Thesis submission for a PhD in Infrastructure Economics and Finance

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The political economy of energy mix in hydropower dependent developing nations – a case study of Zambia

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Dedication

This work is dedicated to the intended beneficiaries of my PhD research: the people of Zambia. I hope this is helpful.

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Abstract

Zambia is one of at least 32 developing countries with a combined population of 1.4 billion people that are more than 25% dependent on hydropower for their grid electricity generation and which have experienced El Niño droughts. El Niño-induced droughts, projected to increase in frequency as average global temperatures rise, mark this reliance as climate vulnerability. Droughts in 2015, 2016, and 2019 rendered low hydropower reservoir levels in Zambia, constraining electricity generation capacity and resulting in unprecedented power outages. Notwithstanding these frailties, the national power utility ZESCO has subordinated the need to achieve system sustainability and diversify its energy supply assets to the path dependent pursuits of subsidising existing consumers and building more hydropower generation assets. The path dependent approach was locked-in by earlier macro-level investment decisions, over which the World Bank had significant influence. Like 17 other countries, Zambia received World Bank investments for hydropower in the 1950s-70s to support mining or industrialisation. Path dependence ultimately undermined the Zambian government and ZESCO's attempts to enhance Zambians' welfare. Through analysis of primary collected data, this research shows that the consequences of ZESCO's path dependence, which resulted in power outages, have had an adverse impact on the driver of Zambia's future industrialisation – its manufacturing sector. The research shows that ZESCO's "least regret" path going forward in terms of baseload power, climate impact, human health and financial lifecycle costs involves charging cost-recovery tariffs and diversifying its portfolio of generation assets. As global average temperatures and the frequency of El Niño events are rising, these findings have implications for the formulation of a low carbon energy policy for a fifth of the world's population living in hydropower dependent countries affected by increasing incidence of drought.

Impact statement

Having worked as an embedded externally-funded transactions advisor to an African government, I became interested in the optimal resource allocation with regards to infrastructure. This PhD has focused my attentions on these concerns in public and academic discourse, with both direct findings from my PhD and lessons applied to topics outside the scope of this particular research. I have presented my findings to the relevant actors identified in this thesis: ZESCO, the Government of Zambia represented by the Energy Regulation Board, Ministries of Energy, Finance, National and Development Planning, donor agencies (including the World Bank covering southern Africa) as well as to the public on prime time Zambian TV news.

Direct applications from this PhD:

1. Signed book contract with Springer Nature/Palgrave Macmillan to publish this thesis with its title as a monograph. Manuscript due 30 January, 2021
2. *Environmental Research Letters,* Impact Factor 6.0*.* "The impact decades-long dependence on hydropower in El Niño impact-prone Zambia is having on carbon emissions through backup diesel generation", Vol 15(12), December 2020
3. *Structural Review and Economic Dynamics* Elsevier/Science Direct journal with Impact Factor 2.0, "Explaining Rwanda's prioritisation of rural electrification over rural clean drinking water through institutional path dependency", Vol 54, September 2020, pp186-201
4. International Growth Centre, "Increasing tariffs to prevent another electricity crisis", April 2019 blog
5. Oxford Policy Management Group, Speaker at Energy and Economic Growth Conference, "The cost of power outages to Zambia's manufacturing firms and households", 4 Feb 2019, Accra
6. International Growth Centre, "The cost of power outages to Zambia's manufacturing sector", 17 Sep 2019. Working Paper, with a separate Policy Brief
7. International Growth Centre, Keynote Speaker, "Nurturing the Manufacturing Sector: Ensuring Strong Roots for Zambian Growth", 4 Sep 2019, Lusaka. Aired on Zambia's main news channel ZNBC at prime time
8. Ministry of National Development Planning, Presenter to the Government of Zambia and ZESCO, "The cost of power outages to Zambia's manufacturing sector", 4 Sep, 2019, Lusaka
9. EBRD*,* Speaker, Conf. on Infrastructure, Growth and Development*,* 6 September 2018, London
10. Bartlett 100, Interview, "Powering the Zambian Economy", 2019. Book and website commemorating 100 years of building a better future
11. UCL website, Interview on my PhD and previous experience, 15 Jan 2019

