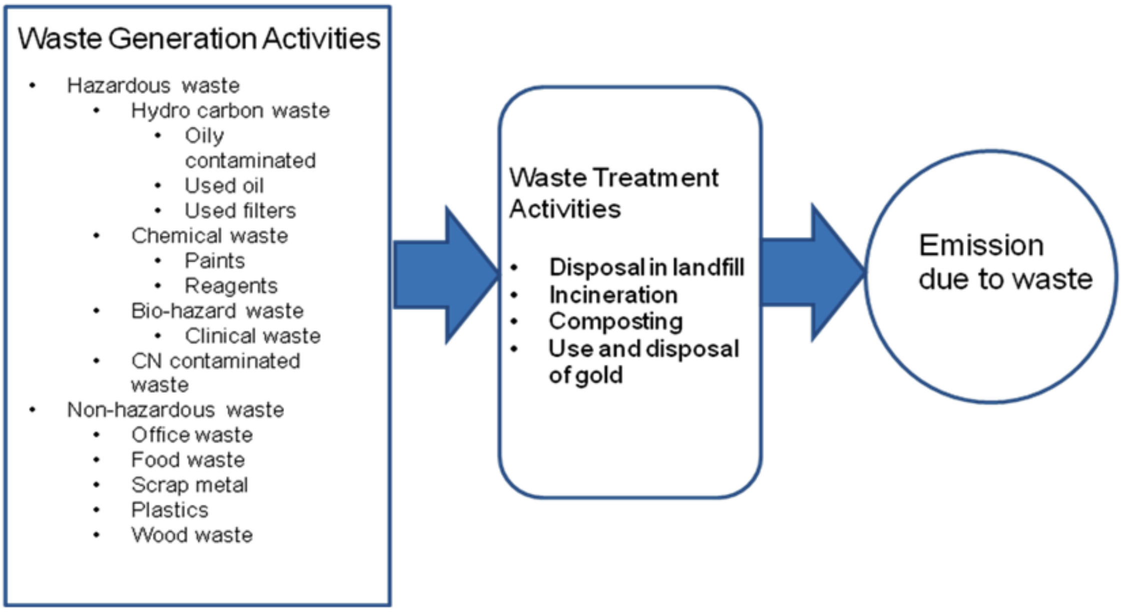

Figure 4: Waste Stream Categorization at Company XYZ

first categorize the waste into appropriate waste stream and apply appropriate methods. Identified sources of waste were as captured in Figure 4.

Following the waste stream model, the IPCC guidance was used to establish emission from 4 main outputs - composting, disposal at landfill and incineration.

Results

GHG Emissions due to Land Use

For the study, only forest land was considered under emissions/ removals. Data on 7433 specie were gathered during the environmental impact assessment of the area prior to mining and this data covered the different specie types and diameter at breast height (DBH) measurement. The computation of this result was carried out on the pre-existing data obtained from the company. Wood density of the various species was obtained from the work of Chave, et al. (2009).

Applying the allometric equation developed by Yeboah, et al. (2014) for biomass carbon (kg/ha) estimation of trees from moist forest zone in Ghana based on diameter at breast height measurement and wood density of tree species, the total carbon stock from aboveground and below ground biomass was computed in Table 2 below using the formula:

$$Y = Y\ (AB) + Y\ (BG) = (a*(\rho*(dbh)^2)^b) \qquad \text{(Equation 9)}$$

Where

Y is the carbon stock for aboveground (AG) and belowground (BG) tree biomass in kilograms, a and b are respective constants for AG and BG, and ρ is tree density and dbh is tree diameter at breast height.

The GHG emission from carbon emission/ removal due to land use was estimated to be 4,706.40 tCO_2-e.

Table 3 gives a summary breakdown of land use activities mainly from deforestation and reforestation projects being undertaken by the Mine.

