COST OF ELECTRICITY LOAD SHEDDING TO MINES IN ZIMBABWE: DIRECT ASSESSMENT APPROACH

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ABSTRACT:

Zimbabwe's mining sector has been hit hard by electricity load shedding from the power utility. Load shedding was seen as a solution to the inability of power utility to supply electricity to meet demand. Electricity supply problems has so many cause and some of which are; inability to expand generation capacity, aging equipment, droughts, cost coal supply to thermal plants, vandalism and political disturbances. Mines flooded as a result poor pumping of water outside the tunnels and mine shafts, and also lost productive hours of production. The researchers applied the direct assessment approach to estimate the cost of load shedding. A survey method was adopted for the mines as they are scattered. A questionnaire was opted as a research instrument and was administered face to face to mine captains. The results revealed that low capacity mines incurred higher load shedding cost compared to high capacity mines. It is also seen that high valued mineral mines (gold, diamond and platinum mines) incurred high outage cost as compared to low valued mineral mines (vermiculite, graphite and phosphate). From the study it can be concluded that electricity load shedding resulted in high cost to mining sector in Zimbabwe. It is recommended that the power utility should increase power supply to minimise the load shedding and cost of load shedding.

KEY WORDS: Load shedding, electricity supply problems, mining sector, expand generation capacity, cost of load shedding, direct assessment approach.

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1. INTRODUCTION:

Zimbabwe's Mining sector has been recovering from the plunging time of hyperinflation and low world prices. Zimbabwe has not been able to solve the electricity crisis problem. Zimbabwe is endowed with mineral wealth, which has been unsuccessfully exploited for economic development of the country (Confederation of Zimbabwe Industries (CZI) 2009). The range of minerals includes gold, coal, nickel, platinum, diamond, chrome and cobalt, and others. Gold, diamonds and platinum are notably Zimbabwe's foreign currency cash cows. However, the exploitation of these minerals has been hampered by persistent electricity load shedding.

Mining takes the third position in terms of GDP contribution at about 12.7 percent and is the second foreign currency earner (ZIMSTATS 2009).This significant contribution to GDP and economic activities of the economy explains why mining is a highly regulated sector. The growth in the mining sector has been driven by the key sub-sectors, including platinum group metals (24%), gold (77%), chrome (147%) and coal (40%) from the previous year - 2008 (Chamber of Mines of Zimbabwe 2010). The diamond sector is expected to become a significant contributor going forward if the disputes with KPCS are sorted out (Chamber of Mines of Zimbabwe 2010).

The key legislation governing this sector is the Mines and Minerals Act (Chapter 21:05), the Minerals Marketing Corporation of Zimbabwe Act (Chapter 21:04) and the Chamber of Mines of Zimbabwe. The said legislation provide for the licensing, exploration and marketing of minerals in Zimbabwe.

Zimbabwean government acknowledges the importance of the mining sector to the socio-economic development of the country. Currently, the sector employs on average, 55000 people formally per annum (ZIMSTATS 2009; CZI 2009 and Chamber of Mines of Zimbabwe, 2010). The figure has been higher than this before but due to downturn of global market prices, world recession and other problems domestically such as political environment and power outages; the sector is not spared but to cut employment (CZI 2009). Mining is particularly susceptible to power quality issues (Bert *et al*. 2006). Many mine sites are remotely located with respect to grid feeder lines (Ministry of Mines 2009). Therefore, they have their direct connection using own transformers (ZESA 2009). This makes it easier to treat mines independently.

The objective of the study is to estimate cost of load shedding to the mining sector in Zimbabwe. Electricity is demanded greatly for mining operations. Continuous load shedding make lives of mining labourers to be on danger. The researchers proposed a survey framework to elicit cost of outages. The study is organised as follows: background of the study, literature review, methodology, survey administration, analysis of data and presentation, conclusion and recommendations.

2. BACKGROUND:

2. 1 The Zimbabwean Problem

Power shortages in Zimbabwe are not a problem for mines only but for the whole nation. The source of this problem is known to all and sundry.

The unprecedented meltdown of Zimbabwe's economy can easily be traced to self-engineered political instability by the present government. Subsequently, the roots of political instability further led to economic mismanagement and corruption in the economy. When in November 1997 it was announced that war veterans were to be given unbudgeted payments of magnitude which threatened fiscal targets, external investors bolted out of the Zimbabwe Stock Exchange and domestic market foresaw an imminent devaluation the Zimbabwe dollar crashed by almost a fourth of its value in local currency terms and it has been sliding by the day since that time. This proved to be the start of real crisis of management of the economy.

By the end ofe 1999 the Zimbabwe economy was already in a severe macroeconomic crisis: GDP had fallen to below two percent, inflation had average 58.5 percent and exports had stagnated, forcing sharp contraction of imports. The government pursued a political agenda instead of formulating an agenda to tackle this downward tumble which further impacted negatively on the economy.