Applications of the thinking for the PhD to other topics:

1. BBC Parliament, 16 Sep 2019 – speech on how OECD nations should subsidise developing nations for pro-environment initiatives
2. *Africa* (Cambridge University Press journal with Impact Factor 1)*,* Review of Ag. Reform in Rwanda: Authoritarianism, Markets and Zones of Governance, 88(4), pp896-897, 2018
3. *Dawn* (Pakistan's newspaper of record)*,* "Seismic costs", 7 Oct 2018 – cost benefit analysis of a mega dam
4. *Dawn*, "Courting Disaster", 18 Aug 2017 – solutions to Pakistan's water scarcity
5. *Financial Times,* "After off-grid electricity, what chance off-grid water?", 31 Jul 2017
6. *Financial Times, "*Leapfrogging into the light", 27 Mar 2017 – advocating space for off-grid electrification
7. *Financial Times,* "PPP success in Rwanda shows potential for greater self-reliance", 2 Apr 2015

Contents

Institutional acronyms

CEC	Copperbelt Energy Corporation
CSO	Central Statistics Office
DfID	UK Department for International Development
ERB	Energy Regulation Board
IBRD	International Bank for Reconstruction and Development
IDA	International Development Association
IGC	International Growth Centre
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
MDNP	Ministry of National Development Planning
MFEZ	Multi-facility economic zone
OECD	Organisation for Economic Cooperation
UCL	University College London
ZACCI	Zambia Chamber of Commerce and Industry
ZAM	Zambia Association of Manufacturers
ZCCM	Zambia Consolidated Copper Mines
ZDA	Zambia Development Agency
ZESCO	State-owned power utility, formerly known as Zambia Electricity Supply Corporation
ZICTA	Zambia Information and Communications Technology Authority

1. Introduction

Global warming is increasing the incidence of droughts which are impacting the energy security of hydropower dependent countries. Many of these are developing countries whose first World Bank investments were in hydropower, predicated on serving mineral extraction and supporting industrialisation. Zambia is one such country and is a useful case study for the lessons that its dependence on hydropower serves.

This research aims to inform better energy policy in hydropower dependent countries which are vulnerable to climate shocks. As global average temperatures rise, so too do the frequency and intensity of El Niño Southern Oscillation-induced droughts (Wang *et al.*, 2017), which in turn threaten the reliability of hydropower. This research therefore focuses on the impact of energy insecurity arising from climate- induced drought, which according to climate modelling, would also result in reduced water availability and crop yields (Conway *et al.*, 2015).

Box 1 The exposure of developing countries to hydropower for their grid electricity

As of 2015 (World Bank, 2020a)
- >58 countries >25% reliance on hydropower for domestic electricity production
  - 78% were not high-income
  - >35 countries, 74% of which were not high-income >50% reliant on hydropower
    - > 32 countries not high-income countries >25% hydropower reliant experienced El Niño droughts (Annex 1)
      - 18 of these countries received early World Bank investments for hydropower (Annex 1)
    - >12 countries, 11 of which were not high-income >80% reliant on hydropower

Genre of countries:
- Heavily Indebted Poor Countries: 46% reliant on hydropower for electricity production (World Bank, 2020a)
- Least Developed Countries: 37% reliant on hydropower (World Bank, 2020a)
- Latin America and Caribbean: 45% grid electricity from hydropower (World Bank, 2020a)
- Sub-Saharan Africa: 160M grid-connected electricity consumers live in countries >50% reliant on hydropower (Falchetta *et al.*, 2019)
  - Almost entirely dependent on hydropower: DRC, Lesotho, Malawi and Zambia (Conway *et al.*, 2015)