TABLE 2
Computation of Carbon Stock from Land Use

SN	Scientific Name	DBH (cm)	Wood Density (ρ) (g/cm3)	Area (Ha)	AG Mass (kg)	AG Biomass (MgC-ha-1)	AG Biomass (MgCF-ha-1)	$C0_2$_AG	BG Mass (kg)	BG Biomass (MgC-ha-1)	BG Biomass (MgCF-ha-1)	$C0_2$_BG	Total CO_2eq
1	Afzelia bella	56	0.637	0.25	14.7836	0.0591	0.0281	0.2168	46.1480	0.1846	0.0876	0.6768	0.8937
13	Albizia adianthifolia	41.6	0.474	0.25	8.1719	0.0327	0.0155	0.1199	25.5092	0.1020	0.0484	0.3741	0.4940
2546	Cedrela odorata	30.4	0.44	0.25	5.5434	0.0222	0.0105	0.0813	17.3042	0.0692	0.0329	0.2538	0.3351
4049	Ceiba pentandra	54.5	0.2142	0.25	4.8380	0.0194	0.0092	0.0710	15.1023	0.0604	0.0287	0.2215	0.2925
4292	Celtis adolfi-fridericii	50.6	0.621	0.25	13.0225	0.0521	0.0247	0.1910	40.6507	0.1626	0.0772	0.5962	0.7872
4954	Celtis mildbraedii	79.6	0.708	0.25	23.3560	0.0934	0.0444	0.3426	72.9075	0.2916	0.1385	1.0693	1.4119
5017	Chrysophyllum perpulchrum	82.5	0.6535	0.25	22.3435	0.0894	0.0424	0.3277	69.7470	0.2790	0.1325	1.0230	1.3507
5262	Daniellia ogea	32.5	0.439	0.25	5.9129	0.0237	0.0112	0.0867	18.4575	0.0738	0.0351	0.2707	0.3574
5568	Gmelina arborea	36.6	0.41	0.25	6.2190	0.0249	0.0118	0.0912	19.4129	0.0777	0.0369	0.2847	0.3759
7433	Zanthoxylum leprieurii	44.2	0.5	0.25	9.1589	0.0366	0.0174	0.1343	28.5903	0.1144	0.0543	0.4193	0.5537

*Sample computation results for species deforested.

TABLE 3
Result of Estimated Carbon Emission/ Removal due to Land Use

Forest Land (Ha) Deforested Due to Pit Development	Carbon Stock (tCO_2-e)
101 ha (forest degraded due to pit development)	4,292.42 C-emission
60 ha (degraded forest land)	457.17 C-emission
60 ha (reforestation project)	43.1994 C-removal
257 ha (reforestation project under 1 year)	0
Total	4,706.40 C-emission

GHG Emission due to Blasting

From blasting operations, results were computed as follows:

Activity Data = total explosives used = 11723.767 t

Emission factor = 0.170 tCO_2-e/ kg (IPCC default value)

CO_2 emission from blasting = 11723767kg * 0.170 tCO_2-e/ kg

Total GHG emission from blasting = 1,993 tCO_2-e

GHG Emission due to Fuel Use by Mobile Equipment

A breakdown of the mobile equipment fleet numbers and the quantity of fuel consumed per each unit is provided in Table 4 below:

TABLE 4
Fuel Consumption by Mobile Equipment Unit Types

Equipment Type	**Fleet Population**	**Fuel Consumed (Liters) (2016 Calendar Year)**
Drill Rigs	6	2,561,128.95
Excavators	9	4,945,756.90
Loaders	7	1,280,112.30
Haul Trucks	19	8,693,205.00
Water Trucks	2	410,814.55
Tow Haul	1	36,181.05
Dozers	6	1,525,061.16
Graders	4	294,822.15
Lube Trucks	4	137,147.61
Auxiliary Equipment	82	603,395.85
Light Vehicles	125	239,406.63
Total	265	20,727,032.15

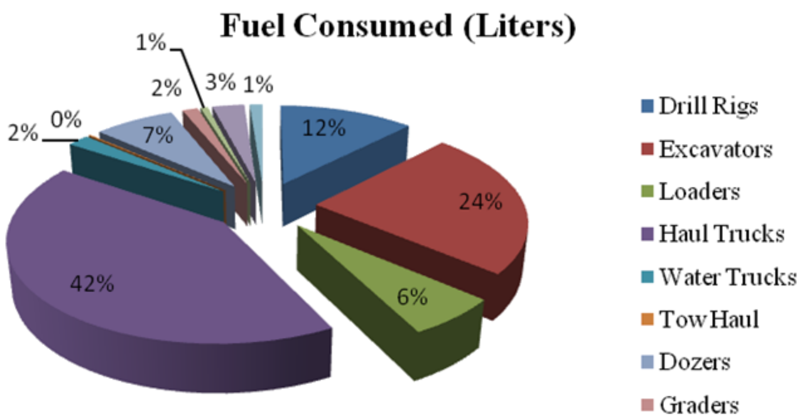

Figure 5: Percentage Fuel Consumption by Fleet Type

Diesel is the sole fuel type used by mining equipment on the mine. Applying the US EPA (2010) methodology for estimating greenhouse gas for diesel powered vehicles, the results were as follows:

To calculate the CO_2 emissions from a gallon of fuel, the carbon emissions are multiplied by the ratio of the molecular weight of CO_2 (44) to the molecular weight of carbon (12), that is 44/12.

The equation for calculating CO_2 emissions from a gallon of diesel is defined as:

CO_2 Emission Factor = Mass of 1 gallon of diesel X Oxidation Factor X Molecular Weight of Carbon

Density of diesel = 0.832kg/L

1 Liter = 0.219961 Gallon

Mass (g) = 3,782.49g

Total fuel used for on-mine transport in 2016 = 4,559,138.72 Gallons

CO_2 Emission Factor = 3,782.49g X 0.99 X (44/12)

= 13,730.4340g/gallon

= 0.01373t/ gallon

CO_2 Emission = Activity Data x Emission Factor

= 4,559,138.72 gallons X 0.01373t/ gallon

= 62,596.97 tCO_2-e

The addition of CH_4 and N2O (5% extra) yields total GHG emissions:

= 65,726.82 tCO_2-e

GHG Emission from Stationary Combustion Sources

Six stationary emission sources were identified as contributing to GHG emission on the Mine: standby power plant, electrowinning stack, smelting stack, elution heater stack, carbon regeneration stack and kiln stack.

In total, stationary combustion contributed 6,150.46 tonnes of carbon dioxide equivalent (tCO_2-e) in the year 2016. The highest GHG emitting stack was the kiln stack which contributed 3,093.58 tonnes of carbon dioxide equivalent (50.30%) followed by the elution heater stack which contributed 1,596.64 tonnes of carbon dioxide equivalent (25.96%). The carbon regeneration scrubber, electrowinning scrubber, smelting scrubber and the standby power plant contributed 663.32, 526.68, 266.50 and 3.74 tonnes of carbon dioxide equivalent respectively making up the remaining 23.74% of the point source GHG emission from the mine's operations for the year 2016. Table 5 below summarizes the results of emissions from the various identified stationary combustion sources on the Mine.

GHG Emission from Electricity Use

Electricity consumption by the operations of the Mine is grouped into nine main units. Eight of these units are operational within the Processing Plant of the company. The remaining unit covers general electricity use by office and accommodation buildings and auxiliary facilities not directly linked to the operations of the company, and this is the least consumption among the nine units.

Major units within the processing plant include primary crushing unit, grinding unit, carbon-in-leach unit, slurry pumping unit, elution unit and electrowinning unit. Average power consumption by each unit is as shown in table 5. The grinding ball mill unit consumed 90,679,906.53 kWh of electricity in the accounting year (2016) followed by the grinding semi-autogenous (SAG) mill unit with 52,681,004.48 kWh. The total consumption from both units outweighs the total of the rest of the units. In total 221,647 MWh of electricity was consumed by the Mine in 2016.

Ghana has a country specific grid emission factor determined from the basket pool of all electricity generating sources at any given period. For the 2016 year, grid emission factor was determined to be 0.43t/MWh (Energy Commission of Ghana, 2017).

$$CO_2 \text{ Emissions} = \text{Electricity used X Emission factor}$$

$$CO_2 \text{ Emissions} = 222{,}792.97\text{MWh X } 0.43\text{t/MWh}$$

$$CO_2 \text{ Emission} = \underline{\mathbf{95{,}800.98\ tCO_2\text{-}e}}$$

TABLE 5
Summary of GHG Emissions Stationary Combustion Sources

Point Source	CO_2 Equivalent (tCO_2-e/day)			Run Time (days)	Total (tCO_2-e)
	CO_2	CH_4	N_20		
Standby Power Plant	14.94	0.0183	0.0055	0.25	3.74
Electrowinning Scrubber	1.3183	0.0899	0.0309	366	526.68
Smelting Stack	0.697	0.0240	0.0071	366	266.50
Elution Heater Stack	4.34	0.0183	0.0041	366	1,596.64
Kiln Stack	8.43	0.0166	0.0058	366	3,093.58
Carbon Regeneration Scrubber	1.79	0.0086	0.0138	366	663.32
TOTAL					6,150.46