From February 2000 the government of Zimbabwe voluntarily abrogated the rule of law by allowing farm invasions, political harassment and murders. The underlying causes of Zimbabwe's economic crisis had started, with its political roots embedded in two main factors:

- Economic activity disruptions as a result of state-sponsored lawlessness; and

- Brushing aside decisions of the law courts by the sitting government.

This clearly undermined business confidence, affected current output and decimated investment, causing fuel shortages, accumulation of arrears in international payments and an increase in the budget deficit.

The government has refused to acknowledge the importance of the environment under which economic progress takes place, and that any improvement of macroeconomic management, investments, liberalization of markets and trade and widening of the space for the private sector activity have to be invariably underpinned by good governance and civic peace

Thus from 1997 the one party government adopted a total irresponsible politically driven economic management system that finally culminated in the 2000 illegal farm invasions and violent disruptions of economic activities that have proved that such venality leads to unsustainable and irretrievable economic downfall of the economy.

Zimbabwe is now being ostracized by her major traditional trading partners. While there are no explicit measures that are being imposed by regional partners the Southern Africa Development Community (SADC), The common Market for East and Southern Africa (COMESA) and the African Union (AU) Zimbabwe has been effectively isolated from many international regional pacts currently enjoyed by other countries in the region. Poor governance and political instability affected domestic electricity production and electricity import facilities. Zimbabwe was cut from the Southern African Power Pool (SAPP) grid due to non-payment and problems within other members of the group.

2.2 Electricity sources in Zimbabwe

ZESA Holdings is the nucleus of the generation, transmission and distribution of electricity in Zimbabwe. Zimbabwe has five major power stations, with a total capacity of 1240 MW (ZESA 2007). These facilities do not meet electricity demand. Electricity generation in Zimbabwe is mainly from coal and hydro plants, with a capacity of 1240 MW, while the Kariba hydropower plant generates 780 MW as shown in table 1 (ZESA 2009).

Table 1: Power Station in Zimbabwe

Station	Plant type	Capacity (MW)	Available Capacity (MW)
Kariba	Hydro	780	740
Hwange	Coal	460	460
Harare	Coal	0	0
Bulawayo	Coal	0	0
Munyati	Coal	0	0
Total		1240	1240

Source: ZESA (2009)

In a bid to solve the problem of power shortages, the country resorted to importation. Zimbabwe used to import 35% of its electricity from neighbouring countries, including the DRC, Mozambique and Zambia.

Table 2: Zimbabwe Power Imports

COUNTRY	Interconnection Voltage kV	Maximum capacity (MW)	Available capacity (MW)
Mozambique	300	300	300
South Africa	0	0	0
Zambia	100	50	50
DR Congo	100	100	100
Botswana	0	0	0

Source: ZESA (2009)

From table 2 it can be seen that the country is not importing much resulting in wider gap between demand and supply. Under capacitated domestic production and lack of imports had created shortages which result in power outages through planned or unplanned load shedding.

2.3 Load Shedding

Load shedding started as early as 1997 (Kayo 2001). Generation plant availability started to decline. Total systems losses have averaged 11% in 1997 (ZESA 2007). The Zimbabwean dollar started depreciating against major currencies. Since over 70% of ZESA are imports of foreign currency related, proper plant, transmission and distribution equipment maintenance was impossible (ZESA 2006). Consequently, ZESA was exposed to foreign exchange fluctuations and also was ill-equipped to manage this risk because of government controls on pricing and the end result was that the tariff had been eroded by the fluctuations (Kayo 2001). ZESA relied much on government support financially to manage the situation at the least minimum load shedding to the consumers. ZESA's costs of operations have increased considerably, particularly those related to payment for import of power in foreign currency and servicing of foreign debt (ZESA 2006).

Serious electricity load shedding started in 2000 soon after the land reform program in Zimbabwe (Kayo 2001). The country was starved of foreign currency required to meet importation of fuel and electricity (Ministry of Energy and Power Development 2005). Foreign suppliers demanded advance payment before electricity is supplied. Foreign currency crisis incapacitated importation of spare parts for plant maintenance. Cost of transporting coal from Hwange (coal mine) to Bulawayo, Munyati and Harare Thermal Power Stations (TPSs) and high maintenance cost to these TPSs resulted in decommissioning of the three TPSs. The TPSs used to contribute (Bulawayo 370MW, Harare 200MW and Munyati 100MW) to the grid (ZESA 2006).

Decommissioning of TPSs worsened the supply of electricity in 2005 when total generation falls below 50% due to 2005/2006 drought (Ministry of Energy and Power Development 2005). The supply was constrained whereas demand was growing high from growth in urban households, rural and growth point electrification (ZESA 2007). In 2006, Zimbabwe was blackmailed for political reasons, suffered foreign currency deficits, tight economic sanctions, hyper-inflation, coal mine squabbles and high brain drain which further worsens power generation problems (ZESA 2006).

