Final report

International Growth Centre

The cost of power outages to Zambia's manufacturing firms

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Summary

Low rainfall, low reservoir levels, almost complete dependence on hydropower and increasing demand for energy resulted in nationwide power outages in 2015 and 2016 that hit Zambia's manufacturing electricity-dependent firms. The manufacturing sector's absolute and relative grid energy consumption fell from 2015 to 2016. Firms unable to self-generate enough diesel-fuelled energy were forced to delay production and firms which delayed production lost clients. The power shortages have sparked a call to arms for Zesco, the Zambian power utility, to expand national installed energy capacity and diverse its portfolio of energy supply. In so doing, Zesco has aimed to raise tariffs to cost-recovery levels inclusive of capacity charges so that it can deliver that extra supply: it did so twice in 2017, while seeking to do so again in 2019. At the same time, the Ministry of Finance called a moratorium on further sovereign guarantees from being issued that would be required to contract energy on a public private partnership basis given Zesco's financial history.

We surveyed 146 large manufacturing firms in Zambia's industrial hubs between April-August 2018 to assess the impact of outages on Zambia's manufacturing sector.

The observed marginal cost of running generators was more than USD 0.25/kWh. A third of respondents said that they would be willing to pay an average increase of USD 0.04/kWh for reliable on-grid energy. The likelihood of a firm that exports being willing to pay more for reliable energy was 0.9. Distrust in Zesco's ability to deliver reliable energy was a reason for many declining to pay a higher tariff, with a quarter of respondents reporting that they never received notifications of outages or that they received inaccurate notifications.

Firms using voltage regulators, capacitors or power surge factor units decreased their chances of damage to inventory or equipment by 50%. Self-generation as an independent variable was statistically significant in determining whether or not production delays occurred, which in turn was associated with loss in clients. 72% of respondents acquired use of a diesel generator, and less than 5% did not use their operational generators. More than 50% of their oldest generators were from 2015 and 2016, the years of the worst outages.

Statistically significant predictors of installed self-generation capacity were firm size, how many hours a week a firm manufactured, whether it exported, and whether it belonged to the food and beverage subsector. Statistically significant predictors of the extent to which a firm used its generators were its size, whether it exported, whether it was located in the town of Kitwe and whether it did not belong to the basic metals subsector.

The tariff differential for peak and off-peak hours is significantly lower than Zambia's neighbouring Zimbabwe which is similarly reliant on Kariba North Dam. The differential for manufacturing wages paid at off-peak hours can far exceed Zesco's tariff differential.

We recommend Zesco increase the tariff differential between standard, off-peak and peak hour tariffs to alleviate pressure to build sufficient installed capacity for peak-hour energy, that it offers a premium service to exporters, and rather than subsidising tariffs for the largest consumers of energy, it save those consumers money by using the extra funds raised by charging more cost-reflective tariffs by investing in and providing them more reliable energy.

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1. Background

Due to overdependence on hydropower and low rainfall 2014-16, Zambia's power utility Zesco was forced to enact load shedding across the country in 2015 and 2016 lasting a minimum of 8 hours a day. The power deficit reached a high of 1,000MW in 2015 and reduced to 526MW in 2016 (Energy Regulation Board, 2017, p15). Had Zesco not mitigated its generation shortfall with the import of 785.2 GWh in 2015 (up from just 12.8 GWh in 2014) and 2,184.9 GWh in 2016 (ibid, p9), the deficits would have been even greater.

Examining Zambia's listed manufacturers' annual reports, power utility Zesco and Energy Regulation Board's data, it is evident that the power deficits of 2015 and 2016 adversely affected the manufacturing sector.

Table 1 below shows that from 2015 to 2017, manufacturing's share of Zambia's electricity consumption fell from 4.6% to 4.1%, and that absolute consumption fell from 2015 to 2016, and had not recovered to its 2015 level by 2017. Electricity-intensive manufacturing lost consumption share to the electricity non-intensive finance and property sector.

Table 1: Manufacturing's share of electricity consumption dropped from 2015 to 2017 in Zambia. Excerpted from Energy Regulation Board of Zambia, 2016, p. 9, 2017b, p. 9, 2018, p. 36

National electricity consumption by economic sector, 2014-2017

Sectors	2014		2015		2016		2017	
	GWh	% share	GWh	% share	GWh	% share	GWh	% share
Mining	5,871	47.3%	6,246	54.5%	5,918	54.5%	6,202	50.9%
Domestic	3,251	26.2%	3,482	30.4%	3,383	31.2%	4,147	34.0%
Finance & property	487	3.9%	517	4.5%	499	4.6%	640	5.2%
Manufacturing	479	3.9%	**531**	**4.6%**	**470**	**4.3%**	503	**4.1%**
Agriculture	241	1.9%	260	2.3%	228	2.1%	262	2.1%
Others	99	0.8%	99	0.9%	80	0.7%	87	0.7%
Trade	107	0.9%	110	1.0%	97	0.9%	110	0.9%
Energy & water	73	0.6%	89	0.8%	88	0.8%	81	0.7%
Quarries	62	0.5%	68	0.6%	60	0.5%	118	1.0%
Transport	31	0.3%	33	0.3%	28	0.3%	32	0.3%
Construction	1,702	13.7%	15	0.1%	7	0.1%	10	0.1%
Total	**12,405**	**100%**	**11,450**	**100%**	**10,857**	**100%**	**12,192**	**100%**

Table 2 below shows how the annual reports of eight listed Zambian manufacturing firms reported the impact of power outages on their operations.

Table 2 Annual reports of listed Zambian manufacturers mentioning the power outages

Key:

Reduced revenues and profits from previous year
Increased revenues but reduced profits from previous year
Reduced revenues but increased profits from previous year
Increased revenues and increased profits from previous year

PF – Power shortages mentioned as a cause of decline of firm performance
PP – Power shortages mentioned as adversely impacting production
PE – Power shortages mentioned as a cause of slow-down of economic growth
T – Mention electricity tariff increase as adversely affecting the company
IF – Improved performance of firm from better power delivery
IP – Improved processes as a result of better power delivery
IE – Improved economic performance from previous year from better power delivery

Firm & annual reports referenced	2015	2016	2017
LaFarge (2016, pp. 11–12, 17, 2017, pp. 3–4, 36, 43, 2018, pp. 4–5, 50, 60)	PF PE	PF PE	T
British American Tobacco (2016, pp. 3–4, 6, 2017, pp. 9, 14, 2018, pp. 8, 23)	PE		IE
National Breweries (2016, pp. 18, 24, 2018, pp. 4, 27)	PE	PE	**IP**
Zambia Bata Shoe Co (2016, p. 10, 2017, pp. 4, 14, 2018)		PP, PF	
Zambeef (2016, pp. 3, 10, 18, 45, 2017, pp. 23, 45, 2018, pp. 2, 10–11, 14–15, 17–18, 53)	PP PE	PP	T IP
Metal Fabricators of Zambia (ZAMEFA, 2016b, p. 5, 2016a, pp. 1, 4, 10, 2018, p. 7)	T	PE	
Zambia Sugar (2016, pp. 1, 11–12, 20, 2017, pp. 24, 41, 2018, pp. 8, 31)	PP Reduces demand for on-grid electricity by generating power for its factory using its waste biomass.	PP Ability to produce own electricity has minimised the impact of load shedding on our operations.	IP
Zambia Breweries (2018, pp. 6, 30)			IP IE
Analysis Power outages mentioned Power outages mentioned as adversely affecting firm performance or production processes (PF, PP) Improvement in on-grid power mentioned	 **5/7** **3/7**	 **6/7** **4/7**	 **5/7**

'PF' in the table above indicates a

- direct attribution of decline in company performance from the previous year due to power outages,
    - For example, LaFarge Zambia reported in its 2015 annual report 'profit before tax was 25% down from 2014 due to fast rising costs, particularly power and major input costs' (2016, p. 11).
- decline in performance in terms of where the company would otherwise have been,
    - For example, Zambia Bata Shoe Company reported lower revenues but higher profits in 2016 from 2015, and attributed the lower sales to the higher costs of production due to power outages: 'We had also the load shedding due to lack of

water in our major dams and rivers for generation of power. Our manufacturing had to run on generators and this increased our input costs reducing our margins as we could not afford to increase our products since most of our customers could not afford such price increases' (2017, p. 4).

While power shortages were one key feature of 2015 and 2016 that adversely affected their operations, the annual reports also mentioned (for the food processing companies) the drought (which also caused the power shortages), increases in fuel costs (which would have been caused by higher demand for diesel fuel for self-generation), inflation (which would have been caused by increased fuel costs), depreciation of the local currency (which would have been caused by inflation), high interest rates (which would have been imposed to control inflation), and low copper prices (likely determined by exogenous market forces).

The power shortages of 2015 and 2016 have resulted in Zesco endeavouring to aggressively expand its installed energy capacity and diversify away from its almost complete dependence on hydropower (interviews with Zesco economists on 10 November, 2017 and 6 June 2018; Zesco Ltd, 2017c). In so doing, Zesco has aimed to raise tariffs to cost-recovery levels it did so twice in 2017 (Zesco Ltd, 2017a). There has been speculation that it has been endeavouring to do so again in 2019 to charge a tariff inclusive of capacity charges so that it can deliver the required extra supply of installed capacity (African Energy, 2019; Phiri, 2019). At the same time, the Ministry of Finance called a moratorium on further sovereign guarantees from being issued (Mwanakatwe, 2018) that would be required to contract energy on a public private partnership basis given Zesco's financial history (interview with a developer on 23 April, 2019). The impact of the power outages of 2015 and 2016 therefore still have important policy implications for today as Zesco seeks to avoid future outages when Zambia next experiences low rainfall.

This research was born out of a commission that University College London won to assess the impact of power outages on Zambia's manufacturing sector in October 2016. The International Growth Centre, largely funded by the UK's Department for International Development (2018), had commissioned the study following almost two years of acute power outages. As its name would suggest, the International Growth Centre aims to promote sustainable growth in developing countries. The study's focus on the impact of outages on the manufacturing sector was then not surprising given the established association between manufacturing and economic growth. Africa in general and Zambia in particular have already seen a period of de-industrialisation, but as Stiglitz (2017) and Barton (2016) suggest, as a result of poor policy rather than natural economic evolution. Given Zambia's more recent resurgence of industrialisation, undersupply of infrastructure poses a threat to its and more generally Zambia's economic growth.

2. Impact of power outages in the literature

Studies on the impact of outages to industry have been carried out since at least 1948, the first perhaps being in Sweden (Bental and Ravid, 1982). Unreliable and deficient power results in welfare losses (Kessides, 1993) and dampens economic growth (Eberhard *et al.*, 2008; IMF, 2008, chap. IV). The lack of quality electricity significantly reduces firms' total factor productivity (Arnold, Mattoo and Narciso, 2008; Escribano, Guasch and Pena, 2010; Sichone *et al.*, 2016). Using World Bank Enterprise Survey data for 1,000 firms in 10 sub-Saharan countries including Zambia, Arnold et al (2008) found that firms in regions with more frequent power outages are less productive than others. Escribano et al (2010) found that poor quality electricity affects allocative efficiency in mainly poor countries such as Zambia. They calculated the contribution of the cost of electricity from the public grid to average log productivity in Zambia as 33% and the contribution of the average duration of power outages to average log total factor productivity as 9%

By removing the use of electronically operated capital, power outages reduce productivity per worker, who can be reassigned to less productive activities. Outages result in restart costs, in lost output and sales for industries dependent on electricity, in damaged equipment, in destruction of raw materials, loss in quality of production, and in lost reputation, such as reduced rankings on export markets' reliability criteria (Beenstock, Goldin and Haitovsky, 1997; Steinbuks and Foster, 2010).

The Word Bank's latest enterprise survey data reveals that 41% of surveyed Sub-Saharan African firms identified electricity as the major constraint to their businesses, compared with 26% identifying transportation as a major constraint. 79% of firms experienced electrical outages, which on average experienced 9 outages in a typical month, and each outage lasted on average 5.8 hours. Outages on average cost 8.5% of annual sales. 53% of firms owned or shared generators. For where generators were used, the average proportion of energy generated was 28% (World Bank, 2018).

Studies assessing the value of unsupplied electricity on the industrial sector come both on the basis of aggregate macro data as well as on the basis of individual plants, forming micro analysis (Bental and Ravid, 1982).

Macro analysis looks at the long-run effects outages have on long-run growth through the lens of the neoclassical Solow growth model (Solow, 1956; Andersen and Dalgaard, 2013). Using outages as a binary variable in a logarithmic regression model, Andersen and Dalgaard estimate that a 1% increase in outages reduces GDP by almost 3% for a sample of 39 sub-Saharan countries, including Zambia. If all African countries had experienced South Africa's power quality, they state, their GDP per capita growth rate would have been increased by 2 percentage points.

The problem with macro analysis is that it assumes no substitution or mitigation strategies. Ways in which firms can respond to unreliable electric supply are by:

1. Insuring against loss of power (or not, as is the case in 25 African countries including Zambia according to Steinbuks and Foster, 2010);
2. Substituting away from electricity to other factors of production in the long-term (Solow, 1956; Bental and Ravid, 1982; Baddeley, 2003);
3. Negotiating flexible labour contracts to counteract reductions in labour productivity (as was the case in Pakistan: Pasha, Ghaus and Malik, 1989);
4. Taking measures to reduce equipment damage, such as installing voltage regulators, protection switch gears, managing loads, conserving energy (Sanghvi, 1982);
5. Carrying larger process inventories (Sanghvi, 1982);
6. Substituting techniques (Samuelson, 1962; Baddeley, 2003);

7. Changing business activity and allowing firms in other locations with more reliable power supply to take over the production activity, or alternatively changing location to an area of more reliable energy supply. Fisher-Vanden, Mansur, and Wang (2015) found that firms in Chinese regions where electric power became scarcer shifted from "makers" to "buyers" of intermediate goods for production;
8. Privately generating their own power. Studies show that firms that self-generate electricity suffer smaller outage losses (Arnold, Mattoo and Narciso, 2008; Steinbuks and Foster, 2010). Self-generation accounts for more than a fifth of generation capacity in some African countries (Foster and Steinbuks, 2009). However, while self-generation reduces outage losses, Oseni and Pollitt (2015) found that self-generation might not necessarily make a firm suffer smaller unmitigated outage losses. In calculating the unmitigated loss, Oseni and Pollitt calculated it as equal to the loss amount less the cost of self-generation. They should have also added to this the cost of self-generating energy above the cost of purchasing energy from the grid.

   Variables correlated with generator installation included size, number of days without power, whether they were foreign and whether they were export-facing, Reinikka and Svensson (2002) in Uganda. Similarly, using business survey data from 25 African countries, Steinbuks and Foster (2010) found that the size of a firm and whether it exports play more important roles than reliable supply of energy in the decision to invest in a back-up generator. Allcott et al (2016) explain the reason for size of firm being a correlate with owning a generator in terms of the rational firm: there are substantial economies of scale in generator costs.

