Cost competitiveness of Ghana's gold mining industry

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

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(Signature of Candidate)

18TH day of SEPTEMBER year 2019

ABSTRACT

The mining sector is a major contributor to tax revenues and foreign exchange earnings in Ghana. Gold accounts for about 95% of all revenues generated from the export of metals. Declining gold price after peaking at an average of US$1 669/oz. in 2012, led to staff rationalization in the gold mining industry. The downsizing reached a crescendo when AngloGold Ashanti shut down its Obuasi mine in 2016 after laying off 4 312 employees. The happenings in the gold mining industry motivated this research to ascertain the cost competitiveness of Ghana's gold mining sector. This research was limited to large-scale mines due to the easy availability of verified data. The period of this study was between 2007 and 2016 to effectively capture a complete gold price cycle. Cost competitive analysis were conducted on all large-scale mines and companies in Ghana using a Microsoft Excel®-based algorithm from Tholana (2012) for constructing industry cost curves.

Newmont's Ahafo and Akyem mines were found to be consistent low unit cost producers. Ahafo and Akyem mines benefited from economies of scale, excellent recovery rate and efficient management. On the other hand, AngloGold Ashanti's Obuasi mine and Golden Star's Bogoso-Prestea mines were found to be consistent high unit cost producers. Obuasi mine was negatively affected by its inefficient labour intensive underground mining methods while the bane of Bogoso-Prestea mine was very low metallurgical recovery rates. Recovery rate and production output were found to have immense influence on unit cost of gold mines in Ghana and ultimately its position on the industry cost curve. Although variation in mill head grade has influence on unit cost for an individual mine, mill head grade had less influence on the position of the mine on the industry cost curve. This was because most surface mines were able to offset the effect of low grades with large production output. Annual escalation in electricity tariffs were also found to have far more effect on unit cost than fuel prices.

Ghana's gold mining industry had a cost competitive advantage over South Africa's gold mining sector from 2009 to 2016. However, unit cost in Ghana's gold mining sector was higher than the world's average unit cost throughout the period of study which implied that Ghana's gold mining industry was not cost competitive.

DEDICATION

This research report is dedicated to the ALMIGHTY GOD,

because He drew me out of a horrible pit, out of a miry clay,

and set my feet upon a rock, steadying my steps and establishing my goings.

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CONTENTS **Page**

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Chapter overview

This chapter gives a background, overview and significance of the research study. The significance of mining to the economy of Ghana and the performance of the gold mining industry is discussed. Also provided are the problem statement, research aims and objectives. A brief description of all the large-scale gold mines and companies operating in Ghana during the period of the study is given. This chapter ends with a chapter summary and a brief description of the structure of the report.

1.2 Research background

1.2.1 Contribution of mining to Ghana's economy

The mining sector is a major contributor to Ghana's tax revenue. Although, the absolute amount of taxes have increased from 10 000 million Ghana Cedis to over 25 000 million Ghana Cedis, its percentage contribution to total tax revenue has decreased from 10% to 6%.as shown in Figure 1.1.

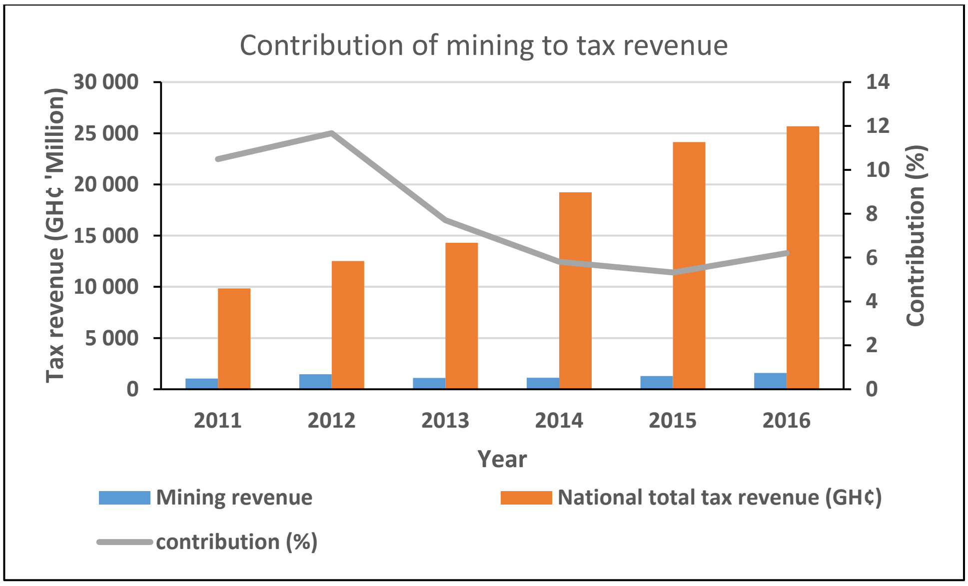

Figure 1.1: Contribution of mining to Ghana's tax revenue

(Source: Bank of Ghana, 2016)

Mining is also a major foreign exchange earner with gold contributing US$4 919.5 million which was 95% of income from metal exports in 2016 (Bank of Ghana, 2016). Mining and quarrying in 2016 accounted for 6.5 % of Gross Domestic Product (GDP) down from about 10% in 2012 as shown in Figure 1.2.

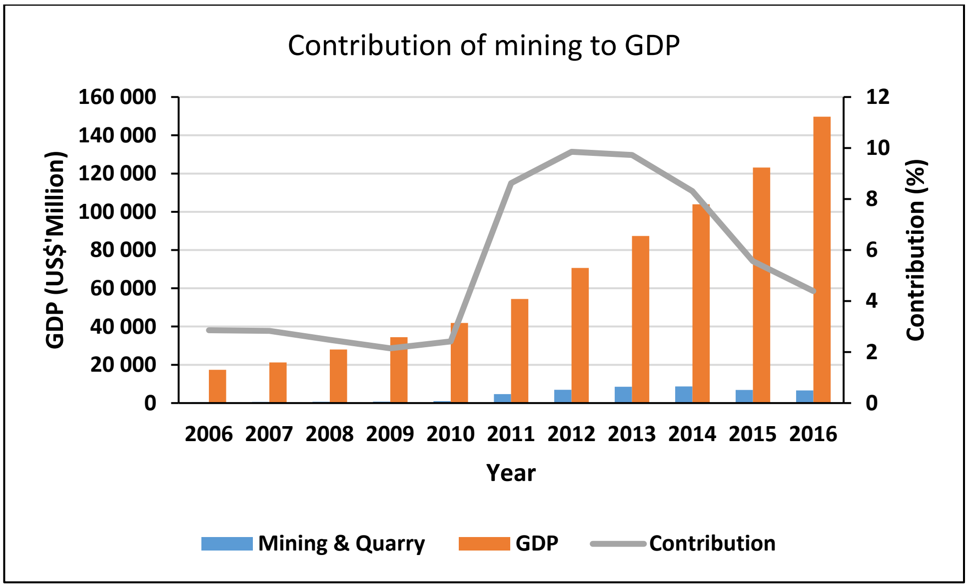

Figure 1.2: Contribution of mining to Ghana's GDP

(Source: Ghana Statistical Services, 2017)

The decline in gold prices from 2013 and the expansion of other sectors of the economy have accounted for the decrease in the contribution of mining to GDP. Figure 1.3 shows employment generated by large scale mines from 2010 to 2016.

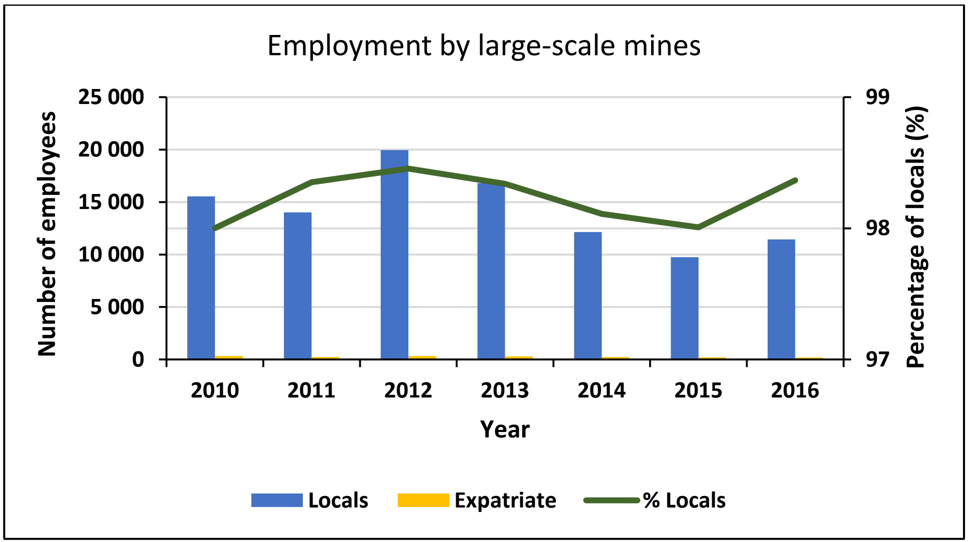

Figure 1.3: Employment by large-scale mines

(Source: Ghana Chamber of Mines, 2016)

Mining sector employment rose to a peak of 20 268 in 2012 followed by a gradual decline afterwards until 2016 when Asanko gold mine started commercial production. The decline in employment has been as a result of staff rationalization and downsizing implemented by most mining companies in an attempt to cut cost and minimise the effect of declining commodity prices. Although the mining sector is not a major direct employer in Ghana, the job multiplier effect is up to 21 times (Kim, *et al*., 2013).

Four commodities namely; gold, diamonds, bauxite and manganese have accounted for revenues generated from mineral exports. Figure 1.4 shows the contribution of various minerals to Ghana's metal export revenue.

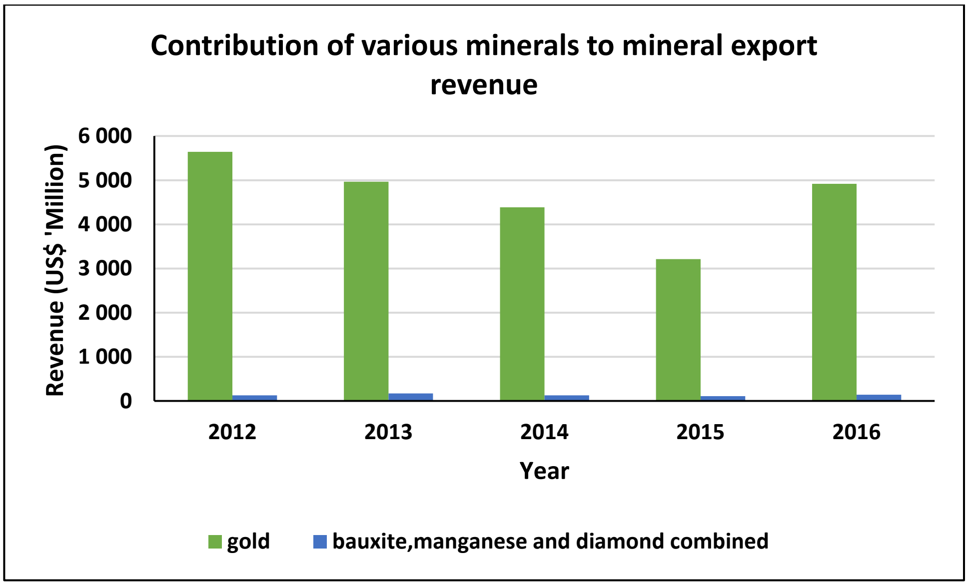

Figure 1.4: Contribution of minerals to Ghana's metals export revenue

(Source: Ghana Chamber of Mines, 2016)

Figure 1.4 shows that gold has contributed about 95% of mineral export revenue from 2012 to 2016. Revenues from gold declined from 2011 to 2015 mainly due to declining gold price. Loss of gold output from the shutdown of Obuasi mine also affected export revenues in 2015. The moderate increase in gold prices and commercial production from Asanko mine increased revenues in 2016. From 2011 to 2016, Ghana was the tenth largest producer of gold in the world, second to South Africa on the African continent (O'Connell, *et al*., 2017).

1.2.2 Performance and contribution of the gold mining sector

Gold production output in Ghana has followed three different trends that reflect the various shifts in minerals policy that governed the minerals sector in the country. Figure 1.5 shows the total gold output from Ghana from 1901 to 2016.

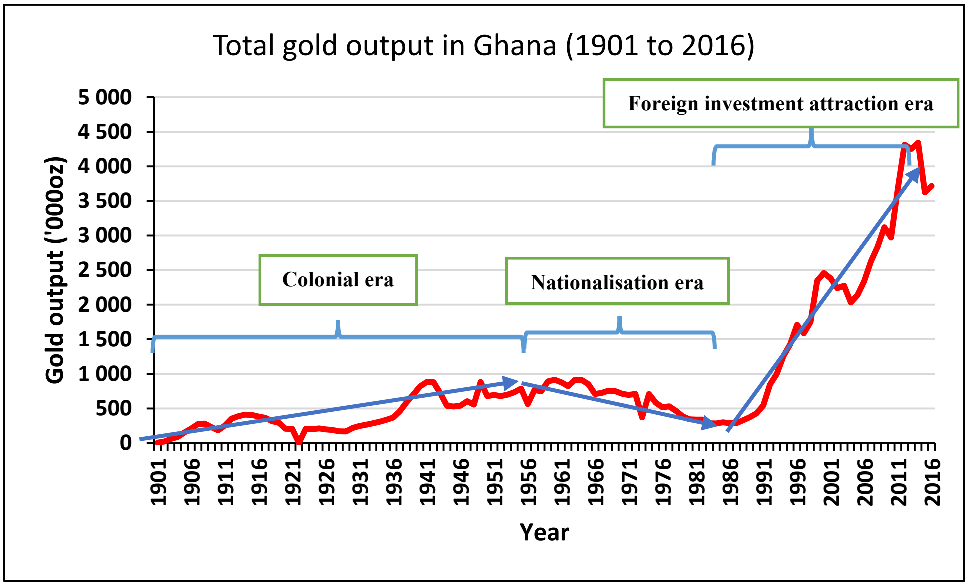

Figure 1.5: Total national gold output from 1901 to 2016

(Source: Minerals Commission, 2016)

Figure 1.5 shows an initial moderate but steady growth in gold production that characterised the colonial era. Colonial era policies were mainly geared towards ensuring self-reliance in the supply of critical minerals to the British Empire (Kesse, 1985). This phase was followed by a period of stagnation and consistent decline in gold production that occurred when mines were nationalised in 1961 (Tsikata, 1997). The last phase indicates a period of astronomical but consistent growth in gold production after policies and laws were enacted to attract foreign direct investment (FDI). During that period, gold production subsequently increased from 282 300 ounces in 1984 to a peak of 4 341 607 ounces in 2014 (Ghana Chamber of Mines, 2016).

The mining sector from 1986 received a substantial increase in FDI, with the gold mining sub-sector attracting an enormous portion of those funds. This was as a result of reforms which were implemented from 1983 by the Government of Ghana with the assistance of the World Bank and the International Monetary Fund (IMF).

These reforms known as the Economic Recovery Programme (ERP) sought to halt the general decline that had bedevilled the economy (Tsikata, 1997). The objectives of the program included lowering inflation rate, stabilising the foreign exchange rate, rehabilitating deteriorating infrastructure, increasing exports and attracting foreign direct investment. Additionally, several legislative instruments were passed to deregulate the foreign exchange regime, privatise state owned enterprise and reduce taxation rates. These were all aimed at making the economy very attractive to foreign investors. Table 1.1 describes the various fiscal incentives that were given to investors.

Table 1.1: Comparison of the fiscal regimes in the mining laws of 1986 and 2006

(Source: Adapted from Government of Ghana, 2010)

FISCAL REGIME	**Minerals & Mining Law 1986 (PNDCL 153)**	**Minerals & Mining Act 2006 (Act 703)**
Royalties	3-12% of total revenue	3-6% amended to 5% of total revenue in 2010. This has been amended again in 2015 and the rate left to the discretion of the sector Minister.
Corporate tax	45% amended to 35% in 1994	25% amended to 35% in 2012
Capital allowance	75% first year, 50% subsequent years	80% deduction in year one and 50% per year on remaining balance. Amended in 2012 to 20% straight line rate for 5 years
Tax losses	Losses can be carried forward	Losses can be carried forward for five years
Investment allowance	Investment allowance of 5%	Not applicable
Exploration expenditure	Capitalisation of reconnaissance and exploration expenditure	Capitalisation of reconnaissance and exploration
Custom duties	Exemption of payment of customs import duties on machinery	Exemption of payment of customs import duties on machinery
Foreign currency repatriation	Retain 25% of foreign exchange earning	Retain 25% of foreign exchange earning
Government ownership	10% Free carried interest	10% Free carried interest

Table 1.1 shows that a generous capital allowance of 75% in the first year and 50% subsequent years was provided but has been amended in 2012 to 20% straight line rate for 5 years. Additionally, a sliding scale royalty regime was introduced which in 2010 has been amended to a flat rate of 5%. The government was, however, entitled to a free carried interest of 10%. Capital equipment and machinery for mining could be imported duty free and dividend paid to foreign shareholders were exempted from withholding tax. Mining companies were also allowed to retain a negotiated portion of their foreign currency to fulfil external obligations and payments. Loss making state mining companies were also sold to strategic investors. Additionally, the government reduced its shareholding in Ashanti Goldfield Corporation.

The Minerals Commission was set up in 1986 to serve as the main regulatory and investment promotion institution in the mining and minerals sector (Tsikata, 1997). The Minerals and Mining Law of 1986 was amended in 1994 to reduce corporate taxes for mining companies from 45% to 35% (AngloGold Ashanti Limited, 2015b). Mining companies were also allowed to keep 25% of foreign exchange earnings abroad to purchase machinery and inputs as well as generous capital allowance.

According to Tsikata (1997), minerals policy from 1986 was focused towards:

- increasing the inflow of foreign investment into the country and private ownership of mineral production;
- restructuring the country's mining institutions to restore productivity in the minerals sector; and
- Increasing the export of minerals and thereby improving revenue generation.

The apparent need to incorporate sustainability into the industry led to the enactment of the Minerals and Mining Act, 2006 (Act 703) which consolidated all mining related laws into a single piece of legislation. Sustainable development concerns were also introduced such as requiring mineral right holders to obtain permissions from the Forestry Commission and the Environmental Protection

Agency before commencement of operations (Government of Ghana, 2010). The entitlements of surface right holders were also recognised and protected by this law. Furthermore, preference for local product and employment of Ghanaians were clearly stipulated in the law. All these were included while maintaining the generous fiscal terms of the previous policy.

The gold mining sub-sector, which attracted most of the FDI's, contributed to 45% of merchandise export revenue in 2016 as shown in Figure 1.6.

Figure 1.6: Contribution of gold to Ghana's merchandise export

(Source: Bank of Ghana, 2016)

Figure 1.6 illustrates that there has been a gradual decline in export revenue percentage contributed by gold from 50% in 2010 to 30% in 2015 before the sudden rise in 2016. Large-scale gold mines contributed 72% of gold produced in the country in 2016 as indicated in Figure 1.7. The remaining 28% of gold produced in Ghana came from small-scale and artisanal miners. Large-scale mines are predominantly owned by multinational mining companies and include but not limited to AngloGold Ashanti Ltd, Gold Fields Ltd, Golden Star Resources Ltd and Newmont Corporation.

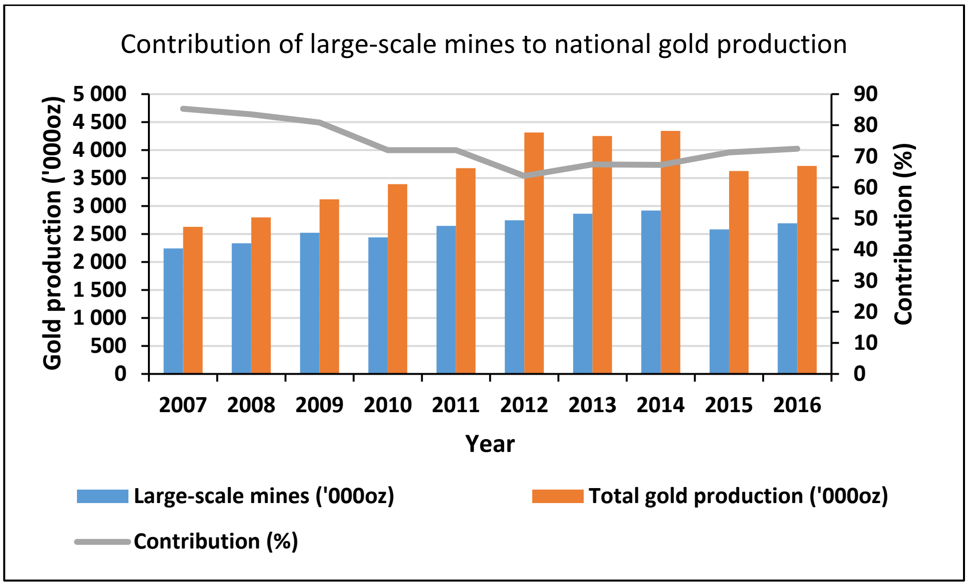

Figure 1.7: Contribution of large-scale mining to national gold production

(Source: Ghana Chamber of Mines, 2016)

1.3 Problem statement and research question

Gold price, which rose to a peak of US$1 800/oz. in 2012, subsequently nosedived but maintained its characteristic extreme volatility. The gradual decline in gold prices affected the profitability of some mines in Ghana. The natural and easiest reactions of companies in Ghana has been to gradually lay off workers in order to offset the decline in profit margins. This downsizing reached a crescendo when 4 312 employees of Obuasi mine lost their jobs between 2014 and 2015 due to the Obuasi mine being put under care and maintenance by AngloGold Ashanti (AngloGold Ashanti Ltd, 2014).

In addition to declining gold price, increasing costs has affected the profitability of mines in the country. Gold Fields Ltd expressed concern about the escalating cost of operating its Damang mine and sought government support through a development agreement. Other mining companies in Ghana through the Ghana Chamber of Mines have also recently been expressing apprehension about the relatively high cost of producing gold in the country. Specifically, they have complained about the high cost of electricity and diesel among other consumables. The importance of gold mining to the economy of Ghana and the concerns raised by mining companies necessitate asking this pertinent question "Is Ghana's gold mining industry cost competitive?"

1.4 Research aim and objectives

The aim of this research is to ascertain the cost competitiveness of the gold mining sector in Ghana. The research objectives are to:

1. Conduct a thorough literature review on costs and industry cost curves;
2. Perform a cost analysis on gold producing mines and companies in Ghana;
3. Determine the characteristics distinguishing high unit cost mines from low unit cost operations; and
4. Analyse the cost competitiveness of Ghana's gold mining industry in relation to South Africa and Australia's gold sectors.

1.5 Research significance

The gold mining industry need this analyses because their final products are fungible hence do not attract any brand loyalty (Kovisar, 1985). The price of a fungible commodity depends on aggregate supply and demand. Market prices and the ability of producers to supply their commodity is key to their success. However, the ability to supply depends on geopolitical considerations and production capabilities. A thorough competitive analysis of Ghana's gold mining industry will also describe the cost structure of the industry hence the amount of supply loss that could occur. A mine's ranking on the industry cost curve should provide an evaluation of the risks and opportunities within the industry. This information is needed for strategic planning both for managers of mining operations and national economic policy makers.

1.6 Research scope

This research analyses the behaviour of unit cash costs of gold mines in Ghana between 2007 and 2016 and ranks them according to their cost performance using industry cost curves. This period was selected as it effectively captures the rapid rise and subsequent decline of gold prices on international markets. The gold sector was chosen primarily because approximately 95% of Ghana's mineral revenue comes from gold (Bank of Ghana, 2016). Although small-scale mining accounts for about 30% of gold produced in Ghana, operational data from these mines is scanty and largely unavailable (Minerals Commission, 2015). This is the reason why this study focussed exclusively on large-scale mines in Ghana. The large-scale gold mining companies operating in Ghana within the time frame of this research included:

- AngloGold Ashanti Limited which operates Obuasi and Iduapriem mines;
- Gold Fields Limited which operates Tarkwa and Damang mines;
- Golden Star Resources Limited. which operates Wassa and Bogoso-Prestea mines;
- Newmont Mining Corporation which operates Ahafo and Akyem mines;
- Kinross Gold Corporation, which operates Chirano mine;
- Perseus Mining Limited, which operates Edikan mine;
- Endeavour Mining Corporation, which operates Nzema mine; and
- Asanko Gold Incorporated, which operates Asanko Gold mine.