Even though Zimbabwe is well networked in the Southern Africa, pressure amounted to foreign suppliers specifically South Africa due to its high domestic demand, Zimbabwe was disconnected from ESKOM supplies in 2007 (ZESA 2007). The problem is threatening the whole region; Zambia is also experiencing the power cuts. Imports from Zambia, Democratic Republic of Congo and Mozambique were cut due to payment problems. ESKOM has converted the debt of electricity to a loan in order to cover its expenses (ZESA 2007). Zimbabwe has to depend solely from its on domestic generation and the guaranteed 100MW from Mozambique.

Zimbabwe faced transmission, distribution and supply infrastructural problems and the west in 2007 due to vandalism. The Electricity Amendment Bill (Number 17) of 2007 stated that vandalism is becoming worse and stiffer penalties need to be implemented to those caught on the wrong side of the law. ZESA technicians and engineers also blamed the poor quality transformers and related equipment being acquired (ZESA 2009). The performance of these equipment resulted in high levels of network electricity losses of 17% in 2009. Maintenance was and is still a big issue in ZESA, qualified engineers, artisans and technicians are leaving for neighbouring countries, with the highest loss in 2007 of eighty (80) engineers and artisans (ZESA 2008).

The generation of electricity in 2009 was at 55% of the potential capacity (ZPC 2009). To meet local demand the rest had to be imported (ZESA 2009). Total electricity supply fell well below demand. To manage the load, the power utility provider resorted to planned and unplanned load shedding. The supply of electricity in Zimbabwe depends on weather conditions because the latter affects water levels for electricity generation at the Kariba Hydro Power Station (HPS) and reliability of coal supply to Hwange thermal power station (TPS). The latter consumes about 6 000 to 9 000 tonnes of coal per day (ZESA 2009).

Due to predictability of peak demand per day and shortages of electricity supply to meet demand, ZESA drafted a load shedding programme for its customer sectors showing the times they would be cut off from power supply (Table 3). The load shedding time table shows the times that consumers would be shed off from the national grid supply.

Table 3: Load shedding program for 2009 and beyond

Customer category	PERIOD			
	Morning Time (0400-1030 hrs)	**During The Day (1030-1700hrs)**	**Evening Times (1700-2100hrs)**	**Night Time (2100-0400hrs)**
Industrial and mining (24 hour)	ON (reduced demand by 50%)	ON	ON (reduced demand by 50%)	ON
Industrial-12 hour	OFF	ON	OFF	OFF
Commercial (CBD)	OFF	ON	OFF	ON
Agricultural	OFF	ON/OFF	OFF	ON
Domestic: Urban	ON	ON/OFF	ON	ON
Domestic: Rural	OFF	ON/OFF	OFF	ON

Notes: 1. Load shedding applies to all areas in the country; 2. The programme applies for all days of the week; 3.Essential services (water works, sewers, hospitals and CBD of Harare and Bulawayo) will not be load shed; 4. Business customers on residential feeders follow domestic time table; 5. Growth points and small towns follow rural timetable; 6. Industrial customers to be switched off if they do not reduce demand during off peak.

Source: ZESA (2009)

3. LITERATURE REVIEW:

The electricity outages (load shedding) have attracted interest from various scholars over the last three decades (Ukpong 1973; Ontario Hydro 1980; Bernstein & Heganazy 1988; Lee & Anas 1992; Tierney 1997; Beenstock *et al*. 1998; Primen 2001; Rose & Lim 2002; Eto, Divan &

Brumsickle 2004; Eto *et al*. 2001; Rose *et al.* 2004; Adenikinju 2005; Bose, Shukla, Srivastava & Yaron 2006). The general conclusion has been that power outages cause significant direct and indirect costs. Empirical evidence links the scale of these costs to variables such as electricity consumption per capita and the number of hours with/without electricity per day. Load shedding is an organised form of electricity outages (Eto, Divan & Brumsickle 2004).

Improved energy supply reliability after the 1950s coincided with rising global economic growth (World Bank 2004:72). This chapter surveys the global and African literature relevant to electricity outages. Energy is a prerequisite for economic growth and development (Ebohon 1996; Rosenberg, 1998; Templet 1999; Boston Institute for Development Economics 2006; Foster & Steinbuks 2008; Calderon 2008). Energy has been shown to be equally as important in production as other factors such as labour, land and capital (European Commission, 1993). The relationship between economic growth and electrical power demand has been found to be close (European Commission 1993; Rosenbergy 1998; Andrews-Speed and Dow, 2000; Ferguson, Wilkinson & Hill 2000). Energy consumption is positively correlated to economic growth (Akinlo 2008).