   Because generators operate a small fraction of the time energy is used, they do not greatly affect the average cost to industry. Indivisibilities occur in back-up investment (Beenstock, Goldin and Haitovsky, 1997). Because of this, it may cost a firm the same to invest in back-up generation for 110% of its energy needs as it costs to back-up 97% of its generation needs, and so it may decide not to back-up against 100% of losses;
9. Reducing output (Adenikinju, 2003); or
10. Changing business and possibly industry. This would be difficult to observe, and we have not seen studies tackling this issue. We would need to take into account survival bias as we interviewed manufacturing firms in Zambia following the major outages of 2015 and 2016.

To illustrate how macro analysis failed, Bental and Ravid (1982) pointed to a Chilean study (Jaramillo and Skoknic, 1973), where the authors inferred that industries which were least electricity-intense would have the largest loss per unit of reduced supply.

Another pitfall with macro studies according to Bental and Ravid is that they estimate the average cost of unsupplied electricity, whereas the relevant estimate would be marginal cost.

The weakness with previous micro studies, Bental and Ravid observed, is that they usually rely on questionnaires, which tend to be prone to inaccuracies as firms may have reason to overstate the damage done of power outages – Beenstock et al (1997) observed a number of instances respondents to surveys reported losses that the authors considered unreasonably large. They interpreted these overstatements as 'protest' responses; the interviewees expressing their discontent with the Israeli Electricity Company.

Another pitfall of subjectively answered surveys is that they could be prone to loss aversion, and this may explain why a number of studies such as Pasha, Ghaus and Malik (1989) and Beenstock et al (1997) concluded that firms overstated their losses. For instance, as Thaler (1980) observed, people suffer from loss aversion: the loss of utility from giving up a valued good is greater than the gain in utility from acquiring the good. Similarly, perceived losses do not necessarily match actual losses if framed in a particular way, contrary to rational expectation.

While prospect theory explains why Pasha et al (1989) and Beenstock et al (1997) noted overstated losses, prospect theory is not the only reason for why they may have observed overstated losses. There is a possibility that firms were simply protesting their losses by overstating them. In reviewing the literature on whether there is a gap between willingness to pay and willingness to accept, however, Plott an Zeiler (2005) point out that there is not a consensus. They themselves used procedures which resulted in no difference between willingness to accept and willingness to pay, calling into question the evidence for prospect theory. The key, they write, is to avoid misconceptions in willingness to pay questions and providing some sort of incentive for truthful revelation of valuations. Willingness to pay could still therefore be potentially useful for gauging the marginal cost of back-up power to a firm. The loss caused by outages is converted into a positive extra price that they would have to pay. The "house money effect" of respondents on behalf of their firms should not come into play since respondents themselves would not be paying the higher tariffs.

To avoid altogether them problem of subjectivity associated with micro studies, as well as the problem of estimating the average cost of unsupplied electricity with macro studies, Bental and Ravid (1982) introduced the test of using firms' observed (rather than hypothetical) behaviour in the generators market to compute the marginal cost of outages.

The formulation for working out marginal cost of back-up power used by Bental and Ravid (1982) and subsequent others, such as Adenikinju (2003), was a function of the capital expenditure of purchasing a given capacity divided by the number of hours of use, plus the variable cost. The marginal cost of self-generation is an observed measure of the floor for willingness to pay for reliable electricity. In the case of Nigeria, Adenikinju found that firms invested in self-generation capacity even though its electricity was on average three times the cost of publicly supplied electricity.

A weakness with Bental and Ravid's approach (1982) was that they assumed that whenever power was cut-off, the back-up system would be used to capacity. While this would have been rational behaviour by the profit-maximising firm, this may not have been possible for practical reasons, such as lack of working capital due to higher running costs. It may also not have been a policy followed because the firms' management suffered from behavioural biases, thus again laying flaw to their method at the hand of another and perhaps lesser form of subjectivity which they assumed away.

Besides computing marginal costs of back-up power for US and Israeli firms, two relationships that Bental and Ravid (1982) surmised were that:

i. as generators become more expensive, firms will purchase less back-up power; and the damage of outages will increase; and
ii. the more reliable the supply of on-grid electricity, the higher the cost of outages, as a result of decreased back-up facilities purchased by the firm. Steinbuks and Foster (2010) have also casually observed that the capital cost of generators tends to be higher in countries with more reliable energy.

Bental and Ravid's findings (1982) in themselves illustrate further weaknesses in the applicability of Andersen and Dalgaard's approach (2013) to Zambia in particular – Zambia's market for generators and power reliability are particular to it, and so a general finding for 39 sub-Saharan countries cannot so accurately be inferred for Zambia, let alone to two decimal points of a percent.

Using the methodology developed by Bental and Ravid, Steinbuks and Foster (2010) applied it to 25 African countries, including Zambia. The found that the average variable cost of self-generated electricity in Zambia was USD 0.27/kWh, the average capital cost of self-generated electricity was

USD 0.18/kWh, that the average total cost of own electricity was USD 0.45/kWh (the sum of the variable and average capital cost), and that when weighted on a time basis with the price of electricity purchased from the public grid at USD 0.04/kWh, the average cost to a firm self-generating electricity during power outages was USD 0.06/kWh. The net impact on the firm that uses self-generation is that it, on average, pays USD 0.02/kWh extra than it would have had power from the grid been reliable, in order to avoid loss in sales. This does not include the cost of replacing machinery damaged by power surges or unfinished produce damaged as power goes out. Again, the study suffers the same problem as Bental and Ravid in that it assumes that firms self-generate for the full duration of power outages. It further suffers from the problem that Steinbuks and Foster assumed the duration of power outages themselves (2010, p. 508). The study is also outdated because Zesco's tariffs have changed; tariffs were revised in 2017 alone.

Further, although proxy methods are useful in estimating outage costs, they do not differentiate outage costs by outage characteristic, nor do they provide information on the distribution of outage costs across industries (Diboma and Tamo Tatietse, 2013).

Beyond the short-run costs to the firm of unplanned outages in terms lost output, there are the costs of higher wear and tear associated with more intense use of machinery during operational hours to make up for lost load and higher staff costs associated with over-time shifts; beyond the cost of longer-term coping strategies, such as larger carrying inventories, self-generation, and installation of voltage regulators, Pasha, Ghaus and Malik (1989) considered the loss to consumer welfare and the multiplier effects. Chen and Vella (1994) also studied the multiplier effect using input-output analysis of various industries and their interdependencies.

Pasha, Ghaus and Malik found that there is major variation between types of industry in the outage cost per kilowatt hour. Continuous-process industries and those more vulnerable to spoilage experience greater losses. To minimise loss, therefore, power-feeders should prioritise these industries. Further, they found that 28% of firms surveyed not operating 24 hours a day would be willing to shift their work timings if lower off-peak tariffs were offered, ranging from 11% in the metal industry to 52% in the paper and wood industry. Chen and Vella (1994) concluded that the impact of outages on upstream industries would be greater on the economy than on industries further downstream, which would be dependent on the upstream industries' output for their inputs. Their policy conclusion was that power-feeders should first cut electricity from final demand consumers who only consume electricity and do not add value to the economy in order to minimise outage losses.

After end-consumers, Chen and Vella suggested targeting industries with relatively low multiplier effects on the rest of the economy as well as with large consumption rates, in order to minimise disruption to the rest of the economy with load-shedding. They concluded that targeting industrial chemicals and steel and iron for load shedding would have the least disruptive impact for the economy and most effective impact for load shedding.

Table 3 Chen and Vella's table (1994) of Taiwanese industries' multiplier effects on the rest of the economy using in-put-output analysis (top 10 industries most relevant to Zambia)

Rank	Subsector	Multiplier value
1	Other industrial chemicals	0.891
2	Steel and iron	0.917
3	Cotton, wool and fabrics	0.917
4	Artificial fabrics	0.918
5	Cement and cement products	0.921
6	Chemical fertiliser	0.921
7	Artificial fibres	0.926
8	Iron and steel products	0.939
9	Non-iron metals and products	0.941
10	Paper, paper products, printing and publishing	0.941

In China, Fisher-Vanden, Mansur, and Wang (2015) found that across all industries, material input expenditures increased by 13% in response to electricity shortages since 1999. They found the largest effects in the wood products, chemicals, food, metal, and textiles industries. However, this was offset by a 5% reduction in unit cost due to savings in other inputs and small total factor productivity improvements.

Fewer long-duration interruptions are less damaging to industry than several interruptions of very short duration (Pasha, Ghaus and Malik, 1989; Diboma and Tamo Tatietse, 2013). This is because short outages are generally not anticipated and second, because the spoilage of inventory and machinery and restart-up costs are linked to frequency and not duration. Spoilage costs spread over a longer duration result in less spoilage per kilowatt hour lost.

Willis and Garrod (1997) defined short interruptions as those in which the voltage falls below 0.1 relative units for a period shorter than or equal to 1 minute. Long interruptions are those in which the voltage falls to zero for a period above a minute. Using collected survey data, Beenstock et al. (1997) found a U-shaped relationship between the loss per unsupplied unit of energy and the duration of the outage. Restart and equipment damage costs per kilowatt hour unsupplied vary inversely with duration, whereas output losses increase with duration. Their data suggests that the cost per kilowatt hour unsupplied reaches a minimum at 45 minutes for the firms that they surveyed in the mid-1990s in Israel. The U-shaped relationship between cost per unit of energy and duration perhaps explains Diboma's observation (2013) that businesses prefer longer, infrequent outages to shorter frequent outages.

To be able to adjust to outages (in terms of shift timings and work days), Pasha, Ghaus and Malik (1989) found that surveyed firms in Pakistan said they needed 6-13 hours lead time between notification and outage. Surveyed firms in Cameroon, meanwhile, estimated that their costs could be reduced by a fifth to a third if they were given reliable advance interruption notices (Diboma and Tamo Tatietse, 2013).

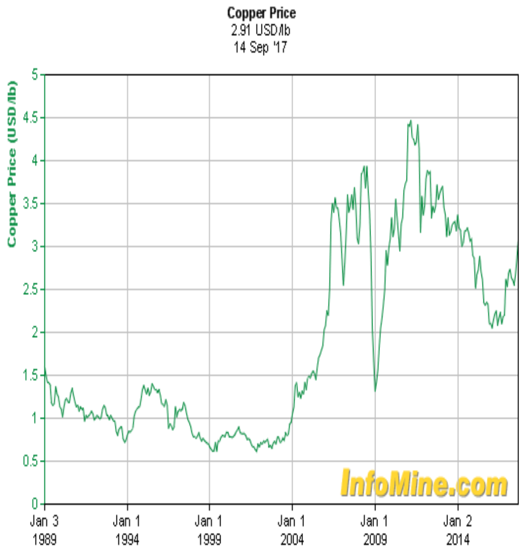
Allcott et al (2016) note that answering how electricity outages affect productivity in the manufacturing sector can be difficult to answer first of all because the quality of data collection in countries in which outages occur is not high, but also because of endogeneity: rapid economic growth could cause an increase in electricity demand that leads to shortages, and poor institutions could lead to insufficient power supply and reduce productivity.

2.1 More recent literature on Zambia's recent outages

While some studies cited above have looked at Zambia, usually amongst other countries, four more recent studies have particular similarities in scope to this one because they examine the impact of the 2015 or both 2015 and 2016 outages or because they look at the impact on manufacturing. These studies are authored by the World Bank (2013), Sichone et al (2016), Mwila et al (2017) and Batidzirai et al (2018).

In its 2013 Enterprise Survey of 720 Zambian firms (ie. even before the outages of 2015 and 2016), the percentage of firms in Zambia that exported at least 1% of their sales directly or indirectly decreased in 2012 to 12% of firms from 15% in 2007 (World Bank, 2014, p. 1), which contrasts with other World Bank data that shows that Zambia's overall exports have generally been increasing. The contrast could be attributed to the fact that Zambia's overall export pattern follows copper prices, while the Enterprise Survey excluded copper mining companies.

Figure 1 Historic copper prices, GDP and export growth. Copper prices have been driving Zambia's overall export and GDP growth, in spite of the percentage of non-mining companies that export decreasing. Source of data for graphs: World Bank, 2017; Investment Mine, 2018



Pre 2015/16 power outages accounted for 5.5% of sales value for the World Bank's surveyed firms. The loss was felt greatest by medium-sized firms employing 20-99 people, which lost 6.9% of value, while it was felt least by large firms employing more than 100 people (accounting for only 4.7% of sales), even though they reportedly faced 8.7 power outages in a typical month, compared to the 5.4 outages per month by medium-sized businesses (World Bank and International Finance Corporation, 2014, p. 14). The reasons for this were not given.

For his University of Lusaka MSc dissertation, a more limited version of which was published (Sichone *et al.*, 2016), Sichone sought to investigate the impact of load shedding on the production and profitability of manufacturing firms in Lusaka, to investigate the coping mechanisms firms used to mitigate the impact of outages and to investigate the impact of outages on Lusaka-based manufacturing firms' competitiveness. He was unable to investigate profitability due to unwillingness on the part of firms to part with profitability information and an inability to talk with more than 10 firms himself (Sichone, personal communication, 26 May, 2018). Therefore other than the study being limited to Lusaka, his study relied heavily on the World Bank's Enterprise Survey of

2014 which was a collection of surveys of 720 firms conducted between 2012 and 2014, ie. preceding the major outages of 2015 and 2016. However, the study contained useful insights.

Sichone et al (2016) found that load shedding had a statistically significant and negative impact on manufacturing output in Lusaka, and that firm age had a statistically significant and positive impact on output. Sichone et al also tested for the proportion of ownership of the firm owned by local shareholders and did not find that it had a statistically significant relationship on firm output.

At the sub-sector level, Sichone et al (2016) found that the impact of power outages was only significant and negative for food and metal fabrication, associated with a 1.9% and 1.4% reduction in sales respectively. The impact was not statistically significant for furniture and wood processing, garments and leather and non-metallic minerals. Sichone et al posit that the insignificant impact of self-generation on the latter three manufacturing sectors is because they are less dependent on electricity for production.

For the food subsector and metal fabrication, when production starts, Sichone told us (Sichone, personal communication, 26 May, 2018) that there are some processes that should not be interrupted. Because spoilage costs exceed the cost of running self-generation, to hedge against spoilage costs, firms in these sectors will run their generators even when the grid is providing power (Sichone, personal communication, 26 May, 2018). In one instance, he saw a glass factory's clinker solidify in pipes, resulting in the need to replace pipes (ibid). He also told us that Zesco would not always keep to its load-shedding schedules.