As Box 1 above illustrates, the exposure of developing countries to hydropower is material. Annex 1 further illustrates that at least 32 countries that were not high-income with a combined population of 1.4 billion people were more than 25% dependent on hydropower and had experienced El Niño droughts.[1] Eighteen of these received early World Bank investments for hydropower predominantly to support industrialisation or mining (Annex 1). In Sub Saharan Africa, 160 million grid-connected electricity consumers lived in countries where hydropower accounted for more than half of total power supply (Falchetta *et al.*, 2019). In 2015 and 2016, El Niño droughts, caused by warming of the Pacific Ocean, resulted in severe power crises in Kenya, Tanzania, Ghana, Zimbabwe and Zambia, with power outages, power rationing and switching to costlier backup diesel generators (Falchetta *et al.*, 2019). Droughts also increased competition for water use between power generation, irrigation and

[1] The World Bank data did not give information for all countries such as Uganda and the Southern African Power Pool countries Lesotho and Swaziland.

municipal water supply (Falchetta *et al.*, 2019). Hydrological-crop and recursive dynamic computable general equilibrium analysis suggested that the climate variable could pull 2% of the Zambian population below the poverty line (Thurlow, Zhu and Diao, 2012).

This research takes Zambia, a landlocked southern African nation of 17.3 million people (World Bank, 2019a), as its case study. It is one of the at least 32 countries that was not high-income and was more than 25% reliant on hydropower, and one of the at least 18 of these countries that received early World Bank investments for hydropower predominantly to support industrialisation or mining. At the beginning of 2015, Zambia was almost entirely dependent on hydropower and it was classed as a lower middle-income country (World Bank, 2019a) with 33% grid electricity connection (ZICTA and CSO, 2018). Pre-independence energy investment was driven by colonial extraction of copper (Bayliss and Pollen, 2019, p. 7). Post-independence energy investment until 2015 had been dominated by the World Bank, which was guided by unbalanced growth theory that perpetuated the generation of energy for the purpose of copper extraction.[2] Themes relating to Zambia's history of energy investment as well as the climate resilience of its energy infrastructure are therefore applicable to a number of other hydropower dependent developing countries.

The research was borne of a commission by the International Growth Centre in October 2016, largely funded by the UK's Department for International Development (International Growth Centre, 2018), to assess the impact of power outages on Zambia's manufacturing sector. The International Growth Centre aims to promote sustainable growth in developing countries. The original focus was on the impact of power outages on the manufacturing sector given the established associations between infrastructure on the growth of manufacturing, and the growth of manufacturing on economic development. Africa in general has experienced a period of de-industrialisation as a result of poor policy (the pursuit of structural adjustments at the behest of the IMF and World Bank) rather than natural economic evolution (Stiglitz, 2017). Given Zambia's manufacturing resurgence since the 2000s, undersupply of energy due to climate-vulnerable power generation infrastructure poses a new threat to Zambia's industrialisation and more generally to the country's trajectory of economic development and diversification away from copper mining, whose export as a raw material dominates Zambia's exports (World Bank, 2020u). The mining sector's profits are largely expatriated to foreign multinationals.[3] By contrast, this research's survey of large manufacturing firms found about half of respondents said that their company owners were Zambian.

Alongside other factors, recent El Niño droughts resulted in reduced power supply to the manufacturing sector and consequently reduced growth. Due to almost complete dependence on hydropower and low rainfall in 2015 and 2016 resulting in low reservoir levels (Mwila *et al.*, 2017, p. v), Zambia's power utility ZESCO was forced to enact nationwide load shedding lasting upwards of 8 hours per day (Energy Regulation Board, 2017, p15). The power deficit reached 1,000MW in 2015 (41% of national installed capacity)[4] 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 (Energy Regulation Board, 2017, p9), the load-shedding would have been even worse. Table 1 below is a compilation of grid electricity consumption by sector collected from Energy Regulation Board reports. It shows that from 2015 to 2017

[2] Independence was achieved on 24th October 1964.