A study by Ferguson *et al*. (2000) that compared correlations between electricity consumption/capita with those between total primary energy supply/capita and GDP per capita showed that there is a stronger correlation between electricity use and wealth creation than there is between total energy use and wealth. The study also shows that in wealthy countries an increase in wealth over time correlates with an increasing proportion of energy used in the form of electricity.

In eleven Sub-Saharan, African countries energy consumption is positively correlated to economic growth (Akinlo 2008). A study on the impact of energy consumption on economic growth in Taiwan, using data for the period 1955-2003, found evidence of a level-dependent effect between the two variables, energy consumption and economic growth (Lee & Chang 2006). A study on the challenges of emerging Asia attributed the accommodation of increased energy consumption as a key contributor to 'miracle growth' (Asian Development Bank (ADB) 1997). Increased energy consumption is correlated with increased life expectancy, improved health, decreased mortality rates and improved productivity since the 1940s.

A World Bank study (1998) found that improved energy supply contributed approximately 0.8 to 1.9 percent of the accelerated annual growth of the Asian Tigers. Increasing electricity use has also been a foundation for all productivity improvements in developed countries and it now fuels the new digital economy (Pineau 2002). Electricity facilitates an array of end-use equipment, including those for cooking, cooling, lighting, safe storage of food, clean water and sanitation (Ikeme & Ebohon 2005).

4. METHODOLOGY:

The methodology of the direct assessment approach uses direct loss by which it estimates the cost of power outages through lost production, lost materials and lost time. The direct assessment method is an economic appraisal tool that estimates the cost of power outages by allowing electricity consumers to express their losses in monetary terms (Bose *et al.* 2006:1439). The approach is based on the principle that the lost production, materials and time in each productive sector, or lost goods during an outage (load shedding), can be estimated directly, and this can be aggregated to a total (de Nooij*et al.* 2006:284). The approach relies on the individual respondent's self assessment method of valuing the cost of electricity outage. Direct cost estimations, such as the direct financial evaluation approach, the gross economic indices approach (GNP divided by total electricity consumption), and the case study approach have been frequently employed in the past (Pollitt, Jamasb & Yu 2006).

In order to estimate the cost of load shedding by the direct assessment, it is important that total value lost by consumers due to load shedding is ascertained by summing all direct cost experienced during load shedding. The direct costs incurred by firms go beyond production loss or output loss. In addition to output loss cost, other direct costs such as materials destruction cost (in stock), labour cost (payment of idle labourers and cost of overtime and bonuses to meet production and orders), damage to equipment cost, restart cost, time or opportunity cost per load shedding are part of the load shedding cost.

$$TDC_i = OL_i + MC_i + LC_i + EDC_i + RC_i \quad (1)$$

Where: TDC_i is the total direct cost for the ith consumer; OL_i is cost of lost output (lost leisure for households); MC_i is the material destruction cost; LC_i is labour cost; EDC_i is the equipment damage and maintenance cost as a result of load shedding; and RC_i is restart cost.

From equation 1 cost per unit of electricity (kWh) lost can be estimated as:

$$OC_i = \frac{TDC_i}{kWhlos_i} \qquad 2$$

Where: OC_i is the cost per kWh lost and $kWhlos_j$ are the total units of electricity (kWh) lost or unsupplied due to load shedding.

5. ADMINISTERING MINING SURVEY:

5.1 Questionnaire Design

The questionnaire used in the mining sector load shedding cost survey was designed in consultation with focus groups i.e. Ministry of Mines, Minerals Marketing Corporations of Zimbabwe (MMCZ), ZESA, Ministry of Energy and Power Development and Mining captains. It was deemed important to understand the electricity load shedding impacts to mines, how they experienced the load shedding, the frequency of the load shedding, the time of the load shedding, the length of load shedding, losses they incur as a result of load shedding and alternative sources available common to mines. The questionnaire was therefore, drawn up with these aspects in mind.

The final questionnaire consisted of two parts. The first part contained questions about the mine considerations i.e. mineral extracted, location, hours of operation, hours of load shedding and the frequency of load shedding, uninterrupted power supply and advance warning arrangement, ranking of electricity infrastructure and other publicly provided infrastructures. The second part included the direct cost estimation of load shedding. This part solicited actual load shedding cost: level of operation affected by load shedding, monthly production losses, damage to equipment, labour cost of idle staff, labourers employed and those laid off and deterred investment as a result of power load shedding. Before the questionnaire was finalised, it was tested in smaller focus groups followed by a final survey study of personally administered questionnaires to 120 respondents.

5.2 Population

The survey population includes all mines connected to the utility grid. The total population for mine consumers is shown in Table 4.