Even with self-generated energy, Sichone et al found that a percentage increase in use of self-generated electricity was associated with a 0.19% decrease in annual sales. This implies that self-generation does not fully cover loss in energy.

Mwila et al (2017) concentrated their focus on small and medium sized enterprises (agnostic of sector) because small businesses were more likely to be adversely affected by load-shedding because they were less resilient and most of them were not insured and had limited resources to invest in alternative energy sources (2017, p. v). They took it as a 'given' that small enterprises were important to the economy (2017, p. v). Small and medium businesses accounted for 56% of the manufacturing sector population in 2011-12 (Ministry of Commerce Trade and Industry, 2014, p. x), and so would have been responsible for significant employment. (Mwila et al estimate that small enterprises across sectors accounted for over 170,000 jobs, although the methodology used to estimate this number was not revealed. Half of small businesses were trade (2017, p. vi).) In terms of importance of contribution to the manufacturing sector's contribution to GDP, however, they accounted for just 1.5% (Ministry of Commerce Trade and Industry, 2014, p. x), making this study, concentrating on large manufacturing firms, the more salient in the absence of focus on this group of manufacturing firms post 2015 and 2016 power outages. Nonetheless, Mwila et al's study contains noteworthy insights.

Drawing a sample of 696 small enterprises that they interviewed in 2015 from an estimated population of 15,415, Mwila et al's found the following:

- Electricity featured as the most popular operational constraint to firms, being voted as the top constraint by 36% of respondents. Access to finance ranked second with 28% of votes and competition ranked third with 20% of votes. These were followed by 'other', labour, security and fuel (2017, p. 20). It should be noted that electricity supply moved up from third most popularly voted operational constraint after access to finance and the informal sector in the World Bank's Enterprise Survey (2014, p. 4)conducted before the outages. The enterprise surveys excluded companies engaged in copper mining. 51% of surveyed firms were in manufacturing. By contrast, however, electricity supply deficit was ranked third most popular constraint in the Bank of Zambia, Central Statistical Office and Zambia Development Agency's 2016 survey (2017, p. x) of 266 firms across sectors, after exchange rate instability and the high cost of borrowing. The difference could have been that Mwila et al focused on small businesses. None of the surveys mentioned competition from Chinese imports as a challenge. It seems that the ranking of the importance of electricity outages in the three sets of surveys was dependent on the time of survey, the sample of respondents, and the options respondents were given. Given the different results of the Bank of Zambia's survey conducted at the time of the worst power outages, it is difficult to conclude that power outages were the biggest challenge to firms, but we can conclude that they were an important challenge.

- Load shedding appears to have most severely affected small businesses in Lusaka, and least of all in Livingstone (2017, p. 24). This perhaps reflects the fact that Livingstone is not known for being host to the manufacturing sector, but instead is heavily services-focused as a result of the Victoria Falls tourist attraction;
- While only 17% of SMEs reported not having received notifications of Zesco's load shedding schedule through any media or members of the public (2017, p. 25), 51% of enterprises reported that Zesco did not follow its own load shedding schedules (2017, p. vii);
- 30% of businesses reported damaged equipment due to load shedding. Only 12% of businesses reported their equipment as insured. Firms also suffered from restarting operations costs (2017, p. vii, 30);
- Load shedding resulted in idle labour and overtime labour costs (ibid, p. 28). 8% of firms reported reducing on labour hours (ibid, p. 36);
- Load shedding resulted in purchases and hiring costs for alternative energy sources (ibid, p. 31). Among the surviving firms that were interviewed, 42% reported to have used generators in 2015 (ibid, p. 33), whereas just 2% reported having used a UPS (ibid, p. 34) and just 2% reported having used surge protectors (ibid);
- Only 0.2% of businesses reported moving (ibid, p. 32). However, the total number that did was 21 businesses, all in Lusaka (ibid, p. 37).
- 7% of businesses reported switching working hours (ibid, p. 38). The report also says that no businesses reported shutting down their operations (ibid, p. 37), but this result would be heavily affected by survival bias;
- 7% of small and medium sized businesses reported backing up data systems (ibid, p. 34);
- 7% of sampled firms used enhanced security (ibid, p. 35), while 21% of firms reported facing theft during load shedding (ibid, p. 39).

Batidzirai et al (2018) concluded that an upward revision of electricity tariffs would facilitate investment in the energy sector, and that most businesses would be willing to pay for improved electricity supplies. Indeed, Zambia's average electricity tariff was as of June 2016 third lowest out of ten in the Southern African Development Community, and less than half of Namibia's (Energy Regulation Board of Zambia, 2017a, p. 61).

Batidzirai et al found that hotels, restaurants and businesses paying a commercial tariff (which would include manufacturing firms) as well as operating hours per day were statistically significant independent variables in a regression where willingness to pay was the dependent variable (2018, p. 23). Variables that did not seem to have an impact on whether a firm was willing to pay were the number of years it had been in business, whether it was profitable and whether a business was a service sector business that was not hospitality (they looked at the financial and wholesale and retail subsectors).

However, it is unclear when their 224 surveys were conducted. They cite electricity tariffs approved by the Energy Regulation Board in March 2017. Because Zesco made tariff revisions in May 2017 and then again in September 2017, it is unclear whether their Batidzirai et al's findings were relevant even at the time of publication. That their surveys were also mostly with micro and small enterprises (93% of their sample, pp. 8,14) is another distinction from the research, which is focused on large manufacturing firms.

Table 4 Zesco revised its tariffs twice upwards in 2017. Source: Zesco.co.zm (Zesco Ltd, 2017a) *accessed as of 29 October, 2018. It appears that 'current' was the tariff prior to 15 May, 2017*

Not secure | www.zesco.co.zm/customerCare/tariffs

Beyond Conflict Free · Vine Engagement Ri · Design My Own Enga · Funding · Conferences · Energy and developm · Rings · Statistics · Honeymoon · Other bookmarks

Current ZESCO Tariffs

CUSTOMER CATEGORY		Current Tariffs	New Tariff 15th May 2017	New Tariff 1st Sept 2017
1. METERED RESIDENTIAL TARIFFS (Prepaid) (Capacity 15kVA)				
	Fixed Monthly Charge(K/Month)	273.62	410.43	478.84
	Fixed Monthly Charge(K/Month)	136.82	205.23	239.44
	Fixed Monthly Charge	55.09	82.64	96.41
	Peak MD Charge(K/KVA/Month)	52.48	78.72	91.84
	Peak MD Charge(K/KVA/Month)	52.19	78.29	91.33
	Fixed Monthly Charge	47.91	71.87	83.84
MD4-Capacity above 7,500kVA	MD Charge(K/kVA/Month)	41.98	62.97	73.47
MD3-Capacity between 2,001-7,500kVA	MD Charge(K/kVA/Month)	41.75	62.63	73.06
	Peak MD Charge(K/KVA/Month)	32.67	49.01	57.17
MD2-Capacity between 301-2,000kVA	MD Charge(K/kVA/Month)	26.13	39.20	45.73
	Off Peak MD Charge (K/KVA/Month)	20.99	31.49	36.73

3. Objectives / hypotheses

As the Zambian government is committed to diversifying Zambia's economy and improving manufacturing productivity, it is important to understand how firms are affected by and cope with energy crises, especially in terms of self-generation of energy. In answer to the research commission, we set out to investigate the following through surveys:

1. the costs to manufacturing firms of power shortages,
2. what characteristics of firms correlate with their ability to implement coping mechanisms,
3. the extent to which these coping mechanisms are effective,
4. predictors of a firm's scale of investment in self-generation as a proxy for what sort of firms would be more likely to be willing to pay higher prices for reliable electricity, and how much.

This research is the first to include an assessment of the effects of the 2015 and 2016 outages on Zambia's large manufacturing firms and is probably the only research to assess firms' willingness to pay for improved electricity supply reliability given where Zesco's tariffs are currently.

More broadly, the research will address two limitations in previous research.

First, most studies do not allow that self-generation does not guarantee 100% mitigation of potential outage costs. Our research assesses the extent to which self-generation mitigates production delays.

Second, previous studies have assumed that firms operating a backup generator use them for the full duration of outages. Our research assesses the extent to which firms use self-generation as a mitigation strategy given their characteristics.

4. Methodology for assessing the impact of power outages on Zambia's manufacturing firms

4.1 Theoretical approaches

The analysis will be founded on three theoretical approaches to assess the impact of power outages on Zambia's manufacturing sector.

1. The first involves calculating the marginal cost of outages, which will be done in two ways:

i. by observing firms' use of self-generation by firm characteristic. A firm experiencing power unreliability would equate at the margin the expected cost of generating its own energy to the expected gain from that self-generation (Bental and Ravid, 1982). That marginal cost has to therefore be greater than the variable cost of self-generated energy less the variable cost of energy (ie. not the fixed monthly charge) that would have been supplied by Zesco (Farquharson, Jaramillo and Samaras, 2018, pp. 592–593). (To the extent that they do not use self-generation is indicative that either the cost of outages is less than the cost of self-generation, or that they lack the capital to purchase self-generation capacity or working capital to finance self-generation);

ii. and by asking firms their willingness to pay for a reliable supply of electricity (as used by Batidzirai et al (2018) for Zambia's previous tariff structure.

2. Given that firms' backup capacities are often smaller than their required electricity loads (Beenstock, Goldin and Haitovsky, 1997), the second approach involves evaluating the efficacy of varying degrees of self-generation in mitigating production delays.

3. The third approach will assess the extent to which self-generation is used by firm characteristic, building on the work of Oseni and Pollitt (2015) who found that some firms that self-generate still suffer unmitigated losses by not generating to the extent that they would have received energy from the grid.

4.2 Research design

The primary data was collected using a structured survey questionnaire (the last iteration of which is included as Annex 1). Face-to-face surveys were conducted with the accountants, production managers and electrician managers by a team of locally recruited enumerators trained by the investigation team.

The survey was designed to:

1. qualify the characteristics of firms (age, size by employees or revenues, energy use, subsector, whether majority foreign owned) to see whether these correlated with the following factors
2. learn when (months and years) firms experienced their worst power outages
3. learn the firms' coping strategies
4. learn the extent of costs incurred as a result of outages
5. see trends in the firms' on-grid energy use
6. see trends in the firms' off-grid energy use
7. learn whether and how much more firms would be willing to pay for reliable on-grid energy after the latest tariff revisions of 1st September, 2017
8. see whether firms experienced unplanned and planned outages differently
9. see correlations between firm characteristics, costs of power outages, coping mechanisms, and willingness to pay a premium on the latest tariff revisions of 1st September, 2017 for more reliable electricity as outlined in 8.1 above.

4.2.1 Sampling frame

We attempted to stratify our sample of Zambia's large manufacturing firms to the extent possible. As explained above, we chose to concentrate on large manufacturing firms because they contribute to 98.5% of the manufacturing sector's contribution to GDP, even though they represent only 44% of the sector population (Ministry of Commerce Trade and Industry, 2014, p. x).

Geographically, 50% of large manufacturing firms were located in Lusaka Province, and 34% were located in Copperbelt Region (Ministry of Commerce Trade and Industry, 2014, sec. Annex 7). Lusaka had 95% of types of manufacturers in the country; Copperbelt 77% (ibid, p. viii). It made sense therefore to concentrate our surveying resources in these two provinces which together accounted for 84% of large manufacturing firms.

Within Lusaka and the Copperbelt, we further stratified by subsector so that our sample was representative of the breakdown of manufacturing subsectors in those provinces. We relied on Appendix 7 of the Ministry of Commerce, Trade and Industry's 2014 report to provide this breakdown. We were unable to get more up-to-date breakdowns, despite requests made of the Ministry of Commerce, Trade and Industry, Bank of Zambia and International Growth Centre's partners at the London School of Economics.

The Ministry's total universe of manufacturing firms as of 2011/12 (3,811) exceeded the number of clients Zesco had reporting themselves as manufacturing concerns (1,336 as of 2011). However, our universe of interest was the 329 large manufacturing firms in Lusaka Province the Copperbelt, according to the Ministry's figures. In the end, we collected results from 146 mostly large firms (which we gauged by the number of people they employed, their revenues or the nature of their business activity).

To get the names and contact information of manufacturing firms in Lusaka Province and the Copperbelt Region, we relied on primarily two lists, obtained by our Field Manager from the Zambia Association of Manufacturers (ZAM) and the Patents and Companies Registration Agency (PACRA). The former is a self-selecting fee-based association which would attract larger manufacturing firms. Given that our focus is on large manufacturing firms, we found using this resource helpful in finding large firms. The latter is a government entity which keeps a record of all companies in Zambia which we resorted to when we ran short of firms in ZAM's list within a sector.

4.2.2 Sampling achieved

On a geographical basis, we were aiming to have 59% of our sample come from Lusaka and the remaining come from the Copperbelt (50/84.1 = 59%). In fact, we ended up with 75% of our sample coming from Lusaka. Although the time we employed enumerators in the Copperbelt was longer than the time we employed enumerators in Lusaka, we ended up having Lusaka overrepresented by 16%. We got a roughly equal number of surveys in Ndola and Kitwe, the two towns of the Copperbelt we surveyed in. We only managed to interview one of seven manufacturing firms in the LSMFEZ and only one firm in Kafue, in Lusaka Province.

On a subsector basis, we ended up with 14% overrepresentation in the food and beverage subsector, 7% overrepresentation in the plastics and rubber subsector, 8% underrepresentation in the non-metallic mineral products subsector and 8% underrepresentation in the machinery and equipment subsector.

Further explanation of how we implemented our surveys, the challenges we faced and what we did to triangulate results by collecting data from key institutions and interviewing key informants is included in Annex 2.

5. Results of our surveys and interpretations

Because of the several iterations that our survey underwent, the 146 firms were not all asked the same questions. Also, for idiosyncratic reasons stemming from either the respondent not answering a question or an enumerator missing asking a question, even when the question was to be put to a firm, a response was not necessarily yielded. This is why we have different numbers of responses to different questions.

5.1 General characteristics of our sample

Geography

- 92% of 125 respondents were located in industrial zones or a Multi-Facility Economic Zone
- 75% of our respondents were based in Lusaka, 13% in Kitwe and 12% in Ndola

International characteristics of our sample

- 39% of 145 respondents reported that they export. Of these, only 2 exported or had exported outside of Africa (QA3 of questionnaire in Annex 1)
- 56% of 63 questioned firms were majority foreign owned (QA5 of questionnaire in Annex 1)

Number of years of manufacturing experience in our sample

Noting that our survey assessing the impact of power outages necessarily suffers from survival bias, the number of years of manufacturing experience of firms in our sample are probably less they would have been had there not been the power outages of 2015 and 2016.