All the gold mines were located within the Paleoproterozoic Birimian Supergroup. Ten of the gold mines were situated along the Ashanti Gold Belt. The location of the various mines with respect to the geology of Ghana is as shown in Figure 1.8.

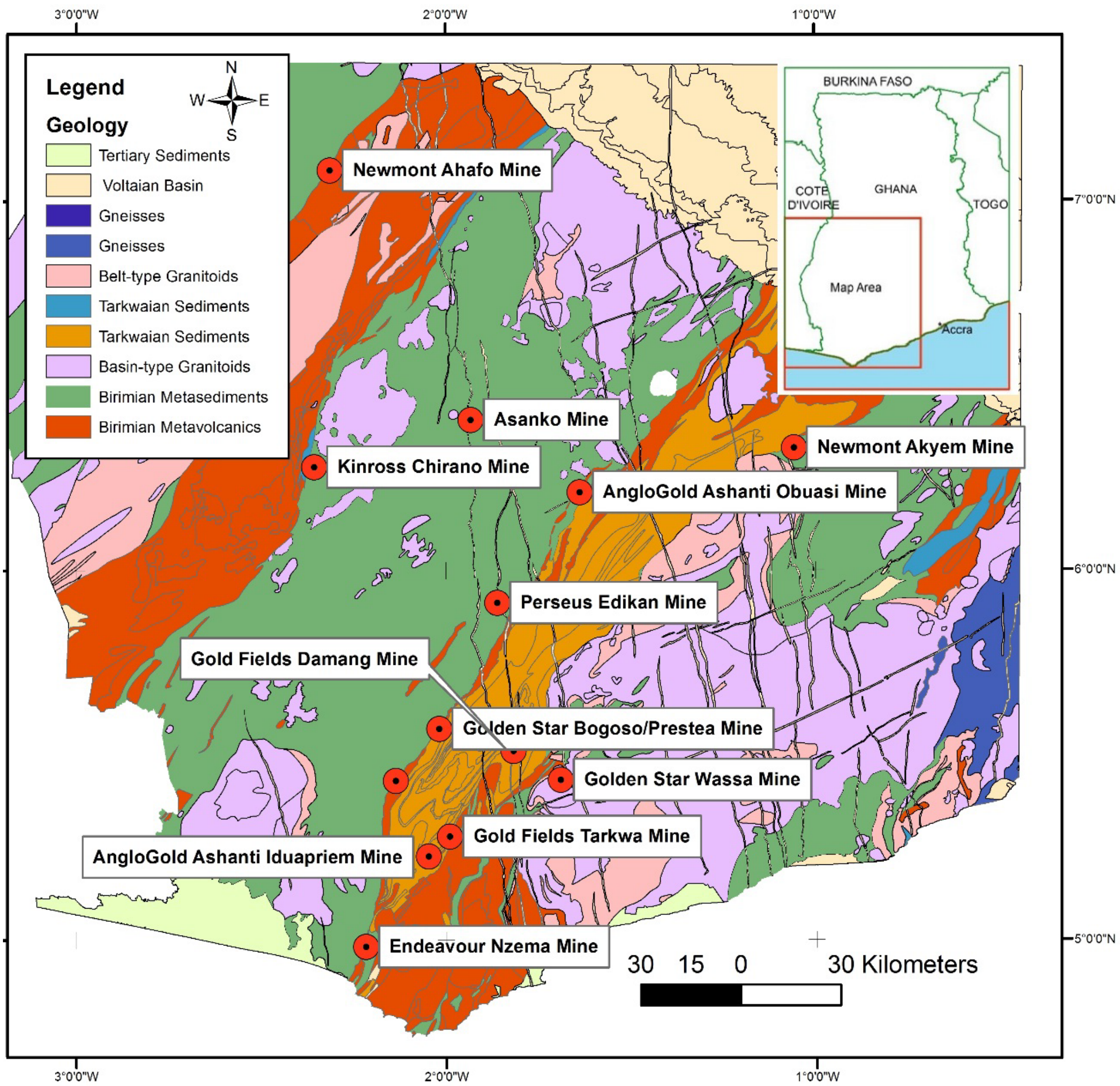

Figure 1.8: Geology of south western Ghana indicating the location of all operating large-scale mines

(Source: Adapted from Ghana Geological Survey Department, 2009)

1.6.1 AngloGold Ashanti Limited

AngloGold Ashanti Limited is listed on the Johannesburg Stock Exchange (JSE), Australian Securities Exchange (ASX), New York Stock Exchange (NYSE) and the Ghana Stock Exchange (GSE) (AngloGold Ashanti Limited, 2015b). Its operations in Ghana include the Obuasi and Iduapriem mines. Obuasi mine is predominantly an underground operation located in Obuasi approximately 320km north-west of Accra. The geology at Obuasi mine consist of Birimian volcano-sedimentary rocks within the Ashanti belt. Shear zones in carbonaceous metasediments and volcaniclastics host mineralization in three trends known as Main, Gyabunsu and Binsere (Griffis, *et al*., 2002). Mineralization at the mine is either refractory or non-refractory. The non-refractory ores are basically quartz veins with free gold and small amounts of iron, zinc and copper sulphides. The refractory ore is mainly fine grained sulphide ores with gold often locked in arsenopyrite (AngloGold Ashanti Limited, 2007). These sulphide ores served as the main ore feed before the mine was shut down in 2015 (AngloGold Ashanti Limited, 2015b). Mining operations takes place at a depth of 1500 metres. Historically, various mining methods have been used to extract the ore. These include conventional cut and fill, shrinkage stoping, sub-level caving and longitudinal and transverse open stoping (Nsarko & Owusu-Mensah, 2012). The longitudinal retreat mining method was being gradually introduced before the mine was put under care and maintenance in 2016.

The sulphide treatment plant processes underground ore while the tailings treatment plant processes tailings from reclamation operations. The sulphide treatment plant, commissioned in February 1994, consists of a bacterial oxidation plant which treats ore concentrated by gravity and flotation (Afidenyo, *et al*., 2010). A CIP process finally leaches out the gold.

Iduapriem mine is located 85km north of Takoradi in the Western Region. Geologically, the mine is located along the southern end of the Proterozoic Tarkwaian basin (AngloGold Ashanti Limited, 2015b). Mineralization consists of palaeoplacer gold contained in the Banket Series. Iduapriem is a conventional open-pit mine with ore that is processed by a CIP plant (AngloGold Ashanti Limited, 2007).

1.6.2 Golden Star Resources Limited

Golden Star Resources Limited is listed on the NYSE, TSX, and the GSE (Golden Star Resources Limited, 2016). It owns both Wassa and Bogoso/Prestea mines.

Wassa mine is located on the southern part of the eastern boundary of the Ashanti Greenstone Belt. The lithology consist mainly of mafic to intermediate volcanic flows interbedded with minor assemblages of volcaniclastics, greywackes and magnetite rich mudstones (Griffis, *et al*., 2002). The structurally controlled mineralization is contained in narrow quartz-carbonate veins hosted in highly altered mafic volcanic rocks. Wassa mine is an open pit operation. Gold recovery at this mine is achieved through the use of conventional carbon-in-leach (CIL) technology (Golden Star Resources Limited, 2015).

The Bogoso-Prestea mine lies within the western boundary of the Ashanti Greenstone Belt. Refractory ores include arsenopyrite-pyrite rich gold mineralization in graphitic shear zones or associated with brecciated iron rich footwall volcanic lenses (Griffis, *et al*., 2002). The non-refractory ore are contained in quartz veins along fault zones and second order structures (Golden Star Resources Limited, 2015). The mine is an open pit operation currently transitioning into an underground mine.

1.6.3 Gold Fields Limited

Gold Fields Limited has primary listing on the JSE and secondary listing on both the NYSE and the Swiss Stock Exchange (SIX) (Gold Fields Limited, 2015). Gold Fields owns both Tarkwa and Damang mines. Tarkwa mine is underlain by the Banket Series with a sequence of auriferous conglomerates bounded by barren quartzites. It is an open pit which employs selective mining techniques to exploit narrow tabular gold bearing conglomerates similar to the Witwatersrand basin (Gold Fields Limited, 2014b). A CIL plant is then used to processes the ore.

The geology at Damang mine consists primarily of the Tarkwaian Group. The mineralization at Damang is distinctive in Ghana by virtue of having hydrothermal mineralisation hosted in Tarkwaian Banket quartzites at the Damang Anticline (Gold Fields Limited, 2011b). A conventional CIL plant processes ore from the pits.

1.6.4 Newmont Mining Corporation

Newmont Mining Corporation is listed on the NYSE (Newmont Mining Corporation, 2016). It owns Ahafo and Akyem mines which are both open pit mines. Ahafo mine is located on the Sefwi Gold Belt and exploits structurally controlled gold mineralization divided into oxide and primary ores. These regional shear structures which cut through granitoids and metasediments host quartz veins containing very fine grained gold. (Griffis, *et al.*, 2002). Although the gold occurs within a sulphide host, they are considered non-refractory. A carbon-in-leach plant is used to process the ore.

The Akyem mine is located 125 km northwest of Accra in the Birim North District of the Eastern Region. The shear zones hosting the gold mineralization are found in green-schist facies Birimian metasediments precisely altered metagreywackes (Griffis, *et al*., 2002). Primary mineralization is associated with quartz veining and pyrite however, it is non-refractory. Processing of the ore is by a CIL plant.

1.6.5 Perseus Mining Limited

Perseus Mining Limited is listed on the ASX and TSX (Perseus Mining Limited, 2015). It owns Edikan mine, an open pit operation located on the western boundary of the Ashanti Greenstone Belt. Gold occurs as both quartz disseminations in granites and in shear zones within the sediments. However, the granites host up to 80% of the estimated Mineral Resource (Runge Limited, 2011). A CIL plant is used to process the ore (Perseus Mining Limited, 2013).

1.6.6 Kinross Gold Corporation

Kinross Gold Corporation is listed on both the NYSE and the TSX (Kinross Gold Corporation, 2015). Kinross's Chirano mine lies along the eastern boundary of the Sefwi volcanic belt. The Chirano Shear is located at the contact zone between the Tarkwaian rocks and the Birimian metavolcanics (Griffis, *et al.*, 2002). Gold mineralization is associated with quartz veins accompanied by pyrite and hosted mainly in granitoids. The primary mineralization have been found to be non-refractory although the fine grained gold is closely associated with pyrite. In 2016, production was only from one open pit supplementing production from two underground operations (Kinross Gold Corporation, 2016). Approximately 65% of gold production is sourced from the underground operation which commenced in 2008 (Red Back Mining Incorporated, 2009). A CIL plant is used to process the ore.

1.6.7 Endeavour Mining Corporation

Endeavour Mining Corporation which is listed on the TSX owns Nzema mine (Endeavour Mining Corporation, 2011). Gold mineralisation are hosted in shear zones at the contact between the greywackes and the phyllites of the Kumasi basin as well as granite sills. The gold occurs in quartz veins in silica-sericite-carbonate altered greywackes or dark grey quartz with pyrite disseminations (Johnson, *et al.*, 2013). This deposit is mined using the conventional open pit mining methods. Gold processing is by a conventional CIL plant (Endeavour Mining Corporation, 2016).

1.6.8 Asanko Gold Incorporated

Asanko Gold Incorporated is listed on both the TSX and the NYSE. Commercial gold production at its Asanko Gold mine started on 1st April, 2016 (Asanko Gold Incorporated, 2016). The mine is located on a complex north-easterly trending shear system at the centre of the Kumasi Basin known as the Asankragwa Gold Belt. Gold mineralisation are hosted in both Birimian metasediments and the granitoids (DRA Projects (Pty), 2014). The mine is an open pit operation with a processing plant that uses conventional CIL technology.

1.7 Chapter summary and outline of report

The mining sector is a major contributor to tax revenues and foreign exchange earnings in Ghana. Gold alone accounts for about 95% of all revenues generated from the export of metals. The decline in gold prices exposed the high unit cost associated with mining gold in Ghana. AngloGold Ashanti shut down its Obuasi mine in 2016 and laid off 4 312 employees. The Ghana Chamber of Mines complained about the high cost of mining in Ghana singling out high electricity cost as a major cost driver. The question that needed to be answered was "Is Ghana's gold industry cost competitive?"

The aim of this research was to establish the cost competitiveness of Ghana's gold mining sector. This research was limited to large-scale mines due to the easy availability of verifiable data. This study focussed on the period between 2007 and 2016 which captured the rapid rise of gold price to an average of US$1 669 in 2012 and its subsequent decline. On average within the period under review, about 70% of gold from Ghana was from large-scale producers. Mining companies with operating gold mines in Ghana included AngloGold Ashanti, Newmont, Golden Star, Gold Fields, Kinross, Perseus, Endeavour and Asanko Gold.

The research report is structured into five chapters. Chapter 1 is summarised in the paragraph above.

Chapter 2 provides a literature review on costs in the mining industry with emphasis on gold mining. Classification and segmentation of costs as well as the factors influencing unit costs are discussed. Further explanation is given on the influence of grade, recovery rate, labour and production output on unit costs. Industry cost curves are also discussed in this chapter together with the evolution of unit costs reporting. This chapter is concluded with discussions on the uses of industry cost curves.

Chapter 3 describes the research methodology. The chapter also explains how data was extracted from annual reports and used to construct industry cost curves. The process of using industry cost curves for cost analyses is also explained in this chapter. Finally, the procedure for performing a regression analysis to ascertain the relationship between costs and other production variables is discussed.

Chapter 4 presents the industry cost curves constructed from a collation of unit cash costs and production output of gold mines and companies that operated in Ghana from 2007 to 2016. Factors accounting for the movements of mines and companies on the industry cost curves are given for each year throughout the period under review. The outcome of the regression analysis conducted on the relationship between unit cash costs and production factors such as recovery rate, production output and head grade are also presented. Explanations are given for the variation in correlation between costs and the previously mentioned production factors. Finally, the cost competitiveness of the gold mining industry in Ghana is established.

Chapter 5 provides conclusions that were drown out of this research study. Recommendations are also given in this chapter to mitigate negative outcomes.

2 LITERATURE REVIEW

2.1 Chapter overview

This chapter reviews literature on costs in the mining industry with emphasis on the gold mining sector. Classification and segmentation of costs are discussed in addition to the factors influencing unit costs. The influence of grade, recovery rate, labour and output on unit costs is explained. Industry cost curves are also discussed together with together with the evolution of unit costs reporting. This chapter is concluded with discussions on the uses of industry cost curves and a chapter summary.

2.2 Cost classification

A company must first of all create value for its shareholders before it can contribute positively to the economic growth of a country. However, since mining companies produce fungible products and operate in a competitive market, they cannot dictate the selling price of their products. The implications are that a mining company has more influence on its costs than the price it receives, hence its ability to manage cost would increase its competitive advantage and ultimately its value (Tholana, 2012). In the mining industry, costs are differentiated into capital costs and operating costs. Capital costs are incurred to acquire physical assets or upgrade current assets which may ultimately grow the business (Energist, 2019). On the contrary, operating costs refer to recurring expenditure on items whose value are used up within the same financial year and are needed to operate a mine. Operating costs in mining may be classified into different categories. These are fixed, variable or semi-variable as shown in Figure 2.1.

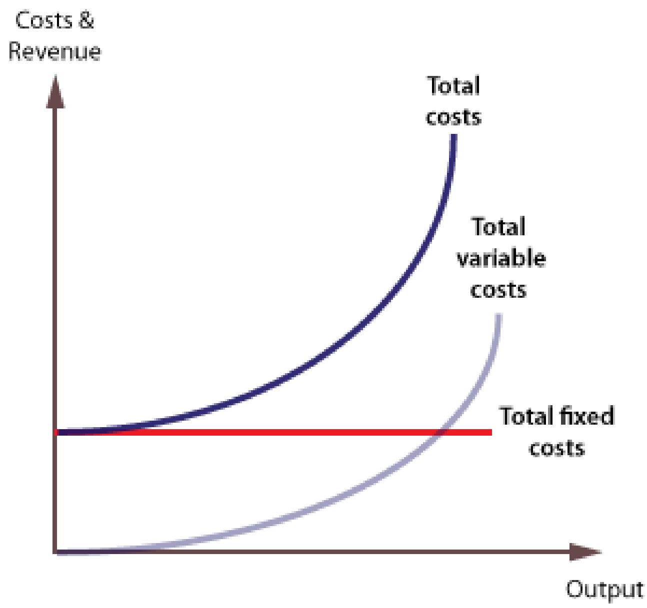

Figure 2.1: Cost-volume relationship

(Source: Economics Online, 2019)

Fixed costs as the name implies do not change with production output within a reasonable range of output. Interest expense, depreciation, ventilation, permit fees are examples. Classifying labour costs into fixed or variable cost has often been problematic. Labour cost may be considered as fixed cost in the short run but variable in the long run in countries with strong labour unions. However, in countries where due to lack of employment opportunities, government has a huge responsibility to provide jobs; labour cost is considered a fixed cost both in the short and long run (Torries, 1988).

Variable costs vary directly with production output. These costs are assumed to have a linear relationship with production output and employee numbers although practically, they are not. Examples include materials and consumables like fuel and electrical power. Semi-variable costs vary with production output but not directly. This may include maintenance costs. When total costs are divided over the amount of tonnes milled or ounces produced, they is referred as unit costs.

2.3 Factors affecting unit costs

Several factors, each having its own amenability to control, interact unpredictably to affect unit costs and hence profitability of gold mines. These factors can be classified broadly into Mineral Resource quality, socio-political factors, input costs and macroeconomics (Fellows, 2011). The cost of inputs into the mining process such as labour costs have influence on unit costs but are far more controllable than power and fuel. Cutting labour costs has historically been the easiest and readily used cost reduction strategy implemented in the mining industry. Although labour costs have increased in the gold mining industry, labour productivity has reduced. Average annual labour productivity in Australia, United States of America and Canada has grown at -4.02%, 0.6% and -2.21% respectively from the year 2000 to 2007 (Ernst & Young, 2013).

2.3.1 Cut-off grade

A critical factor in the management of every mine is cut-off grade strategy (COGS) because it guides the rate of production, mining and processing methods and ultimately the life of mine (Fellows, 2011). COGS, however, must be influenced by the quality of the Mineral Resource. The profitability, volume of output and the life span of the mine depends on the cut-off grade selected (Fellows, 2011). Managers of mines usually respond to changing metal prices by varying the cut-off grades. When prices rise, mine life is extended by reducing cut-off grade but this could also reduce gold output. Conversely, mining high grade Mineral Reserves may be done in an attempt to cut unit costs. In addition to cut-off grades, mill head grades also affects unit costs.

2.3.2 Mill head grade

Mill head grade affects the output of processing plants and ultimately the unit costs of producing gold. For gold mines on a global scale, on average, a 10% fall in head grade results in about $50/oz. rise in unit costs and vice versa (Fellows, 2011). The highest profit margins and conversely the lowest unit costs are achieved when processing plants operate at full capacity. Processing higher grades leads to lower unit costs for the individual mine because comparatively less amount of electricity, reagents and other consumables are required to produce an ounce of gold compared to lower grade ores.

Conversely, across a portfolio of mines, gold mining operations extracting low grade deposits are not necessarily high unit cost producers and vice versa (Ulrich & Trench, 2016). This phenomenon is evident in Australian gold mines where a study of fifty-three operating gold mines in Australia and three from New Zealand have revealed that the type of mineralisation rather than grade has more influence on unit cost (Kanakis, 2014). The study found out that mines that extract disseminated vein style deposits have lower costs per ounce than those extracting vein/reef type deposits. The amenability of disseminated mineralisation to bulk mining hence benefiting from economies of scale as compared to the application of selective mining to vein or reef type deposit was given as explanation for their low unit costs (Kanakis, 2014). Ore mineralogy or metallurgical characteristics therefore has a greater influence on unit costs than ore grade (Solomon, 2012).

2.3.3 Metallurgical characteristics of ore

Gold ore can be categorised into two based on their metallurgical characteristics namely; refractory and non-refractory (Goodbody, 2012). The metallurgical characteristics of the ore affects the recovery rate which in turn affects unit costs. This is because the metallurgical processing method selected is dictated by the metallurgical characteristics of the ore and the aim is to attain the highest possible gold recovery rate. Recovery rate has enormous influence on unit costs and also the positioning of the mine on the cost curve. A 10% decrease in recovery rate on a global scale for gold mines may lead to about $55/oz. increase in unit costs (Fellows, 2011). When recovery rate is low, the implication is that the mineral processing method is inefficient.

Refractory gold ore, due to their low response to the standard metallurgical recovery process, require physical or chemical pre-treatment to increase its degree of recovery (Aylmore & Jaffer, 2012). This is because the gold particles are encapsulated in cyanide-leach resistant pyrite and arsenopyrite making it difficult to liberate (Goodbody, 2012). Additional energy and consumables are required for the pre-processing of the refractory gold ores to make them responsive to cyanide leaching. This therefore increases the processing costs of these ores. The economics of pre-treatment methods are shown in Table 2.1.

Table 2.1: Economic consideration of pre-treatment methods

(Source: Mineral Engineering Technical Services, 2009)

Aspect	Roasting	Bacterial leaching	Pressure oxidation	Ultra- fine grinding
Capital cost	prohibitive	high	high	low
Operating cost	low	high	high	low
Cyanide use	medium	high	high	modest
Power consumption	low	very high	high	medium
Recovery	very good	subject to health of bacteria	excellent	grind sensitive

Hydrometallurgical pre-treatment processes such as pressure oxidation and bacterial leaching have added additional options to ultra-fine grinding and roasting in the treatment of these ores (Goodbody, 2012). Table 2.1 shows that ultra-fine grinding, although increasingly energy intensive compared to roasting, has a lower recovery rate (Goodbody, 2012). Ultra-fine grinding, therefore leads to comparatively high unit costs. Gold recovery by roasting is comparatively higher leading to comparatively lower unit costs but higher capital costs needed to deal with negative environmental outcomes have made the process less attractive in regions with stringent environmental standards and regulations (Aylmore & Jaffer, 2012). Recovery rates from pressure oxidation are most often 10% better than that from roasting but its capital cost is higher than both roasting and bio-oxidation (BIOX) (Goodbody, 2012). High electricity and cyanide consumption makes the unit costs of operating the pressure oxidation method comparatively higher than roasting. BIOX, most often produces the best economic option for mining operations (Goodbody, 2012).

Various research and laboratory tests conducted have concluded on some bacteria and fungi that could increase recoveries for carbonaceous refractory ores. The first is a two stage bio-oxidation process using chemolithotrophic bacteria to oxidize the sulphides and Streptomyces setonii to passivate the carbonaceous materials (Amankwah, *et al*., 2005). The two steps resulted in a final gold recovery of 94.7% from double refractory ore. The other method uses a fungus, Phanerochaete chrysosporium, which decrease preg-robbing by about 90% and overall leaching rate from cyanidation improved by about 10% (Ofori-Sarpong, *et al*., 2010). Unfortunately, none of these research outcomes have been commercialized.

Outotec's proprietary High Temperature Caustic Conditioning (HiTeCC) technique offers a way out to recover gold in gold loaded CIL tailings as a result of preg-robbing. This technique desorbs gold from activated carbon loaded with gold using caustic soda at high temperatures. Kirkland Lake Gold's Fosterville gold mine in Victoria has used this circuit as a treatment route for their BIOX process since 2010 resulting in an improved overall recovery rate of 90% in 2015 from an average of 85% in 2011 (Mining Data Solutions, 2018). Suzdal mine in Kazakhstan with overall recoveries of 65%, the second to install this circuit in addition to their BIOX plant in 2016 expects 40-70% additional recoveries from tailings (Outotec Pty., 2016).