Table 4: ZESA mining electricity supply capacity classification

Tariff Class	Total Number of Customers
Low Capacity (LC) Mining	123
High Capacity (HC) Mining	48
TOTAL	**171**

Source: ZESA (ZEDTCO), (2009)

5.3 Sampling Design and Sample Size

Multistage sampling design was adopted for the mining electricity load shedding cost estimation survey. Mines were first stratified into low capacity (LC) and high capacity (HC) mines as per utility electricity supply capacity classification as shown in Table 4. The second stratification was in terms of the mineral exploited, 14 minerals highly mined in Zimbabwe were considered. These minerals include gold, platinum, limestone, iron, vermiculite, phosphate, chrome, nickel, diamond, coal, lithium, graphite, black granite and asbestos.

The selection of the type and units for the survey was based on secondary data on electricity purchased, sanctioned load, electricity generated by captive units and also utility recommendations. The sample size was reached by applying the Cochran (1977) approach to sample determination. This approach makes an assumption that there is normal distribution of the estimated sample size. The sample size estimates for the selected mine electricity consumers are shown in Table 5.

Table 5: Sample sizes based on electricity tariff classification

Tariff Class	Number of Customers	Sample size of respondents	Sample size as percentage of population
Low Capacity Mining	123	85	69%
High Capacity Mining	48	35	73%
TOTAL	**171**	**120**	**70%**

Table 5 shows close link between electricity consumption through tariff classification from the utility (ZESA) and the number in the sample. This suggests that the sample may be considered an acceptable representation of the population.

5.4 Data Collection and Analysis

The actual mining survey was administered by the researchers and research assistants, who were trained on administering the questionnaires. Personally administered questionnaire survey was used to collect the data in order to reduce mis-information biases. The respondents were informed of the purpose of the research in advance through telephone or email. The data from the questionnaires was cleaned, coded, collated as Excel spreadsheets and Statistical Package for Social Scientists (SPSS) 13 and Eviews 6 were used for data analysis.

6. ANALYSIS OF DATA:

6.1 Descriptive Analysis

A total of 74 out of the 120 questionnaires (62%) were successfully collected and analysed. The distribution of the mines by electricity supply capacity, scale of operation, location and mineral mined is shown in Table 6. For the purpose of this survey, mines connected to voltage supply of below 300kVa were regarded as Low Capacity (LC) and those above 300kVa as High Capacity

(HC); and mines employing less than 150 were classified as small scale, between 150 and 450 medium scale and above 450 large scale. Table 6 shows 41.9 percent are HC mines and 58.1 percent are LC mines. About 40.5 percent are small scale mines, 27.1 percent medium scale and 32.4 percent large scale. The survey reported that most mines are located in other areas (55.4%) and others around cities or towns. The mines selected spread across mineral type extracted, gold being the highly mined mineral (43.2%) and vermiculite and graphite are the lowest (1.4%).

Table 6: Respondents distribution by power supply capacity, mineral, scale and location

Item of Analysis	Consideration	Frequency	Percentage
Power Supply Capacity	High Capacity (HC) mines	31	41.9
	Low Capacity (LC) mines	43	58.1
Scale of Operation	Small Scale (SS)	30	40.5
	Medium Scale (MS)	20	27.1
	Large Scale (LS)	24	32.4
Location	Harare	7	9.5
	Bulawayo	1	1.4
	Mutare	2	2.7
	Kwekwe	10	13.5
	Kadoma	7	9.5
	Chegutu	3	4.1
	Chinhoyi	3	4.1
	Other areas	41	55.4
Mineral Mined	Gold	32	43.2
	Platinum	5	6.8
	Limestone	5	6.8
	Iron	5	6.8

Vermiculite	1	1.4
Phosphate	3	4.1
Chrome	9	12.2
Nickel	1	1.4
Diamond	3	4.1
Coal	2	2.7
Lithium	2	2.7
Graphite	1	1.4
Black Granite	3	4.1
Asbestos	2	2.7

The crisis of electricity supply to the mining sector and economy can be seen in Table 7, 8, 9 and 10 which confirms the load shedding problem. On average, mines experienced load shedding 5 times a week and the load shedding times ranged from a minimum of 1 to a maximum of 7 per week (see Table 7). About 41.9% mines surveyed showed they experienced 5 load shedding per week, 8.1% mines reported they experienced load shedding daily and also 8.1% mines reported they experienced a single load shedding per week. No mine has reported zero load shedding per week reflecting that all mines were exposed to the power problem although frequencies differ.

Table 7: Frequency of weekly load shedding experienced by mines

Number of load shedding per week	Frequency	Percentage
1	6	8.1
2	2	2.7
3	11	14.9
4	9	12.2
5	31	41.9
6	9	12.2
7	6	8.1

Table 8: Average duration of load shedding in hours reported by mines

Average load shedding duration (hours)	Frequency
0.5	2
1	4
2	2
4	10
5	6
6	10
7	14
8	8
9	8
10	8
12	2

The average hours of load shedding by mines ranged from a minimum of ½ an hour per load shed for one of the mines to 12 hours for another mine (Table 8). About 14 mines experienced average length of 7 hours, 2 mines reported that they experienced maximum average duration of 12 hours per load shed and also 2 mines reported that they experienced minimum average duration of ½ an hour load shed. This reflects that mines were exposed to different load shedding of different duration. Again this has a different effect on how each mine operations is affected by load shedding. The frequency and duration of load shedding differs depending on whether there is an arrangement with the power utility by the mine for an uninterrupted power supply or not.