Given that we were asking personnel at companies for the number of years of that their firms had been manufacturing and not checking their responses with official documents, we do not think it useful to take our numbers as precise, but rather as approximations. We therefore hesitate to quote the maximum number of years of experience quoted to us. The median years of manufacturing experience was 13, and the interquartile range was 6-28. The least experienced firm with which we talked was less than a year old. The firm with the greatest experience was older than Zambia.

Table 5 Years of manufacturing experience in our sample of manufacturing firms

Measure	Years of manufacturing experience
median	13
standard deviation	18
mean	20
upper quartile	28
lower quartile	6
min	0.75
max	Before independence

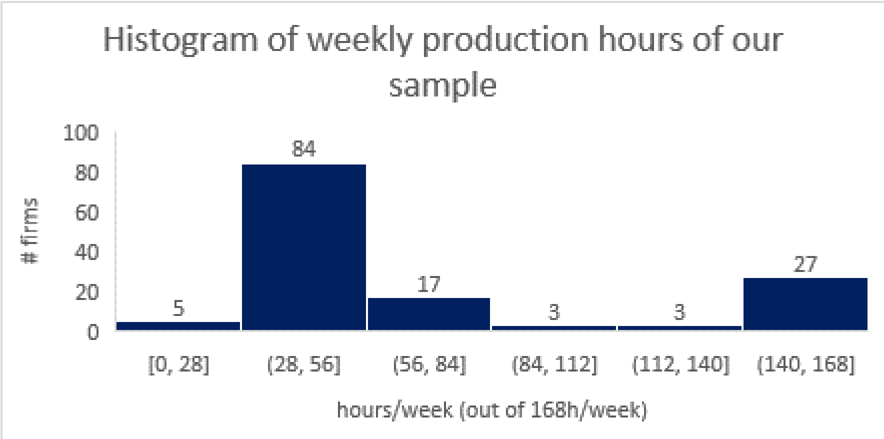
Weekly production hours

18 of 139 companies (ie 13% of our sample) for which we collected production hour data manufactured 24 hours 7 days of the week. However, the interquartile range of production hours was 48-77 hours. The distribution of production hours is represented by the below histogram.

Figure 2 Histogram and averages of production hours of our sample

Weekly hours worked

168	Mode
48	Lower quartile
53	Median
77	Upper quartile
74	Mean



5.2 Periods of worst outages

5.2.1 Years of worst production outages and extent of production losses

Of 2014-2018, respondents at firms regarded 2016 as the worst year in terms of production losses, followed by 2015. 2017 was worse than 2018. (QB1bbb of questionnaire in Annex 1).

Surviving firms reported losses towards the higher spectrum of 16-30% in 2015 and 2016. Even in 2018, firms were on average reporting production losses of 1-15%

Robustness of results: Respondents were asked to rank a year 0-4 for losses. 0 represented no losses in production, 1 represented 1-15% losses of targeted production, 2 represented 16-30%, 3 represented 31-50% losses and 4 represented more than 50% of losses.

We got 64 responses for 2018, 62 responses for 2017, and just 45 responses for 2014. This was a function of respondents at firms not having served for the full time period of investigation, of firms being new as well as of memory lapses. To account for the heavy skew towards the most recent years, we summed the total of responses for a given year and divided it by the number of responses for that year.

Table 6 2016 saw even worse production losses than 2015, with surviving firms reporting losses on the higher spectrum of 16-30%. Even in 2018, firms were on average reporting production losses of 1-15%

Year	2018	2017	2016	2015	2014
Sum of 0-4 responses	68	116	164	139	88
Number of responses for year	64	62	58	52	45
Average score for year	1.06	1.87	2.83	2.67	1.96
Ranked in terms of worst year	5	4	1	2	3

5.2.2 When firms purchased their oldest generator still in use

The modal year for the oldest generators still in use was 2016. Of 94 responses, 26 (28%) of firms bought their first generator in 2016, while 24 (26%) of firms bought their first generator in 2015. Together, 2015 and 2016 accounted for 53% of first-time generator purchases.

5.2.3 Months of worst electricity reliability in general

October was noted as the worst month for outages, followed by August. The month least reported for outages was April, which is in the dry season and when Zesco produces less than average energy.

5.3 Damages incurred from Zesco's outages

Unplanned outages did more damage than planned damages. However, 35 (24% of) firms that we interviewed said that they received no notifications of or unreliable notifications of Zesco outages. This meant that all outages for these firms were as bad as they could possibly be, because they could not plan for outages.

Extra pay and transport costs for staff to stay on to work was the most common cost of power outages, followed by damage to equipment, damage to firm reputation and damage to inventory. The most serious cost – loss in clients, ranked 7th of 12 costs that we classified.

Table 7 Most common & severe costs of power outages

Type of extra cost or damage	Cumulative score	Responses	Cum score/responses	Rank
Unplanned outage - extra staff cost	224	141	1.59	1
Unplanned outage - damage to equipment	212	142	1.49	2
Unplanned outage - damage to firm reputation	203	140	1.45	3
Unplanned outage - damage to inventory	189	140	1.35	4
Planned outage - extra security costs	122	99	1.23	5
Unplanned outage - extra security costs	164	136	1.21	6
Unplanned outage - loss in clients	151	138	1.09	7
Planned outage - extra staff costs	105	105	1.00	8
Planned outage - damage to firm reputation	85	104	0.82	9
Planned outage - loss in clients	72	103	0.70	10
Planned outage - damage to equipment	45	105	0.43	11
Planned outage - damage to inventory	33	105	0.31	12

5.4 Damage mitigation strategies

The number of responses for each type of coping strategy varies because all the coping strategies had not been thought of until the surveys had started. Responses may have been biased by those that appeared first (see QB2 of the survey in Annex 1) – voltage regulators, surge protectors were the first two responses available, and rank as the two most popular interventions by firms to mitigate against power outages. However, power factor units appeared as the third available intervention in the questionnaire, and ranks 7th. Interestingly, self-generation appeared as only the fourth most popular intervention after delaying production.

Table 8 Popularity of mitigation interventions

Strategy	Cumulative score 0-4	# responses	Cum score/responses	Rank
Surge protectors	120	34	3.53	1
Voltage and/or capacitors	98	33	2.97	2
Delay production	301	141	2.13	3
Self-generation	300	144	2.08	4
Voltage regulators	229	111	2.06	5
Insurance	256	134	1.91	6
Power Factor Correction Units	56	37	1.51	7
Reduce output	214	144	1.49	8
Capacitors	44	32	1.38	9
Less energy intensive	185	142	1.30	10
Larger inventory	171	143	1.20	11
Reschedule workers	163	144	1.13	12
Back-up data system	29	34	0.85	13
Lay-off workers	63	139	0.45	14

Descriptively, firms with voltage regulators, capacitors and power surge factor units were half as likely to report damage to equipment and inventory than those without any of these. Of 83 firms that had a voltage regulator, capacitor or power surge factor unit, 17 saw damage to either their inventory or equipment. Of 40 firms that did not have a voltage regulator, capacitor or power surge factor unit, 16 saw damage to either their inventory or equipment.

5.5 Marginal cost of outages

Section 8.3 showed the most common costs of outages. Section 8.4 showed that using self-generation was the fourth most favoured means of mitigating these costs. This section measures the first approach of assessing the impact of power outages on manufacturing firms by working out marginal costs of outages mentioned in section 4.1, by:

i. Asking firms' production managers and accountants their willingness to pay for a reliable supply of electricity, and
ii. Observing firms' use of self-generation.

5.5.1 Marginal cost of outages inferred from willingness to pay for more reliable energy

33% of respondents at 141 firms said that their firms would be willing to pay a higher electricity tariff for more reliable energy. Of those that were not willing to pay, one response was that they had already secured a bilateral agreement with Zesco to give them secure energy, while several firms expressed that the tariff was already high and that the tariffs had already been raised. Distrust in Zesco to deliver what they paid for was another factor in clients saying that they would not pay Zesco a higher tariff, with some respondents citing the complete lack of notification or unreliable nature of Zesco's planned outage notifications as evidence. We noted above that 24% of respondents said that they either did not receive notification or received inaccurate and therefore useless notifications. (Mwila et al (2017, p. 45) found that 17% of businesses said that they did not have access to information for load shedding.)

One firm noted that it had 'established good communication with Zesco', which resulted in texts every time power was to go out. Given that 92% of our respondents were either located in industrial zones or an MFEZ, these reflect poorly on Zesco. Another reason some firms gave for not wanting to buy energy at a higher rate was that they felt that they were already subsidising the mining sector.

Of the 46 firm's representatives that said that they would be willing to pay a higher tariff for more reliable electricity supply, 16 gave responses expressed in K/kWh and 19 gave responses expressed as an percentage increase. 11 firms did not say by how much more they would be willing to pay.

Five outlier results expressed the increase they would be willing to pay in K/kWh for a value higher than the variable cost of running a diesel generator. For this reason, we excluded them from the average increase firms would be willing to pay. See more in the discussion.

For the firms which did not express a value increase, we inferred an increase of K 0.01/kWh, the minimum increase possible. For values expressed as a percentage increase, we multiplied the firm's standard tariff by the percentage increase. We knew the firm's standard tariff because we asked them what kVA levels they were using. The commercial standard tariffs are K 0.35/kWh for 16-300 kVA, K 0.30/kWh for 301-2,000 kVA and K 0.25/kWh for 2,000-7,500 kVA (Zesco Ltd, 2017a).

The mean increase for 141 firms that responded is K 0.22/kWh (USD 0.017/kWh), whereas the median increase is K 0/kWh. Because not all firms were willing to pay a higher tariff, we investigated whether there were predictors of whether a firm would be willing to see an increase in tariff, and amongst those who would be willing to see an increase in tariff, what increase they would be willing to pay.

5.5.1.1 Willingness to pay by firm characteristics

By subsector, the percentage of firms willing to pay more did not vary much from the manufacturing sector wide percentage, other than for wood and wood products, where 60% of firms said they would be willing to pay more. However, the sample of 5 firms from that subsector was too small to draw a firm conclusion, or statistical significance in our logistic regression (see below), and this could be an area for further research with a greater sample of manufacturing firms working in the wood and wood products subsector. Of subsectors with more than 20 firms that we surveyed, the chemicals subsector (dominated by firms manufacturing painting products) had the least willingness to pay increased tariffs, with just 18% of firms expressing a willingness to pay more.

Table 9 Percentage of respondents willing to pay a higher tariff by manufacturing subsector

Ministry of Commerce subsector categorisation	# firms by subsector	% of firms by subsector	# firms WTP more	% of firms WTP more in the subsector
Food&bev	61	43%	24	39%
Textiles&garments	11	8%	3	27%
Wood	5	4%	3	60%
Chemicals	22	16%	4	18%
Plastics&rubber	21	15%	5	24%
Non-metallic mineral products	1	1%	0	0%
Basic metals	9	6%	3	33%
Fabricated metal products	15	11%	3	20%
Machinery&equipment	1	1%	0	0%
Electronics	0	0%	0	
Other	0	0%	0	

When we used whether a firm was willing to pay for more reliable energy as a binary dependent variable in logistic regressions, we hypothesised that several independent variables at our disposal would not have a statistically significant impact on the likelihood of a firm's willingness to pay for more reliable electricity. These variables included firm characteristics (whether a firm was foreign owned, exported, how many employees it had, its revenues, its production hours per week, what subsector it belonged to, its location) and the extent to which firms used various mitigation strategies. The only meaningful variable that was statistically significant and disproved the null hypothesis was whether a firm exported.[1] We could not regress more than two variables at a time because of the limited number of observations that we had.

Table 10 Exports was the only meaningful variable that we found to be statistically significant in determining whether a firm responded that it would pay more for more reliable electricity

	(1)
VARIABLES	WTP
exports	0.903**
	(0.395)
Angela	1.761***
	(0.555)
food & bev	0.370
	(0.416)
basic metals	0.450
	(0.777)
constant	-1.577***
	(0.355)
Pseudo R2	0.1101
Observations	140

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

It is not surprising to find that firms that the likelihood of a firm that exports being willing to pay more for reliable energy is 0.9. One would expect exporters' clients to be more demanding and less tolerant of failure, especially those with a large pool of potential suppliers.

5.5.1.2 Willingness to pay more by how much

Of the firms willing to pay more, for those that stated a K/kWh value below the cost of self-generation or as a percentage (and not counting the results of firms saying that they would be willing to pay more but did not state by how much more they would be willing to pay), the mean increase respondents were willing to accept was K 0.56/kWh (USD 0.04/kWh), whereas the median increase was K 0.11/kWh (USD 0.008/kWh).

5.5.1.3 Peak and off-peak usage

We collected the Zesco bills for 48 companies whose respondents told us that they manufactured for 84 hours of the week or fewer. Their median off-peak energy consumption was 6% and median peak energy consumption was 3%. 5% of these companies consumed more than 30% of their energy during off-peak hours. None of these companies consumed more than 20% of their energy during peak hours.

We collected the Zesco bills for 23 companies whose respondents told us that they manufactured for more than 84 hours of the week. Their median off-peak energy consumption was 16% and mean peak energy consumption was 9%. 9% of these companies consumed more than 30% of their energy

[1] The other was whether a firm had been interviewed by our enumerator Angela Hamakando. Of 22 responses she attained, only 6 (27%) of her respondents said that they would not pay more, in stark contrast to the 75% rejection to a tariff rise by firms answering to other enumerators. She did not elicit any of the five outlier results which were more than the cost of self-generation. Zesco may want to consult Angela how she managed to elicit such a high positive response rate!

during off-peak hours. 2% of these companies consumed more than 20% of their energy during peak hours.
To test whether the difference in tariffs were insufficient to alter energy consumption behaviour, Field Manager Graham Sianjase called in April 2019 17 firms that we had earlier interviewed that manufactured 24 hours a day to ask whether there were differentials in the wages that were paid for different times. He got through to 3 firms and these were the results:

1. A beverages company
    - Normal shift: 8am – 5pm (wage: normal)
    - Changeover shift: 5pm – 7pm (wage: normal x2)
    - Night shift: 7pm – 7am (wage: normal x2)
    - Changeover shift: 7am – 8am (wage: normal x2)
2. A beverages company
    - Normal shift: 4am – 12pm (wage: normal)
    - Normal shift: 12pm – 10pm (wage: normal)
    - Normal shift: 4am – 10pm (wage: normal)
3. A steel manufacturer
    - Normal shift: 8am – 5pm (wage: normal)
    - Night shift: 5pm – 7am (wage: normal + allowance), allowance details not disclosed.
    - Changeover shift: 7am – 8am (wage: normal + allowance), allowance details not disclosed.

Other than knowing that the beverages company with 100% differential in costs in labour for night shifts faces 23% lower electricity tariffs at night than the base tariff, we are unable to take a view of whether the company is more labour or capital intensive. It has 1,500 kVA of self-generation capacity and employs 200 full-time and 115 part-time staff.