[3] Metal and ores have accounted for between 70-80% of the country's exports since 2005 (World Bank, 2020u). 80% of Zambia's copper comes from four mines. Barrick Gold, a Canadian corporation, owns Lumwana mine. First Quantam Minerals, a Canadian corporation, runs Kansanshi mine. Glencore International, a British corporation headquartered in Switzerland, and First Quantam Minerals own Mopani Copper Mines. Vedanta, an Indian corporation, majority owns Konkola Copper Mines, while the remaining fifth is owned by ZCCM, majority owned by the Zambian government and listed in Lusaka and on Euronext.

[4] National installed capacity was 2,411MW in 2015 (Energy Regulation Board of Zambia, 2016a).

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. Figure 1 below charts the growth rate of Zambia's manufacturing value-added in constant local currency figures from the World Bank's indicators. It shows that growth in the sector fell from 6.5% in 2014 to 1.9% in 2016.

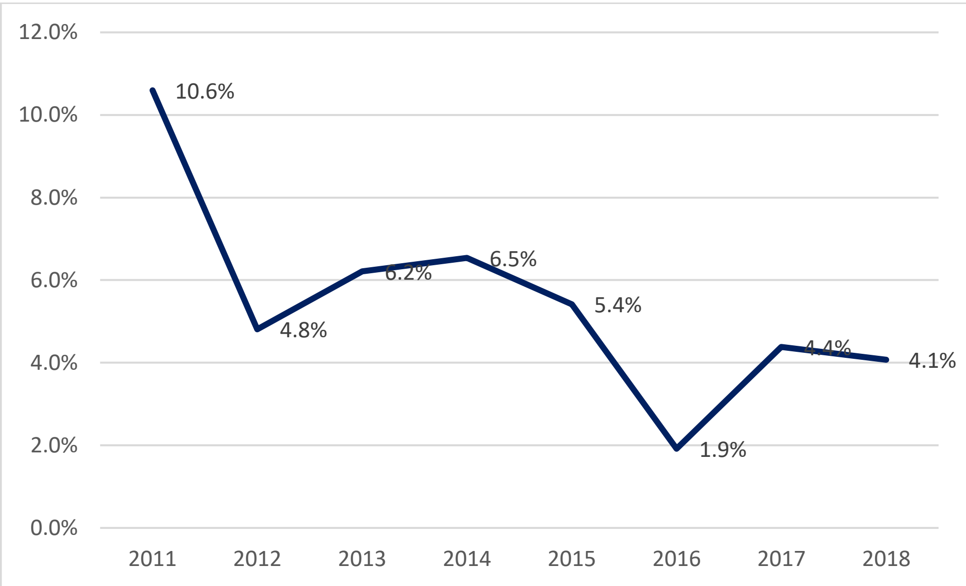
Table 1: Manufacturing's share of electricity consumption dropped from 2015 to 2017 in Zambia

National electricity consumption by economic sector, 2014-2018

Sectors	2014		2015		2016		2017		2018	
	GWh	% share	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%	6,682	54.8%
Domestic	3,251	26.2%	3,482	30.4%	3,383	31.2%	4,147	34.0%	4,337	35.6%
Finance & property	487	3.9%	517	4.5%	499	4.6%	640	5.2%	714	5.9%
Manufacturing	479	3.9%	**531**	**4.6%**	**470**	**4.3%**	503	**4.1%**	593	**4.9%**
Agriculture	241	1.9%	260	2.3%	228	2.1%	262	2.1%	297	2.4%
Others	99	0.8%	99	0.9%	80	0.7%	87	0.7%	84	0.7%
Trade	107	0.9%	110	1.0%	97	0.9%	110	0.9%	114	0.9%
Energy & water	73	0.6%	89	0.8%	88	0.8%	81	0.7%	69	0.6%
Quarries	62	0.5%	68	0.6%	60	0.5%	118	1.0%	148	1.2%
Transport	31	0.3%	33	0.3%	28	0.3%	32	0.3%	33	0.3%
Construction	1,702	13.7%	15	0.1%	7	0.1%	10	0.1%	11	0.1%
Total	**12,405**	**100%**	**11,450**	**100%**	**10,857**	**100%**	**12,192**	**100%**	**13,080**	**107%**