On the other hand, non-refractory gold ore are amenable to recovery by direct cyanidation and carbon adsorption. This makes the recovery process for non-refractory gold ores relatively easier and less costly. The recovery process includes crushing, grinding, gravity concentration and cyanidation (Afidenyo, *et al*., 2010). The cyanidation process could either be a CIL or CIP process. Carbon is added directly to the leach circuit in the CIL process hence leaching and adsorption occur concurrently (Stange, 1999). Conversely, in the CIP process, carbon is added in separate tanks subsequent to leaching. Although the CIL process is arguably more efficient than the CIP, the CIL process has an advantage of producing higher recoveries for reclaimed low grade dump materials and pre-treated refractory ores containing carbonaceous materials (Stange, 1999). Higher recoveries from the CIL process can therefore offset part of the unit costs associated with processing refractory ores.

Geometallurgy should be used to predict plant performance throughout the life of mine. This should help reduce risk and better assess the profitability of mining projects. Geometallurgy combines two disciplines in the mining industry namely geology and mineral processing. Geological and metallurgical information are used to create a spatially-based predictive model through the measurement and understanding of ore properties to optimise mineral processing (Lund & Lamberg, 2014). The traditional procedure in the minerals sector is for geologist to create 3D models of ore bodies based on ore grades and lithology. They also provide daily forecasts on grades, tonnage and ore types for the process plant. Geometallurgy, however provides measured parameters needed to manage and optimise mineral processing and also forecast metallurgical performance of plant feed.

According to Lund & Lamberg (2014), geometallurgy is implemented through:

- Collection of drill core logs, rock mechanical and chemical analysis, and petrophysical parameters analysis;
- Ore sampling programme for metallurgical testing using geological data for sample point selection;
- Ore variability laboratory testing of samples to be used to construct processing model;
- Metallurgical validation of geological ore-type definitions and incorporation of geometallurgical domains into it;
- Development of mathematical relationships for estimating metallurgical parameters throughout the geological database;
- Development of a metallurgical model based on the previously set metallurgical parameters;
- Plant simulations using the metallurgical process model; and
- Standardisation of model for the operation.

It is very important as with every sampling programme that enough representative samples are collected from the ore body and carefully prepared and laboratory tested to avoid sampling errors. A geometallurgical model therefore combines geological and mineral processing information to create a spatial model that is incorporated in production planning and economic valuations (Lund & Lamberg, 2014)

The benefits of a geometallurgical modelling is best utilised when it is available at the feasibility study stage. This is because the mine plan for producing mines are difficult if not impossible to change particularly for underground mines.

2.3.4 Production scale

Unit costs are influenced by the scale of production (Costa Lima & Suslick, 2006). The relationship between unit cost and volume of production is such that the greater the production output, the lower the unit costs (Garson, 1984). This phenomenon is referred to as economies of scale (Crowson, 2003). Economies of scale occur in mining operations because the contribution of fixed costs to total production costs is more substantial than that from variable costs (Tholana, 2012). An increase in production output, therefore, does not lead to a directly proportional increase in total production costs. Unit costs, which is total production costs divided by total production output, therefore reduces as production output increases. An example is when a larger truck is used to transport ore. It would result in the use of fewer drivers and also fewer trips for the same quantity of ore thereby lowering unit production costs. Most operations however find it difficult to attain effective maximum production mostly due to periodic unavailability of the required grade of ore (Torries, 1988). According to Savant (2012), apart from lower grades, production output could also be hampered by:

- Stoppages in order not to compromise safety; and
- Technical hitches.

2.3.5 Mining methods

Mineral production from underground mines are more likely to be more costly than from surface operations (Garson, 1984). Underground operations tend to be high unit cost operations because highly sophisticated infrastructure and technologies are required to sustainably and safely extract the orebody (Tholana, 2012). Furthermore, a far more highly skilled labour is required to deal with the increased complexities associated with underground mining (Savant, 2012). Additionally, unit costs of production escalates because ventilation and cooling requirements must be met by refrigeration as mines get deeper.

Man and materials transportation and hoisting costs also increase as an operation gets deeper (Tholana, 2012). These processes are electrical energy intensive. Underground mines are also prone to rock bursts hence sophisticated and expensive rock support techniques are therefore required. These are additional costs to underground mines.

The choice of an underground mining method depends on the depth, size and inclination of the orebody. The geotechnical characteristics of the host rock is also an important factor. Relatively, block caving underground mining method has the lowest unit costs because of the little drilling, blasting and rock support needed. It is also amenable to large production output (911 Metallurgist Corporation, 2018). Sublevel caving, which has a relatively higher unit costs than block caving, has all the advantages of block caving. It is expensive because ventilating in this kind of mine is difficult to set up and development costs are high (911 Metallurgist Corporation, 2018).

Generally as mines mature, haulage distance from the mine face becomes longer and most often grades fall leading to the extraction of lower grades (Savant, 2012). Additional energy and input costs therefore make matured mines more expensive to operate than less matured ones.

The level of mechanisation and automation also influences unit costs (Tholana, 2012). Mechanisation has been used in mining typically to improve safety, working condition and productivity (Vogt & Hattingh, 2016). It is an important strategy for modern mine development and ultimately should reduce direct mining costs. Safety performance is improved when less people are exposed to potentially dangerous mining faces especially in underground mines. The deployment of machines to do physically demanding work helps improve labour productivity (Singh, 2017).

Mechanised mines are lower cost producers as compared to labour intensive mines. This is because mechanisation improves productivity and production output leading to economies of scales. Automation eliminates humans from controlling these mechanised equipment. The level of automation vary from remote tele- operation with driver assistance to driverless full automation (Vogt & Hattingh, 2016). Automation, therefore further improves the benefits of mechanisation with regard to productivity and production costs. If the mines are located in remote areas in countries with high wage, then accruals from automation in terms of cost savings are considerable.

2.3.6 Labour productivity

High labour productivity would lead to high production output. High production output would consequently lead to low unit costs. Different kinds of skill set and knowledge are required in mining operation. However, the degree of mechanisation will determine number of employees required. Many countries have seen labour costs rise above the rates of inflation. Labour costs in South Africa range from 20% to 25% of total production costs for mechanized open pit operations but 50% to 60% for mature deep level conventional underground mines (Ernst & Young, 2017). On the other hand, labour productivity in South African gold mines measured in kilogrammes of gold produced by each employees, has declines by 35% from 2007 and 2012 (Ernst & Young, 2013). Although labour productivity has maintained a continuous decline since 2007, real labour costs per kilogramme of gold produced have escalated by 150% from 2002 to 2012. Statistics from Australia also shows that labour productivity in gold mines has reduced by 50% from 2001 to 2012 (Ernst & Young, 2017).

2.4 Cost segmentation

Typically, unit costs in most mining companies are distributed across three broad functional departments specifically mining, milling (or processing), and general and administration (G & A) as shown in Table 2.2.

Table 2.2: Cost breakdown

(Source: Curry, *et al*., 2014)

Department	Costs
Mining	Drilling, blasting, loading, hauling, equipment maintenance and repair, mine overheads, mine specific labour requirements
Milling	Power, grinding media and mill linings, consumables, reagents, equipment maintenance and repair, maintenance materials, milling specific labour, milling overheads
General and Administration (G & A)	Management costs, staffing for human resources, environment, health and safety, training, communications, community relations, camp and catering, mobile equipment, insurance

Table 2.2 shows that mining costs typically include costs of drilling, blasting, loading, haulage, labour among others. Milling costs include grinding, electricity and fuel usage, reagents and consumables. General and Administration costs are associated with the management of personnel, legal and accounting costs and logistics besides other assorted non-technical expenses. The contribution to costs from the three departments to unit costs in Australian gold mines is shown in Table 2.3.

Table 2.3: Cost analysis of Australian gold mines

(Source: Curry *et al*., 2014)

	Number	Mean (%)	Median (%)	95% confidence interval
Mining costs				
Both	11	47.9	47.7	±5.9
Open pit	41	40.3	42.3	±4.6
Underground	9	51.5	55.6	±11.4
Milling costs				
Both	11	39.3	39.0	±6.6
Open pit	41	48.9	49.5	±4.6
Underground	9	34.1	35.1	±8.3
General & Administration costs				
Both	11	12.8	11.7	±4.9
Open pit	41	10.8	9.5	±1.9
Underground	9	14.4	14.6	±5.5

Table 2.3 shows that mining departments of underground mines averagely accounted for about 51.5% of unit costs of underground mines. Mining departments' contribution to unit costs were however lower for open pit mines where it accounts for 40.3%. This can be explained by the fact that energy requirements for ventilation, refrigeration, men and material hoisting and haulage in underground mining are additional costs that are not incurred in open pit mines. Milling costs contribution to unit costs were higher for surface mines at 48.9% than for underground mines which was 34%. This was explained by the fact that the lower grades exploited by open pit operations generate substantial amount of waste although significant amounts of electricity and reagents are consumed (Curry*, et al.*, 2014). While departmental costs analysis focused on costs within a typical gold mine, industry cost curves are used to perform cost analysis across a group of mines.

2.5 Industry cost curves

Industry cost curves are produced from the summation of cost curves of individual firms which are neither connected nor affected by each other's costs or decisions (Torries, 1988). Graphically, the horizontal bar that represents unit costs is flat for the entire width which represents total production output of a particular mine. The horizontal bar may shift vertically upwards for the next mine. An industry stepwise cost curve or supply curve can then be constructed by summing up the cost curves for all individual mines in the industry for a particular period across their production volume. Therefore, industry cost curves are graphical representations showing unit cash costs of individual mines plotted against cumulative production in a ranking order as shown in Figure 2.2.

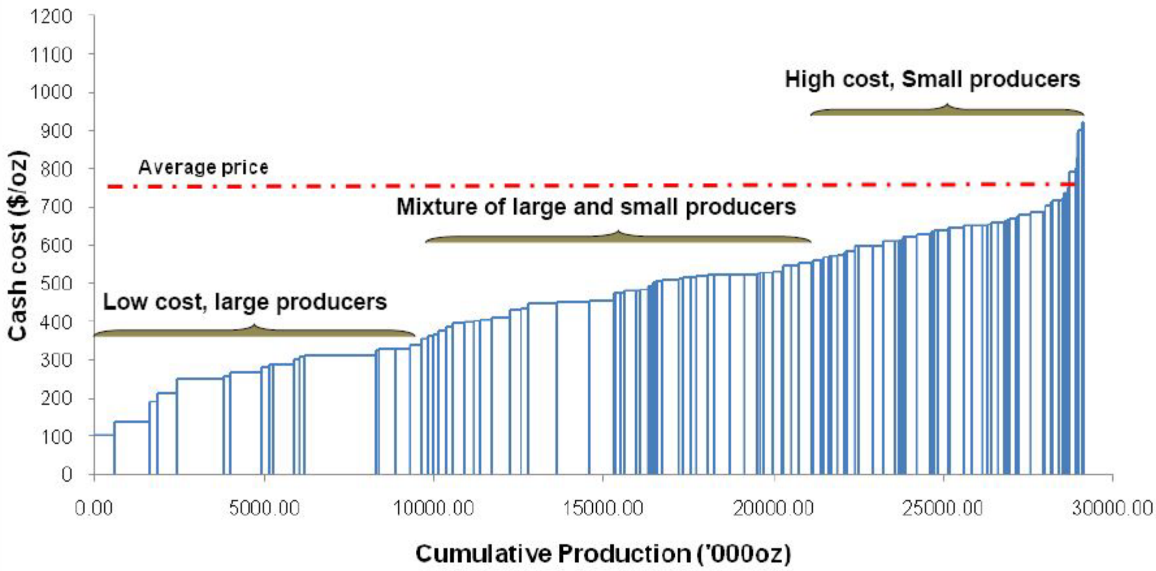

Figure 2.2: A typical cost curve

(Tholana, 2012)

The mines are ranked, from the lowest at the extreme left of the horizontal axis and the highest to the extreme right, according to their unit costs. The width of each bar, corresponds to production output of an individual mine. The height of the bar also reflects the unit cash cost of that same mine.

2.6 Uses of industry cost curves.

Industry cost curves have considerable uses in the mining industry especially because the producers attract almost the same price for their end products. The industry cost curve therefore helps investors, managers, industry analysts and other stakeholders to ascertain and evaluate the cost structure within the industry. During feasibility studies, industry cost curves helps to benchmark operating costs of a new operation with comparable existing ones (Tholana, 2012). A lower quartile positioning is an indicator of the ability of the new project to withstand price volatility before it reaches full operation. Industry cost curves can be used to forecast earnings hence ascertain the profitability of both new and existing projects. Financial institutions can therefore assess the credit worthiness of both existing and new projects. Additionally during mergers and acquisition, knowing the position on the cost curve of the mine to be acquired, helps to ascertain the associated risk or value involved. Using industry cost curves for competitive cost analysis provides the needed information for strategic planning. This analysis defines the position of the mine with respect to other producers within the industry regarding the availability or the lack thereof of profit margins (Solomon, 2012). The analysis shows the current situation as well as the opportunities for expansion or new projects. More importantly, it provides a prior notice on the need to reconsider uncompetitive operations.

2.7 Costs metrics used in constructing industry cost curves

Table 2.1 shows how to calculate the recently introduced cost metrics by the World Gold Council (WGC) which are all-in sustaining costs (AISC) and all-in costs (AIC). These cost metrics have come about because primarily, the Generally Accepted Accounting Principle (GAAP) standards for reporting costs which is “cost of sales” does not adequately capture the total costs incurred in producing gold (Whelan, 2013).

Table 2.4: World Gold Council cost metrics guidelines

(Source: World Gold Council, 2013)

Cost elements	**Location in a financial report**	**US $/ gold ounces sold**
On-Site Mining Costs (on a sales basis)	Income Statement	(a)
On-Site General & Administrative costs (G&A)	Income Statement	(b)
Royalties & Production Taxes	Income Statement	(c)
Realized Gains/Losses on Hedges due to operating costs	Income Statement	(d)
Community Costs related to current operations	Income Statement	(e)
Permitting Costs related to current operations	Income Statement	(f)
3rd party smelting, refining and transport costs	Income Statement	(g)
Non-Cash Remuneration (Site-Based)	Income Statement	(h)
Stock-piles / product inventory write down	Income Statement	(i)
Operational Stripping Costs	Income Statement	(j)
By-Product Credits	Income Statement	(k) Note: this will be a credit
Sub-Total (Adjusted Operating Costs)		(l) = (a) + (b) + (c) + (d) + (e) + (f) + (g) + (h) + (i) + (j) + (k)
Corporate General & Administrative costs (including share-based remuneration)	Income Statement	(m)
Reclamation & remediation – accretion & amortization (operating sites)	Income Statement	(n)
Exploration and study costs (sustaining)	Income Statement	(o)
Capital exploration (sustaining)	Cash Flow	(p)
Capitalized stripping & underground mine development (sustaining)	Cash Flow	(q)
Capital expenditure (sustaining)	Cash Flow	(r)
All-in Sustaining Costs (AISC)		(s) = (l) + (m) + (n) + (o) + (p) + (q) + (r)
Community Costs not related to current operations	Income Statement	(t)
Permitting Costs not related to current operations	Income Statement	(u)
Reclamation and remediation costs not related to current operations	Income Statement	(v)
Exploration and study costs (non-sustaining)	Income Statement	(w)
Capital exploration (non-sustaining)	Cash Flow	(x)
Capitalized stripping & underground mine development (non-sustaining)	Cash Flow	(y)
Capital expenditure (non-sustaining)	Cash Flow	(z)
All-in Costs (AIC)		= (s) + (t) + (u) + (v) + (w) + (x) + (y) + (z)

The Gold mining industry, therefore adopted "cash costs per ounce" in 1996 as a standardised costs measure (World Gold Council, 2013). This non-GAAP measure was used for cost analysis at mine to mine level to test the economic viability of operating mines (KordaMentha, 2013). Non-GAAP reporting may however fail to accurately portray the operations of a mining company since it does not comply with standardized financial reporting developed by the Financial Accounting and Standards Board (FASB). Cash costs did not include non-cash costs such as depreciation and amortisation because they did not represent actual monetary outflow (Tholana, 2012). Cash costs per ounce, which is the direct costs of producing an ounce of gold, however created the impression that high margins were being realised from the gold mining industry. The income statements of mining companies, however, did not reflect these high margins. This brought to the fore the shortcoming of cash costs as a measure of gold mining costs. Cash costs per ounce did not account for the portions of costs that are needed to develop and sustain gold operation in the long run. This was because exploration, capital and reclamation expenditures are excluded from the calculation of cash costs per ounce (Whelan, 2013). Therefore, the actual margins being made in the gold mining industry were being less accurately estimated.

The introduction of AISC per ounce, an extension of the existing cash costs per ounce metrics incorporates the expenditures made to sustain production (World Gold Council, 2013). This new metric incorporates corporate overheads, reclamation and capital costs. Table 2.1 gives the guidelines for calculating the new costs metrics and the portions of the financial statements where the inputs could be found. The other metric, AIC, includes extra costs related to producing gold over the lifecycle of a mine as well as costs not related to that specific mine. From the table, it is observed that the sub-total "adjusted operating costs" represents the previously widely used cash costs per ounce. The addition of costs associated with general and administration, reclamation and remediation, stripping and development, sustaining exploration and amortisation to the adjusted operating costs yields AISC. These metrics should uncover the true cost of producing an ounce of gold. It will also dispel the perception that margins from gold mining are extremely huge (Fellows, 2011).

Some level of ambiguity still exists between costs classified as sustaining and those classified as non-sustaining. However, for a cost to be classified as sustaining, it must first and foremost be related to the existing operation (Whelan, 2013). Table 2.2 shows a comparison between cash costs per ounce, all-in sustaining costs and all-in costs.

Table 2.5 Comparison of cost metrics

(Source: Adapted from KordaMentha, 2013)

	Cash costs	**All-in-sustaining cost**	**All-in cost**
Direct mining costs	√	√	√
Operational stripping costs	√	√	√
Royalties and production taxes	√	√	√
Third party smelting, refining and transport cost	√	√	√
General and administration	On-site	On-site and corporate	On-site and corporate
Community costs	Current operations	Current operations	Current and related operations
Reclamation and remediation	×	Current operations	Current and related operations
Capital expenditure	×	Current operations	Current and related operations
Capital exploration	×	Current operations	Current and related operations
Capitalised stripping and underground mine development	×	Current operations	Current and related operations

KordaMentha (2013) defined sustaining and non-sustaining costs. Sustaining costs refers to all costs deemed necessary to maintain the current mine or asset only. Non-sustaining refers to all expenditures associated with the current or related assets necessary to increase production capacity of the mine (KordaMentha, 2013). When non-sustaining costs are added to AISC, the resultant costs is referred to as AIC.

The following expenses, according to Whelan (2013), were however not included in the calculation of the new costs metrics:

• Income tax;

• Working capital (except for adjustments to inventory on a sales basis);

• All financing charges (including capitalised interest);

• Costs related to business combinations, asset acquisitions and asset disposals;

• Items needed to normalise earnings, for example impairments on non-current assets and one-time material severance charges.

Cash costs per ounce was used in this study for the construction of industry cost curves for mining operations in Ghana from 2007 to 2014. However, from 2015 to 2016, AISC per ounce was used in the analysis.

2.8 Effect of cost on mineral rent

Operations whose unit costs are greater than the prevailing commodity price may not be recovering their capital investments and would more likely to be shut down especially if the prevailing commodity price does not increase. Such operations may be uncompetitive. If return on invested capital is assumed as being part of costs then such mines would be making less profits than anticipated. Figure 2.3 shows a cost curve indicating distributable mineral rent.

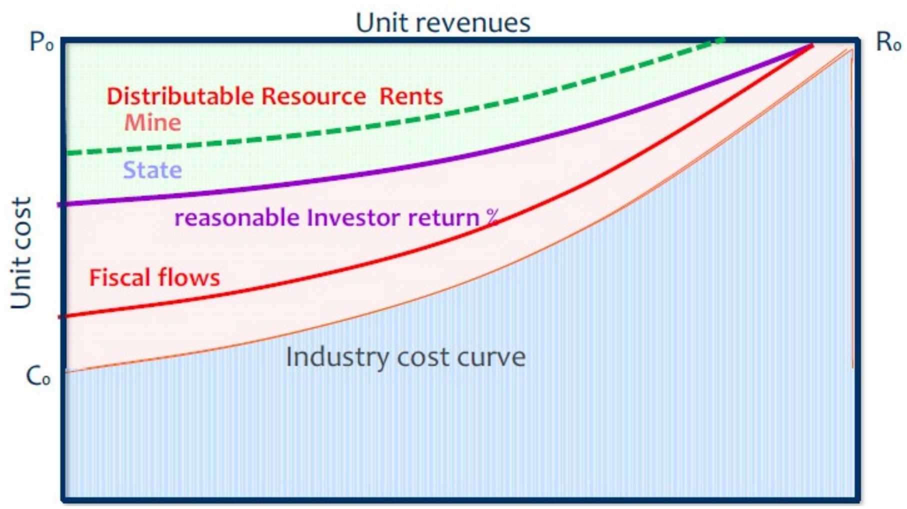

Figure 2.3: Cost curve indicating distributable mineral rent (P_0-unit profit, C_0-unit cost, R_0-unit revenue)

(Source: Solomon, 2012)

In Figure 2.3, return on capital is the cost of using owner's capital. Conversely also, those mines operating with unit costs less than the prevailing commodity price are making additional profits than anticipated and are collecting rents. This additional profit that is above the normal profit of doing business is called economic rent (Solomon, 2012).

Practically, rent calculation is problematic but it must be taxed by government as custodians of the nation's mineral resources. Such taxation should ideally not affect either the rate of extraction or the levels of investments especially if the size and nature of the mineral rent is known (Stilwell & Minnitt, 2006). At any point of a commodity price cycle, the lower cost mines at the left side of the industry cost curve are likely to have an extra profit after a reasonable return than the higher cost mines to the right. Movement of mines into the lower half is not only advantageous to the company with respect to profitability, but the market and investors react positively because it is interpreted as value creation through cost reduction.

The lowest cost mine is likely to generate sustainable economic rent in spite of the prevailing commodity price. Economic theory suggest that whenever economic rents exist in a particular industry, theoretically, new firms will enter the industry until those rents are no longer available (Torries, 1988). In a free market system, sustained periods of low commodity prices will lead to the closure of marginal mines leading to loss of supply. The closure of marginal mines have repercussions on both direct and indirect employment as well as fiscal contributions to the state. The inability to exploit these mineral assets adversely affect the economic potential of a country's mineral sector thereby diminishing its contribution to economic growth (Solomon, 2012).

2.9 Chapter summary

Gold mining companies have more influence on costs than on price because their product is fungible. Costs in mining are either fixed, variable or semi-variable. Summation of cash costs from the mining, processing and general and administration departments of a typical mine make up total cash costs. When total cash costs is divided by total output sold, the outcome is unit cash costs. Unit costs are influenced by production output, recovery rate and ore quality, among other determinants. The greater the production output, the lower the unit cost of production, a phenomenon known as economies of scale. A lower recovery rate also leads to an increase in unit costs and vice versa. Ore mineralogy determines the metallurgical processing method that will be appropriate for the highest possible gold recoveries. A change in mill head grade influences unit costs but grade has little influence on whether a mine is a low cost or high cost producer particularly for surface mines.

Industry cost curves are graphical representations showing unit costs of individual mines plotted against cumulative production in a ranking order. The unit costs metrics “cash costs per ounce” has been used until the introduction of AISC and AIC by the WGC. These new non-GAAP cost metrics are aimed at establishing the true costs of mining gold. Using industry cost curves for competitive analysis provides the needed information for strategic planning. This analysis defines the position of a mine with respect to other producers within the industry regarding the availability or lack thereof of profit margins. Basically a low cost mine is likely to generate sustainable economic rent no matter the prevailing commodity price.

3 RESEARCH METHODOLOGY

3.1 Chapter overview

This chapter mentions the data that was collected from annual reports to construct industry cost curves. The process of using industry cost curves for cost analyses is also described. Finally, the procedures for performing a regression analysis to ascertain the relationship between costs and other production variables are discussed. A chapter summary concludes this chapter.

3.2 Input data collected and sources

The selected companies for analysis in this report are large-scale mining companies listed on various stock exchanges around the world as listed and explained in Chapter 1.

In adherence to rules and regulations governing listing, the respective companies publish annual reports and quarterly financial statements. Annual reports are documents available on the public domain hence no copyright laws were infringed. Cash costs per ounce and all-in-sustaining costs per ounce of gold sold were extracted from the annual reports from 2007 to 2014 and 2015 to 2016, respectively for each mine. This is in accordance with the WGC directive regarding the reporting of costs which took effect from 2014 although full compliance really started in 2015. Total ounces of gold sold annually were also extracted from the annual reports. The period 2007 to 2016, as already explained in Chapter 1, gives a perfect time frame to effectively track and capture the rapid and continuous rise in gold prices as well as the sudden decline that happened afterwards.