5.5.2 Marginal cost of outages inferred from firms' use of self-generation

It costs approximately USD 0.29/kWh to self-generate electricity (interviews with manufacturing firms and key informants). The variable cost of power outages per kilowatt hour of energy lost therefore has to exceed the differential between this and the cost of power at a given time of day (because there are three tariffs depending on the time of day) for firms to rationally decide to engage in self-generation once they have acquired generators. As of 31 August, 2018, when we finished collecting firm data, the ZMK/USD varied around 13. (It is 12.11 as of 3 April, 2019 according to Google.com.) The table below shows what firms' marginal cost/kWh would have had to exceed for them to self-generate:

Table 11 Lowest marginal costs for firms of varying maximum demand capacity to self-generate in 2018

Assumptions: 13 K/USD as of 31 August, 2018
0.29 USD/kWh variable cost of self-generation

Marginal cost of power outages - differential between self-generation and Zesco tariff in 2018

	% of respondents who fall into this category	Marginal cost, USD/kWh	% different from standard 16-300kVA
Maximum demand capacity 16-300kVA	50%		
Standard charge, 6am-6pm		0.263	0%
Off-peak charge, 10pm-6am		0.270	3%
Peak charge, 6-10pm		0.256	-3%
Maximum demand capacity 301-2000kVA	37%		
Standard charge, 6am-6pm		0.267	1%
Off-peak charge, 10pm-6am		0.272	4%
Peak charge, 6-10pm		0.262	-1%
Maximum demand capacity 2001-7,500kVA	13%		
Standard charge, 6am-6pm		0.271	3%
Off-peak charge, 10pm-6am		0.276	5%
Peak charge, 6-10pm		0.267	1%
Maximum demand capacity 7,500+kVA	0%		
Standard charge, 6am-6pm		0.274	4%
Off-peak charge, 10pm-6am		0.278	6%
Peak charge, 6-10pm		0.271	3%

The table shows that the marginal cost of self-generation reduces during peak charge hours when Zesco's tariffs are highest because that is when the differential between the cost of self-generation and Zesco's tariff is lowest. The table also does now show a great deal of variation between off-peak and peak tariffs, nor between the supposedly more generous tariffs to larger electricity consumers. 50% of respondents fell into the category that saw them being charged the highest commercial tariff as the smallest commercial consumers. 37% of respondents bought energy at slightly lower tariffs for companies with maximum demand capacity of between 301 and 2,000kVA. 13% of respondents bought energy at the yet lower tariffs for companies with maximum demand capacity of between 2,001 and 7,500kVA.

Of 145 firms asked, 105 (ie. 72%) responded that they had acquired use of a generator, through one mechanism or another (if not from out-right purchase and sole ownership), and 1 firm responded that they were waiting for the shipment of a generator.

By contrast, 97 out of 144 firms (67%) said that they used their generator, ie. not all firms that had acquired access to a generator used them. The discrepancy for 3 firms that had acquired use of a generator at one time but did not use it was explained by the fact that their generators were no longer operational. One of them was engaged in trying to repair its generator. The other two did not report trying to repair or replace their generator. Taking these three firms out of consideration, 69% of firms reported using generators. The discrepancy therefore between firms that responded that they had acquired use of a generator and those that used them was less than 3%, ie. less than 5% and therefore not significant. Firms that acquired generators therefore largely used them to varying degrees, meaning that at least for some business operations, the marginal cost of outages to firms that owned generators exceeded the differential between USD 0.29/kWh and Zesco power.

To gauge the degree to which the loss of operations exceeded the variable cost of self-generation, the field team asked firms to inform them of the extent to which the firms used self-generation to mitigate power outages on a scale of 0 to 4, 0 being not at all, 4 being to cover all power losses (see question B2 in Annex 1).

5.6 Production delays prevented by self-generation

We measured the efficacy of varying degrees of self-generation in mitigating production delays (the second approach of measuring the impact of power outages on manufacturing firms mentioned in 4.1).

Self-generation as an independent variable was statistically significant in determining whether or not production delays occurred. The increased use of self-generation by 1 on a scale of 0-2 resulted in the reduction of production delays by -0.46 on a scale of 0-2 in our tobit regression. Rescheduling workers also has an obvious statistically-significant increasing impact on delayed production. The other independent variable listed in the regression below has a logical endogeneity issue – reduced output as a strategy could both cause production losses as well as be caused by production losses. The R^2 of the regression below is low because of the number of observations that could be collected within budget.

Table 12 Tobit regression with delay in production as the dependent variable, and self-generation, rescheduled workers and reduced output as the independent variables

	(1)
VARIABLES	Delay recat
Selfgen recat	-0.461***
	(0.118)
Resch recat	0.372***
	(0.126)
Reduce recat	0.712***
	(0.128)
Constant	1.355***
	(0.225)
Pseudo R2	0.1993
Observations	140

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Delayed production in turn had a statistically significant impact on loss in clients. A tobit regression with loss in clients on a scale of 0-4 as the dependent variable and self-generation on a scale of 0-2, reduced output on a scale of 0-2, delay in production on a scale of 0-2 and rescheduled workers on a scale of 0-2 showed reduction in output and delay in production as statistically significant independent variables: as they increase in magnitude by 1 on a scale of 0-2, the loss in clients increases by 0.33 and 0.35 respectively on the scale of 0-4.

Table 13 Tobit regression with loss in clients as the dependent variable, and self-generation, reduced output, delay in production and rescheduled workers as the independent variables

	(1)
VARIABLES	Loss in clients
Selfgen recat	-0.0618
	(0.108)
Reduce recat	0.227*
	(0.123)
Delay recat	0.254*
	(0.134)
Resch recat	0.0222
	(0.110)
Constant	0.211
	(0.244)
Pseudo R2	0.062
Observations	98

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.7 Predictors of a firm's likelihood to invest in and intensity use of self-generation

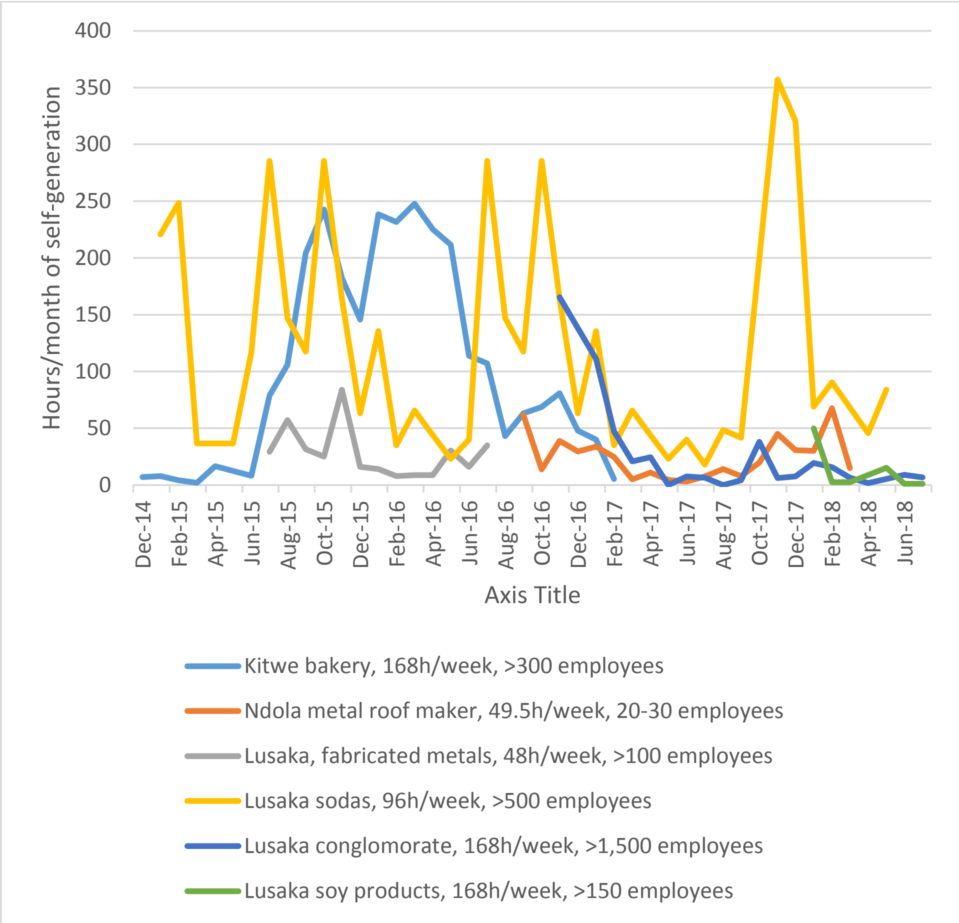
The third approach mentioned in 4.1 to assessing the impact of outages on manufacturing firms is to assess the extent to which self-generation is used by looking at firm characteristics.

Section 8.2.2 reported that 50% of firms interviewed that gained access to generators did so for the first time in the years of worst outages (2015 and 2016). Section 8.5.2 reported that 97 firms used generators, while 102 firms reported having access to operational generators, so that less than 5% of firms that reported having access to an operational generator did not use them.

Six large manufacturing firms shared with us generation hours per month for varying periods. Their hours are charted below. As we can see, the most concentrated period of outages was between June 2015 and October 2016.

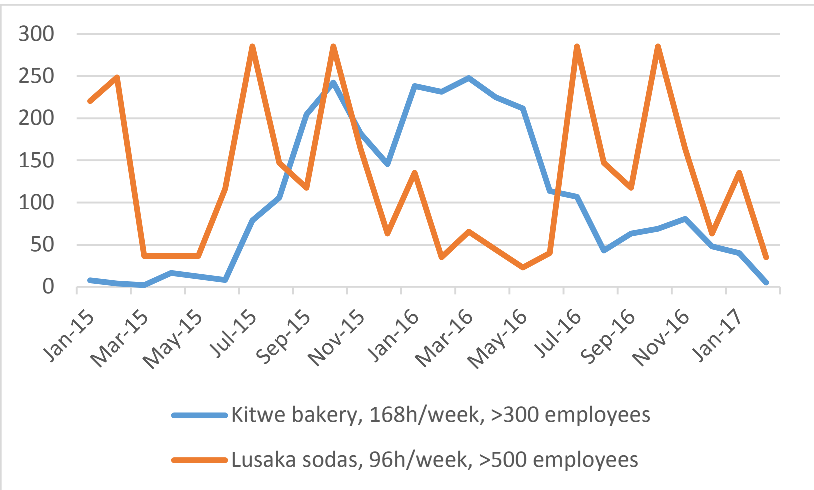
We also observe extreme use of self-generation in November and December 2017 for a particular company, and several companies were still using self-generation as late as April, May, June and July, 2018.

Figure 3 The self-generation hours/month profiles of 6 large manufacturing firms, Dec 2014-July 2018. Note: empty bars do not necessarily mean no generation hours that month



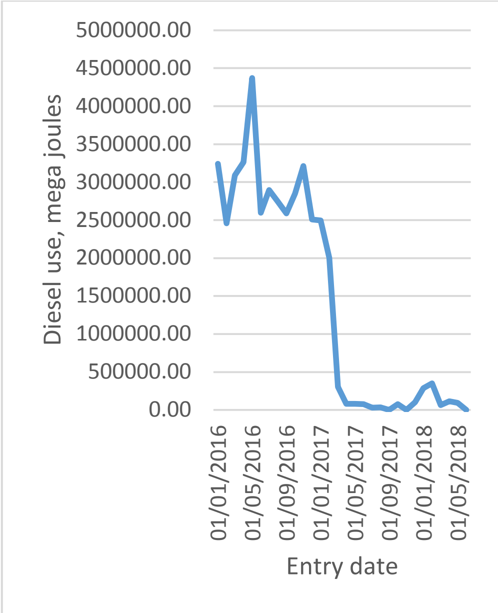
Zooming in on the hours of self-generation for the period January 2015-February 2017 for two large food and beverage companies, one located in Kitwe and one in Lusaka, the self-generation patterns are an almost perfect inflection of one another, suggesting that outages between the two cities were alternating.

Figure 4 Self-generation hours/month profiles of one large manufacturing firm in Kitwe and one large manufacturing firm in Lusaka, Dec 2014-July 2018. Note: empty bars do not necessarily mean no generation hours that month



Diesel use by a large beverages company dramatically tailed-off in 2017 when reservoir levels returned to normal.

Figure 5 Diesel use by a large beverages company in Lusaka, Jan 2016-Jun 2018



5.7.1 Predictors of a firm's scale of investment in self-generation

An ordinary least squares regression model was used to predict the kVA of installed generator capacity that firms invested in by various characteristics. Characteristics found to be statistically significant were the firm's number of employees, whether it exported, how many hours it operated in a week and whether belonged to the food and beverages subsector.

One employee increases the installed diesel-generation capacity by 0.5 kVA; if a firm exported, capacity increased by 587 kVA; every additional hour increased kVA by 4.8; if a firm was in the food and beverage subsector, capacity increased by 344 kVA.

Table 14 An OLS regression found employees, whether a firm exported, the number of hours it operated & whether it belonged to the food and beverages subsector to be statistically significant predictors of installed self-generation capacity

VARIABLES	(1) kVa
employees	0.496**
	(0.250)
exports	587.3***
	(170.9)
hours	4.846***
	(1.815)
food & bev	343.5**
	(170.1)
fabricated metals	139.2
	(272.6)
Constant	-328.0*
	(178.7)
Observations	134
R-squared	0.226

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

5.7.2 Predictors of a firm's likelihood to use self-generation

Ordinal logistic regression analysis was used to identify which firm-level variables impacted the extent to which self-generation was used. The dependent variable was the extent to which a firm used its generator. Because responses differed in this section for a firm interviewed twice (in November 2017 as a pilot and in August 2018, by two different enumerators, and responded by two different managers), the categories were collapsed. 0 remained 0. '1' and '2' collapsed into '1'; '3' and '4' collapsed into '2'. The new ordinal scale therefore became 0, 1, 2.

Regressions were run against at most six independent variables at a time, because of the limited number of observations. It was hypothesised that the independent variables, which were firm characteristics (whether a firm was foreign owned, exported, how many employees it had, its revenues, its production hours per week, what subsector it belonged to, its location), would not have an impact on the dependent variable.

Four variables disproved the null hypothesis, with their statistical significance below the 5% level of probability: whether or not the firm belonged to the basic metals subsector, whether or not the firm was based in Kitwe, its number of employees, and whether or not the firm exported.

Because the ordinal logistic regression was run, the assumption that the parallel regression assumption had to be tested for validity, ie. that all the coefficients on independent variables were equal for every ordinal value, using the Brant test. The Chi-squared for the model below was not significant in the Brant test, which meant that the parallel regression assumption had not been violated.