Sources: Energy Regulation Board of Zambia, 2016, p. 0, 2017a, p. 9, 2018, p. 36, 2019, p. 39

Figure 1 Zambia's real manufacturing value-added growth declined following the power outages of 2015 and 2016



Data source: World Bank, 2020d; graph: own

Why should we focus on manufacturing, other than for the fact that this research was funded to focus on it, when its energy supply is a tenth of mining's and its contribution to GDP lags not only mining but retail and construction (CSO, 2018)? First, manufacturing provides better value in terms of contribution to GDP and employment per kWh of energy than does mining. Although it consumes less than a tenth of energy that mining does, it contributes three-quarters of what mining does to GDP, and employs almost three times the workforce.[5] Second, focusing on manufacturing allows us to

[5] Mining, which consumed more than half of Zambia's electricity, contributed to 11.2% of GDP less net taxes, compared with manufacturing which consumed 4.3% of electricity but contributed to 8.5% of GDP less net taxes (CSO, 2018). Manufacturing employs 8.1% of employed people while mining employs 2.9% (CSO and Ministry for Labour and Social Security, 2019). The CSO statistics for manufacturing include food, beverages, tobacco and textiles which the World Bank's definition exclude (CSO, 2018; World Bank, 2020c).

interrogate the political economy of funding for energy as well as Zambia's system of provision's path dependence and underlying economic assumption of allocative efficiency in charging subsidised tariffs that together resulted in, by 2015, underinvestment in diversified power generation. The investment rationale of supplying power for mineral extraction, beneficiation and industrialisation that holds for Zambia vis-à-vis the World Bank's history of prioritisation of hydropower can also be seen to directly apply to Brazil, Colombia, Ethiopia, Ghana, Kenya and Turkey. Further, because the World Bank's early appraisals of hydropower 'rarely' investigated the 'possibility of a thermal alternative' (Mason and Asher, 1973, p. 237), countries receiving hydropower investment were set on a trajectory of building power generation infrastructure that would later prove not to be climate resilient.

This thesis builds upon the commission's study and assesses the political economy of energy in Zambia which like 17 other hydropower dependent countries is now prone to El Niño-induced droughts and also received early World Bank investments for hydropower predominantly to support industrialisation or mining (see Annex 1). In Africa over the past three decades, only some countries have diversified from hydropower: Tanzania, where hydropower's contribution to energy generation fell from 95% in 2000 to a low of 37% thanks to the installation of a 700MW gas-fired power plant in the past decade; the Republic of Congo, where a 300MW gas-fired power plant led to diversification; and Ghana, where hydropower's share fell from 80% in 2000 to 50% in 2015 (Falchetta *et al.*, 2019). Besides Zambia, the regions of Africa which face the likeliest threat of low hydropower capacity factors due to an increasing frequency and intensity of El Niño droughts. Hydropower accounted for more than 50% of installed power capacity in Mozambique, Namibia, Angola, Ghana, Sierra Leone and until recently Cameroon (Falchetta *et al.*, 2019).

This thesis lays out the historical, political and economic forces that saw the propagation of hydropower across the developing world; assesses why Zambia had no diversity in its energy production portfolio prior to 2015; investigates and assesses the implications of an undiversified energy mix to microeconomic subgroups (of which the cost to manufacturing firms of Zambia's power outages is a major component, as well as a new household survey to assess the effects on individuals), as well as to the environment; reviews options for a "least regret" energy mix;[6] and concludes with recommendations. In so doing, it attempts to answer the following research questions:

1. How did Zambia come to be so reliant on hydropower?
2. What are the impacts of this reliance on Zambia's industrialisation; how do manufacturers respond; and how effective are their responses?
3. How does Zambia avoid power outages and its associated costs in the future in a cost-effective and minimally destructive manner with respect to the climate crisis?