Table 6 gives a breakdown of electricity consumption by the various units of the Mine in the year 2016

TABLE 6
Electricity Use by Company XYZ for 2016

Processing Unit	Electricity Consumed (kWh)
Surface Dewatering (kWh)	0
Primary & Oxide Crushing (kWh)	6,549,930.00
Grinding - Auxiliary Units (kWh)	15,822,846.00
Grinding Ball Mills (kWh)	90,749,095.00
Grinding SAG Mills (kWh)	69,010,167.00
CIL, Tails, Carbon Handling (kWh)	20,797,183.30
Tails Decant & Raw Water (kWh)	2,737,830.00
Elution, EW & Reagents (kWh)	10,053,734.00
Infrastructure and Utilities (kWh)	7,072,182.70
Total Power Consumption (MWh)	222,792.97
Grid Emission Factor (tCO_2/Mwh)	**0.43**
Total Emission (tCO_2-e)	95,800.98

GHG Emission from Waste Incineration

The company categorizes its solid wastes into two types - hazardous and non-hazardous waste. Hazardous wastes are mainly waste from hydrocarbon contaminated waste while non-hazardous are non-hydrocarbon contaminated wastes. Non-hazardous waste include food waste, construction debris, papers, scrap wood, tyres, plastics, metals and grey water.

Hazardous waste on the other hand come from maintenance activities and equipment operations; they include absorbent pads, oily rags, used oil, contaminated soil, empty hydrocarbon drums, medical waste, paint/ solvents, used batteries, used hosed, aerosol cans, fluorescent tubes, sludge, electronic waste, expired chemicals and dewatered filter cake. Medical waste generated on site is treated as hazardous waste. For the year 2016, total amount of solid waste generated on the Mine was 1,900 tonnes.

Waste generated undergoes recycling/ reuse, incineration, disposal and composting. The greater amount of solid waste is recycled or reused. 59.61% of the total waste generated in 2016 on site was reused or recycled. Scrap metals generated in 2016 were sent to Tema Steel works while plastics and rubber waste such as conveyor belt scrap were sent to Kumasi and Ofinso for recycling into secondary products. e.g. slip wear. Contaminated soil is recovered through the use of biogel (an environmental chemical product) to break the hydrocarbon bonds and thereby take out the inorganic factor in the soil. Used grease and used oil are sent to the Tema lube industries where they serve as raw material or are treated for re-use. Scrap metal forms the highest category in the reused/ recycled waste (696.40t) while contaminated soil (4.40t) constitutes the least. Greenhouse gas emission from this category

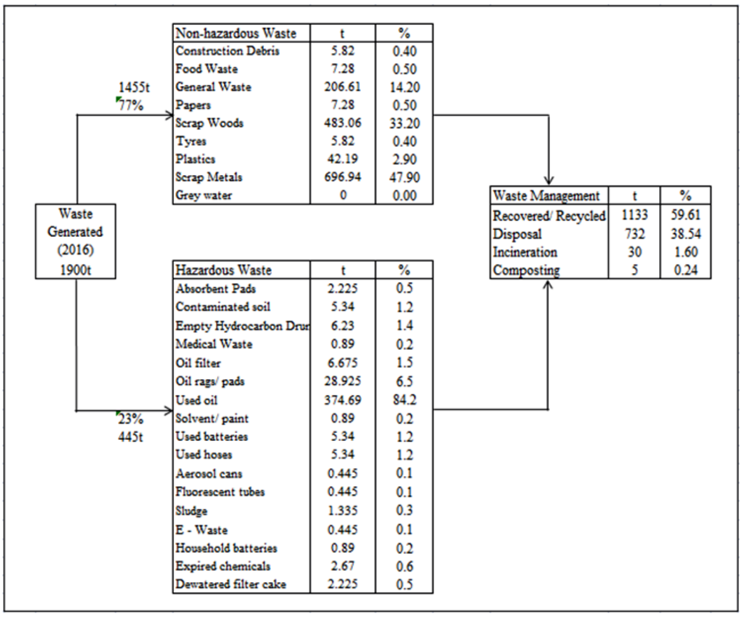

Figure 6: Waste Stream Categorization

of waste is minimal as a result of reuse. For the study, emissions from recycling of waste were not estimated.