All the gold companies except Perseus Mining Limited had their financial year ending in December. The quarterly financial statement for March, June, September and December were used to compile the ounces sold and the cash costs per ounce for Perseus Mining Limited. All averages used in this report are weighted averages. Weighted average allows the final average to reflect the differences in output of each mine making it more accurate than a simple average.

3.3 Cost curve construction and analysis

This industry cost curves were constructed using a Microsoft Excel®-based algorithm demonstrated by (Tholana, 2012). Ten tables were produced and populated with annual gold ounces sold and the associated unit cash costs for each mine for every particular year from 2007 to 2016. The data were then sorted in ascending order of unit cost. The tables were used to produce cost curves for each year. The cost curves for the mining companies were produced by the same technique. Total production output for companies were determined by totalling output in gold ounces sold from all the mining operations owned by the companies for that particular year. Unit cash costs for companies used in the construction of the company cost curves were the weighted average unit cash costs for all the individual mines owned by the companies. Equation 3.1 shows the formula that was used to calculate the companies' unit costs.

$$\textbf{Unit cash costs} = \frac{\Sigma\ (\text{[mine 1's production x mine1's unit cost]+[mine 2's production x mine 2's unit cost]..})}{\Sigma\ (\text{mine 1's production + mine 2's production....})}$$

……equation 3.1

A red dotted horizontal line was drawn across each industry cost curve showing the average gold price for that particular year. Mines and companies that fall below the dotted line were considered profitable while those below the dotted line were considered unprofitable for the period under analysis. The mine or company positioned at the extreme left side of the industry cost curve was the lowest cost producer while the mine or company at the extreme right side was the highest cost producer. These mines were further investigated to ascertain the reason behind their ranking. Significant movements along the cost curve over the period under review were noted and investigated.

Weighted average unit cash costs were computed for Ghana gold industry and compared with the gold sectors of South Africa, Australia and the world's average using a time series graph. South Africa was chosen because although it was ranked as the eighth gold producer in the world, it was ranked first in Africa in 2016 (O'Connell, *et al*., 2017). China was ranked first in gold production in the world but the unavailability of easily verifiable data did not allow China's gold sector to be used for analysis. Australia was then chosen because verifiable data were easily available although it was ranked the second largest gold producer in the world in 2016 (O'Connell, *et al*., 2017).

The worlds' average unit cash cost was used as the defining standard to determine the cost competitiveness of the gold sectors of the selected countries. At the international level, countries with average unit cash costs below the worlds' average unit cash costs were considered as having a cost competitive advantage while countries above the world's average were considered as not being cost competitive.

Industry cost curves were also constructed for gold mines in Ghana using the amount of tonnes milled and the unit cost per tonne from 2014 to 2016. This was done to ascertain the influence of mill head grades on unit cost.

3.4 Regression analysis

A regression analyses was conducted and correlation coefficients were calculated for the variables listed below against unit cash costs. The variables are:

- Production output;
- Mill head grade;
- Recovery rate;
- Electricity prices; and
- Diesel prices.

These analyses were done to ascertain the influence of these parameters on unit cash costs at mine to mine level in Ghana' gold sector. A regression analysis between unit cash costs and production output was performed to give indications as to whether economies of scale exists in the gold mining sector in Ghana. A regression analysis between unit cash costs and mill head grade was also performed to determine whether the "grade is king" mantra is applicable to Ghana's gold mining sector. The need to determine the influence of ore mineralogy on the profitability of mining operations informed the decision to conduct a regression analysis between unit cash costs and recovery rate. The regression analyses between the three parameters and unit cash costs were done on a year by year basis. The regression analyses between unit cash costs and both electricity tariffs and diesel prices were performed to determine which of the two parameters drove escalations in unit cash costs in mining operations in Ghana. These analysis were done on a mine by mine basis.

The correlation coefficient '*r'* measures the strength and direction of a linear relationship between two variables on a scatterplot (Mukaka, 2012). According to Mukaka (2012), correlation coefficient should be interpreted as follows:

- **r** = **-1.** A perfect negative linear relationship
- **-0.70 ≥ r < -1.** A strong negative linear relationship
- **-0.30 > r < -0.70.** A moderate negative relationship
- **0 > r ≤ -0.30.** A weak negative linear relationship
- **0.** No linear relationship
- **0 > r ≤** +**0.30.** A weak positive linear relationship
- +**0.30 > r ≤** +**0.70.** A moderate positive relationship
- +**0.70 > r ≤** +**1.** A strong positive linear relationship
- **Exactly +1.** A perfect positive linear relationship

3.4.1 Hypothesis testing

A hypothesis test was conducted to confirm results from the regression analysis. The P-value of the correlation coefficient determines whether a relationship exists between any pair of parameters at a proposed significance level which is usually 0.05 or 5% (Nangolo, 2011). However, although the number of samples used in this study represents the total number of large-scale gold mines in Ghana, the number of sample is quite small. To prevent type Π error where the null hypothesis is accepted when it is indeed false, a significance level of 0.2 or 20% was used which is still very conservative and equivalent to an 80% confidence level (Kim, 2015). The *P*-value is determined by referring to a *t*-distribution with *n*-2 degrees of freedom. T-distribution is used when the sample size of the population is small or less than 30. The hypothesis were set as follows:

- Null Hypothesis H_0: $\rho = 0$

This implied that there is no correlation between unit costs and the five parameters: grade; production output; recovery rate; electricity; and diesel cost.

- Alternative Hypothesis H_A: $\rho \neq 0$

This was interpreted as there is a linear relationship between unit costs and the five parameter: grade; production output; recovery rate; electricity; and diesel cost. The decision was taken as follows

- If the calculated *P*-value was smaller than the theoretical statistic at the suggested significance level of 20%, the null hypothesis was rejected and the alternative upheld. This implied that a linear relationship existed between unit costs and the previously mentioned parameters at the significance level.
- If the calculated *P*-value was larger than the theoretical statistic at the suggested significance level of 20%, the null hypothesis was accepted. This implied that at that significant level, there was insufficient evidence to suggest the existence of a linear relationship between unit costs and the previously mentioned parameters.

3.5 Chapter summary

This research used a Microsoft Excel®-based algorithm from Tholana (2012) for constructing industry cost curves. Data consisting of gold ounces sold and cash costs per ounce were extracted from the annual reports of the gold mining companies selected for this study. Cost curves were developed from the compiled data for all the selected mines and companies from 2007 to 2016. Weighted average annual cash costs were computed for the gold sector in Ghana and compared with that of South Africa and the world's average unit cash costs using a time series graph. A regression analysis was conducted on five selected parameters to determine their relationship with unit cost.

4 RESULTS AND DISCUSSIONS

4.1 Chapter overview

This chapter presents the industry cost curves that were constructed for the selected gold mines and companies in Ghana from 2007 to 2016. The relative positions and movements of mines and companies on the industry cost curves are explained for each year for the period of analysis. Results from the regression analysis conducted on the relationship between unit cash costs and recovery rate, production output, head grade, electric and diesel costs are also presented. Explanation are given for the variation in correlation between unit costs and the five variables. Finally, a determination on the cost competitiveness of Ghana' gold mining industry is made. A chapter summary concludes this chapter.

4.2 Mine cost curves

Figure 4.1 shows the industry cost curve for gold mines operating in Ghana in 2007. Data used to construct the industry cost curve are shown in Appendices 7.1.

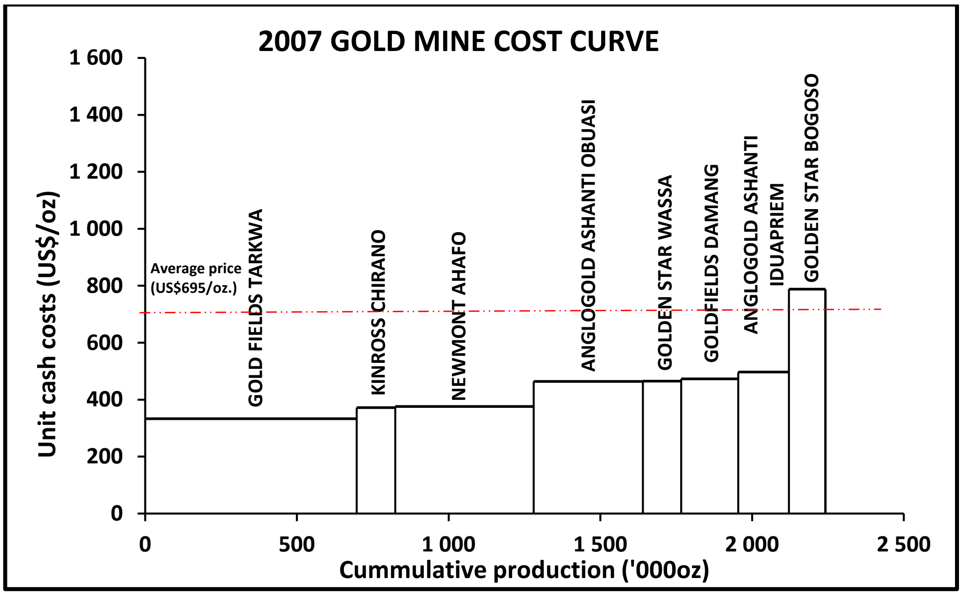

Figure 4.1: Cost curve of gold mines in Ghana for 2007

(Source: AngloGold Ashanti Limited, 2008; Gold Fields Limited, 2008; Golden Star Resources, 2008; Kitco, 2018; Newmont Mining Corporation, 2007; Red Back Mining Incorporated, 2007)

In 2007, Gold Fields Tarkwa mine was positioned in the lower quartile as the lowest cost mine in Ghana. Tarkwa mine by virtue of its volume of production benefited from economies of scale with a total output of 697 000 ounces of gold. Bogoso-Prestea mine, which was the highest cost mine in 2007, made a negative profit margin as its unit cash cost of US$788/oz. was far higher than the average gold price of US$695/oz. Bogoso-Prestea mine is a high cost mine because of a low overall recovery rate of 52.1% in 2007 (Golden Star Resources, 2008). The industry cost curve for 2008 is shown in Figure 4.2. Data used to construct the industry cost curve are shown in appendix 7.2

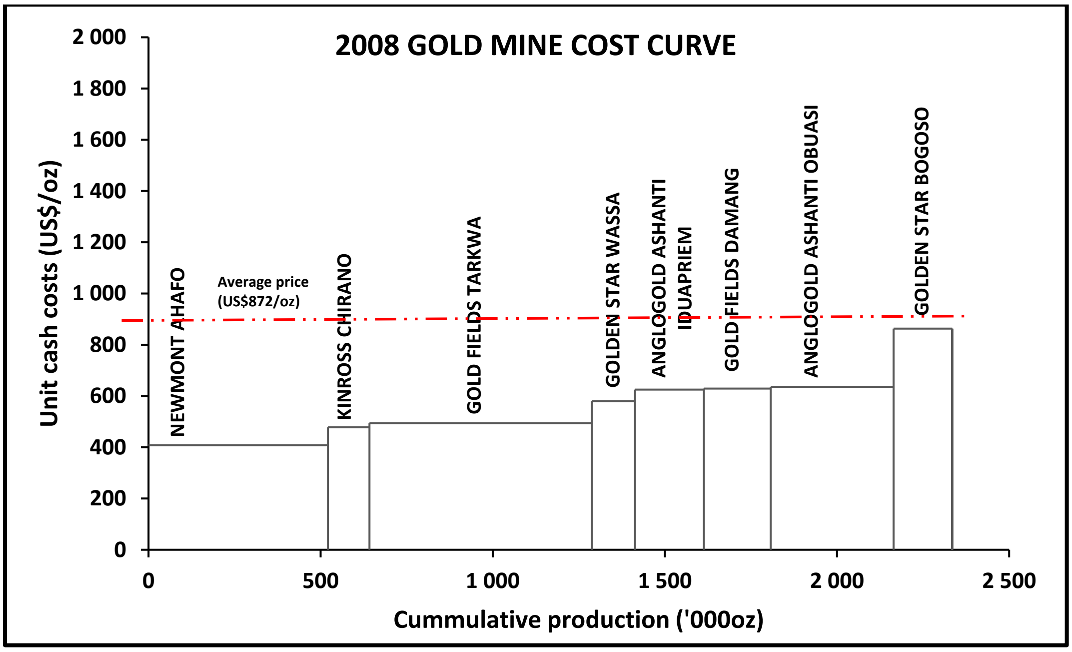

Figure 4.2: Cost curve of gold mines in Ghana for 2008

(Source: AngloGold Ashanti Limited, 2008; Gold Fields Limited, 2008; Golden Star Resources, 2008; Kitco 2018; Newmont Mining Corporation, 2009; Red Back Mining Incorporated, 2009)

Newmont's Ahafo mine, after ramping up production from 456 000 ounces in 2007 to 521 000 ounces in 2008, became the lowest cost mine in Ghana. Ahafo mine benefitted from economies of scale as well as the efficiencies of newly installed equipment. Ahafo mine achieved nominal throughput capacity one month after the commissioning of its processing plant (Mitchel & Jorgenson, 2007). Additionally, the installation of a counter-current decantation tails wash system which reduced tailings spigot discharge to 50ppm WAD (Weak Acid Dissociable) cyanide helped to reduce operating costs (Mitchel & Jorgenson, 2007). Processing costs were also relatively low and recoveries are high from processing predominantly oxide ores. The highest cost mine, Bogoso-Prestea mine, made only a tiny profit margin of US$9/oz. because the average gold price had risen to US$872/oz. from US$695/oz., in 2007 while its cash costs escalated from US$788/oz. in 2007 to US$863/oz. in 2008. Low recoveries was still the bane of Bogoso-Prestea mine. Figure 4.3 shows the industry cost curve at mine level for 2009. Data used to construct the industry cost curve are shown in appendix 7.3.

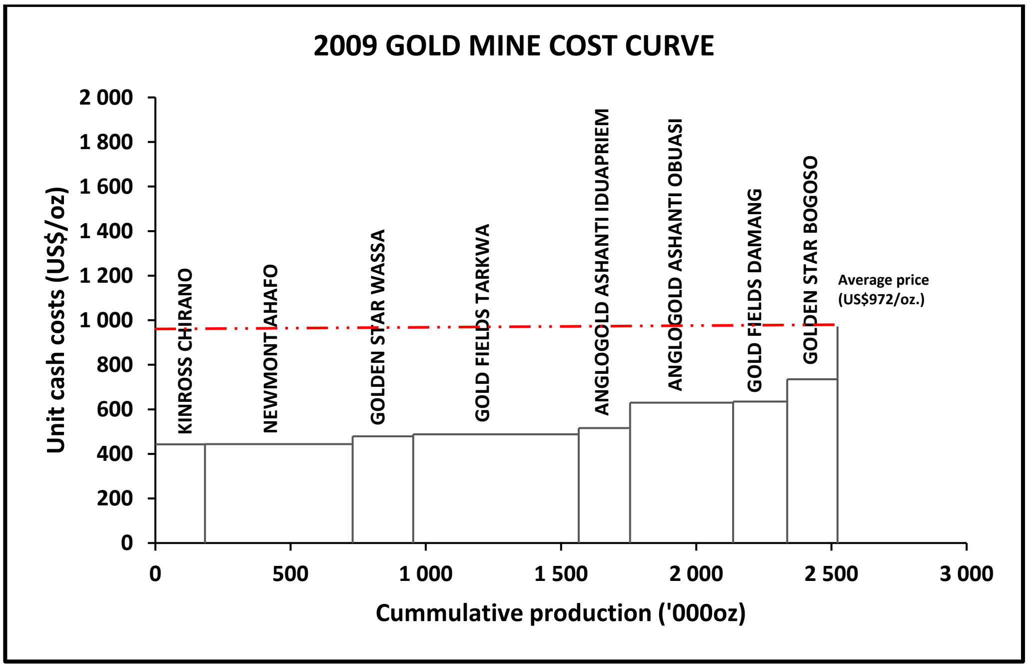

Figure 4.3: Cost curve of gold mines in Ghana for 2009

(Source: AngloGold Ashanti Limited, 2009; Gold Fields Limited, 2009; Golden Star Resources, 2009; Kitco 2018;Newmont Mining Corporation, 2009; Red Back Mining Incorporated, 2009)

Figure 4.3 shows a general improvement in profit margins for all the mines as average gold price rose from US$872/oz. in 2008 to US$972/oz. in 2009. The highest cost producer, Bogoso-Prestea mine made a profit margin of US$237/oz. with a unit cash cost of US$735/oz. primarily due to the increase in gold price. The mine benefited from an increase in production output from 170 000 ounces to 186 000 ounces as well as an improvement in recovery rate from 66.5% to 70.7% in 2008 and 2009 respectively.

Chirano mine has always been a low cost producer since 2007 reflecting in its position in the lowest cost first quartile. A whopping 51% increase in output from 121 000 ounces in 2008 to 183 000 ounces in 2009 helped to reduce unit cash costs from US$478/oz. to US$443/oz. in 2009 (Red Back Mining Incorporated, 2009). This made Chirano mine to become the lowest cost producer in Ghana in 2009. This phenomenon demonstrates the influence of output on unit cash costs. Higher mill head grades at Chirano may be the reason why Chirano mine had a lower unit cost than Tarkwa mine although the latter had a larger output. The gold industry cost curve for 2010 for gold mines is shown in Figure 4.4. Data used to construct the industry cost curve are shown in appendix 7.4.

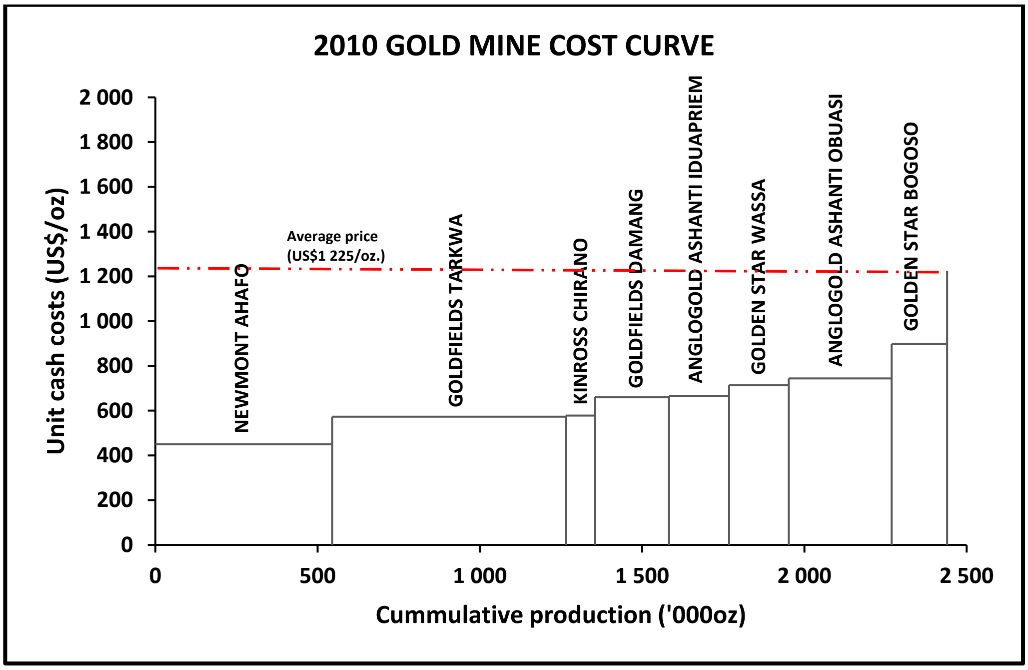

Figure 4.4: Cost curve of gold mines in Ghana for 2010

(Source: AngloGold Ashanti Limited, 2010; Gold Fields Limited, 2010; Golden Star Resources, 2010; Kinross Gold Corporation, 2010;Kitco, 2018; Newmont Mining Corporation, 2010)

It can be observed in Figure 4.4 that Chirano mine moved from being the lowest cost mine into the third quartile in 2010. This is because Chirano started commercial production from its underground operations. Unit cash costs consequently increased by 30% from 443 in 2009 to 578 in 2010. Underground mines are relatively more expensive to operate than surface mines.

Ahafo mine therefore replaced Chirano mine as the lowest cost producer in Ghana. Ahafo mine continued to benefit from economies of scale, efficient machinery and the extraction of oxide ores. Bogoso-Prestea however maintained its position as the highest cost mine in the country. This is because Bogoso-Prestea obtains comparatively low recoveries from processing carbonaceous sulphide ore. The overall recovery rate at Bogoso-Prestea for 2010 was 65.7%. Apart from the fact that oxidative pre-treatment incurs additional costs, a lower recovery rate implies that those costs do not produce additional ounces of gold as discussed in Chapter 2.

Figure 4.5 shows the industry cost curve for mines in Ghana for 2011. Data used to construct the industry cost curve are shown in appendix 7.5.

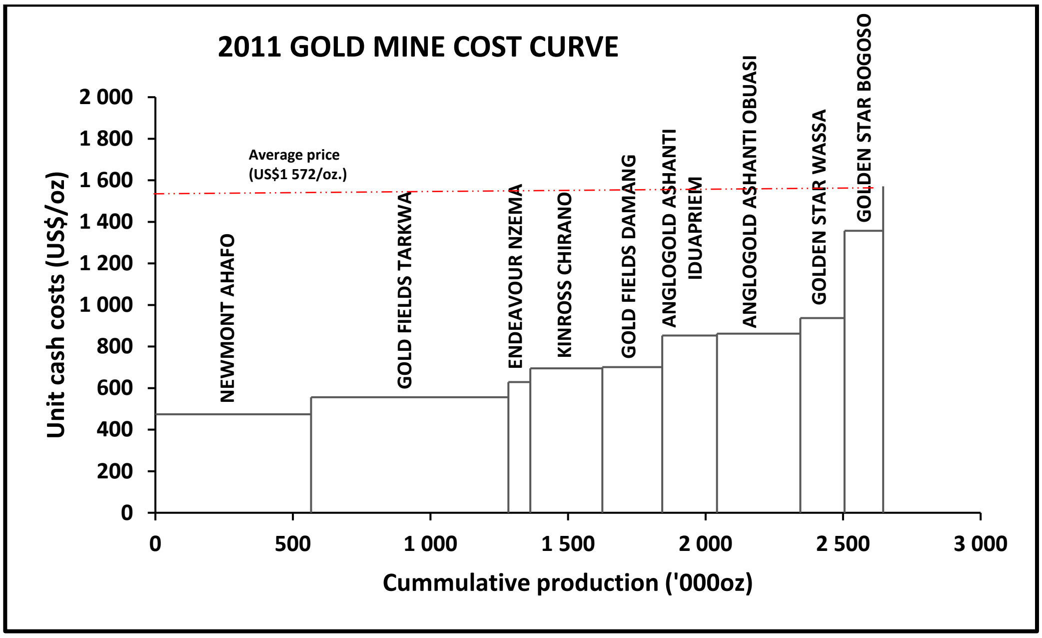

Figure 4.5: Cost curve of gold mines in Ghana for 2011

(Source: AngloGold Ashanti Limited, 2011; Endeavour Mining Corporation, 2011; Gold Fields Limited, 2011a; Golden Star Resources, 2011; Kinross Gold Corporation, 2011; Kitco, 2018; Newmont Mining Corporation, 2011)

Figure 4.5 shows the emergence of Endeavour Nzema mine in the third quartile as a result of attaining full commercial production. Nzema mine produced 80 000 ounces of gold at a cash costs of US$694/oz. Nzema mine was still in the ramp-up phase and hence did not benefit from economies of scale. Nzema mine from the onset decided not to extract and process carbonaceous sulphide ores although it has Mineral Reserves of this type of ore (Johnson, *et al.*, 2013). This brings to the fore the difficulty in processing these carbonaceous sulphide ores due to their double refractoriness as explained in Chapter 2. Ahafo mine maintained its position as the lowest cost mine while Bogoso-Prestea was the highest cost mine in Ghana. There were no significant movement of mines along the cost curve in 2011. The gold price, however, moved from US$1 225/oz. in 2010 to US$1 572/oz. in 2011 (Kitco, 2018). Figure 4.6 shows the gold industry cost curve for mines for 2012. Data used to construct the industry cost curve are shown in appendix 7.6.