Table 15 Best model for predicting the extent to which a firm used self-generation, and the accompanying Brant test showing that our use of an ordinal logistic regression was valid

VARIABLES	(1) Selfgen recat	(2) Selfgen recat	(3) Selfgen recat
Kitwe	1.411**	1.53**	1.425**
	(0.607)	(0.607)	(0.626)
employees	0.00326**	0.00344**	0.00335**
	(0.00141)	(0.00145)	(0.00145)
exports	1.196***	1.255***	1.246***
	(0.392)	(0.401)	(0.403)
food & bev	0.359	0.32	0.0384
	(0.364)	(0.385)	(0.596)
textiles garments		0.441	0.150
		(0.6777)	(0.826)
wood		0.441	-1.761*
		(0.946)	(1.035)
chemicals			-0.380
			(0.697)
plastics rubber			-0.295
			(0.695)
non-metallic mineral products			-14.61
			(1,359)
basic metals	-1.982**	-2.105**	-2.348**
	(0.833)	(0.856)	(0.952)
Constant cut1	0.233	0.229	-0.0758
	(0.294)	(0.315)	(0.569)
Constant cut2	1.115***	1.127	0.830
	(0.308)	(0.329)	(0.572)
Pseudo R2	0.1186	0.1302	0.1357
Observations	144	144	144

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Brant Test of Parallel Regression Assumption

Variable	p>chi2
All	0.572
Kitwe	0.462
employees	0.164
exports	0.304
food & bev	0.703
textiles garments	0.925
wood	0.405
basic metals	0.884

A significant test statistic provides evidence that the parallel regression assumption has been violated.

Subsector analysis

Of all the subsectors, we only found basic metals to have a statistically significant impact on the extent to which a firm chose to use self-generation. If a firm was in the basic metals subsector, it would have a score of 2.3 points lower than if it were not in this subsector, ie you would expect it to not have a generator.

Location

Location in Kitwe had a statistically significant impact on the extent to which a firm used self-generation. A firm located in Kitwe would on average have a self-generation score 1.48 higher than a firm not located in Kitwe.

Number of employees

The number of employees was another statistically significant variable for its impact on the extent to which self-generation was used. For every additional employee, a firm would self-score its self-generation use by 0.004 more points. For a firm to score 1 point more on the 0, 1, 2 self-generation scale, our model predicts it would need 280 more employees than another firm.

Exports

Whether a firm exported or not was another statistically significant variable for its impact on the extent to which self-generation was used. A firm that exported would be expected to score 1.2 more points than a firm that did not export.

Foreign ownership

We did not find statistical significance for foreign ownership as a variable impacting the extent to which self-generation was used.

Years of production experience

We did not find years of production experience to be a statistically significant variable impacting the extent to which self-generation was used.

5.8 Special energy provision for important clients

Zesco's economists (Zesco economists, personal communication, 10 November, 2017) informed us that clients whose power needs exceeded 10MW or were anticipated to exceed 10MW, or whose smooth supply of power was seen as a matter of national interest, would be awarded power purchase agreements and prioritised for reliable energy. We encountered one such company in the light industrial area of Lusaka in the course of our surveys, as well as another company that reported being refused for this service, and instead advised to invest in a transformer. By contrast, contrary to our expectation that MFEZ clients would have reliable energy, the one manufacturing firm with which we managed to secure an interview that was located in the south Lusaka Multi-Facility Economic Zone reported 4 hours of self-generated energy in the week prior to our interview with its assistant supervisor of production.

5.9 Willingness to sell energy back to the grid

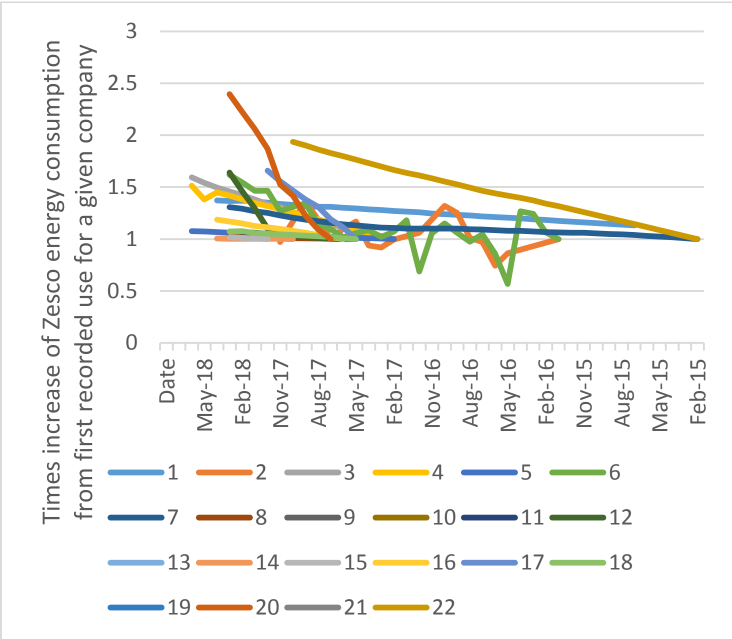
While prospecting, we discovered a cement manufacturer in the Copperbelt that used entirely self-generated energy from its own purpose-built power plant. It expressed its interest in selling excess generated energy back to the grid.

29% of 82 respondents said that their firm would be willing to sell energy back to the grid.

5.10 Pattern of Zesco energy consumption

Of 19 firms for which the enumerator team got more than 3 months of Zesco-grid records, continuous growth in energy consumption without a month of negative growth is evident for 17 firms, in spite of power outages (see figure below). For manufacturing firms, energy consumption is a good proxy for revenues given that more consumption leads to more production which leads to more revenues.

Figure 6 The Zesco-grid electricity consumption patterns of 19 Zambian manufacturing firms



6. Discussion

6.1 Periods of worst outages

6.1.1 Years of worst production outages and extent of production losses

2015 and 2016 were reported as the worst years for production outages out of 2014-2018. This was corroborated with our observation that self-generation was used most by firms between June 2015 and October 2016. Over 50% of our respondents' diesel-generators were purchased for the first time in the years 2015 and 2016.

6.1.2 Months of worst electricity reliability in general

Our findings that October followed by August are the worst for outages and that April is the least reported for outages is surprising because both October and August occur during the wet season when Zambia has historically had more energy production, while April is in the dry season and when energy production has historically been lower (compare the below results in Table 15 with Table 2 reproduced below).

Table 16 Contrary to expectations, the worst months for power outages are rainy season months when Zesco produces more energy on average, and the best month is a dry season month when Zesco produces less energy than average

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Number of votes	10	9	8	2	7	10	12	23	19	27	20	16
Rank of month	7	9	10	12	11	7	6	2	4	1	3	5

Reproduced for reference

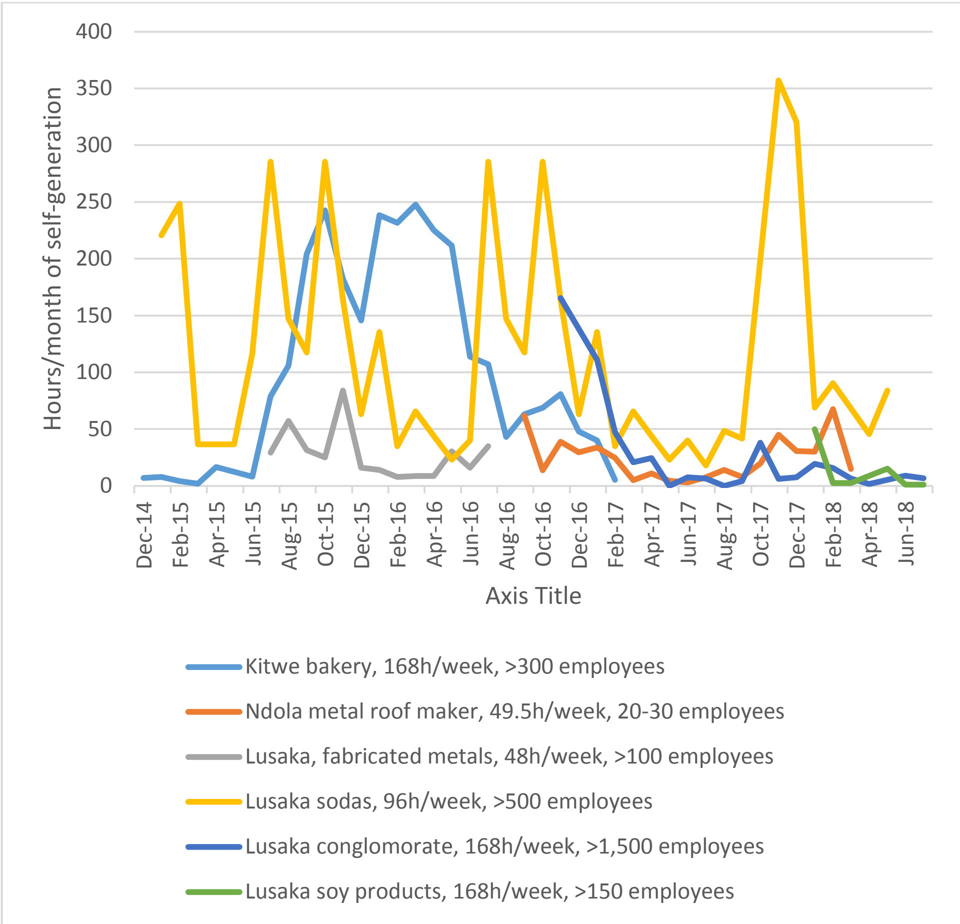
Table: How seasonality affects Zambia's hydro power production

	% difference in power production for month from average production/month of calendar year												% of production from hydropower
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
2010	-4%	-16%	-10%	-2%	-4%	1%	7%	6%	5%	5%	4%	7%	99.9
2011	-4%	-12%	-4%	-4%	0%	1%	1%	8%	4%	3%	1%	6%	99.9
2012	-3%	-8%	-3%	-3%	0%	5%	6%	9%	6%	-8%	-10%	9%	99.9
2013	-4%	-9%	-3%	-2%	-1%	-5%	6%	5%	2%	5%	1%	4%	99.9
2014	-2%	-12%	-7%	-2%	-1%	2%	4%	3%	3%	2%	3%	7%	97.2
2015	3%	-7%	0%	1%	5%	5%	7%	6%	-2%	-1%	-10%	-8%	
2016	-5%	-9%	-6%	-8%	-1%	3%	9%	3%	3%	5%	1%	6%	
mean average	-3%	-10%	-5%	-3%	0%	2%	6%	6%	3%	2%	-1%	4%	*Source: World Bank*
median average	-4%	-9%	-4%	-2%	-1%	2%	6%	6%	3%	3%	1%	6%	
Wet season	*Source: Zesco*												
Dry season													

Two explanations are possible:

i. The data for precipitation patterns and Zesco energy production upto and including 2016 is not representative of 2017 and 2018, for whose months respondents will have better memory. Looking at the self-generation data we have for 6 firms, we notice that October 2015 and 2016 (years for when we have data in table 3) were bad months in terms of self-generation for a Lusaka-based sodas manufacturing firm. This is not a lot of data to argue against the hypothesis. More up to date Zesco records will reveal whether 2017 and 2018 had different energy patterns.

Reproduced for reference – hours of self-generation for six firms



ii. Firms ramp up production in the wet season in expectation of more reliable power supply, and because of this expectation, suffer more when precipitation levels in a given year are lower.

6.2 Damages incurred from Zesco's outages

Our findings do not go to the same depth as Pasha et al (1989) and Diboma and Tamo Tatietse's (2013) with regards to the lead time required for planned outages and the quantified cut in cost with planned outages, but do support the thesis that planned outages, when they come with notification, considerably reduce costs.

24% of Zesco clients said that they never received notifications or accurate notifications for planned outages. This impacted their decision to say 'no' to paying Zesco for more reliable energy, because they lacked faith in Zesco's ability to deliver.

6.3 Mitigation strategies and their efficacy

20% of firms that had a voltage regulator, capacitor or power surge factor unit saw damage to their inventory or equipment, in contrast with 40% of firms that did not have these seeing damage to their inventory or equipment. Firms using these interventions therefore seem to have decreased their chances of damage by 50%.

The extent to which self-generation was used had a statistically significant relationship in decreasing delays in production, and decreasing delays had a statistically significant relation with reduction in loss of clients.

Although the flow of causality is a logical one and one would not expect reverse causality in these instances, to address criticisms of endogeneity through reverse-causality, a follow-up study with the same firms could clarify through semi-structured interviews what caused loss in clients, what caused production delays, how far self-generation mitigated these, and how decisions to invest in self-generation capacity and then use self-generation were made on an ex-ante and on an ex-post basis.

6.4 Marginal cost of outages

There is a large discrepancy between the observed marginal cost to firms of power outages and their stated willingness to pay for more reliable energy. However, this is not to be unexpected. Running diesel-generators does not represent business-as-usual, and indeed the fact that firm size is correlated with generation-use suggests that the costs of self-generation are prohibitive to smaller firms, or firms that use electricity to the degree that the basic metals subsector does.

In terms of firms refusing to accept higher tariffs, distrust of Zesco's competence was one major important reason. The other – that manufacturing firms felt they were subsidising the mining sector – was reiterated by the CEO of the Zambia Association of Manufacturer (interviewed on 28 May, 2018). The Director of Economic Regulation at the Energy Regulation Board (interviewed on 6 June, 2018) said that the Energy Regulation Board was endeavouring to regulate Zesco's tariff to the Copperbelt Energy Corporation, which was low, by pushing through legislation enabling it to do so.

While almost a quarter of a firms stated that they never received notifications of outages from Zesco or did not receive accurate notifications,

Firms' observed marginal cost of generation, ie. the difference between self-generation and the Zesco tariff, is north of USD 0.25/kWh. That this number is as high as it is in part a function of Zambia's very low tariff rates. Zesco's tariffs for large manufacturers are as low as USD 0.01/kWh and as high as USD 0.03/kWh for smaller manufacturers at peak-hour (Zesco Ltd, 2017b). By contrast, in neighbouring Zimbabwe, which shares Zambia's Kariba North Dam (this dam accounted for 45% of Zambia's installed power capacity in 2017 and 51% of Zimbabwe's installed capacity in 2016 (CIA, 2016; Energy Regulation Board of Zambia, 2018, p.63)), the Zimbabwean utility charges manufacturers USD 0.04/kWh for off-peak electricity and USD 0.13/kWh for on-peak energy (ZETDC, 2014). Part of the reason for this discrepancy may be that Zesco's tariff is calculated based on the marginal operating costs of a fully-amortised asset, and assumes no future construction costs. This issue seems to be recognised by Zesco in its recent application for tariff increases (African Energy, 2019; Phiri, 2019).

It should be further noted that the marginal cost of outages is greatest for firms using the most energy, because they are offered the cheapest Zesco tariffs, ie. the firms most able to pay cost-recovery tariffs are charged the lowest tariffs.