Disposed waste category comprised of oil filters, used batteries, electronic waste, paint/ solvents, aerosols, used hoses, debris, food waste, general waste, papers, scrap wood, used tyres, expired chemicals and dewatered filter cakes are disposed off at land fill sites either on the Mine or sent to Kumasi Metropolitan Assembly (KMA) landfill site. Emission from landfill site was not captured as part of the study mainly due to the first order decay (FOD) principle. Transformation of degradable material in the solid waste disposal sites (SWDS) to CH_4 and CO_2 is by a chain of reactions and parallel reactions (IPCC, 2006). A full model is likely to be very complex and vary with the conditions in the SWDS. However, laboratory and field observations on CH_4 generation data suggest that the overall decomposition process can be approximated by first order kinetics (e.g., Hoeks, 1983), and this has been widely accepted. Half-lives for different types of waste vary from a few years to several decades or longer (IPCC, 2006). The FOD method requires data to be collected or estimated for historical disposals of waste over a time period of 3 to 5 half-lives in order to achieve an acceptably accurate result (IPCC, 2006). Good practice requires the use disposal data for at least 50 years as this time frame provides an acceptably accurate result for most typical disposal practices and conditions (IPCC, 2006). Considering the fact that, the mining company in question has barely seen 5 years of active operations, it was thought wise to leave out the computation of emissions due to landfill disposal on site. Amount of waste sent to the KMA landfill site totals less than 20 tonnes and this yields an insignificant value when subjected to the IPCC waste model calculator.

Waste contaminated with hydrocarbon such as oily rags and adsorbent pads, and medical wastes are incinerated on the Mine. For this study, stack emission monitoring and measurement was carried out on the incinerator. A tier 3 approach was used for the determination of greenhouse gas emission.

Isokinetic test was used to determine the greenhouse gases present in the emissions from the stack as well as measure their concentrations. Concentrations of N_2O, CH_4 and CO_2 were measured to be averages of 0.053ppm, 10.900ppm and 6.84% respectively. The number of hours run by the incinerator was recorded and converted into days. It was found that the total run hours of the incinerator for the year 2016 was 794.7 hours and this is equivalent to 33.11 days. Converting from volume to mass and applying conversions to carbon dioxide equivalent yielded results as expressed in Table 7. Total GHG Emission from Solid Waste Incineration was computed to be 329.39 tCO_2-e.

TABLE 7
GHG Emission Measurement from Incinerator Stack

GHG	Run	ppm	$mg.Nm^{-3}$	$ton.day^{-1}$	CO_2-e	Days Run	Total (tCO_2-e)
N2O	Run 1	0.054	0.107	7.9×10^{-6}	0.0021	33.11	0.695
	Run 2	0.052	0.103	7.6×10^{-6}			
	Average	0.053	0.105	7.8×10^{-6}			
CH4	Run 1	11.000	7.876	5.8×10^{-4}	0.0162	33.11	0.536
	Run 2	10.800	7.733	5.8×10^{-4}			
	Average	10.900	7.804	5.8×10^{-4}			
CO2	Run 1	6.65%	130580	9.6587	9.930	33.11	328.782
	Run 2	7.02%	137846	10.1962			
	Average	6.84%	134213	9.9275			
TOTAL							329.39

* $N_2O = 265CO_2$-e, $CH_4 = 28CO_2$-e

Discussion

Combining results from all six (6) key areas covered by the study - land use, blasting operation, mobile combustion, stationary combustion, electricity and waste; Table 8 gives a breakdown of the emissions generated from the identified sources of Company XYZ's operations in the year 2016. Figure 7 expresses it in percentage terms.