Table 9: Availability of uninterrupted supply and warning arrangement with power utility

	Frequency	Percentage	Average	Average outage

			weekly outages	duration (hours)
Mines without arrangement	54	73.0	6	8
Mines with arrangement	20	27.0	2	2

Table 9 showed that 27% surveyed mines, reported they have an arrangement with the power utility for an uninterrupted power supply, while 73% reported that they do not have. Those having an arrangement have fewer load shedding per week than those without. Also, they have lesser duration of load shedding than those without. The arrangement was signed for uninterruptive power supply contracts and advance warning between mines and the power utility where by mines pay their utility bills in foreign currency for ZESA to pay for power imports. However, all mines acknowledged that the arrangement for an uninterrupted supply and advance warning could not be achieved 100 percent with the prevailing worsened electricity supply problems.

Table 10: Decline in mining operation levels caused by load shedding

Percentage Decline in Mining Operations	Frequency	Percentage
Decline by 0%	1	1.4
Decline by 0-25%	7	9.5
Decline by 26-50%	23	31.1
Decline by 51-75%	26	35.1
Decline by 76-99%	13	17.6
Decline by 100% (no activity)	4	5.4

Among the surveyed mines, 5.4 percent reported having to shut down production at one time or the other in the year due to load shedding, 35.1 percent reported between 51 and 75 percent decline, 31.1 percent reported between 26 and 50 percent decline, 17.6 percent reported between 76 and 99 percent decline while a single mine reported no decline.

6.2 Decomposition of Load Shedding Cost by Type of Cost

Table 11 provides a decomposition of cost by type using the mean values from the surveyed mines. The table also confirms the survey expectations that lost output is the major type of direct cost incurred by mines.

Table 11: Decomposition of direct cost by type

Cost Type	Amount (US$)	As % of Total
Lost output	1919059.65	92.48
Labour cost	72745.95	3.51
Destruction of material (raw materials and stocks)	40816.22	1.97
Restart costs,	28313.51	1.36
Damage to equipment	14156.76	0.68
Total	**2075091.14**	**100**

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The mean cost totalled over two million dollars (US$) in 2008. Using the total mean of the direct cost components, the total load shedding cost of the mining sector was found to be US$153556744. The total cost for the sector translates to US$354840585.

6.3 Decomposition of direct cost per mineral

Table 12 provides a decomposition of losses by type of mineral extracted. The table shows output loss cost, labour cost, material cost, other cost (restart and damage to equipment cost) and total direct cost. Some mines pointed out that output loss is more significant per load shed if the load shedding affects the whole shift in operation. Labourers have to be paid regardless of idleness due to load shedding. Low material destruction cost shows that mineral ores are not much subjected to load shedding while in stock.

Table 12: Decomposition of cost by type of mineral mined

Mineral Type	Output Loss Cost (US$)	Labour Cost (US$)	Material Cost (US$)	Other Cost(US$)	Total Direct Cost (US$)
Gold	2688563	82725	44531	44700	2860519
Platinum	1342800	151200	53280	53280	1600560
Limestone	180000	28800	6000	15600	230400
Iron	1801680	64800	25200	34800	1926480
Vermiculite	24000	6000	42000	42000	114000
Phosphate	372000	34000	38000	22000	466000
Chrome	570000	49333	37667	34000	691000
Nickel	3000000	90000	0	18000	3108000
Diamond	700000	104000	126000	134000	1064000
Coal	3612000	75000	9000	105000	3801000
Lithium	2970000	66000	96000	12000	3144000
Graphite	180000	90000	6000	18000	294000
Black Granite	2080000	26000	8000	16000	2130000
Asbestos	4200000	54000	30000	30000	4314000

From the table, asbestos reported the highest output loss cost while vermiculite reported the lowest. However, it was different with labour cost where platinum reported the highest while vermiculite the least again. For material destruction cost diamond reported the highest while nickel reported the lowest with zero cost. Diamond mines reported the highest for other cost while limestone the least. Overall, asbestos reported the highest total direct cost while vermiculite reported the lowest cost.

6.4 Distribution of cost per kWh lost by mineral type

Load shedding cost per kWh lost was obtained by adding all the direct cost. Annual kWhs of unsupplied electricity due to load shedding from the power utility grid were also computed. A simple division was then performed dividing total direct cost by unsupplied kWhs.