The originality and contribution to knowledge of this thesis stands on

- an incremental expansion of the historical institutional path dependency model, fusing together the way in which Mahoney, Pierson and Skocpol, and Stinchcombe (Stinchcombe, 1968; Mahoney, 2000; Pierson and Skocpol, 2002) model it and building upon their combined framework
- bringing new insight into how Zambia's system of provision of energy became locked into what Liebowitz and Margolis (Liebowitz and Margolis, 1995) classify as
    - first-degree path dependence (where sensitivity to starting points exist but do not result in inefficiency) with respect to choice of energy mix for investment decisions made prior to the 1950s;

[6] It appears as though use of the term "least regret" with respect to future energy scenarios started gaining traction in 2015/2016 (National Grid, 2015; Sanders *et al.*, 2016; Zachary, 2016). I first heard its use at the Energy and Economic Growth Grid Reliability and Utility Operations conference in February 2020 in Accra, Ghana.

  - second-degree path dependence (the inferiority of a chosen path that is unknowable at the time a choice was made) for investment decisions made in the 1970s;
  - and third-degree path dependence for investment decisions made in the 2010s, where dependence is based on initial conditions and ignores information (about the increase and frequency of El Niño-induced droughts, and the competition for water that exists between hydropower and food and water) that implies that it is inefficient
- the primary data collected through
  - surveys with manufacturing firms to bring fresh insight into the impact of path dependence on electricity consumers
  - interviews to contextualise and triangulate interpretations with key informants from
    - within the Zambian government and ZESCO
    - among private energy developers
    - among the interface between Zambian manufacturers and the government
    - within a donor
    - among Zambian researchers
    - among other sources
- unique analysis of both the primary and secondary data.

Thanks to the International Growth Centre research grant, this study was able to hire and project manage a team of eight in Zambia to collect 123 surveys (a third of the population) from a representative sample of large manufacturing firms located in Zambia's main industrial hubs of Lusaka, Ndola and Kitwe. The objectives of the survey were to inform what the costs were of power outages to large manufacturing firms, and to inform what coping mechanisms firms employed, with the underlying hypothesis that backup diesel generators are at the forefront of such coping mechanisms. The survey sought to understand the extent to which diesel generators are successful in mitigating firms' costs, and what costs they in turn bear on the environment. It further sought to identify predictors of firms' propensity to invest in backup generator capacity, firms' propensity to use that installed capacity, firms' carbon emissions from backup generation, and to estimate the extent of emissions from diesel generation by the manufacturing sector.

This study finds that because of the lock-in into hydropower resulting from path dependence, Zambia's system of energy provision did not adapt to warnings given as early as 2001 (IPCC, 2001) that hydropower in the Zambezi River Basin was no longer going to be the dependable source of baseload power generation that it once was due to climate change. The increase in global temperatures was forecast to increase the frequency and intensity of drought and low reservoir levels and therefore hydropower capacity factors (Harrison and Whittington, 2002; Beilfuss, 2012; Spalding-Fecher, 2012). Further, with the lock-in into hydropower, Zambia's system of grid electricity provision was going to be increasingly competing with food and water. The lock-in of low tariffs to consumers further exacerbated the issue by financially constraining ZESCO's ability to contract the additional required power generation. ZESCO had the opportunity to respond to the threat of El Nino droughts with greater urgency when it was forced to negotiate by the Government of Zambia with the independent power producer for the Maamba Collieries coal power plant, but ZESCO delayed contracting a non-hydropower source of energy first by stalling on the tariff negotiation. A new power plant's capital expenditures would not have been fully amortised, compared to the majority of ZESCO's power generating assets, which had for decades allowed ZESCO to charge a tariff to consumers lower than what it would have cost ZESCO to purchase power from an IPP. Second, ZESCO stalled by delaying the construction of infrastructure to connect the power plant with its grid. Had ZESCO not been locked into seeing only the merit of hydropower generation and had ZESCO not been locked into a mindset of being able to continue charging low tariffs to consumers, ZESCO would have treated as urgent diversification away from hydropower from 2012-2015. Maamba Collieries would have started delivering energy to the grid in 2015, thus preventing the power outages of 2015 and 2016, which adversely impacted Zambia's manufacturing firms.