TABLE 8
Total Greenhouse Inventory from an Open Pit Gold Mining Operation in Ghana

Activity	Emission (tCO_2-e)
Land Use	4,706
Blasting	1,993
Mobile Combustion	65,726.82
Stationary Combustion	6,150.46
Electricity	95,800.98
Waste	329.39
Total	174,707.08

Electricity is the most important source of energy used on the Mine and in the same manner, the highest contributor to greenhouse gas emission. Consumption of power from the national grid is critical to sustaining the life of the business. Electricity use accounted for 54.84% of the total greenhouse gas emission from the study confirming the fact that it is the main drive for the mining industry and accounts for the second most utilized sector of the total electricity used in the country (Energy Commission of Ghana, 2016).
After electricity use, mobile combustion from vehicle contributed 37.62% of the total GHG emission for the 2016 year utilized by the Mine under study. Transportation within the Mine is vital. Although, conveyors are used to transport material from stockpile to the milling unit, transporting ore or waste from the pit cannot be handled by conveyors. Heavy mobile equipment run twenty-four hours every day to deliver ore to the stockpile. The Mine has a fleet of 19 haul trucks supported by shovels/ excavators, dozers, graders, loaders, among other heavy equipment that consume high amount of diesel fuel and are run in a twenty-four hour operation. Emission from land use and stationary combustion together contributed 6% while blasting activities and waste management contributed less than 2% in total to the t otal greenhouse gas emitted in the period.

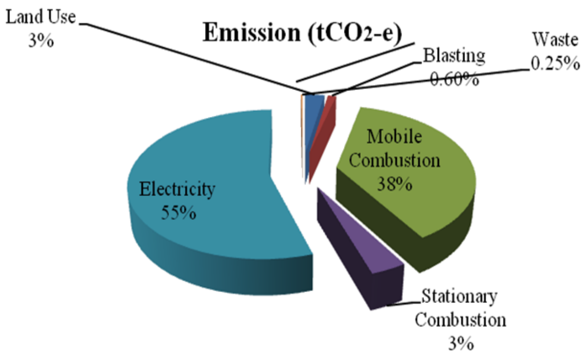

Figure 7: Greenhouse Gas Emission Inventory by Category

Outlook of the Ghana Gold Mining Industry and GHG Emission

There are eight (8) large scale mining companies operating in Ghana. Four (4) of these companies have two (2) mine sites in the country, making a total of 12 operational sites. Table 9 lists the large-scale gold mining companies in Ghana as of December, 2016.

TABLE 9
Large Scale Gold Mining Companies Operating in Ghana

Company	Operations
AngloGold Ashanti	Obuasi Mine
AngloGold Ashanti	Iduapriem Mine
Asanko Gold	Asanko Mine
Goldfields Ghana Limited	Tarkwa Mine
Goldfields Ghana Limited	Damang Mine
Golden Star Resources	Bogoso/ Prestea Mine
Golden Star Resources	Wassa Mine
Chirano Gold Mine	Chirano Mine
Newmont Gold Ghana Limited	Ahafo Mine
Newmont Golden Ridge Limited	Akyem Mine
Adamus Gold Mine	Adamus Mine
Perseus Mining Limited	Perseus Mine

(Source: Ghana Chamber of Mines, 2016)

Using the methodology adopted for the study to draw comparison with the Ghana National GHG Inventory report prepared for 2014; the fuel and electricity consumption data for Mining Companies was obtained from the Ghana Chamber of Mines for the various mining companies as shown in Table 10:

CO_2 Emission for Fuel Use = Activity Data x Emission Factor
= 55,955,676.12 gallons X 0.0137t/ gallon
= 766,592.76 tCO_2-e

TABLE 10
Fuel Consumption by Mining Companies in Ghana in 2016

Company	Electricity Consumed (MW-hr)	Fuel Consumed (Liters)
AngloGold Ashanti- Obuasi Mine	86,601.73	486,623.19
AngloGold Ashanti- Iduapriem Mine	133,238.93	13,861,931.19
Asanko Gold Limited	94,479.27	18,951,426.80
Goldfields Ghana Limited- Tarkwa Mine	272,782.00	75,697,789.18
Goldfields Ghana Limted - Damang Mine	128,142.03	16,954,334.47
Golden Star Resources - Bogoso/ Prestea Mine	46,631.00	3,493,899.57
Golden Star Resources - Wassa Mine	82,618.00	13,174,656.46
Chirano Gold Mine	131,435.87	13,103,589.97
Newmont Ghana Limited - Ahafo Mine	255,558.68	36,698,555.50
Newmont Ghana Limited - Akyem Mine	222,792.97	20,727,032.15
Adamus Resources Limited	37,706.20	7,677,680.68
Perseus Gold Limited	118,123.30	28,595,320.43
TOTAL	1,610,109.98	254,889,078.61