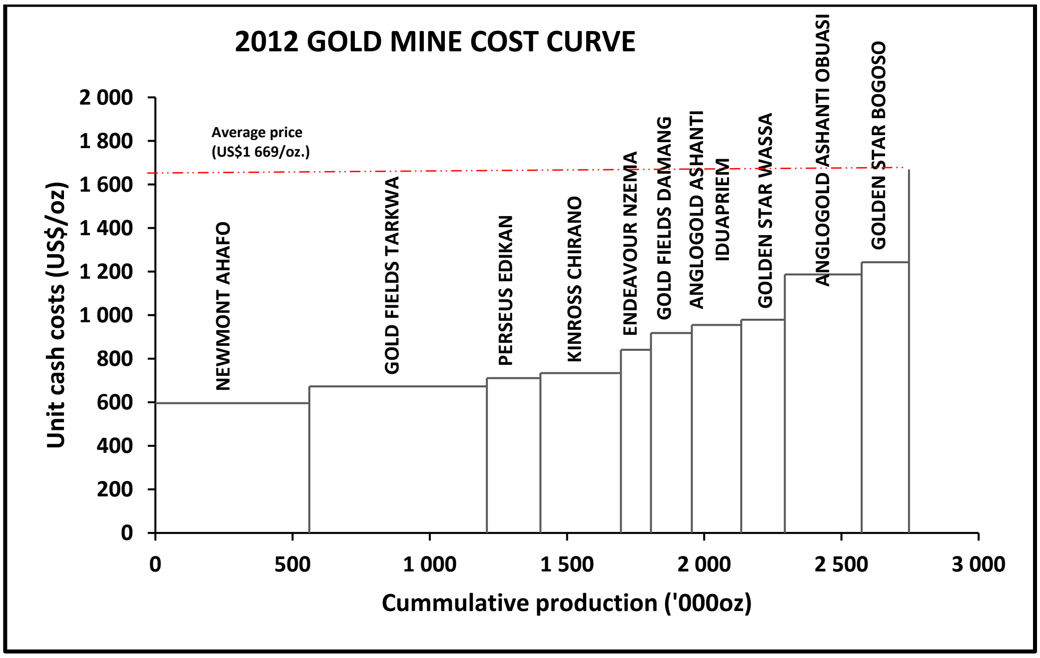

Figure 4.6: Cost curve of gold mines in Ghana for 2012

(Source: AngloGold Ashanti Limited, 2012; Endeavour Mining Corporation, 2012; Gold Fields Limited, 2012; Golden Star Resources, 2012; Kinross Gold Corporation, 2012; Kitco, 2018; Newmont Mining Corporation, 2012; Perseus Mining Limited, 2012)

The year 2012 marked the first year of commercial production for Perseus Edikan mine. Edikan mine was positioned in the second quartile with an output of 195 000 ounces and unit cash costs of US$711/oz. Edikan was still in the process of ramping up production and recovery rate was also moderate at 83.3% in 2012. This implies that it is neither benefitting from economies of scale nor the efficiency of its processing plant. Gold prices peaked in 2012 averaging US$1 669/oz. (Kitco, 2018). Ahafo and Bogoso-Prestea mines maintained their positions as the lowest and highest cost mines in the country respectively. Figure 4.7 shows the gold industry curve for 2013. Data used to construct the industry cost curve are shown in appendix 7.7

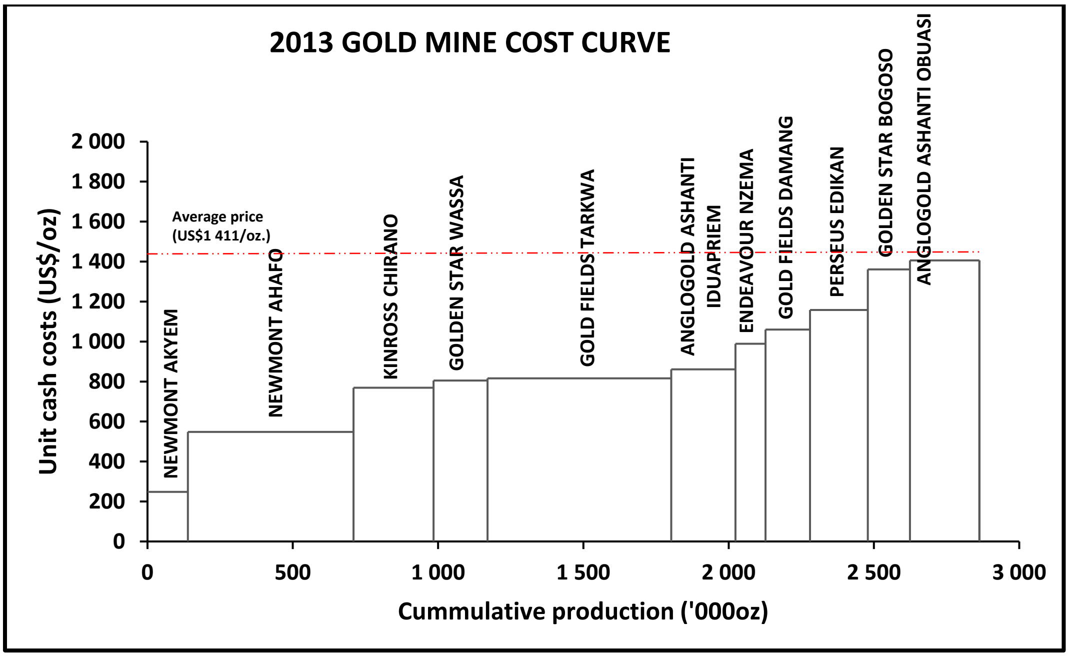

Figure 4.7: Cost curve of gold mines in Ghana for 2013

(Source: AngloGold Ashanti Limited, 2013; Endeavour Mining Corporation, 2013; Gold Fields Limited, 2013; Golden Star Resources, 2013; Kinross Gold Corporation, 2013; Kitco, 2018; Newmont Mining Corporation, 2013; Perseus Mining Limited, 2013)

Newmont Akyem mine appeared on the cost curve for the first time with an output of 139 000 ounces at cash costs of US$248/oz. in 2013 after attaining a full year of commercial production. The Akyem mine was also the lowest cost mine in 2013 while Obuasi mine was the highest cost mine in 2013. Akyem mine benefited from high recovery rate of 92% from the processing of oxide ore and relatively good grades of 2.4 g/t.

The changeover from contract mining to owner mining at Obuasi mine affected production leading to a lower output of 239 000 ounces in 2013 from 280 000 ounces in 2012 (AngloGold Ashanti Limited, 2013). Consequently productivity at Obuasi measured by Total Employment Cost (TEC), therefore fell from 5.19 oz./TEC in 2012 to 4.10 oz./TEC (AngloGold Ashanti Limited, 2013). Obuasi mine therefore did not benefit from economies of scale and therefore replaced Bogoso mine as the highest cost mine. Edikan mine moved into the fourth quartile in this same year. Mill head grades reduced at Edikan from 1.5g/t to 1.2g/t from 2012 to 2013 leading to a marginal increase in output from 195 000 ounces in 2012 to 199 000 ounces in 2013. Edikan therefore did not benefit from economies of scale. Figure 4.8 shows gold industry cost curve for 2014. Data used to construct the industry cost curve are shown in appendix 7.8.

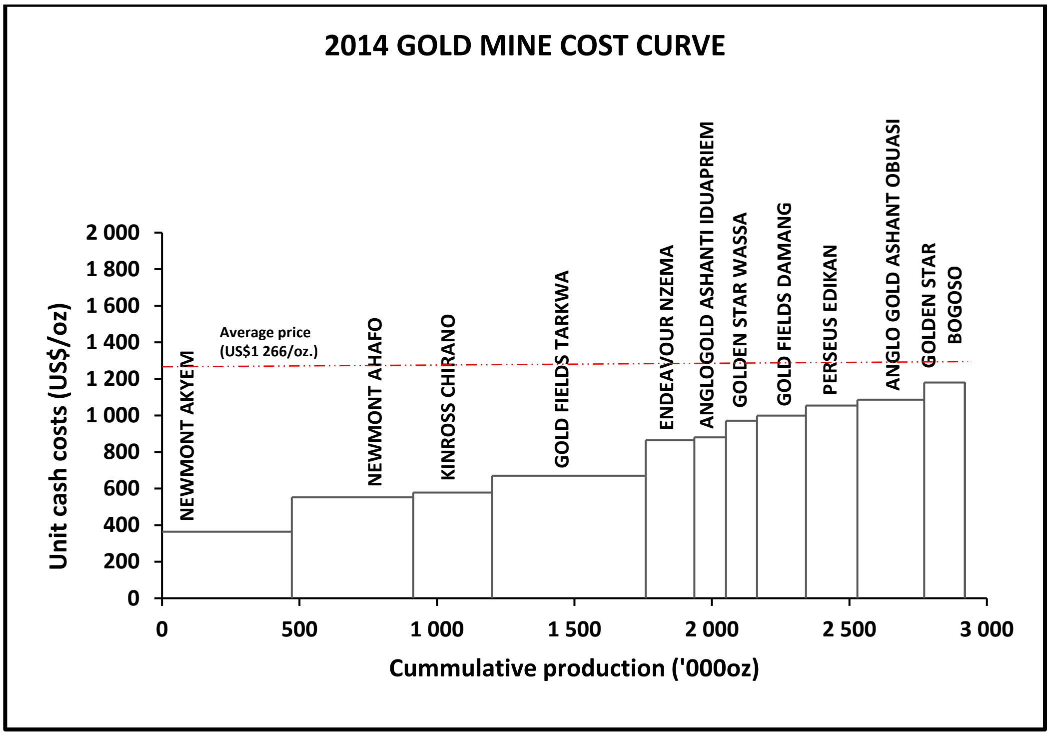

Figure 4.8: Cost curve of gold mines in Ghana for 2014

(Source: AngloGold Ashanti Limited, 2014; Endeavour Mining Corporation, 2014; Gold Fields Limited, 2014a; Golden Star Resources, 2014; Kinross Gold Corporation, 2014; Kitco, 2018; Newmont Mining Corporation, 2014; Perseus Mining Limited, 2014)

Akyem mine ramped up production with an output of 472 000 ounces at a cash cost of US$364/oz. therefore, it still maintained its position as the lowest cost mine from 2014. Akyem mine continued to benefit from economies of scale by ramping up production. Being a relatively new mine, it still extracts oxide ore which are relatively less costly to process and produce high recoveries. Lastly, Akyem open pits are still quite shallow therefore incurred low haulage costs. Bogoso-Prestea mine regained its position as the highest cost mine from Obuasi mine. A 1% increase in output from 239 000 ounces to 243 000 ounces helped Obuasi mine move a step leftwards (AngloGold Ashanti Limited, 2014). Bogoso-Prestea processing plants produced gold in 2014 at a recovery rates of 70.3%. This recovery rate is modest considering that most mines in Ghana during the period under review had recovery rates between 90% and 95%. Low recoveries and oxidative pre-treatment makes the processing of carbonaceous sulphide ores very costly and hence made the mine the highest unit cost producer.

Edikan mine also moved from the third quartile to the fourth. Edikan faced operational challenges in 2014 with head grades reducing approximately 20% from 1.2 g/t in 2013 to 1.0 g/t in 2014 leading to a decline of 6% from 199 000 ounces to 186 000 ounces in gold output (Perseus Mining Limited, 2014). The decline in head grade and gold output produced escalations in unit cash costs hence the movement of Edikan mine into the highest cost quartile. Figure 4.9 shows the gold industry cost curve in Ghana for 2015. Data used to construct the industry cost curve are shown in appendix 7.9.

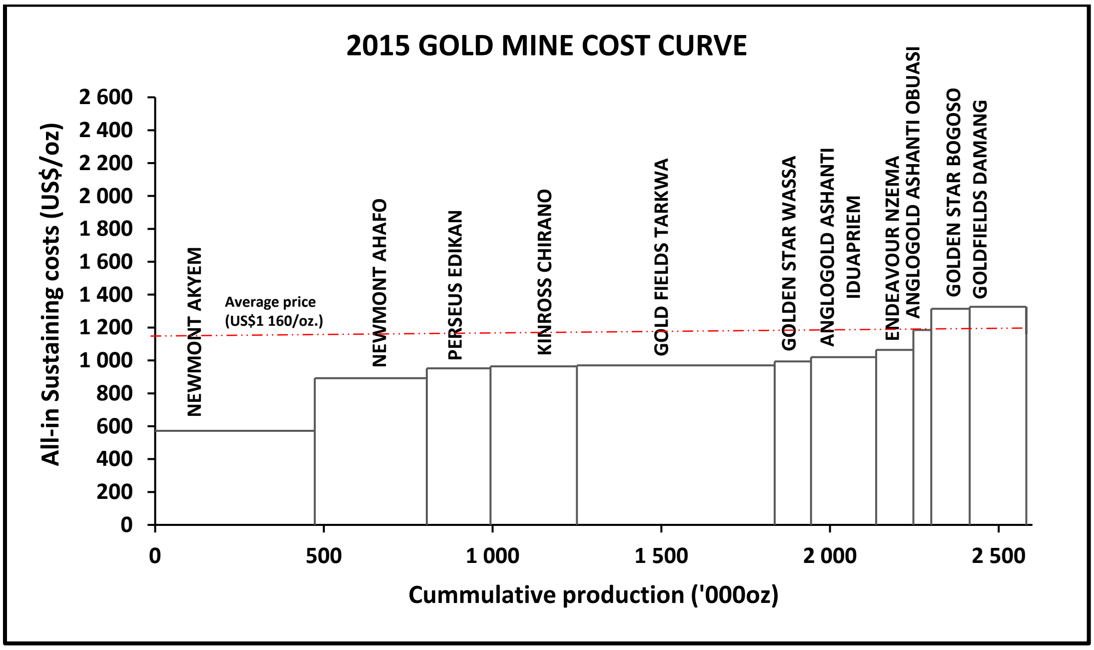

Figure 4.9: Cost curve of gold mines in Ghana for 2015

(Source: AngloGold Ashanti Limited, 2015; Endeavour Mining Corporation, 2015; Gold Fields Limited, 2015; Golden Star Resources, 2015; Kinross Gold Corporation, 2015; Kitco, 2018; Newmont Mining Corporation, 2015; Perseus Mining Limited, 2015)

Akyem mine maintained its position as the lowest unit cost mine while Damang displaced Bogoso-Prestea to be the highest unit cost mine in 2015. Average gold price in 2015 declined to US$1 160/oz. from US$1 266/oz. in 2014. Bogoso-Prestea and Damang experienced negative profit margins as their AISC were US$1 314/oz. and US$1 326/oz. respectively. Costs at Damang mine started escalating after production fell from 218 000 ounces in 2011 to 149 000 ounces in 2012. This 32% loss in output led to an increase in unit cash costs from US$701/oz. in 2011 to US$918/oz. in 2012. Damang has since not been able to meet its 2012 output level hence the mine has not been able to take advantage of economies of scale. Management of Damang mine attributed the loss in production to lack of access to higher grades at deeper levels below the original open pits (Gold Fields Limited, 2015). Capital investments would therefore be required to a push-back expose and gain access to these high grade orebodies. Figure 4.10 shows the gold industry cost curve for 2016. Data used to construct the industry cost curve are shown in appendix 7.10.

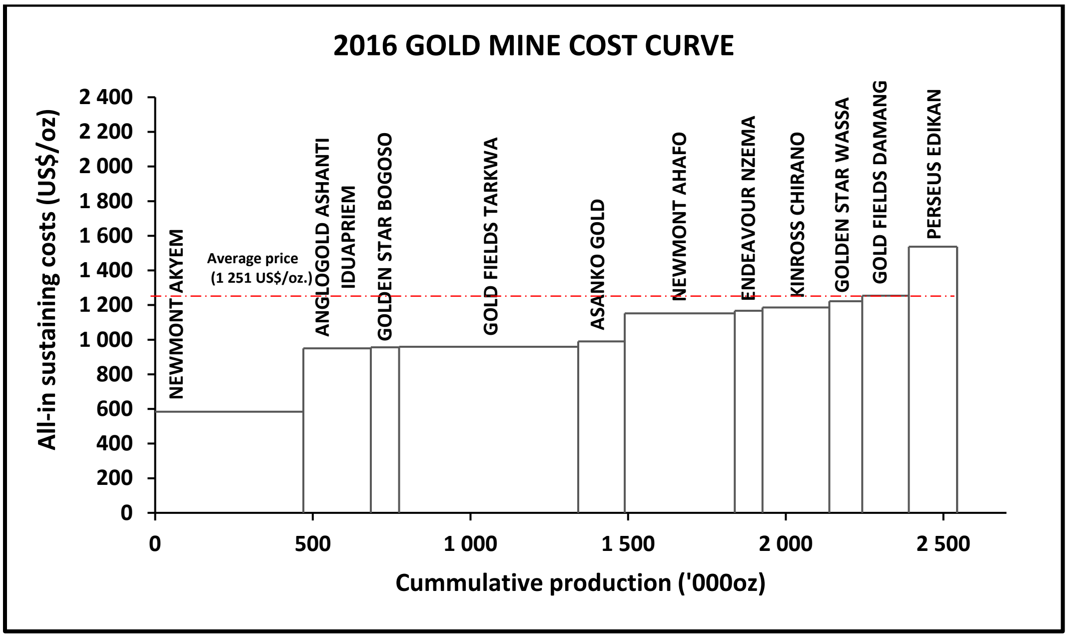

Figure 4.10: Cost curve of gold mines in Ghana for 2016

(Source: AngloGold Ashanti Limited, 2016; Asanko Gold Incorporated, 2016; Endeavour Mining Corporation, 2016; Gold Fields Limited, 2016; Golden Star Resources, 2016; Kinross Gold Corporation, 2016; Kitco, 2018; Newmont Mining Corporation, 2016; Perseus Mining Limited, 2016)

Asanko attained full commercial production in 2016 with an output of 148 000 ounces at an AISC of US$998/oz. Akyem mine maintained its position as the lowest unit cost mine in 2016 while Edikan mine displaced Damang mine to become the highest cost mine. Output from Edikan mine reduced by 20% from 110 000 ounces in 2015 to 88 000 ounces in 2016. Gold output has immense influence on unit cash costs. Both Damang and Edikan mine made negative profit margins with AISC of US$1 254/oz. (Golden Star Resources Limited, 2016) and US$1 538/oz. (Perseus Mining Limited, 2016) respectively while average gold price for 2016 was US$1 251/oz. (Kitco, 2018).

Ahafo mine moved from the lowest cost quartile in 2015 to the third quartile in 2016. This was attributed to lower grades and depletion of oxide ore which affected production output (Newmont Mining Corporation, 2016). Grades declined from 1.8g/t in 2015 to 1.6g/t in 2016 although output increased from 332 000 ounces in 2014 to 349 000 ounces in 2016. A decline in head grade leads to an increase in unit costs because more tonnes of ore need to be extracted and processed to produce an equivalent amount of gold ounces.

Bogoso-Prestea mine moved significantly from the fourth quartile to the second quartile. The movement is because the management of the mine decided at the end of 2015 to shut down the BIOX plant and halt the extraction and processing of carbonaceous sulphide ore (Golden Star Resources Limited, 2016). The cessation of the processing of sulphide ore eliminates extra costs associated with the oxidative pre-processing stage as discussed in Chapter 2. Overall recovery rates improved from 67.5% to 83.9% although output fell from 114 000 ounces to 90 000 ounces (Golden Star Resources Limited, 2016).

Generally, the gold industry cost curve produced from 2007 to 2016 have features that are common to the typical industry cost curves as shown in Figure 2.1.The large sized gold producing mines are typically low unit cost mines and occupy the lower quartile of the industry cost curve while the gold mines with smaller output occupy the higher quartile of the cost curve because they are high cost mines. The interquartile range was dominated by a mixture of small and large sized mines.

The Industry cost curves was dynamic and mines moved along the curves each year into different quartiles. Most mines have moved mainly due to variations in output, grades and recovery rates.

4.3 Low unit cost producers

Newmont's Ahafo mine and after 2014, Akyem mines have consistently positioned themselves in the lower quartile of the industry cost curve. While Ahafo is a matured mine, Akyem is a relatively new operation. Newmont has been committed to continuous improvement of operations at Ahafo and Akyem mines.

As a mine matures, the focus of management shifts towards improvement and optimization. Newmont introduced a Business Excellence programme across all its mines in 2010 (van Huyssteen & Cantor, 2011). The aim of this programme is to continually improve processes and eliminate waste through best practices. This has ensured that no human activity utilizes resources without creating value over and above the resources absorbed. According to van Huyssteen and Cantor (2011), Business Excellence as implemented at Newmont had three major components which were:

- Management Operating Systems which focused on performance management ensuring that plans were carried out every day;
- Operational Standards and Standardization which ensured that the application of technology was optimized and business processes made efficient; and
- Continuous Improvement which ensured that the quality of product outputs were improved by the identification and removal of defects in installations.

This programme empowered personnel to solve problems they identified from their daily activities especially in areas where managers tend to focus less. An added advantage was that every employee had an opportunity both to contribute to improved productivity and also share in whatever benefits that accrued.

Newmont's Ahafo and Akyem mines have benefitted from economies of scale. In 2016, Akyem and Ahafo mines ranked second and third in Ghana with gold output of 470 000 ounces and 349 000 ounces, respectively. Declining grades at Ahafo mine from 2014 has led to an annual decline in gold output from 442 000 ounces in 2014 to 349 000 ounces in 2016. Declining grades were due to the depletion of oxide ores. Unit cash costs has also escalated accordingly from US$552/oz. in 2014 to US$1 152/oz. in 2016. In 2016, Ahafo mine moved into the third quartile of the cost curve (Newmont Mining Corporation, 2016). This is because unit cost in Ghana is influenced by production output.

Oxide ores were the main ore feed at Akyem mine. Oxide ores are non-refractory and comparatively less costly to process. As the Akyem mine matures more primary ore will contribute to the ore feed. Although they are also non refractory, recovery rates may decrease due to the hardness of the ore.

4.4 High unit cost producers

Obuasi mine and Bogoso-Prestea mine have consistently been positioned at the fourth highest cost quartile of the industry cost curve. This implies that both mines are high costs producers. Obuasi mine as indicated earlier is an underground mine that has been in operation since 1897. Being the only wholly underground operation in Ghana, it is expected to be a high unit cost mine. Obuasi mine has over the years operated a costly outmoded labour-intensive longitudinal and transverse open stoping mining method (AngloGold Ashanti Limited, 2016a). Its infrastructure is also considered suboptimal and deteriorating (AngloGold Ashanti Limited, 2015b). Various attempts were made in the past to mechanise the mine but the large capital investment required stalled such initiatives although some rehabilitations were done.

Obuasi mine also suffered a number of challenges that negatively affected production output. These included the following:

- In 2010, Obuasi mine suffered operational challenges due to a decline in mine face development rate and the formation of hang-ups in ore-passes. Gold output therefore dropped by 17% from 381 000 ounces in 2009 to 317 000 ounces in 2010. Cash costs per ounce of gold consequently escalated 15% from US$630/oz. in 2009 to US$744/oz. in 2010. This resulted in Obuasi mine switching from contract mining to owner mining (AngloGold Ashanti Limited, 2011);

- In 2012, the mining operation also suffered from erratic power supply which negatively affected production output (AngloGold Ashanti Limited, 2012). Gold output consequently fell by 7% from 303 000 ounces in 2011 to 280 000 ounces in 2012. Unit cash costs consequently escalated by 38% from US$862/oz. in 2011 to US$1 187/oz. in 2012.

Generally, gold output from Obuasi mine has been declining year on year since 2010. The decline in output has consequently led to annual escalations in unit cash costs. Escalation in unit cash costs has also been influenced by relatively low average recovery rates of 85% at Obuasi mine (Afidenyo, *et al*., 2010). The difficulty of unlocking the gold from arsenopyrite, coupled with carbonaceous material also adsorbing some of the gold have reduced recovery rates at Obuasi mine. Low recoveries occur despite additional costs incurred from the energy and consumables needed to operate the oxidative pre-treatment plant.