Table 13: Distribution of per kWh cost by power capacity, scale, location and mineral

Factor		Production Loss cost per kWh (US$)
Power Supply Capacity	High Capacity (HC) mines	26
	Low Capacity (LC) mines	91
Scale of Operation	Small Scale	79.07
	Medium Scale	74.26
	Large Scale	59.43
City of Location	Harare	75
	Bulawayo	10
	Mutare	37
	Kwekwe	58
	Kadoma	21
	Chegutu	20

	Chinhoyi	27
	Other areas	63
Mineral Type	Gold	54
	Platinum	19
	Limestone	22
	Iron	16
	Vermiculite	2
	Phosphate	23
	Chrome	41
	Nickel	56
	Diamond	13
	Coal	32
	Lithium	49
	Graphite	12
	Black Granite	47
	Asbestos	61

Table 13 shows load shedding cost per kWh. Among the minerals, asbestos, nickel and gold mines recorded the highest load shedding cost per kWh ranging between US$54 to US$61, followed by lithium, black granite, chrome and coal mines ranging between US$32 to US$ 49, then phosphate, limestone, platinum, iron, graphite and diamond mines ranging between US$12 to US$23 and vermiculite reported the lowest cost of US$2 per kWh. The overall mean kWh cost was found to be US$31.07. The cost variation across location is also presented in Table 13. Of the locations, mines around Harare reported the highest load shedding cost per kWh of US$75, followed by other small mining towns reporting US$63 per kWh, while Bulawayo reported the lowest load shedding cost of US$10 per kWh. In terms of electricity supply distribution voltage, Low Capacity (LC) reported the higher load shedding cost per unsupplied kWh of US$91 and High Capacity (HC) mines reported load shedding cost of US$26 per kWh unsupplied. This reflects the presence of arrangement between the power utility and HC mines.

Using the average kWh cost of US31.07, the total direct cost incurred by mines due to unsupplied kWhs is US$154179096 for 2008 with an average cost per mine of US$2083501. Considering the total number of mines connected to the grid, this translates to US$356278721. The two approaches to direct assessment method shows a smaller difference of load shedding cost, hence reflecting reliability of the data obtained using questionnaires.

6.5 Analysis of Regression Results

The relationship of the factors which contribute to the level of load shedding cost was modelled by assuming a simple linear relationship between load shedding cost and observed variables. The relevant dependent and independent variables making up the model, together with expected signs of their coefficients are described in Table 14.

Table 14: Description of all variables used in multiple regressions

Dependent Variable	**Description**	**Expected Sign**
TDCOST	Total direct cost incurred by mines as a result of electricity load shedding	
Independent Variables		
TONUOUT	Total number of outages through load shedding	+
ADHORS	Average duration of load shedding in hours	+
TOKWHLOS	Total kWh lost	+
TWHRS	Total working/operational hours (business hours)	+
CAPACITY	Capacity level of operation	+
REV	Revenue income from the mine	-
ELEXP	Electricity expenditure	-

NEMPL	Number employed	+
DUMARR	Dummy for uninterrupted supply arrangement: 1 for arrangement and 0 otherwise	-
DUMBE	Dummy for backup equipment: 1 for presents and 0 otherwise	-

Table 15 showed the complete OLS regression results on the determinants of load shedding cost. In the complete OLS model, the statistically significant coefficients, in the case defined as significance of less than or equal to 10% ($p \leq 0.10$) were the coefficients of the variables ADHORS, TOKWHLOS, TWHRS and DUMARR. These variables were then used in a reduced OLS model (see Table 16). Although not statistically significant TONUOUT, CAPACITY and NEMPL, coefficient signs explain the relationship to load shedding cost. Similarly, the presence of backup equipment had a reduction effect on load shedding cost. Only one variable ADHORS has shown unexpected sign although significant.

Table 15: An OLS model fit to the complete determinants of load shedding cost

Dependent Variable: TDCOST

Method: Least Squares

Included observations: 74

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	275169.6	1443720.	0.190598	0.8495
TONUOUT	3306.371	3856.601	0.857328	0.3945
ADHORS	-423275.2	112328.3	-3.768198	0.0004
TOKWHLOS	2.700418	0.843590	3.201102	0.0021
TWHRS	509.2823	120.5471	4.224758	0.0001

CAPACITY	15695.51	19135.96	0.820210	0.4152
REV	-0.007238	0.006249	-1.158299	0.2511
ELEXP	-0.020050	0.138995	-0.144247	0.8858
NEMPL	160.1790	784.3026	0.204231	0.8388
DUMARR	-2468656.	710083.3	-3.476572	0.0009
ABE	-173364.1	754676.2	-0.229720	0.8191

R-squared	0.479555	Mean dependent var	2075092.
Adjusted R-squared	0.396945	S.D. dependent var	2519494.
S.E. of regression	1.956554	Akaike info criterion	31.94764
Sum squared resid	241.1486	Schwarz criterion	32.29013
Log likelihood	-1171.062	Hannan-Quinn criter.	32.08426
F-statistic	5.805023	Durbin-Watson stat	1.259181
Prob(F-statistic)	0.000004		

The adjusted R-squared of the model represent how well the model fits the data (Mendenhall and Sincich, 1996:78). A minimum adjusted R-squared of 15% or more is considered acceptable (Hanley and Splash, 1993). At 39.6% for the complete OLS model, the adjusted R-squared is above minimal acceptability.