The willingness-to-pay survey will have been prejudiced by respondents seeking to protect their firms from tariff hikes. In this light, the higher mean average of 28 positive responses for a higher tariff should be reflective of the tariff hike that respondents who would like more reliable energy would be happy with – K 0.56/kWh (USD 0.04/kWh).[2]

[2] Our finding that firms that the 0.9 probability that a firm that exports will be willing to pay for more reliable energy agrees with Batidzirai et al (2018)'s findings of whom they found would pay for more reliable electricity, except our finding still holds for tariffs post 2017 and for large manufacturing firms. The coefficient will have been affected by omitted variable bias. An extended budget would allow for more observations to be collected in order for a more robust logistic regression model to be constructed.

In addition to increasing the tariff, it is worth considering restructuring the tariff.

First, the tariff becomes smaller for firms consuming more, effectively subsidising the most those most able to pay cost-recovery tariffs. This should not be so.
Second, the tariff differentials for peak-hour and off-peak hours should be revisited. Reducing peak hour demand would reduce the pressure on Zesco to increase its installed power capacity.

84 hours represents operating during the standard energy tariff hours of 06:00-18:00, seven days a week. Firms working more than those hours would necessarily see a higher proportion of their tariffs fall into the off-peak and peak tariff hours. While we saw 16%:9% off-peak to peak consumption by firms consuming more than 84 hours a week, if firms had been operating 168 hours a week (the maximum number of hours in a week), we would have seen them consume at a 33%:17% ratio since 8 hours of the day are off-peak (22:00-06:00) and 4 hours of the day (18:00-22:00) are peak. We therefore see under-consumption of energy during off-peak hours for firms producing more than 84 hours a week but fewer than 168 hours (the maximum number of hours in a week) per week.

For firms manufacturing 84 hours or fewer, only 5% optimised their energy consumption so that more than 30% of energy consumption fell during off-peak hours. The median off-peak energy consumption was just 6%, suggesting that the differential of K 0.07/kWh (USD 0.005/kWh) between the standard tariff and the peak/off-peak tariffs for 300 kVA and 2,000 kVA capacity connections is not enough to incentivise firms to shift their work hours when Zesco's baseload demand is lowest. By contrast, the difference for Zimbabwean manufacturing firms is USD 0.03/kWh for off-peak energy and USD 0.06/kWh for peak-hour energy. Seeing that two of three respondents said that they paid higher wages for workers working off-peak hours, and one of those respondents specified that they paid twice the wages that they did during normal business hours, the difference in cost between off-peak and standard energy would have to off-set this.

6.4.1 Self-generation patterns

While the worst outages were in 2015-16 (and these years were the most popular years of purchase for firms' oldest generators in use), we saw that one firm used its generator to the same extent as it did in 2016 in November and December 2017.

Generator records also showed us that firms were still self-generating as recently as June, July and August, which does not accord with what Zesco's economists told us (Zesco economists, personal communication, 6 June, 2018): that load shedding came to an end in 2016 and that only maintenance outages take place on Sundays (it is possible that the power outages were not due to load shedding but other factors impacted by poor maintenance). Zesco's own website shows load-shedding schedules past 2016, but shows none more recent than March, 2017 (Zesco Ltd, 2017e). We observed first-hand the gap between what Zesco says and what clients experience.

6.4.2 Predictors of a firm's likelihood to invest in and intensity use of self-generation

Given the limited number of observations we were able to collect within budget, the number of independent variables we were able to include on the right hand side of our regression models were limited, and they likely suffered from omitted variable bias. The study could be extended to collect more observations to yield better fit models.

Subsector

Sichone et al (2016) found that the food and beverages and fabricated metal products subsectors were statistically significantly and negatively impacted by power outages. Complementing this finding, we found that whether a firm was in the food and beverage subsector was a statistically significant predictor of installed diesel generation capacity, adding 343kVA of capacity for the subsector. We did not find other subsectors to be statistically significant in predicting installed generator capacity.

We did, however, find that belonging to the basic metals subsector was a statistically significant predictor that a firm would not self-generate energy. We speculate that this is because it becomes particularly uneconomical to do so for the subsector. Further semi-structured interviews would clarify this.

Descriptively, we found that for firms for which we had a sample of more than 5 or more firms, we could rank the subsectors as follows in terms of those that marked that they used self-generation 'most' or 'all' of the time:

1. Fabricated metals
2. Food and beverages
3. Textiles and garments
4. Chemicals
5. Plastics and rubber
6. Basic metals (for which we found statistical significance that one would not expect this subsector to run to a great extent a generator)
7. Wood and wood products

Table 17 Firms by subsector and whether they use self-generation to a major extent or all the time and whether they use capacitors, voltage regulators and/or surge protectors all of the time

Firms by subsector and whether they use self-generation to a major extent or all of the time	Food&bev	Textiles&garments	Wood	Chemicals	Plastics&rubber	Non-metallic mineral products	Basic metals	Fabricated metal products	Machinery&equipment
# firms that self-generate levels 3 or 4	34	6	1	10	9	0	2	10	0
# firms surveyed in subsector	61	11	5	22	21	1	9	15	1
% subsector that self-generates levels 3 or 4	56%	55%	20%	45%	43%	0%	22%	67%	0%
Firms by subsector and whether they use capacitors, voltage regulators and/or surge protectors all of the time									
# firms that protect against power surges all the time	34	6	2	12	10	1	4	10	0
% subsector that use protection all the time	56%	55%	40%	55%	48%	100%	44%	67%	0%

A former production manager at a milk factory gave us a qualitative explanation for why self-generation was important for milk production, which falls within the food and beverages subsector. He told us that even half a second of power outage would result in the reset of the manufacturing process for eight hours because of the vulnerable sterilisation process. To prevent this from happening, the firm used Zesco to charge the batteries for their Uninterrupted Power Supply machines, which they used all of the time. Their machines were not run on Zesco power directly.

This accorded with what Pasha et al (1989) found that there is a major variation between type of industry and the cost of an outage: continuous-process industries are more vulnerable to spoilage and would therefore do the most to protect against losses.

We did not expect to find statistical significance for wood, non-metallic mineral products, machinery and equipment, electronics and 'other', because we had less than five observations for these subsectors. We had 21 observations for plastics and rubber and 22 observations for chemicals.

Incidentally, we found the same ranking of subsectors (where we had a sample of more than five firms) to hold for highest proportion of firms that used capacitors, voltage regulators or surge protectors all of the time:

1. Fabricated metals
2. Food and beverages
3. Textiles and garments
4. Chemicals
5. Plastics and rubber
6. Basic metals
7. Wood and wood products.

However, when we look at sectors for which we had more than five firms, the ranking by willingness to pay for more reliable electricity is not what we would expect given that investment in self-generation is a proxy for marginal cost and its ranking matches investment and use of capacitors, voltage regulators and surge protectors. The ranking is thus:

1. Wood and wood products
2. Food and beverages
3. Basic metals
4. Textiles and garments
5. Plastics & rubber
6. Fabricated metal products
7. Chemicals

Subsectors were not statistically significant in predicting whether a firm would be willing to pay more so perhaps we should not look too deeply into this.

Location

Because we only had one enumerator survey firms in Kitwe, we suspected that the result that Kitwe was statistically significant in determining whether a firm would have a generator was contaminated by the particular enumerator's proclivity to score highly the extent to which firms used self-generation. To triangulate the result, we looked further into the details of the firms interviewed by Beauty Nkosha in Kitwe.

Out of the 18 firms which she interviewed, 83% had generators, which is higher than the 65% average for all firms interviewed in Lusaka, Ndola and Kitwe. Of Kitwe firms with generators, 73% had purchased their generators *prior* to 2015. Recall that in our overall survey of firms in Lusaka, Ndola and Kitwe, 53% of firms had purchased their generators in 2015 or 2016. The Kitwe result therefore seems to be statistically significant not because of the way in which the enumerator filled the surveys, but because of how firms in Kitwe were actually using their generators.

One reason for why firms in Kitwe might have used self-generation more is because they experienced worse outages than firms in the other two industrial towns. This seems to be suggested by figures 10 and 11 which shows the extent to which a firm in Kitwe had to use self-generation, which is very different from the profile of generator hours for firms in Lusaka for the same period.

Number of employees

Firm size in terms of employees was both a statistically significant predictor of installed diesel generation capacity (for every additional employee, installed capacity increased by 0.5kVA) as well as the extent to which a firm used its generators. This makes sense because larger firms would have the resources for the required capital expenditure, benefitting from economies of scale on a levelised cost of self-generated energy basis. They would also have the working capital to run their generators as much as they wanted.

Descriptively, of 88 firms with more than 50 employees, 64 (73%) had self-generation capability. Of 45 companies with fewer than 30 employees, 20 (44%) had self-generation capability. Firms with more than 50 employees were therefore 64% more likely to have a generator than firms with fewer than 30 employees.

Similarly, we found that firms larger than 50 employees were 40% more likely to use voltage regulators, capacitors and power surge factor units than firms with less than 30 employees, and therefore see less damage to equipment and inventory.

Our result triangulates with the World Banks which found that firms employing more than 100 employees felt less of an impact in loss of revenue than firms with 20-99 employees (World Bank and International Finance Corporation, 2014, p. 14). It also accords with Alcott et al's rationale that larger firms benefit from economies of scale in generator costs (2016).

Exports

Exports was a statistically significant predictor of both installed self-generation capacity (if a firm exported, it would on average have 590 kVA more of installed capacity than if it were a firm that did not) as well as extent to which generators were used. This makes sense because exporters' clients often have a larger pool of potential suppliers for commodities and therefore tend to be more demanding and less tolerant of failure.

Descriptively, of 54 firms that exported, 48 (89%) had self-generation capability. Of 87 firms that did not export, 47 (54%) had self-generation capability. Firms that exported were therefore 65% more likely to have a generator than those that did not.

This, and size of firm, triangulates with Steinbuks and Foster's (2010) findings.

Hours of weekly production

Hours of weekly production were a statistically significant predictor of a firm's installed capacity; for every additional hour of work, a firm would have on average 4.8 additional kVA self-generation capacity. While firms working around the clock have more latitude of when they have to operate their generators (which explains why weekly hours did not appear as a statistically significant predictor of intensity of self-generation use), they also tend to be larger and better-resourced.

Foreign ownership, years of production experience

Our finding that foreign ownership and years of production experience were not statistically significant factors in determining whether a firm owned and used a generator contrasts with Sichone et al's finding that foreign ownership and years of existence had a statistically significant impact on Lusaka-based manufacturing firm productivity (2016).

Descriptively, **o**f 36 firms that were foreign-owned or owned by non-black Zambians, 26 (72%) had self-generation capability. Of 27 domestically and black-owned companies, 13 (50%) had self-generation capability.

Of the 66 firms with more than 15 years of manufacturing experience, 43 (65%) had generators. Of the 39 firms with fewer than 7 years of experience, 26 (67%) had generators. The difference in years of experience seemed insignificant. Given that more than half of firms purchased their first generators as recently as in 2015 or 2016, the dire necessity for generators only then perhaps explains why years of experience was not a factor.

6.5 Pattern of Zesco energy consumption

Our sample was too small and for too small a period to infer that Zambia's manufacturing firms have been growing every month since January 2015. When we look back at table 1, we see a sector wide decrease in energy consumption for manufacturing. Nor can we infer that the surviving manufacturing firms are increasing their consumption every month, because the per capita consumption rate dipped from January to February in 2017 (Zesco Ltd, 2017d)[3].

However, generally observed month-to-month growth in energy consumption indicates that firms are not producing at capacity and are risk averse: they are expanding production incrementally once demand has been proven, in part at least because of the negative spill-over effects that power outages have on even parts of the economy which are not so directly impacted in a costly manner. This is not so dissimilar from what the Ministry of Commerce, Trade and Industry found for firms in 2011-12 (2014, pp. 49–50): firms reported capacity utilisation of 53% in 2006, rising to 66% in 2010, signifying an inefficient use of capital. The Ministry ranked certain subsectors from least efficient in terms of capacity utilisation to most efficient (2014, pp. 50), with textiles (38% capacity utilisation) as least efficient for 2006-10, and tobacco (88% capacity utilisation) as most efficient.

Beyond the outsized impact of a drop in copper prices and other factors such as exchange rate fluctuations, inflation and access to finance, the 2015/16 power outages would have slowed growth, and we can see this from the generally gentler slopes of growth of energy consumption in figure 6 for 2015 and 2016 than the steeper slopes for 2017 and 2018 because a) from an input perspective, there was less energy available for the firms to use and b) from an output perspective, demand for their products would have slowed down as other firms were also forced to slow down their expansion.

Another reason for slow expansion in capacity utilisation is what Allcott et al (2016) predict: rapid economic growth could cause an increase in electricity demand that leads to shortages, which then reduces productivity.

The perpetual and recent growth we have observed in firms' energy consumption from their Zesco bills suggests that belief that power capacity is a bottleneck to growth is causing the belief to be a bottleneck to more rapid growth. A way to address that belief is for firms to stop experiencing outages.

7. Conclusions and policy recommendations

Besides the cost of extra security for planned outages, every other cost of outage went down when firms were able to plan for it. For unplanned outages, damage to equipment and inventory ranked as the second and fourth highest costs. With planned outages, these ranked as the two lowest cost

[3] We examined consumption data we received from Zesco for 8,842 anonymised accounts which used 300kVA or more of maximum demand capacity for Jan-April 2017. 142 clients were categorised as delinquent accounts. We looked at total consumption by month and the number of clients clients consuming more than 0 kWh.

damages. Firms using voltage regulators, capacitors or power surge factor units reported damage to inventory or equipment half as often as firms that did not use these.

Self-generation as an independent variable was statistically significant in determining whether or not production delays occurred, which in turn was associated with loss in clients. 72% of respondents acquired use of a diesel generator, and less than 5% did not use their operational generators. More than 50% of their oldest generators were from 2015 and 2016, the years of the worst outages. Statistically significant predictors of installed self-generation capacity were firm size, how many hours a week a firm manufactured, whether a firm exported, and whether it belonged to the food and beverage subsector. Statistically significant predictors of the extent to which a firm used its generators were its size, whether it exported, whether it was located in the town of Kitwe and whether it did not belong to the basic metals subsector.

The observed marginal cost of running generators was more than USD 0.25/kWh. The larger the firm's consumption, the larger the marginal cost because larger firms pay lower tariffs than smaller firms. For planned outages, the justification for running generators was to mitigate against extra staff costs, damage to the firm reputation and loss in clients, the three highest ranked costs of planned outages.

A third of respondents said that they would be willing to pay an average increase of USD 0.04/kWh for reliable on-grid energy. The likelihood of a firm that exports being willing to pay more for reliable energy was 0.9. Distrust in Zesco's ability to deliver reliable energy was a reason for many declining to pay a higher tariff, with a quarter of respondents reporting that they never received notifications of outages or that they received inaccurate notifications. Not wanting to subsidise Zambia's mining companies was another reason for not wanting to pay more.