The thesis is structured as follows.

Chapter 2 provides the context for how Zambia's system of energy provision came to be as it was. It describes the underlying economic theory and empirical evidence connecting energy and economic development through the medium of industrialisation. It introduces the agents within Zambia's system of provision, and explains the importance of the World Bank, which had financed power generation assets that had generated 81% of Zambia's energy in 2014 right before the power outages of 2015 and 2016. It then goes into the political context of the World Bank's decision-making, as well as the economic rationale explained by its economists and top executives. Chapter 2 then rounds out with a look at how the provision of energy impacted growth of the manufacturing sector in Zambia, and how successfully it contributed overall to development. In spite of manufacturing's inability to materially affect structural employment away from subsistence agriculture prior to 1991, its resurgence since the 2000s has seen it return more employment than the mining sector and more GDP per kilowatt hour of energy consumed.

With the threat power outages pose to this resurgence, Chapter 3 reviews the literature and provides initial desk analysis on the impact of power outages on manufacturing. The end of the chapter identifies gaps in the literature. Chapter 4 develops a methodology for gathering data to fill the gaps.

Chapter 5 presents the results and interpretations of the survey on the impact of power outages on Zambia's manufacturing sector. Chapter 5 provides fresh insights into the impact of power outages on Zambia's manufacturing firms through the collection of surveys on a representative sample of 123 large manufacturing firms. It ranks damages incurred from outages by manufacturing firms, ranks their use of mitigation strategies, show how the costs of power outages differ for firms using differing coping strategies, identifies firm characteristics that can be used to predict differing coping mechanisms, and cost the damages for firms. It explains why firms rank months with the most rainfall as the worst for power outages. It identifies firm behaviours that are suboptimal for grid efficiency, but also identify ways in which firms are willing to give back to the grid.

Chapter 6 attempts to explain why Zambia's system of energy provision did not prevent the power outages of 2015 and 2016. First, it notes the rising incidence of transmission and distribution losses. It then diligences a donor's forecast of Zambia's demand for grid-electricity by 2030 to assess the additional power generation Zambia will require net of reducing transmission and distribution losses. It then presents the literature Zambia's system of energy provision had at its disposal through the 2000s prior to the power outages of 2015 and 2016 on how vulnerable additional investment into hydropower in the Zambezi River Basin would be to climate change. Given that the system of provision proceeded to invest in hydropower in the Zambezi River Basin anyway, the chapter then explains how the historical institutional path dependence framework explains this. The chapter also explains how path dependent industrial strategy together with electoral politics contribute to our understanding as to why the system of provision has not sought a more equitable tariff structure and distribution of grid energy.

Chapter 7 offers supply and demand-side recommendations for the agents in Zambia's system of provision. Chapter 8 zooms back out to the broader applicability of the case study of Zambia to low carbon policies that ensure energy security for a fifth of the world's population.

2. Energy, industrialisation and economic growth

As of 2014, 81% of Zambian grid- electricity was powered by assets financed by the World Bank – all of it hydropower. The World Bank's investment in hydropower came at a time when 85% of Zambia's electricity was by Zambia's copper mining industry, which was also its direct intended beneficiary in 1973. In general, thinking within the Bank held that allocating resources for 'productive' sectors of the economy was justified because those sectors would then pay the taxes required to pay for 'social' infrastructure. Human development indicators do not suggest an improvement in quality of life for Zambians following the power investments until decades later, and for that the causality cannot be convincingly attributed to power generation. By 2018, only a third of the population was connected to the grid, meaning that investment in power for the mining sector still has not trickled down in power for all. Mining's growth did however spur manufacturing growth, but that was stymied by neoliberal economic restructuring by the Zambian government on the advice of the Bretton Woods organisations in the 1990s. Manufacturing shows greater potential and better value per kWh of energy than mining for generating employment and GDP.