To determine emission from fuel consumed by Large Scale Gold Mining Companies in Ghana in 2016; the US EPA (2010) guideline is followed:

The equation for calculating CO_2 emissions from a gallon of diesel is defined as:

CO_2 Emission Factor = Mass of 1 gallon of diesel x Oxidation Factor x Molecular Weight of Carbon

- Density of diesel = 0.832kg/L
- 1 Liter = 0.219961 Gallon
- Mass (g) = 3,782.49g

Total fuel used by large scale mining companies in 2016 = 55,955,676.12 Gallons

CO_2 Emission Factor = 3,782.49g x 0.99 x (44/12)
= 13,730.44g/gallon
= 0.0137t/ gallon

Factoring in CH_4 and N_2O (5%), Emission from Fuel:
= 804,922.40 tCO_2-e
= 0.805 Mt CO_2-e
Total GHG Emission from Mining Industry Fuel Use (2016) = **0.805 $MtCO_2$-e**

For Electricity Consumption:
Applying the grid emission factor of 0.43 t/ MW:
= 1,610,106.98 X 0.43
= 692,346.00 tCO_2-e
= 0.692 Mt CO_2-e
Total GHG Emission from Mining Industry Electricity Use (2016) = **0.692 $MtCO_2$-e**

Table 11 gives a summary of fuel use and electricity consumption by gold mining companies and its related GHG emission contribution to the national GHG inventory.

TABLE 11
Large Scale Mining Industry versus National GHG Inventory Report

Sector	2016 Ghana Large Scale Mining GHG Inventory ($MtCO_2$-e)	2014 Ghana National GHG Inventory ($MtCO_2$-e)	Approximate Contribution of Large Scale Gold Mining (%) to GHG in Ghana
Fuel for Transport	0.805	6.46	12.46
Electricity	0.692	7.05	9.82
Total	1.497	13.51	11.08

Comparing GHG emission due to energy consumed by Mining Companies in 2016 (1.497 $MtCO_2$-e) with the Ghana GHG Inventory report for 2014 (MESTI, 2015) for same category of fuel for transport and electricity consumed (13.51 $MtCO_2$-e); Large-Scale Gold Mining accounts for 11.08% of the total greenhouse gas emission. This makes the mining industry a significant contributor to greenhouse gas emission in Ghana with the potential of generating more than 10% of the total GHG emissions in the country on annual basis. This deduction excludes small-scale mining companies and other extractive industrial processes such as bauxite, manganese and industrial minerals.

To appreciate the extent of greenhouse gas emission by large-scale gold mining companies, it was necessary to compare the emission intensity from the company's operation to other companies in the same environment. Using the ounces of gold produced in 2016 by Company XYZ (471,202.38 ounces), emission intensity was calculated by dividing the greenhouse gas emission for the year 2016 (174,707.08tCO_2-e) by the total ounces produced within the same period. This gives a figure of 0.3715 tonnes CO_2-e/ ounce of gold.

Conclusion

The study aims is to bring stakeholders to the realization that the mining sector has some work to do in the area of greenhouse gas emission from its operations. Since this sets the benchmark, annual monitoring of reductions by key stakeholders such as the EPA would go a long way to helping track and reduce their emissions. At present, Ghana's emission reduction goal as part of its commitment to the UNFCCC is to unconditionally lower its GHG emissions by 15 percent relative to a business-as-usual (BAU) scenario emission of 73.95$MtCO^2$e by 2030 (GH–INDC, 2015). The areas being considered for these reductions does not include the mining sector and this is the reason why this paper highlights the need to have mining included as a key contributor needing effort to manage its GHG emission risk.