Table 16: An OLS model fit to the reduced determinants of load shedding cost

Dependent Variable: TDCOST

Method: Least Squares

Included observations: 74

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	-26496.41	1180346.	-0.022448	0.9822
TONUOUT	5284.395	3592.949	1.470768	0.0014
ADHORS	-345856.2	94610.22	-3.655590	0.0005
TOKWHLOS	2.146680	0.701349	3.060787	0.0032
TWHRS	495.6780	108.1326	4.583983	0.0000
DUMARR	-2335158.	658571.7	-3.545792	0.0007

R-squared	0.450337	Mean dependent var	2075092.
Adjusted R-squared	0.409921	S.D. dependent var	2519494.
S.E. of regression	1,935390	Akaike info criterion	31.86712
Sum squared resid	255.3564	Schwarz criterion	32.05394
Log likelihood	-1173.083	Hannan-Quinn criter.	31.94164
F-statistic	11.14245	Durbin-Watson stat	1.186583
Prob(F-statistic)	0.000000		

The results of this model provided a higher level of significance for each variable except for the constant. The results showed positive values for TONUOUT, TOKWHLOS and TWHS reflecting increase in load shedding cost due to increase in these variables and negative values for ADHORS and DUMARR reflecting decrease in load shedding cost due to increase in duration and presence of uninterrupted supply arrangement. ADHORS reported unexpected sign again.

As with the complete model, the adjusted R-squared was used as a measure of the fit; 40.99% of the variation in load shedding cost was explained in the OLS reduced model. The adjusted R-squared value is almost similar to that observed in the complete model, suggesting that no significant variables were left out of the reduced model. It is however, unadvisable to make deductions about which model is preferred for determining determinants based on a perceived negligible change in the adjusted R-squared value. Additional inferential tests, such as hypothesis testing, should be used for this purpose (Hanley and Splash, 1993). The relevant hypothesis tests in this regard are:

H_0: The exclude variables in the reduced model do not improve the model

H_1: At least one of the excluded variables in the reduced model improves the model.

The complete and reduced OLS models were compared to determine which one better fits the data using F-test. The F-statistic was calculated as follows:

$$F = \frac{(SSE_R - SSE_c)\Big/No.of\ \beta's\ tested}{MSE_c}$$

$$= \frac{(255.3564 - 241.1486)/5}{1.93539^2}$$

$$= 0.759 < F_{0.05}(5,62)$$

$$= 0.759 < 2.37$$

Given that the test statistic is less than the critical value, the null hypothesis cannot be rejected in favour of the alternative. It was concluded that the reduced OLS was superior to the complete OLS model for the determining the determinants of load shedding cost as the omitted variables did not significantly improve the model.

6.6 Mining Load Shedding Cost Impact Assessment

The impact of load shedding was assessed using total sector load shedding as a proportion of GDP. The load shedding cost scale was assessed as a proportion of the GDP of US$5.4 billion for 2009 (RBZ 2010). The impact of load shedding for the mining sector was 4.6 percent of GDP.

7. CONCLUSION:

One strong conclusion of the study is that poor state of electricity supply in Zimbabwe has imposed huge cost on the mining sector. The bulk of the cost come in the form of lost output or lost production. Furthermore, it is concluded that load shedding costs vary proportionately with power supply capacity and scale of operations. Small scale mines which form the greater proportion of Low Capacity (LC) mines are more heavily affected by electricity load shedding compared to High Capacity (HC) mines which form the greater proportion of large scale mines due to availability of uninterrupted power supply and advance warning arrangement signed by the majority of HC mines. It is also conclude that mineral type has an influence on the cost of load shedding, high valued minerals (diamond and gold mines) have generally reported the highest load shedding cost in both total and per unit of unsupplied kWh and low valued minerals (vermiculite mines) the least.

8. RECOMMENDATIONS:

Research results have shown that load shedding result in significant cost to mines. Therefore, the researchers recommend the following:

1. The power utility to increase power generation in order to reduce load shedding to mines.
2. Power utility to communicate to the mines before load shedding them in order for them to prepare for the load shedding.
3. Mines to concentrate on other activities which do not require electricity during load shedding times.
4. The power utility (ZESA) should prioritise mining sector as there is a lot of potential for economic growth and employment through mining and mining related activities.

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