Although the Obuasi deposit is classified as high grade averaging 8.1g/t with reserves of about 34.1Moz, the mine was put under care and maintenance in 2015 (AngloGold Ashanti Limited, 2015b). Feasibility studies conducted by the company has established Obuasi mine as viable and could be developed into a mechanised underground mine (AngloGold Ashanti Limited, 2016a). The mine will be mechanised and automated to improve efficiencies in operation. This will lead to a smaller and better skilled workforce of about 2 000 persons which will be far less than the over 4 000 that were employed before the shutdown. These measures will reduce unit cost and move Obuasi mine leftwards on the industry cost curve.

The Bogoso-Prestea mine is a high unit cost producer mainly because of extremely low recoveries rates obtained from processing its ores. Lower recovery rates in leads to higher unit operating costs. Carbonaceous materials present in the mineralized sulphide ore at Bogoso-Prestea makes them double refractory. The BIOX process, despite the additional costs incurred to operate it, is unable to deactivate the carbonaceous materials (Adam, *et al*., 2017). Carbonaceous materials, therefore, adsorbs some of the gold particle resulting in gold rich tailings. The BIOX plant at Bogoso-Prestea mine was assessed by SRK Consultants (2014) and found to be grossly inefficient because of its poor design. Table 4.1 shows recovery rates at Bogoso-Prestea mine.

Table 4.1: Metallurgical recovery rate at Bogoso-Prestea mine from 2007 to 2016

(Source: Golden Star Resources, 2016)

Year	Refractory (%)	Non-refractory (%)
2007	52.1	73.3
2008	66.5	66
2009	70.7	
2010	65.7	43.5
2011	69.8	
2012	71.2	59.9
2013	68.7	48.1
2014	70.3	39.2
2015	67.5	64.3
2016		83.9
Mean	**66.94**	**59.78**
Standard deviation	**5.55**	**14.4**

Table 4.1 shows that the average recovery rate of 67% was extremely lower than the 90% obtained during metallurgical test works (SRK Consulting, 2014). Factors identified as contributing to the poor recovery rate include deficiency in plant design, poor plant layout and low grade feed mix (SRK Consulting, 2014). Average recovery rates of 60% obtained from processing non-refractory ore between 2007 and 2016 were also abysmally low.

The management of Bogoso-Prestea mine, at the end of 2015, made a strategic decision to cease the exploitation of its sulphide Mineral Reserves (Golden Star Resources Limited, 2016). This singular decision helped reduce AISC per ounce by 27% from US$1 314/oz. in 2015 to US$956/oz. in 2016 although output also fell 21% from 114 000 ounces to 90 000 ounces. That notwithstanding, overall recovery rate improved 30% from 66% to 84% in 2016 (Golden Star Resources Limited, 2016). Consequently, Bogoso-Prestea mine moved from the fourth quartile into the second quartile on the industry cost curve.

4.5 Regression analysis between production output and unit cost

Table 4.2 presents the result of a regression analysis between production output and unit costs. Data used to perform the regression analysis are shown in appendix 7.11.

Table 4.2: Correlation coefficients between production output and unit cash costs

Year	Number of mines	Correlation coefficient	Interpretation of relationship	P-value	Null hypothesis
2007	8	-0.55	Moderate negative	0.16	reject
2008	8	-0.48	Moderate negative	0.23	accept
2009	8	-0.35	Moderate negative	0.39	accept
2010	8	-0.53	Moderate negative	0.18	reject
2011	9	-0.54	Moderate negative	0.13	reject
2012	10	-0.51	Moderate negative	0.13	reject
2013	10	-0.54	Moderate negative	0.03	reject
2014	11	-0.77	Strong negative	0.01	reject
2015	11	-0.64	Moderate negative	0.03	reject
2016	11	-0.90	Strong negative	0.00	reject
Average correlation coefficient		**-0.55**	Moderate negative		

Table 4.2 shows that there is a moderate negative linear correlation between unit cost and production output except in 2014 and 2016 when it was particularly strong. It means that an increase in production output leads to a reduction in unit cost (Gajigo & Mouna., 2015). This accurately reflects the theory of economies of scale. The moderate strength of the linear correlation coefficient implies that production output is not the only influencing factor. The change in absolute value of the correlation coefficient means that the influence of production changes annually depending on the strength of the other factors.

The hypothesis test resulted in the rejection of the null hypothesis in seven out of ten cases. The rejection of the null hypothesis implies that certainly, a relationship exists between unit costs and production output and that there is an eighty percent confidence that the relationship is not just coincidental. The dominance of high volume mines in the first half of the cost curve also gives credence to the fact that economies of scale exist in gold mining in Ghana.

4.6 Regression analysis between mill head grade and unit cost

Table 4.3 presents the results of the regression analysis between mill head grade and unit cost. Data used to perform the regression analysis are shown in appendices 7.11 and 7.12.

Table 4.3: Correlation coefficients between mill head grade and unit cost

Year	Number of mines	Correlation coefficient	Interpretation of relationship	P-value	Null Hypothesis
2007	8	0.18	Weak positive	0.67	accept
2008	8	0.31	Moderate positive	0.46	accept
2009	8	0.30	Weak positive	0.47	accept
2010	8	0.35	Moderate positive	0.40	accept
2011	9	0.27	Weak positive	0.48	accept
2012	10	0.47	Moderate positive	0.18	reject
2013	11	0.20	Weak positive	0.55	accept
2014	11	0.05	Weak positive	0.89	accept
2015	11	0.10	Weak positive	0.78	accept
2016	10	-0.46	Moderate negative	0.19	reject

Table 4.3 shows a weak positive linear relationship between mill head grade and unit cash costs. The implication of this relationship is that the lowest unit costs producer is not necessarily the mine with the highest mill head grade. The converse also holds true. In order to put this interpretations into perspective, it must be noted that over 80% of gold production from Ghana is from surface mines. Most surface operations in Ghana have used large production outputs to offset the low grade deposits they exploit (Crowson, 2003). Hypothesis testing also shows that year on year, there exists no linear relationship between mill head grade and unit cost.

This interpretation does not contradict with the already established fact that in an individual mine, unit cost is sensitive to variation in head grade. The ounces of gold produced from a higher grade deposit will be more than the ounce produced from a lower grade assuming a constant amount of tonnes milled. Furthermore, if the same production costs is incurred processing the same volume or tonnes of rocks, then a higher grade ore would yield higher amount of ounces at the same cost. It is important also that the expected ounces are recovered from the ore feed sent to the processing plant. Figures 4.11 to 4.13 shows industry cost curves using unit cash costs per ore tonne milled against production output in ore tonnes milled. Data used to construct the industry cost curves are shown in appendices 7.13 to 7.15.

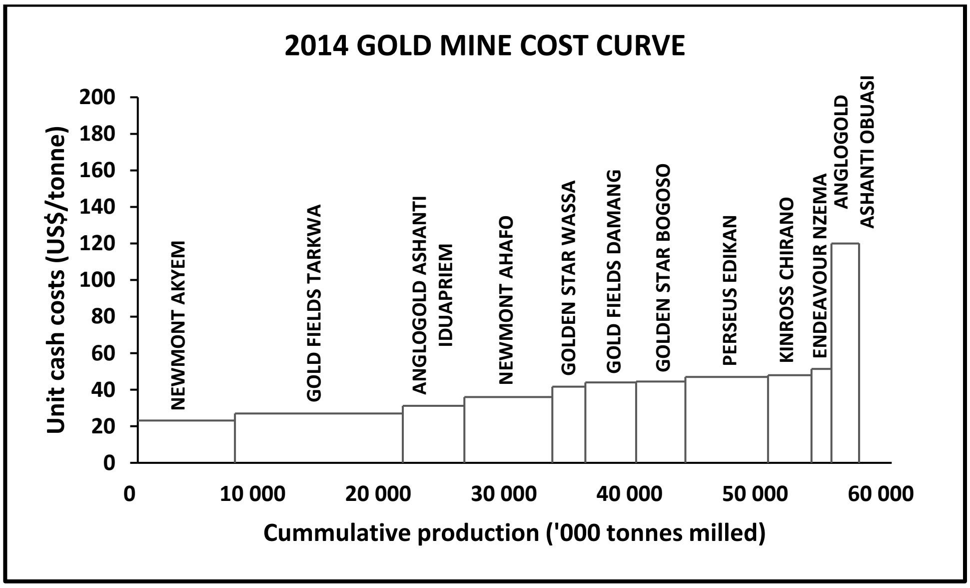

Figure 4.11: Cost curve of gold mines in Ghana for 2014 (tonnes milled)

(Source: AngloGold Ashanti Limited, 2014; Endeavour Mining Corporation, 2014; Gold Fields Limited, 2014; Golden Star Resources, 2014; Kinross Gold Corporation, 2014; Newmont Mining Corporation, 2014; Perseus Mining Limited, 2014)

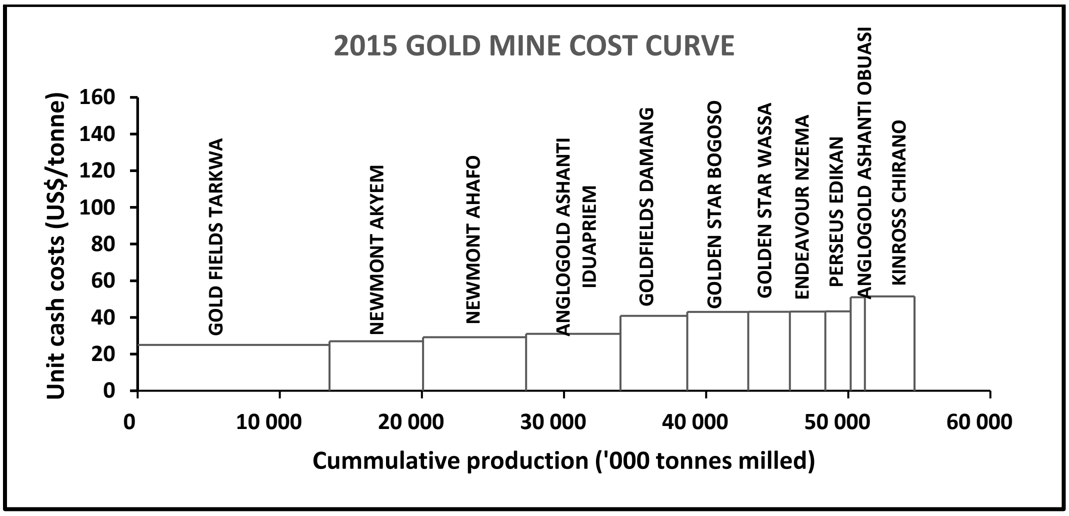

Figure 4.12: Cost curve of gold mines in Ghana for 2015 (tonnes milled)

(Source: AngloGold Ashanti Limited, 2015; Endeavour Mining Corporation, 2015; Gold Fields Limited, 2015; Golden Star Resources, 2015; Kinross Gold Corporation, 2015; Newmont Mining Corporation, 2015; Perseus Mining Limited, 2015)

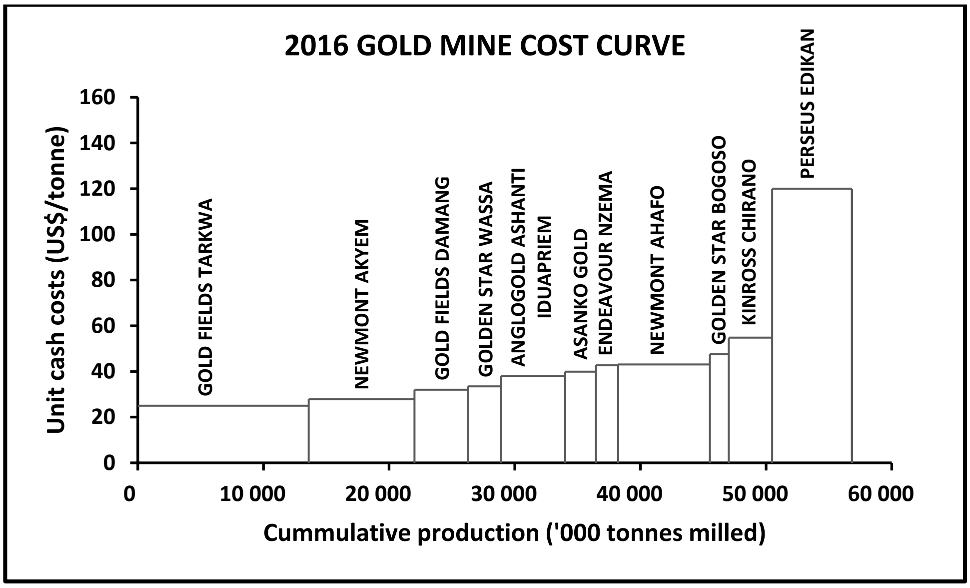

Figure 4.13: Cost curve of gold mines in Ghana for 2016 (tonnes milled)

(Source: AngloGold Ashanti Limited, 2016; Asanko Gold Incorporated, 2016; Endeavour Mining Corporation, 2016; Gold Fields Limited, 2016; Golden Star Resources, 2016; Kinross Gold Corporation, 2016; Newmont Mining Corporation, 2016; Perseus Mining Limited, 2016)

Figure 4.11 shows that Akyem mine was the lowest unit cost mine while Obuasi mine was the highest cost mine in 2014. It also shows a preponderance of mines with large production throughput in the lower quartile and mines with lower production throughput in the higher cost quartile. This phenomenon confirms the existence of economies of scale in Ghana's gold mining industry. Figures 4.12 and 4.13 shows that Tarkwa mine with a throughput 13.5 million tonnes and 13.6 million tonnes in 2015 and 2016, respectively was the lowest unit cost mine in 2014 and 2015 (Gold Fields Limited, 2016). Figures 4.9, 4.10, 4.12 and 4.13 shows that Akyem mine had lower cash costs per ounce compared to Tarkwa mine although Tarkwa mine also had lower cash costs per tonne of ore milled compared to Akyem mine in 2015 and 2016. This was mainly because mill head grades at Akyem mine which were 1.8 g/t and 1.6 g/t respectively for 2015 and 2016 were higher than Tarkwa mine which had mill head grades of 1.4 g/t and 1.3 g/t. The implication is that grades becomes an important distinctive factor when comparing mines with near similar production throughput and recovery rates. However, an industry cost curve analysis using costs per ounce is a more efficient method of analysing production costs than using costs per tonne milled since the former measures output while the latter measures throughput. It is much preferable to know the cost of producing the end product.

The use of outmoded labour intensive underground mining methods explains Obuasi mine's position on the industry cost curve as the highest unit cost mine in 2014. Chirano mine, a hybrid mine, was the highest unit cost mine in 2015 due to its comparatively low production throughput and costly underground operations. Edikan mine became the highest unit cost mine in 2016 because of lower grade coupled with low recovery rates.

4.7 Regression analysis between recovery rate and unit cost

Table 4.4 shows the outcome of a regression analysis between unit costs and recovery rate. Data used to perform the regression analysis are shown in appendices 7.11 and 7.12.

Table 4.4: Correlation coefficients between recovery rate and unit cost

Year	Number of mines	Correlation coefficient	Interpretation of relationship	P-value	Null Hypothesis
2007	5	-0.96	Strong negative	0.01	reject
2008	7	-0.73	Strong negative	0.06	reject
2009	8	-0.69	Moderate negative	0.05	reject
2010	8	-0.58	Moderate negative	0.10	reject
2011	8	-0.72	Strong negative	0.04	reject
2012	9	-0.52	Moderate negative	0.15	reject
2013	10	-0.72	Strong negative	0.02	reject
2014	10	-0.52	Moderate negative	0.10	reject
2015	10	-0.70	Strong negative	0.02	reject
2016	8	-0.34	Moderate negative	0.43	accept
Average correlation coefficient		**-0.65**	Moderate (negative)		

The results show a moderate negative correlation between recovery rate and unit cost. The inverse relationship shows that gold mines in Ghana with high recovery rates are likely to be low cost producers and vice versa. Furthermore, the hypothesis test shows that there is a linear relationship between recovery rate and unit cost.

The variation in the absolute value of the correlation coefficient shows that the relationship is dynamic. In 2016, when no carbonaceous sulphide ore was processed due to the shutdown of the BIOX plants at Obuasi and Bogoso mines, the correlation coefficient was low at 0.34. This implies that in 2016, the influence of recovery rate on unit cost for gold mines in Ghana was low. Recovery rates improved remarkably in 2016.

4.8 Effect of electricity tariffs on unit cost

Regression analysis between the annual escalation in electricity tariffs and the annual rise in unit cash costs of individual gold mines in Ghana shows there is a strong positive linear correlation between the two parameters as shown in Table 4.5. Data used to perform the regression analysis are shown in appendices 7.11 and 7.16.

Table 4.5: Correlation coefficients between electricity tariff and unit cost

Mine	Number of years	Correlation coefficient	Interpretation of relationship	P-value	Null hypothesis
Obuasi	9	0.62	Moderate positive	0.07	reject
Iduapriem	10	0.7	Strong positive	0.02	reject
Tarkwa	10	0.77	Strong positive	0.01	reject
Damang	10	0.76	Strong positive	0.01	reject
Ahafo	10	0.88	Strong positive	0	reject
Akyem	4	0.74	Strong positive	0.25	accept
Bogoso-Prestea	10	0.36	Moderate positive	0.3	accept
Wassa	10	0.85	Strong positive	0	reject
Chirano	10	0.86	Strong positive	0	reject
Edikan	5	0.88	Strong positive	0.04	reject
Nzema	6	0.68	Moderate positive	0.13	reject

Hypothesis tests also indicate that in nine out of eleven gold mines, there is a relationship between escalation in electricity prices and unit cost. This implies that electricity is a driver of unit cost in Ghana.

Ghana experienced electricity shortages in 2007, 2015 and 2016 due to a significant decline in hydro-power generation because of a shortfall in rainfall as shown in Figure 4.14.

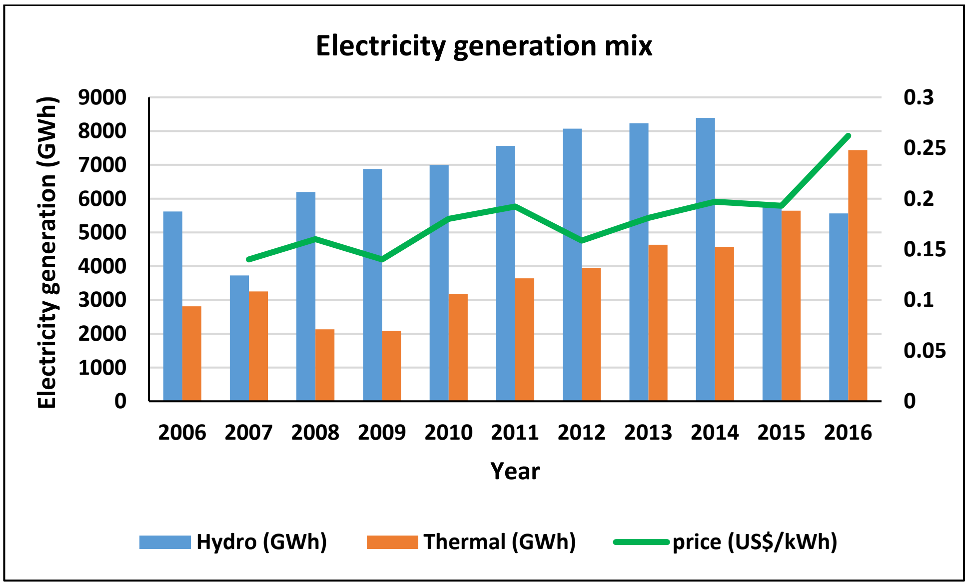

Figure 4.14 Electricity generating mix in Ghana from 2007 to 2016.

(Source: Energy Commission, 2016)

In 2015, mining companies were asked to reduce their power consumption by 30% in 2015 and then to 25% in 2016 (AngloGold Ashanti Limited, 2016a). Mining companies were forced to resort to independent power producers to meet their energy requirement. Tariffs charged by thermal plants in Ghana are comparatively higher than hydro-power plants.

According to the Ghana Chamber of Mines (2015) from 2014 to 2015, the percentage of mineral revenues used to purchase both fuel and electricity increased from 17% to 20%. Power tariffs in 2016 was increased by 37% from US$0.19/kWh in 2015 to US$0.26/kWh.

With electricity demand in Ghana expected to surpass generation capacity until 2020, Gold Fields Limited, owners of the Tarkwa and Damang mines have initiated a number of activities as part of their five-year energy security plans. The company has constructed two Genser gas turbine power plants to supply a total of 40MW of electricity to both mines (Gold Fields Limited, 2016). The total capacity of the Tarkwa plant (three 11MW units) and the Damang plant (five 5.5MW units) are above the current power requirements. These plants commissioned in December 2016 would ensure a supply stability and cost reduction at both mines. Electricity cost at the Tarkwa and Damang mines are expected to reduce by about 14% and 30% respectively (Gold Fields Limited, 2016).

4.9 Regression analysis between diesel price and unit cost

Table 4.6 shows the correlation coefficients between diesel prices and unit cost. Data used to perform the regression analysis is shown in appendices 7.11 and 7.16.

Table 4.6: Correlation coefficient between unit cash costs and diesel prices

Mine	Number of years	Correlation coefficient	Interpretation of relationship	P-Value	Null Hypothesis
Obuasi	9	0.39	Moderate positive	0.3	accept
Iduapriem	10	0.27	Weak positive	0.45	accept
Tarkwa	10	0.11	Weak positive	0.76	accept
Damang	10	0.12	Weak positive	0.75	accept
Ahafo	10	0.13	Weak positive	0.73	accept
Akyem	4	0.67	Moderate positive	0.33	accept
Bogoso-Prestea	10	0.57	Moderate positive	0.08	reject
Wassa	10	0.09	Weak positive	0.8	accept
Chirano	10	0.04	Weak positive	0.8	accept
Edikan	5	0.58	Moderate positive	0.3	accept
Nzema	6	0.42	Moderate positive	0.4	accept

Table 4.6 shows that the annual rise in the price of diesel in is weakly correlated to unit costs among gold mines in Ghana. Hypothesis tests also confirms that there is no linear relationship between increase in diesel fuel prices and annual unit costs escalations in gold mines in Ghana.

4.10 Company industry cost curves

Figures 4.15 to 4.24 are cost curves for gold mining companies operating in the country from 2007 to 2016. Data used to construct the industry cost curves are shown in appendices 7.1 to 7.10.