The tariff differential for peak and off-peak hours is significantly lower than Zambia's neighbouring Zimbabwe which is similarly reliant on Kariba North Dam. The differential for manufacturing wages paid at off-peak hours can far exceed Zesco's tariff differential. Firms that operate 84 hours are not producing as much during off-peak hours as they could.

Recommendations

We recommend that the Ministry of Finance not change the waiver of import duties on back-up generators, since their acquisition results in their use to mitigate the impact of outages in more than 95% of observed cases.

We recommend that Zesco improve its outage forecasting and communication with customers about when they can expect power outages in order to build confidence in its ability to deliver reliable energy at higher rates.

Regarding tariffs, we make four recommendations.

To complement Zesco's effort of building trust with its clients, we recommend that Parliament allow the Energy Regulation Board to regulate Zesco's tariffs to the Copperbelt Energy Corporation to address manufacturers' concern that they subsidise mining companies' low electricity tariffs.

Second, we recommend that Zesco stop charging larger consumers lower tariffs. The savings it could make from an incremental increase in these tariffs could be used to finance the installation of more power generation capacity, which larger firms would value given that their marginal cost of power outages is greater than the marginal cost of power outages than smaller firms when they self-generate electricity.

Third, we recommend that Zesco provide an initial premium service of reliable energy to exporters. This service offering should prove more popular with a broader array of clients once this premium service's reliability has been demonstrated, once Zesco starts offering accurate outage forecast communication and once it is perceived that the mining sector and larger consumers of electricity are not being subsidised.

Fourth, to reduce pressure to rebuild reliable installed capacity to meet peak demand, we further recommend that Zesco increase the tariff differential between its off-peak, peak and standard tariffs.

We encourage further qualitative research into why firms in the basic metals subsector are not using their generators to a great extent.

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Annex 1– Last iteration of questionnaire used, July 2018

Important Instruction: The items in this **questionnaire** ask about the performance of electricity supply, how it affects firms' operation, and your establishment's dispositions towards improved electricity service. Answers will be received in complete confidence. The researcher is only interested in the data obtained, not in who you are. Please be frank and respond as honestly as possible as this research is completely non-judgmental. Please note that all responses are coded and general trends reported so that no individual is identified in write ups of the survey.

Background firm information to be collected pre-interview

Name of enumerator(s):

Name of firm:

Address(es) (district(s), province(s)):

MFEZ, Light or Heavy Industrial Zone or none of the above?

Size of firm by employees:

Maximum power load consumed by firm, kVA:

What does the firm produce?:

Industry:

Date of survey:

Names, job title and contact details of people interviewed:

Pre-interview requests

Please ask the firm to have ready the following information for when you go to interview them:

1. Zesco bills by month / records of Zesco kWh consumed for each month of 2016-present as well as March and August 2014 and 2015
2. Logs of genset usage in terms of diesel fuel used (litres) and hours used for each month 2016-present as well as Feb and July 2014 and 2015
3. Details of generators (kVA, year purchased in)

Questions for accounts

Questions for manufacturing operations

Questions for manufacturing operations that accounts might have

Section A: General information questions for management / accounting

A1. In what year did your firm start manufacturing? ....

Please note that this does not preclude name changes so long as the company was manufacturing before, as opposed to just trading.

A2. Please fill in the below

Type of employee	Number of employees
Full-time	
Part-time	
Casual	

A3a. Does your firm export? Yes ☐ No ☐

If yes, A3b. please fill below:

Transcontinental?	List of countries
Inside Africa	
Outside Africa	

A4. What were your firm's revenues in the last fiscal year? ZMK ___________

A5. Is your firm majority owned by non-Zambians? Yes ☐ No ☐

A5a. If so, what is the majority nationality owner?

Section B: Energy Consumption, Capacity Utilization and Electricity Supply Performance for engineers/accounting/management

B1bbb. How much did power outages account for loss in production and revenues in the following years?

Year	No loss in production due to power outages (0)	Lost 1-15% of targeted production (1)	Lost 16-30% of targeted production (2)	Lost 31-50% of targeted production (3)	Lost more than 50% of targeted production (4)
2018 Jan – present					
2017					
2016					
2015					
2014					

B1dd. Can you name specific months when power outages have been particularly disruptive to your firm?

B1c. Please share with us records of your firm's on-grid energy consumption (kWh) by month for all months from 2016-present and for March and August 2015 and 2016. **[We would like to take photocopies of your records and not waste your time filling this out in front of you. We would like monthly on-grid energy consumption, in kWh]**

B1cii. Can we request for your on-grid energy consumption (kWh) from Zesco?

B2. What coping strategies does your company adopt for outages when they occur?

	Do not use (0)	**Use a bit (1)**	**Use to a moderate extent (2)**	**Use to a major extent (3)**	**Rely upon all the time (4)**
Voltage regulators and/or use capacitors					
Use surge protectors					
Use power factor correction units					
Reduce output					
Delay production					
Reschedule worker hours (and if so, what percentage of the workforce?)					
Lay-off workers					
Self-generation of power as back-up (and if so, what percentage of normal energy consumption do they make up?) and/or use UPS and/or back-up batteries					
Back-up data system					
Carry larger inventory than otherwise would					
Switch to less energy intensive operation					
Insurance					
Injury to workers					
Other:					

B3a. Please fill out the below table if the company has generators

	Generator 1	Generator 2	Generator 3	Generator 4
i. Financing mechanism 1 Purchased outright 2 Lease 3 Borrow 4 Share 5 Do not possess 6 Other 7 Bought by parent company **If 5, skip to B4a.** Other_______				
ii. Capacity, kVA iia. Capacity, litres				
For purchased generators				
iii. Year of purchase				
Variable costs				
v. Fuel, litres/month for all months 2016-present and Feb and July 2014, 2015 vi. Hours of generator use/month for 2 for all months 2016-present and Feb and July 2014, 2015 **[We would like to take photocopies of your records and not waste your time filling this out in front of you]**				

B3b. When the grid power goes out, does your company use all of its available self-generation capacity? Please circle **ONE** of the 4 options below:

0. No, we barely use our generators at all for either planned or unplanned outages.
1. We use our generators to maximum capacity for planned outages, but this does not generate as much energy as we would have used had the grid not gone out. We do not use our generators for unplanned outages.
2. We use our generators to maximum capacity for both planned and unplanned outages, but this does not generate as much energy as we would have used had the grid gone out.
3. Yes, we use our generator(s) at full load, and this helps us replace all the energy we would have used if the grid power had not gone out.

B3bii. If the answer is 1 or 2, does self-generation exclude production? Yes ☐ No ☐

B3e. Would your firm sell electricity back to the grid if there was a mechanism to do so?

Yes ☐ No ☐

B4a. Using your diary, please provide us a picture of the outages and generated hours in the last week **that there were outages** -

Day of the week	**i Production hours** (example: 6am-6pm)	**ii Frequency of planned outages** (example: 2x)	**iii Cumulative planned outages, hours** (example: 2h)	**iv Frequency of unplanned outages** (example: 4x)	**v Cumulative unplanned outages, hours** (example: 0.5h)	**vi Cumulative hours of self-generated power, hours** (example: 2h)
Monday						
Tuesday						
Wednesday						
Thursday						
Friday						
Saturday						
Sunday						

B5a. To what degree do **unplanned** power losses cause each of the following?
B5b. To what degree do **planned** power losses cause each of the following?

Please note that this question is seeking whether there is a difference between the damage between planned and unplanned. Please see next table.

B7. Would you pay a higher tariff if it guaranteed more reliable supply? Yes ☐ No ☐

B8. If yes, up to how many ZMK/kWh on top of the current tariff would it make sense for this firm to pay?..........................

Thank you for your time. We will share our overall results with you.

Annex 2– Research implementation, challenges, sources of data and key informants

Annex 2.1 Building and incentivising a field team

The first member of the field team that the investigating team hired was Mr Graham Sianjase, a recent graduate and prize-winner of UCL's MSc in Telecommunications with Business, as well as a Chevening Scholar.

Graham and key informants connected us to the six enumerators we hired from 9 April – 31 August, 2018 – one of them surveyed exclusively in Kitwe, five surveyed in Lusaka, and one of those also surveyed in Ndola. Three enumerators had prior survey experience. Five had or were enrolled in Bachelor's degree programmes.

To control quality, one investigator input every survey's results manually into Excel. This allowed him to query enumerators when answers were unclear or unexpected. His exchange of emails and ongoing training of enumerators by phone and email resulted in better surveys.

Annex 2.2 Iterations of questions we asked, and the learning process of asking the right questions

The survey in Annex 1, drafted in July 2018, is the last of many iterations that were used. Changes to surveys were based on patterns observed by the inputting investigator as to what were redundant questions, what were relevant questions to ask based on incoming responses outside the scope of the questions asked, and what was omitted on the basis of continued reading of new literature.

Annex 2.3 Weaknesses of the survey

The first firm that we visited through our pilot was revisited by an enumerator. While some responses remained consistent, others came back different – both in the subjective responses, as well as to questions of fact. This highlighted the weakness of estimating costs other than by having access to hard data. Different people give different answers. It is entirely possible that the same people who responded to our questions could have responded differently on different days, in different seasons.

Recognising these limitations, some of our analyses below are based on bands rather than by precise responses. For example, if a respondent said that their company had 60 employees, we banded it with firms that had between 50-100 employees. Similarly, where we have responses categorised as 0, 1, 2, 3 and 4 for assessing the extent of impact or extent of use of a coping strategy, we sometimes collapsed 0 into 0; 1 and 2 into 1; and 2 and 3 into 2; or sometimes 0, 1, 2 as 0; and 3 and 4 as 1.

A willingness to pay question does not necessarily incentivise truthfulness. Respondents might feel duty-bound to not disclose a willingness to pay for a higher tariff for reliability, or feel duty-bound to not disclose the full extent to which they would be willing to pay for a higher tariff for reliability.

Annex 2.4 Challenges faced in interviewing firms

A challenge we faced with getting information from most firms was that we had to initiate conversations without knowing anyone at them. In some cases, this resulted in five follow-ups to a single firm to initiate a survey or to close-out collection of Zesco invoices. In one case, after five positive conversations with a firm CEO, the CEO declined to give the survey.

Enumerators Mundia Kayamba and Johanna Mwila outlined some of the challenges they faced in closing interviews:

i. suspicion that the information would be used to increase tariffs or used to increase taxes;
ii. respondents did not appreciate the benefits of participating in the survey;
iii. the initially onerous request for records going back to 2012 put some respondents off;
iv. companies had policies to not disclose sensitive information;
v. respondents felt that the research was no longer timely since they were no longer experiencing load-shedding as when it was at its worst.

Challenges that these enumerators had in collecting all the data requested also stemmed from poor-record keeping on the part of companies or poor communication by Zesco about planned outages:

i. most respondents did not keep records of generator-set fuel costs separate from diesel used for their vehicles;
ii. some companies no longer even had records of how much on-grid energy they consumed since they shifted to a pre-paid system;
iii. planned Zesco power outages are rare, and when they occur, they are not consistent with what Zesco has communicated, which makes it difficult for respondents to answer questions related to impact of planned outages. (In cases where firms did not receive notifications of planned outages or did not feel that notifications were accurate, we noted this down.)

Annex 2.5 Challenges exogenous to the questionnaire itself

UCL received the commission to execute this research project in October 2016. However, for the following reasons, it is only in November 2018 that we are submitting our final report:

1. Delay in receiving funds from the IGC;
2. Personnel changes: the original two Principal Investigators and Research Assistant left UCL and moved continents;
3. A cholera outbreak in Zambia in late 2017 and early 2018 delayed the start of our surveys;
4. Internal UCL bureaucracy led to delays in payments to our overseas field team.

Annex 2.6 Triangulation and contextualisation: conversations with key informants

In addition to our primary data collection through surveys, our investigator Imad Ahmed conducted unstructured interviews with the following key informants to help triangulate our findings and improve our understanding of the context of Zambia's outages:

Government stakeholder interviews

1. Zesco's economists Puseletso Mwakalombe, Mukuka Mubanga, Temwani Chirwa on 10 November, 2017 and Puseletso Mwakalombe on 6 June, 2018 in Lusaka
2. Department of Energy Power Development Officer Winford Simwanza on 6 June, 2018 in Lusaka
3. Energy Regulation Board Director of Economic Regulation Alfred Mwila, also Principal Investigator, Impact of Load Shedding on Small Scale Enterprises on 6 June, 2018 in Lusaka

Private energy developer interviews

4. CEO of a developer of an independent coal power plant on 4 June, 2018 in Lusaka
5. Mikko Marttala, CFO at KPA Unicon, a developer and engineering, procurement, construction contractor of energy solutions using industrial waste on 2 November, 2018 in London

6. Cathy Oxby, Commercial Director at Africa GreenCo on 23 April, 2019 in London

Public and private advocates for the manufacturing and private sector

7. Zambia Association of Manufacturers CEO Chipego Zulu on 28 May, 2018 in Lusaka
8. Zambia Development Agency M&E Officer Sampa Chilanga on 30 May, 2018 in Lusaka

Colleague researcher interviews

9. Yimbilanji Sichone, Principal Author of Electricity load shedding: An econometric analysis of the productivity of firms in the manufacturing sector in Lusaka on 26 May, 2018 in Lusaka
10. IGC Zambia Country Economist Miljan Sladoje on 28 May, 2018 in Lusaka

Other useful unstructured conversations

11. Wamulume Kalabo, Chairman of Zambia Chamber of Commerce and Industry (ZACCI), 2004-07
12. Chibelushi Maxwell Musongole, Lecturer and retired Assistant Director at the Central Bank of Zambia on 28 May, 2018 in Lusaka
13. Bruce Bouchard, USAID's Power Africa Uganda Electricity Supply Accelerator with over 40 years of energy experience in Zambia on 27 Feb, 2019 by telephone with him in Cape Town and me in London
14. Michael Mainelli, consulting partner with BDO Binder Hamlyn in Zambia, an international consulting and accounting firm, 1987-1994 on 3 February, 2019 in Budapest
15. Natty Chilundiki, Research Coordinator, on 29 May, 2018 in Lusaka
16. Jim Friedlander, a lawyer with decades of experience working in Africa, on 3 May, 2018 in London

We also visited the following institutions for requests for data:

17. Patents and Companies Registration Agency (PACRA)
18. Bank of Zambia on 30 May, 2018
19. Ministry of Commerce, Trade and Industry on 30 May, 6 June, 2018
20. Central Statistical Office on 30 May, 6 June, 2018
21. Zambia Meteorological Department on 26 October, 2018

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