The absence of baseline information makes it difficult to set target and monitor progress on reduction. The Australian mining sector has increased its emissions by 22 per cent since 2005 (EY, 2015). This increase contrasts with the Australian Government's target of a 26 to 28 per cent reduction in emissions by 2030 from the 2005 baseline (Commonwealth of Australia, 2015) and the mining industry is being held to account for not meeting its emission target. With measurable indices set for the mining industry, it becomes easy to hold the mining companies to account and this is what is lacking with the Ghana National Greenhouse Gas Inventory. Ghana has no set threshold for the mining industry. Goldfields Ghana Limited is one of the mining companies in Ghana who following the tracking of their emissions are able to report on substantial reductions. What is needed is the enforcement by regulatory bodies such as the EPA.

The small scale and illegal mining sector was not considered in the scope of the study. It is difficult to quantify emissions from illegal mining due to lack of governance around their operations. Most likely, their contribution would not be too significant since they use alluvial processes. Other than the destruction of vegetation, equipment use is mainly limited to excavator use which compared to large scale mining is relatively insignificant.

Best management practices (BMPs) discussed in the recommendations are all relevant and implementable at all the established locations of mining in the country. What is important is the combination of alternatives in addition to existing energy sources. As an example all mining companies are sited close to water bodies and can readily dam these streams of water to generate electricity. This could go a long way to offset the total reliance on thermal generated electricity from the national grid.

Recommendations

To best manage greenhouse gas emission, it is important to consider innovations that rely on greener technologies. The study unearthed high emissions due to electricity and fuel use as key categories contributing to emissions. It would be useful for the mining industry to embrace renewable type energy instead of relying solely on fuel based systems in current use. Combining renewable energy technologies with current practices could go a long way to reduce carbon emissions of companies. Wind power is one of the most successful, popular, and fastest growing forms of renewable energy available today (Adey et al., 2011). In 2009, wind power was estimated to produce 157.9 GW of energy per annum worldwide; that figure having grown by 31% from 2008 (GWEC, 2010). There can be no doubt that wind farms are a significant and growing energy source. A popular emerging alternative to diesel only, is to use combination wind/ diesel generators; which are optimized at 40% wind generated energy and 60% diesel power (Neilson, 2007). An average mine site diesel generator reduces CO_2 emissions by 1.8 lbs per kWh when used in conjunction with wind power (Neilson, 2007). A one megawatt wind farm responsible for 35% of the power supply will generate an average of 3,066,000 kWh of electricity per annum; thereby reducing $C0_2$ emissions by up to 2,759 tonnes per year (Neilson, 2007). In addition to this, wind power typically costs \$0.06-\$0.08 USD per kWh which is lower than the average diesel power generator which costs between \$0.09-\$0.19 USD per kWh under typical conditions (Neilson, 2007). An example of a mining company employing the benefits of Wind Power is Barrick Gold, the world's largest gold company. In 2007, they received approval to build a US\$70 million wind farm in the Coquimbo region of Chile (Barrick, 2010). They have constructed ten wind turbines that provide 36 MW of power to the Chilean grid each year. This is currently the largest wind farm in Chile and an excellent example of a mining company not only reducing their own carbon footprint but working to reduce the carbon footprint of the region they operate in.

Another renewable energy source is solar energy. It is a form of power that utilizes sunlight to generate electricity. In 2008 solar energy accounted for 0.02% of global energy consumption (Solarbuzz, 2009) and just 0.08% in the USA (Hutchinson, 2008). In recent years solar power has come to play a growing role in the mining industry with mining companies building solar power systems ranging in size from small projects acting in combination with other energy supplies to large facilities powering nearby communities and homes. Ghana is within the equator region and as such enjoys sunshine for the greater part of the year. A combination of solar energy and grid electricity can help reduce the greenhouse gas of the company significantly. Opportunity sits with providing solar energy for offices and infrastructure use while large facilities such as the Processing unit feed on the national grid.

A noteworthy mention on the study is the proactiveness of the company in undertaking a reforestation and concurrent reclamation program to restore degraded lands into forest. This must be encouraged among all mining companies as replacement of carbon stock forestalls emissions from similar operations that emit greenhouse gases into the atmosphere. Another avenue in reducing emissions is the use of non-governmental organizations, schools within catchment area of mining and other stakeholders through corporate social responsibility programs to plant trees.

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