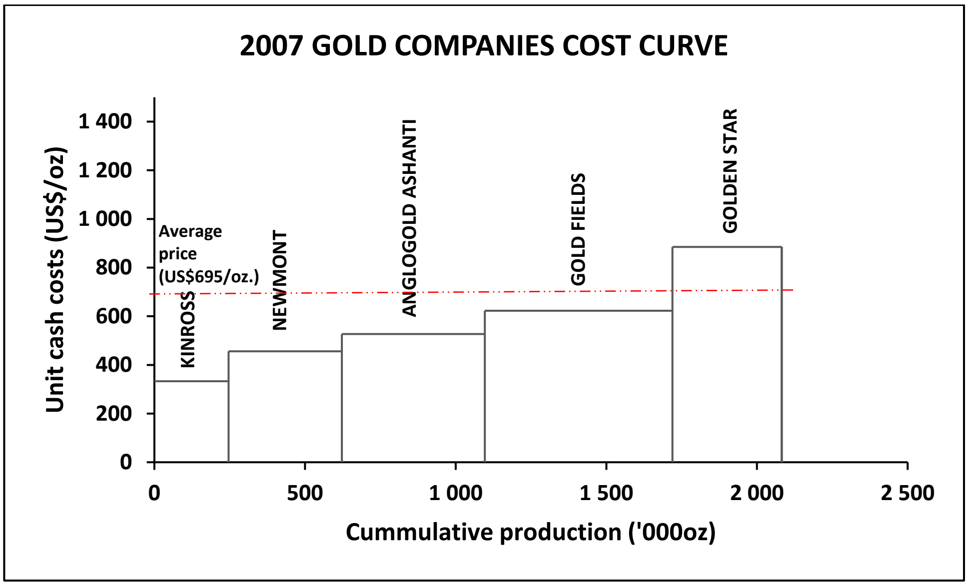

Figure 4.15: Cost curve of gold companies in Ghana for 2007

(Source: AngloGold Ashanti Limited, 2008; Gold Fields Limited, 2008; Golden Star Resources, 2008; Kitco, 2018; Newmont Mining Corporation, 2007; Red Back Mining Incorporated, 2007)

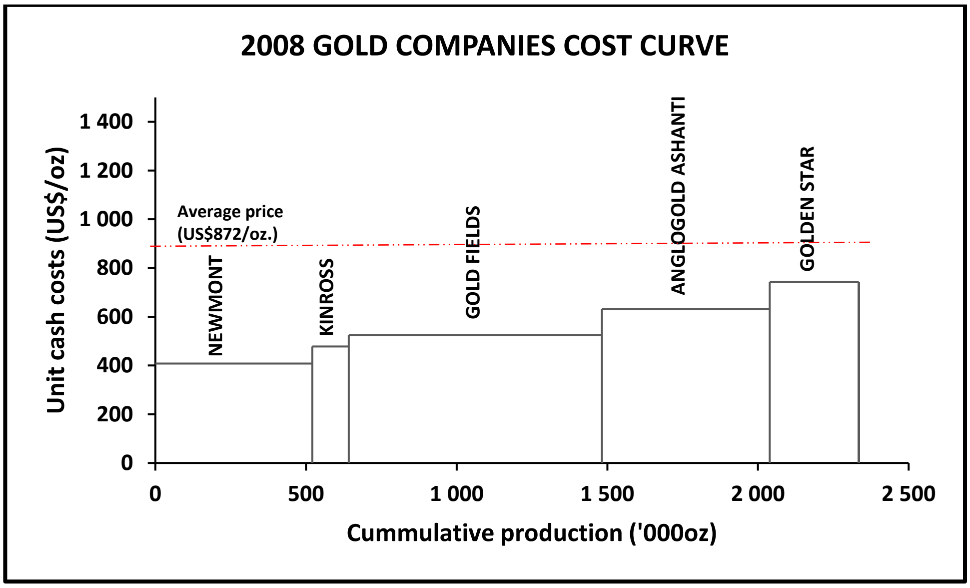

Figure 4.16: Cost curve of gold companies in Ghana for 2008

(Source: AngloGold Ashanti Limited, 2008; Gold Fields Limited, 2008; Golden Star Resources, 2008; Kitco, 2018; Newmont Mining Corporation, 2009; Red Back Mining Incorporated, 2008)

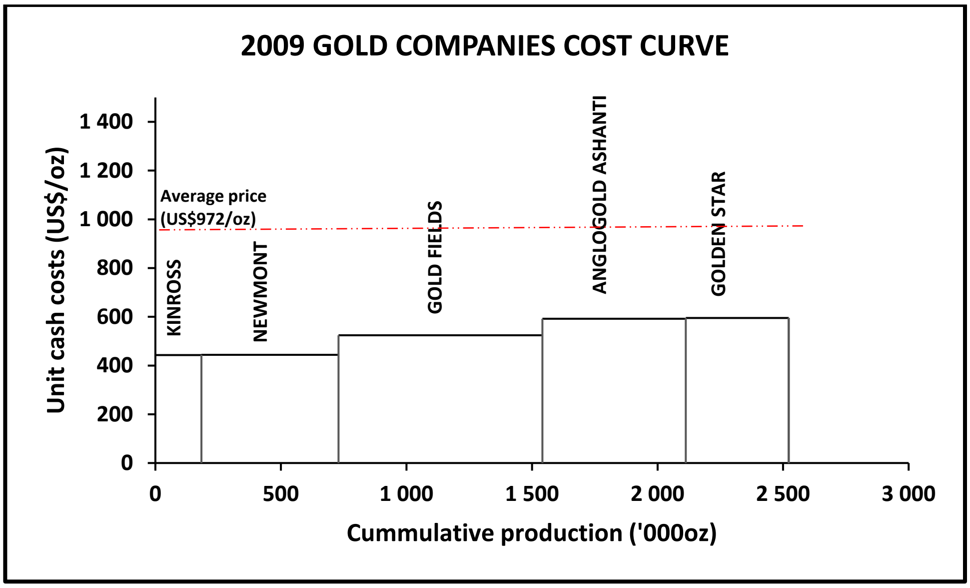

Figure 4.17: Cost curve of gold companies in Ghana for 2009

(Source: AngloGold Ashanti Limited, 2009; Gold Fields Limited, 2009; Golden Star Resources, 2009; Kitco, 2018; Newmont Mining Corporation, 2009; Red Back Mining Incorporated, 2009)

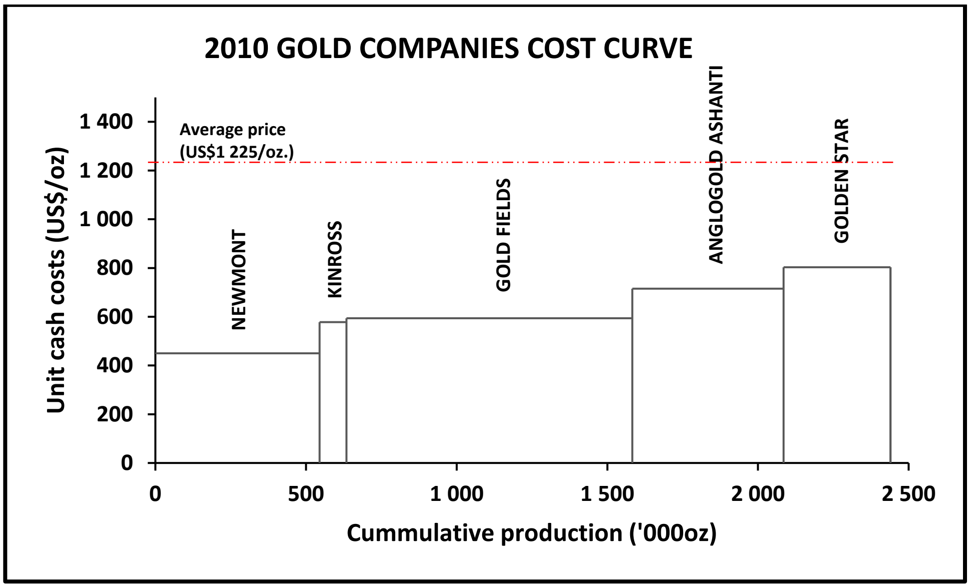

Figure 4.18: Cost curve of gold companies in Ghana for 2010

(Source: AngloGold Ashanti Limited, 2010; Gold Fields Limited, 2010; Golden Star Resources, 2010; Kinross Gold Corporation, 2010;Kitco, 2018; Newmont Mining Corporation, 2010)

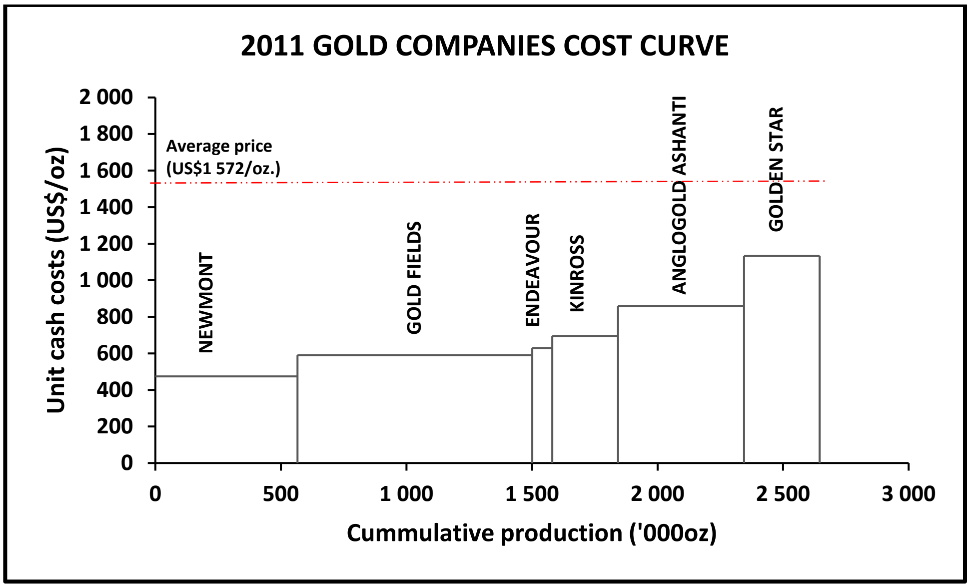

Figure 4.19: Cost curve of gold companies in Ghana for 2011

(Source: AngloGold Ashanti Limited, 2011; Endeavour Mining Corporation, 2011; Gold Fields Limited, 2011; Golden Star Resources, 2011; Kinross Gold Corporation, 2011; Kitco, 2018; Newmont Mining Corporation, 2011)

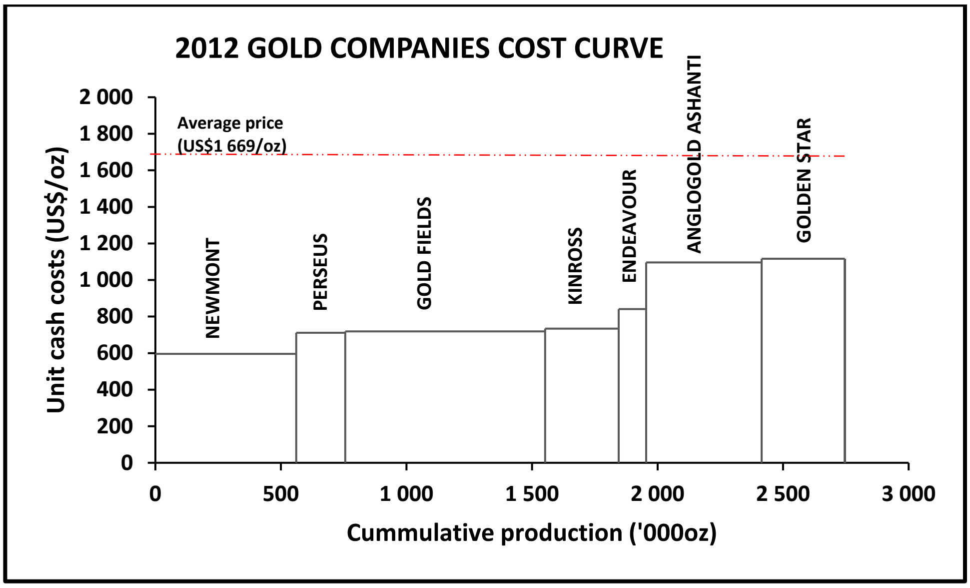

Figure 4.20: Cost curve of gold companies in Ghana for 2012

(Source: AngloGold Ashanti Limited, 2012; Endeavour Mining Corporation, 2012; Gold Fields Limited, 2012; Golden Star Resources, 2012; Kinross Gold Corporation, 2012; Kitco, 2018; Newmont Mining Corporation, 2012; Perseus Mining Limited, 2012)

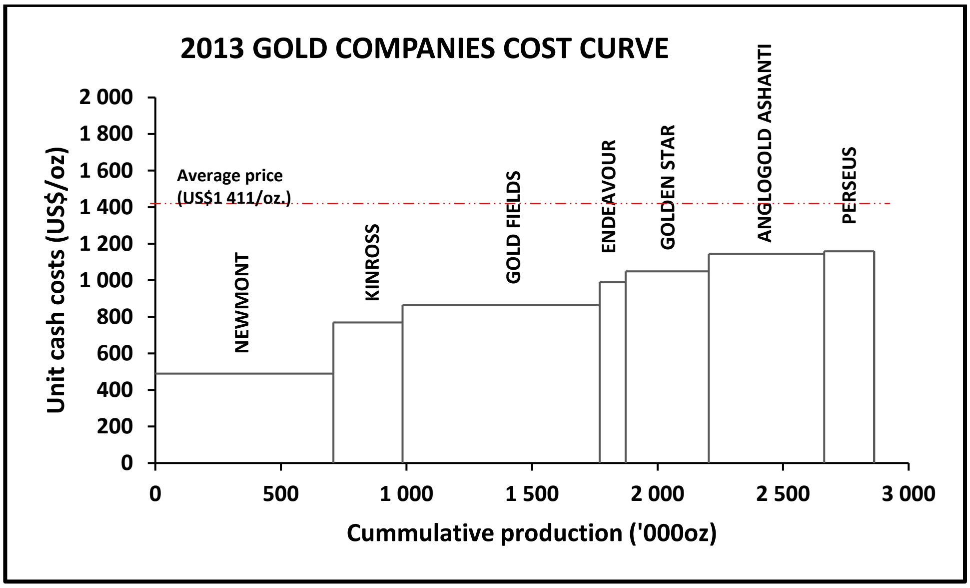

Figure 4.21: Cost curve of gold companies in Ghana for 2013

(Source: AngloGold Ashanti Limited, 2013; Endeavour Mining Corporation, 2013; Gold Fields Limited, 2013; Golden Star Resources, 2013; Kinross Gold Corporation, 2013; Kitco, 2018; Newmont Mining Corporation, 2013; Perseus Mining Limited, 2013)

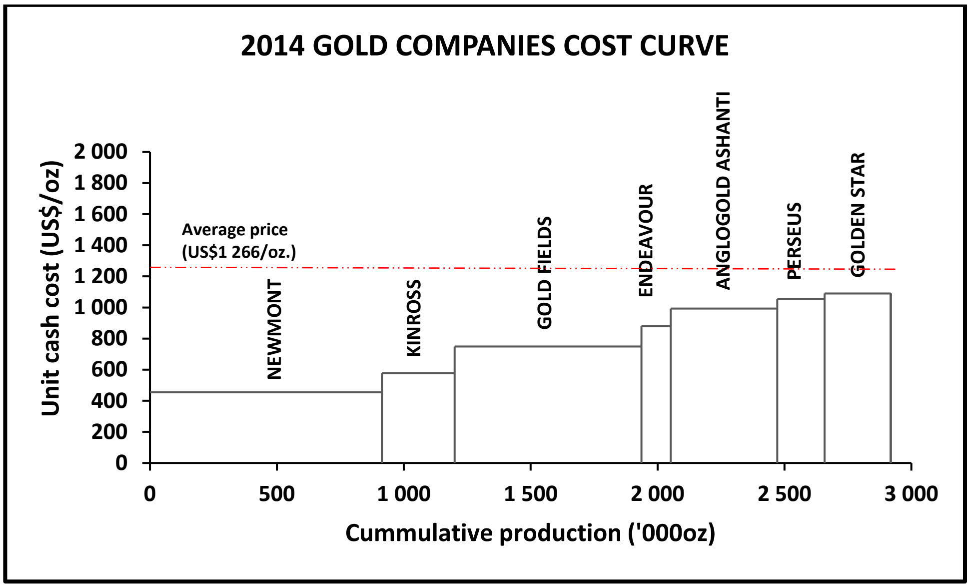

Figure 4.22: Cost curve of gold companies in Ghana for 2014

(Source: AngloGold Ashanti Limited, 2014; Endeavour Mining Corporation, 2014; Gold Fields Limited, 2014; Golden Star Resources, 2014; Kinross Gold Corporation, 2014; Kitco, 2018; Newmont Mining Corporation, 2014; Perseus Mining Limited, 2014)

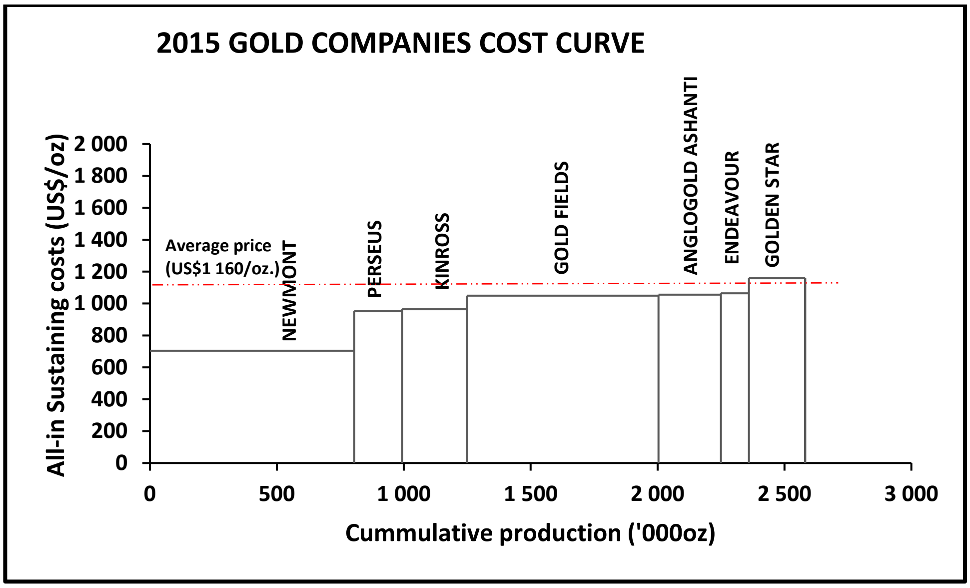

Figure 4.23: Cost curve of gold companies in Ghana for 2015

(Source: AngloGold Ashanti Limited, 2015; Endeavour Mining Corporation, 2015; Gold Fields Limited, 2015; Golden Star Resources, 2015; Kinross Gold Corporation, 2015; Kitco, 2018; Newmont Mining Corporation, 2015; Perseus Mining Limited, 2015)

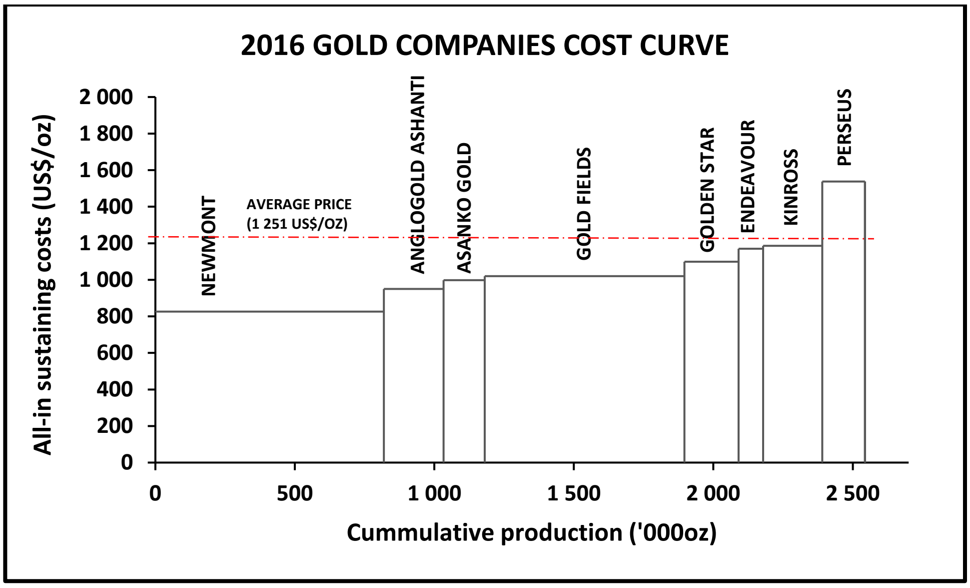

Figure 4.24: Cost curve of gold companies in Ghana for 2016

(Source: AngloGold Ashanti Limited, 2016; Asanko Gold Incorporated, 2016; Endeavour Mining Corporation, 2016; Gold Fields Limited, 2016; Golden Star Resources, 2016; Kinross Gold Corporation, 2016; Kitco, 2018; Newmont Mining Corporation, 2016; Perseus Mining Limited, 2016)

The position of a company on an industry cost curve is a reflection on the aggregate cost performance of the number of mines it owns in the country. In 2007 and 2009, Kinross was the lowest cost gold producing company in Ghana. This changed in 2010, when Chirano started commercial production from its underground mine in addition to existing surface operations Chirano mine. Underground operations are comparatively expensive to operate hence Kinross was never able to regain the position as the lowest unit cost mine.

From 2010 till 2016, Newmont took over as the lowest cost gold producing company in Ghana. Newmont's gold production came only from Ahafo mine from 2007 until 2013 when commercial production started at Akyem mine. These two mines are consistent low cost producer which has been translated to the company level. Ahafo mine has reached maturity hence output started to decline from 2014 due to the depletion of its oxide ores with a consequential increase in unit cash costs. At company level, however, these escalation in unit costs at Ahafo mine has been balanced by low unit costs at Akyem.

Golden Star has consistently been the highest cost gold producing company from 2007 until 2015. Its two mines, Bogoso-Prestea and Wassa are high cost gold producers. Its Bogoso-Prestea mine has consistently been the highest unit cost mine in Ghana. This is due to low recoveries obtained from the extraction and processing of carbonaceous sulphide ores. Additional costs incurred during oxidative pre-treatment do not result in increased gold recoveries due to preg-robbing. Management at Golden Star decided to cease extraction of their sulphide Mineral Reserve from 2016 and rather exploit its free milling gold Mineral Reserves. Recovery rates have increased in 2016, Bogoso-Prestea is in the second quartile and Golden star is no more the highest cost producer of gold in Ghana.

4.11 Cost competitiveness of Ghana's gold mining industry

Figure 4.25 shows a time series graph comparing unit cash costs for Australia, South Africa and Ghana. Data used to construct this graph is shown in appendix 7.17 All-in sustaining costs per ounce were used for the analysis for 2015 and 2016.

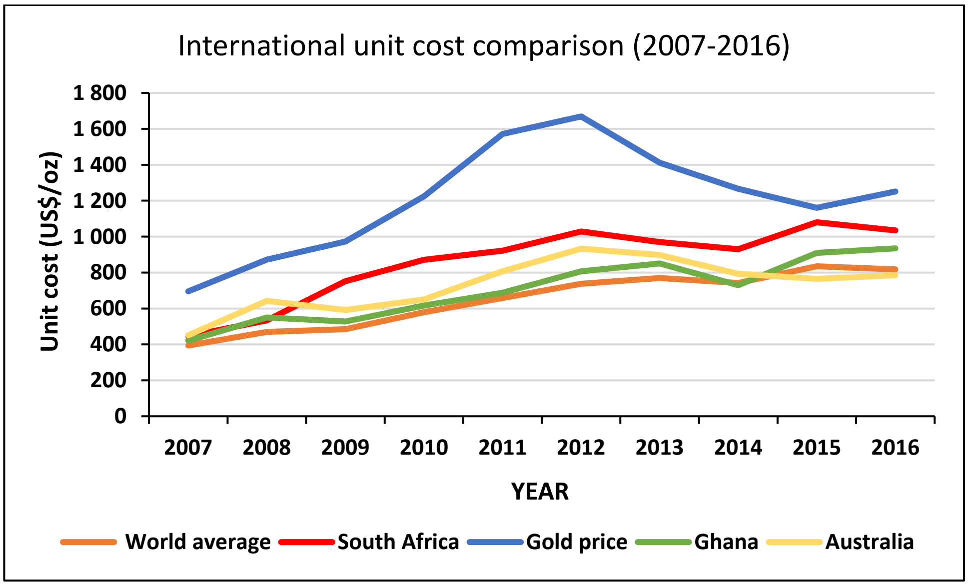

Figure 4.25 International unit cost comparison from 2007-2016

(Source: Adapted from O'Connell, *et al*., 2017)

Australia was the second largest producer of gold in 2016, South Africa was eighth in the world but first in Africa while Ghana was tenth in the world but second in Africa (O'Connell, *et al.*, 2017). Averagely, mines in the three countries have enjoyed healthy profit margins from 2007 to 2016. Costs have also generally escalated annually from 2007 while gold prices also rose rapidly peaking at US$1 669/oz. in 2012. As gold price declined to US$1 411/oz. in 2013, mines in Australia and South Africa succeeded in reducing costs from US$933/oz. to US$898/oz. and US$1 029/oz. to US$980/oz. respectively but costs in Ghana rather increased from US807/oz. to US$851/oz. In 2014, however cost cutting measures manifested in the unit cash costs which reduced to US$730/oz.

In 2008, the average unit cash costs in Ghana's gold mining industry was marginally higher than South Africa's gold mining sector. From 2009 to 2016, average unit cash costs in Ghana's gold mining industry remained lower than average unit cash cost in South Africa's gold mining industry. The primary reason was that about 90% of gold produced in Ghana were from surface mines. Obuasi mine was the only complete underground operation in Ghana while Chirano mine was a hybrid operation. The converse existed in South Africa where over 90% of gold production were from underground operations. South African gold mines are among the deepest in the world reaching depths of up to 4 000 metres (Ernst & Young, 2017). Conventional labour-intensive deep-level underground mines require more energy to haul men and materials to and from the mine face which adds up to operational costs. Rock temperatures at those depths are about 50°C and vertical pressures are around 100MPa (Ernst & Young, 2013). These requires sophisticated ventilation and refrigeration system to maintain temperatures that are conducive to humans.

Labour costs make up 50-60% of production costs for mature labour-intensive conventional deep-level mines in South Africa (Savant, 2012). The frequency and durations of labour agitations and strikes in these labour intensive mines have led to loss of revenue and increased labour costs. Labour costs have increased at a rate of 12% between 2007 and 2012 while revenues of ZAR 350 000 million is lost daily during these stoppages (Ernst & Young, 2017).

52% of gold production output from Australia in 2016 were sourced from underground mines while 30% came from open pit operations (Ulrich & Trench, 2016). The surface operation exploited mainly oxidised ore which are less costly to mine and process as discussed in Chapter 2. Australian underground mines are highly mechanised compared to South African mines. Mechanised underground mines have lower unit costs compared to labour-intensive conventional underground mines. These factors made Australia's gold industry more cost competitive compared to South Africa.

From 2007 to 2014, average unit costs in Ghana's gold sector were lower than average unit cost in Australia's gold sector. However, from 2015 to 2016, average unit cost in Australia's gold sector became lower than average unit costs in Ghana's gold sector and also lower than the world's average unit cost. This was attributed to cost cutting measures implemented in Australia's gold sector which included cuts in employee numbers. Other measures included improved mine planning and mine processes in addition to better partnerships with suppliers (PWC, 2018).

From 2007 to 2016, Ghana's gold sector was more cost competitive compared to South Africa's gold sector. Ghana's gold sector was also more cost competitive compared to Australia's gold sector from 2011 to 2014 but lost that competitive advantage from 2015 to 2016. Despite Ghana's cost advantage, average unit cash costs were always above the world's average. Ghana's gold sector is therefore not cost competitive with regards to producing an ounce of gold. Ghana must emulate Australia which was able to bring average AISC lower than the world's average in 2015 and 2016.

4.12 Chapter summary

Tarkwa mine was the lowest cost gold producer in Ghana in 2007 mainly due to its large production output of 697 000 ounces. After ramping up production from 456 000 ounces in 2007 to 521 000 ounces in 2008, Ahafo mine was the lowest cost producer in 2008. Tarkwa and Ahafo mines benefited from economies of scale due to their large production output. Ahafo mine was the lowest unit cost gold producer from 2010 to 2012 because besides its large output, it processes oxide ores which are easy and less costly to process. Depletion of its oxide reserves led to a decline in production output and an escalation in unit cost in 2015 and 2016. Ahafo mine subsequently moved into the third quartile from the first in 2016. From 2013 to 2016. Akyem mine was the lowest unit cost producer in Ghana due to its large output, low processing costs and the efficiency of new machinery. Bogoso-Prestea mine, on the other hand, was the highest unit cost mine in Ghana from 2007 to 2014. This was mainly due to low recoveries obtained from the processing of carbonaceous sulphide ore even though these ore are more costly to process.

Newmont's Ahafo and Akyem mines were consistently low unit cost producers resulting in Newmont Corporation being a low unit cost company from 2008 to 2016. Newmont benefited from economies of scale, excellent recovery rates and efficiency. On the other hand, AngloGold Ashanti's Obuasi mine and Golden Star's Bogoso-Prestea mines were consistently high unit cost producers. This made Golden Star the highest unit cost gold producing company from 2007 to 2015. Lower unit cost at its Wassa mine could not offset higher unit cost at Bogoso-Prestea mine.

Recovery rate and production output have immense influence on unit cost of mines in Ghana and ultimately the position of the mine on an industry cost curve. Although variation in mill head grade has influence on unit cost for an individual mine, mill head grade has less influence on the position of the mine on the cost curve. This is because most surface mines offset lower grades with large production output. Annual escalation in electricity tariffs has immense effect on unit cost than fuel prices.

Finally, the average unit cost in Ghana's gold mining sector was lower than the average unit cost in South Africa's gold mining industry from 2009 to 2016. Average unit cost in Ghana's gold mining sector was also lower than average unit cost in Australia's gold mining sector from 2007 until 2015 when the reverse happened. Ghana' gold mining sector had a cost competitive advantage over South Africa and Australia from 2009 to 2016 and 2007 to 2014 respectively but lost that advantage to Australia from 2015 to 2016. Throughout the study period, average unit cost in Ghana's gold mining industry was higher than the world's average unit cost, hence Ghana's gold mining industry was not cost competitive.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Chapter overview

This chapter concludes the research study and summarises the research findings. Recommendations are also given to mitigate negative outcomes.

5.2 Conclusions

The mining sector is a major contributor to tax revenues and foreign exchange earnings in Ghana. Gold alone accounts for about 95% of all revenues generated from the export of metals. The decline in gold prices have exposed the high unit cost associated with mining gold in Ghana. AngloGold Ashanti shut down its Obuasi mine in 2016 and laid off 4 312 employees. The Ghana Chamber of Mines has complained about the high cost of mining in Ghana singling out high electricity cost as a major cause.

The aim of this research was to ascertain the cost competitiveness of Ghana's gold mining sector from 2007 to 2016 using industry cost curves. Cost analysis was done because gold mining companies have more influence on costs than on price because their product are fungible. This research was limited to large-scale mines due to the easy availability of verified data from these companies. The period was chosen because it captured a complete gold price cycle. On average, about 70% of gold from Ghana was from large-scale producers. Mining companies selected for the analysis were AngloGold Ashanti Limited, Newmont Mining Corporation, Golden Star Resources Limited, Gold Fields Limited, Kinross Gold Corporation, Perseus Mining Limited, Endeavour Mining Corporation and Asanko Gold Incorporated.

Costs in mining can be differentiated into capital costs and operating costs. Operating costs are either fixed, variable or semi-variable. Summation of cash costs from the mining, processing and general and administration departments of a typical mine make up total cash costs. When total cash costs is divided by total output sold, the outcome is cash costs per ounce. Unit costs are influenced by production output, recovery rate and ore mineralogy, among other factors.

Industry cost curves are graphical representations showing unit costs of individual mines plotted against cumulative production in a ranking order. The unit costs metrics “cash costs per ounce” has been used until the introduction of ‘all-in sustaining costs’ AISC and “all-in costs AIC by the World Gold Council. Using industry cost curves for competitive analysis provides the needed information for strategic planning. This analysis defines the position of a mine or company with respect to other producers within the industry regarding the availability or the lack thereof of margins. Basically a low cost mine is likely to generate sustainable economic rent no matter the prevailing commodity price.

This research used a Microsoft Excel®-based algorithm from Tholana (2012) for constructing industry cost curves. Data consisting of gold ounces sold and unit cash cost per ounce were extracted from the annual reports of gold mining companies. Cost curves were developed from the compiled data for all the mines and companies under consideration from 2007 to 2016. Weighted annual cash cost averages were computed for Ghana and compared with that of South Africa and the world’s average using a time series graph. A regression analysis was conducted to determine the relationship between unit costs and the following production parameters: production volume; mill head grade; recovery rate; electricity prices; and diesel prices. The following subsections are the findings of the research study.

5.2.1 Low unit cost mines and companies

Tarkwa mine was the lowest unit cost gold producer in Ghana in 2007 mainly due to its large output of 697 000 ounces. After ramping up production from 456 000 ounces in 2007 to 521 000 ounces in 2008, Ahafo mine became the lowest unit cost producer in 2008, 2010, 2011 and 2012. Tarkwa and Ahafo mines benefited from economies of scale due to their large output. Additionally, Ahafo mine benefited from exploiting mainly oxide ores which are easy and less costly to process. From 2013 to 2016, Akyem mine was the lowest unit cost producer in Ghana due to its large output, low processing costs and the efficiency of new machinery. Depletion of its oxide Mineral Reserves at Ahafo mine led to a decline in output and an escalation in unit cost in 2015 and 2016. Ahafo mine subsequently moved into the third quartile from the first in 2016. Consistent low unit costs Ahafo and Akyem mines made Newmont Mining Corporation the lowest unit cost company from 2007 to 2016.

5.2.2 High unit cost mines and companies

Bogoso-Prestea mine, was the highest unit cost mine in Ghana from 2007 to 2014. This was mainly due to low recovery rates obtained from the processing of carbonaceous sulphide ore even though these ores are comparatively more costly to process. AngloGold Ashanti's Obuasi mine was also a consistent high unit cost producer because it is an underground mine and used outmoded labour-intensive mining techniques. High unit costs at Bogoso-Prestea mine could not be compensated by lower unit costs at Wassa mine hence Golden Star Resources Limited was the highest unit cost gold producing company from 2007 to 2015.

5.2.3 Drivers of unit cost

Recovery rate and production output had immense influence on unit costs of mines and ultimately the position of the mine on the industry cost curve. High recovery rates and production output reduced unit costs of mining operations and positioned them in the lower cost quartile on the industry cost curve. Mill head grade had less influence on unit costs and the position of mines on the cost curve. This was because most surface operations were able to offset low grades with large production output. Electricity tariffs also had greater influence in unit costs escalation in mining operations than fuel prices.

5.2.4 Ghana's gold mining industry's cost competitiveness

Finally, average unit costs in the Ghana's gold mining sector was lower than South Africa's gold mining sector from 2009 to 2016. This was mainly because Ghana's gold mining industry was dominated by surface mines while South Africa's gold industry was dominated by underground operations. Ghana's gold mining industry had a cost competitive advantage over South Africa's gold mining industry throughout most of the period under review. Average unit costs in Ghana's gold mining industry was also lower than average unit cost in Australia's gold mining sector until 2015 when the reverse occurred. The reverse can be attributed to cost cutting measures such as employee layoffs, improved mine planning and better partnerships with suppliers that were implemented in Australian gold mines. Throughout the study period, average unit cost in Ghana's gold mining industry was higher than the world's average unit cost, hence Ghana was not cost competitive.

5.3 Recommendations

It is recommended that low unit cost gold mines must maintain or increase production output and recovery rates in order to maintain their position on the industry cost curve. High unit cost gold producers must certainly improve recovery rates and increase production output to reduce unit cost and hence improve on their position on the industry cost curve. Mining companies certainly need to build a more comprehensive understanding of their resource base and replenish Mineral Reserves depleted by increased production output if they want to remain profitable.

Gold recovery rates may vary throughout the life of mine (LOM) because mining companies may not be able to test all the variables of the ore types during the metallurgical testing phase of the feasibility study stage. It is essential that no matter how good the recovery rates are during the metallurgical test work, there is still the need to fully analyse and understand the mineralogical composition of the ore body. Geometallurgy should be used to predict processing plant performance throughout the LOM. This can reduce risk and better assess the profitability of mining projects.

The government of Ghana must ensure that investments are made in the energy sector to guarantee the supply of reliable and comparatively cheaper electricity. This is a major step to improve the cost competitiveness of the gold mining sector in the country. On the other hand, mining companies must implement energy saving procedures in addition to finding alternative electricity supply sources.

5.3 Limitations of this research

Although the intentions of this study was to be as comprehensive as possible, there are a few limitations in its scope. The mines included in this research report represents all the large-scale gold mines in Ghana, however, their contribution to total national gold supply has reduced from over 80% in 2007 to approximately 72% in 2016. The rest of the gold is supplied by both legal and illegal small-scale and artisanal mining. This sub-sector is semi-regulated and the availability of data is scarce and cannot be validated.

5.4 Recommendations for future research

This research should be replicated using a larger sample size. The sample size must include possibly all small-scale gold mines in Ghana in order to reflect different geology, mining methods. This should help test accurately the relationship between or the influence of parameters such as mine size, recovery rate and mill head grade on unit cost at a higher confidence level. Now that new cost measurement metrics such as AISC have been adapted and implemented in the gold mining industry, it will be necessary to test the relationship between these metrics and the parameters previously addressed in this research report.

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7 APPENDICES

7.1: Input data for 2007 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production ('000 oz.)
AngloGold Ashanti	Obuasi	464	360
	Iduapriem	497	167
Gold Fields	Tarkwa	333	697
	Damang	473	188
Newmont	Ahafo	376	456
Golden Star	Bogoso	788	120
	Wassa	465	126
Kinross	Chirano	372	127

7.2: Input data for 2008 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production ('000 oz.)
AngloGold Ashanti	Obuasi	636	357
	Iduapriem	625	200
Gold Fields	Tarkwa	494	646
	Damang	629	194
Newmont	Ahafo	408	521
Golden Star	Bogoso	863	170
	Wassa	580	125
Kinross	Chirano	478	121

7.3: Input data for 2009 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production ('000 oz.)
AngloGold Ashanti	Obuasi	630	381
	Iduapriem	516	190
Gold Fields	Tarkwa	488	612
	Damang	635	200
Newmont	Ahafo	444	546
Golden Star	Bogoso	735	186
	Wassa	479	224
Kinross	Chirano	443	183

7.4: Input data for 2010 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production ('000 oz.)
AngloGold Ashanti	Obuasi	744	317
	Iduapriem	666	185
Gold Fields	Tarkwa	573	721
	Damang	660	228
Newmont	Ahafo	450	545
Golden Star	Bogoso	899	171
	Wassa	714	184
Kinross	Chirano	578	89

7.5: Input data for 2011 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production (‘000 oz.)
AngloGold Ashanti	Obuasi	862	303
	Iduapriem	853	199
Gold Fields	Tarkwa	556	717
	Damang	701	218
Newmont	Ahafo	474	566
Golden Star	Bogoso	1 357	141
	Wassa	937	161
Kinross	Chirano	695	262
Endeavour	Nzema	585	80

7.6: Input data for 2012 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production (‘000 oz.)
AngloGold Ashanti	Obuasi	1 187	280
	Iduapriem	955	180
Gold Fields	Tarkwa	673	647
	Damang	918	149
Newmont	Ahafo	596	561
Golden Star	Bogoso	1 243	172
	Wassa	979	159
Kinross	Chirano	734	293
Perseus	Edikan	711	195
Endeavour	Nzema	753	109

7.7: Input data for 2013 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production ('000 oz.)
AngloGold Ashanti	Obuasi	1 406	239
	Iduapriem	861	221
Gold Fields	Tarkwa	816	632
	Damang	1 060	153
Newmont	Ahafo	548	570
	Akyem	248	139
Golden Star	Bogoso	1 361	145
	Wassa	805	186
Kinross	Chirano	769	275
Perseus	Edikan	1 158	199
Endeavour	Nzema	917	104

7.8: Input data for 2014 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production ('000 oz.)
AngloGold Ashanti	Obuasi	1 086	243
	Iduapriem	865	177
Gold Fields	Tarkwa	670	558
	Damang	999	178
Newmont	Ahafo	552	442
	Akyem	364	472
Golden Star	Bogoso	1 180	148
	Wassa	971	113
Kinross	Chirano	578	287
Perseus	Edikan	1 054	186
Endeavour	Nzema	880	115

7.9: Input data for 2015 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production ('000 oz.)
AngloGold Ashanti	Obuasi	1 185	53
	Iduapriem	1 020	193
Gold Fields	Tarkwa	970	586
	Damang	1 326	168
Newmont	Ahafo	892	332
	Akyem	572	473
Golden Star	Bogoso	1 314	114
	Wassa	994	108
Kinross	Chirano	964	256
Perseus	Edikan	952	189
Endeavour	Nzema	1 064	110

7.10: Input data for 2016 gold mines/companies cost curve

Company	Operation	Unit cash costs (US$/oz.)	Production ('000 oz.)
AngloGold Ashanti	Iduapriem	950	214
Gold Fields	Tarkwa	959	568
	Damang	1 254	148
Newmont	Ahafo	1 152	349
	Akyem	584	470
Golden Star	Bogoso	956	90
	Wassa	1 222	140
Kinross	Chirano	1 186	212
Perseus	Edikan	1 538	153
Endeavour	Nzema	1 167	88
Asanko	Asanko	990	148

7.11: Unit cash costs and production output data for gold mines from 2007 to 2016

MINES		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	Unit cash costs (US$/oz.)	464	636	630	744	862	1 187	1 406	1 086	1 185	
AngloGold Ashanti Obuasi	**Total production ('000oz.)**	360	357	381	317	303	280	239	243	53	
	Unit cash costs (US$/oz.)	497	625	516	666	853	955	861	865	1 020	950
AngloGold Ashanti Iduapriem	**Total production ('000oz.)**	167	200	190	185	199	180	221	177	193	214
	Unit cash costs (US$/oz.)	333	494	488	573	556	673	749	670	970	959
Gold Fields Tarkwa	**Total production ('000oz.)**	697	646	612	721	717	647	632	558	586	568
	Unit cash costs (US$/oz.)	473	629	635	660	701	918	1 118	999	1 326	1 254
Gold Fields Damang	**Total production ('000oz.)**	188	194	200	228	218	149	153	178	168	148
	Unit cash costs (US$/oz.)	376	408	444	450	474	596	548	552	892	1 152
Newmont Ahafo	**Total production ('000oz.)**	456	521	546	545	566	561	570	442	332	349
	Unit cash costs (US$/oz.)							248	364	572	584
Newmont Akyem	**Total production ('000oz.)**							139	472	473	470
	Unit cash costs (US$/oz.)	788	863	735	899	1 357	1 243	1 361	1 180	1 314	956
Golden Star Bogoso-Prestea	**Total production ('000oz.)**	120	170	186	171	141	172	145	148	114	90
	Unit cash costs (US$/oz.)	465	580	479	714	937	979	805	971	994	1 222
Golden Star Wassa	**Total production ('000oz.)**	126	125	224	184	161	159	186	113	108	104
	Unit cash costs (US$/oz.)	372	478	443	578	695	734	769	578	691	975
Kinross Chirano	**Total production ('000oz.)**	127	121	183	89	262	293	275	287	256	212
	Unit cash costs (US$/oz.)						711	1 158	1 054	952	1538
Perseus Edikan	**Total production ('000oz.)**						195	199	186	189	153
	Unit cash costs (US$/oz.)					629	841	989	880	1 064	1 170
Endeavour Nzema	**Total production ('000oz.)**					80	109	103	115	110	88
	Unit cash costs (US$/oz.)										998
Asanko Gold	**Total production ('000oz.)**										148

7.12: Mill head grades and recovery rates for gold mines from 2007 to 2016

MINES		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	Mill head grade (g/t)	4.4	4.4	5.2	5.2	4.8	4.8	4.9	1.7	1.5	
AngloGold Ashanti Obuasi	**Recovery rate (%)**	79.2	78.4	82.4	85.4	85.4	85.4	85.4	85.4	85.4	
AngloGold Ashanti	**Mill head grade (g/t)**	1.9	1.8	1.7	1.7	1.4	1.4	1.4	1.1	1.3	1.3
Iduapriem	**Recovery rate (%)**		93.0	95.0	95.0	96.0	95.5	95.0	95.0	95.0	95.0
	Mill head grade (g/t)	1.0	1.2	1.1	1.0	1.2	1.2	1.3	1.3	1.4	1.3
Gold Fields Tarkwa	**Recovery rate (%)**			90.0	90.0	92.0	90.2	90.2	97.3	96.8	97.0
	Mill head grade (g/t)	1.1	1.3	1.2	1.3	1.5	1.3	1.4	1.5	1.5	1.1
Gold Fields Damang	**Recovery rate (%)**		93.8	93.1	93.3	91.9	90.2	89.2	91.0	91.0	91.9
	Mill head grade (g/t)	1.9	2.3	2.3	2.4	2.4	2.3	2.4	1.9	1.8	1.6
Newmont Ahafo	**Recovery rate (%)**		89.7	87.2	86.1	89.8	92.1	94.0	92.7	89.6	90.3
	Mill head grade (g/t)							2.4	1.9	1.8	1.6
Newmont Akyem	**Recovery rate (%)**							92.5	91.7	90.8	91.7
	Mill head grade (g/t)	2.3	2.8	2.8	2.8	2.6	2.4	2.0	1.8	2.4	2.2
Golden Star Bogoso	**Recovery rate (%)**	52.1	66.5	70.7	65.7	69.8	71.2	68.7	70.3	67.5	83.9
	Mill head grade (g/t)	1.2	1.3	2.8	2.8	2.0	2.1	2.3	1.4	1.5	1.3
Golden Star Wassa	**Recovery rate (%)**	92.0	93.6	95.3	94.7	94.3	94.6	94.5	92.7	93.4	93.6
	Mill head grade (g/t)	2.2	1.9	2.3	2.3	2.5	2.9	2.7	3.1	2.5	2.1
Kinross Chirano	**Recovery rate (%)**	90.3	91.8	90.4	91.3	91.6	93.0	93.8	91.9	90.6	91.4
	Mill head grade (g/t)						1.5	1.2	1.0	1.0	0.9
Perseus Edikan	**Recovery rate (%)**					83.5	83.3	84.3	87.9	83.1	83.0
	Mill head grade (g/t)					1.7	1.8	1.9	2.5	2.2	1.9
Endeavour Nzema	**Recovery rate (%)**								90.0	87.0	83.0
	Mill head grade (g/t)										2.0
Asanko Gold	**Recovery rate (%)**										93.5

7.13 Input data for 2014 gold mines cost curve

Mines	Total production ('000 tonnes milled)	Unit cash cost (US$/tonne milled)
Newmont Akyem	7 731	23.2
Gold Fields Tarkwa	13 360	27.0
Endeavour Nzema	1 587	51.4
AngloGold Ashanti Iduapriem	4 900	31.2
Newmont Ahafo	7 000	36.0
Golden Star Wassa	2 629	41.7
Gold Fields Damang	4 040	44.0
Golden Star Bogoso	3 920	44.5
Perseus Edikan	6 578	47.0
Kinross Chirano	3 458	48.0
Anglo Gold Ashanti Obuasi	2 200	120.0

7.14: Input data for 2015 gold mines cost curve

Mines	Total production ('000 tonnes milled)	Unit cash cost (US$/tonne milled)
Gold Fields Tarkwa	13 500	25.0
Endeavour Nzema	1 783	43.3
Perseus Edikan	6 582	27.0
Newmont Akyem	7 250	29.2
Newmont Ahafo	6 640	31.0
AngloGold Ashanti Iduapriem	4 700	40.9
Goldfields Damang	4 290	43.0
Golden Star Bogoso	2 930	43.1
Golden Star Wassa	2 495	43.2
AngloGold Ashanti Obuasi	1 000	51.0
Kinross Chirano	3 492	51.5

7.15: Input data for 2016 gold mines cost curve

Mines	Total production ('000 tonnes milled)	Unit cash cost (US$/tonne milled)
Perseus Edikan	6 350	120.0
Endeavour Nzema	1 761	42.7
Gold Fields Tarkwa	13 600	25.0
Newmont Akyem	8 420	27.9
Kinross Chirano	3 458	54.8
Gold Fields Damang	4 270	32.0
Golden Star Wassa	2 622	33.5
AngloGold Ashanti Iduapriem	5 100	38.0
Asanko Gold	2 455	39.9
Newmont Ahafo	7 300	43.1
Golden Star Bogoso	1 500	47.6

7.16: Electricity tariffs and diesel prices in Ghana from 2007 to 2016

(Source: Energy Commission. 2016)

Year	Electricity price (US$/kWh)	Diesel price (US$/L)
2007	0.14	1.00
2008	0.16	1.07
2009	0.14	0.73
2010	0.18	0.82
2011	0.19	1.01
2012	0.16	0.97
2013	0.18	1.06
2014	0.20	1.02
2015	0.19	0.81
2016	0.26	0.81

7.17: Gold prices and country average unit costs from 2007 to 2016

(Source: O'Connell, *et al*., 2017)

YEAR	Gold price (US$/oz.)	Average unit cost (US$/oz.)			
		World average	**South Africa**	**Australia**	**Ghana**
2007	695.4	394	446	451	421
2008	872.0	470	534	642	550
2009	972.4	485	752	592	528
2010	1 224.5	579	871	650	617
2011	1 571.5	658	922	807	688
2012	1 669.0	738	1 029	933	807
2013	1 411.2	770	970	898	851
2014	1 266.4	742	930	793	730
2015	1 160.1	835	1 080	765	910
2016	1 250.7	818	1 035	785	935