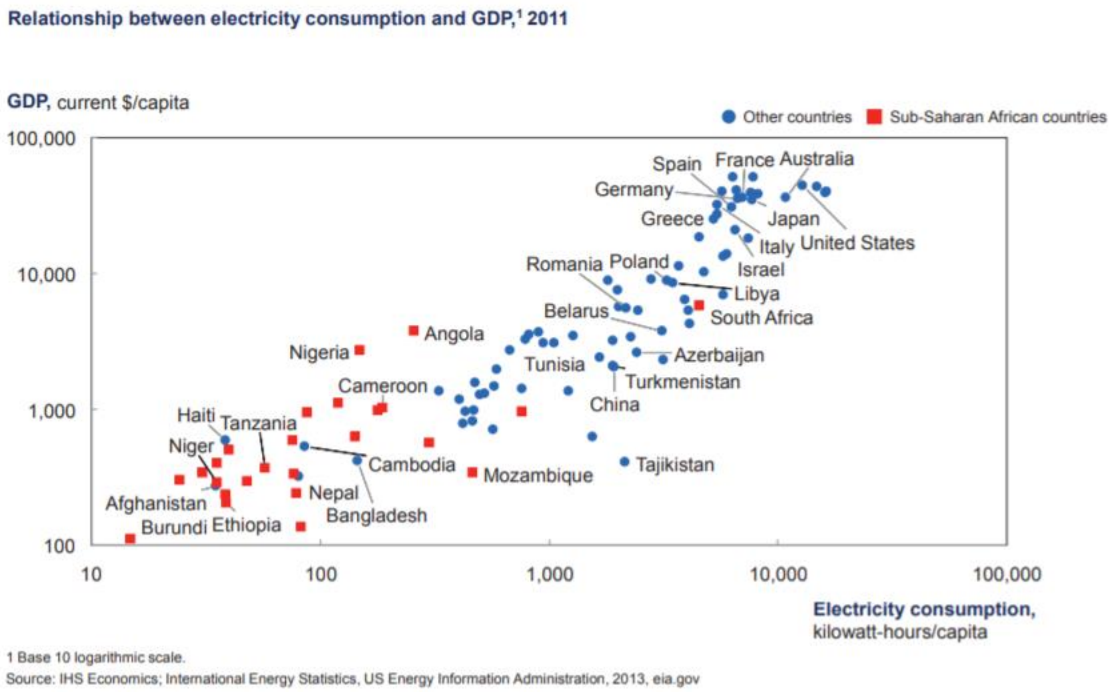
In this chapter we explore the theory justifying supplying energy supply for manufacturing by linking manufacturing to economic development; the agents in Zambia's system of energy provision and the importance of the World Bank among them; the underlying political interests and economic rationale within the World Bank for promoting hydropower and exporting the Tennessee Valley Authority template to low-income countries; and how application of the TVA template played out in Zambia. We will seek to understand how energy supply and other factors gave rise to Zambia's industrialisation, deindustrialisation and reindustrialisation to then set the scene in chapter 3 for the more recent threat of power outages on Zambia's industrialisation.

2.1 Mechanisms by which industrialisation drives economic growth

Economic prosperity and electricity consumption have gone hand-in-hand. The log of electricity consumption is positively correlated with the log of countries' gross domestic products (Castellano *et al.*, 2015, fig. 1) (Figure 2). One, however, does not directly cause the other.[7] Rather, causality goes both ways through intermediate steps. On the one hand, with greater prosperity, consumers move up the energy ladder and purchase more goods such electric cookers, refrigerators and water heats (Tobey, 1996, pp. 122, 157–162). The consumption in turn drives sales of appliances which need to be manufactured, which takes energy. Increased manufacturing means increased jobs, which means increased disposable income to buy further goods which need to be purchased. This is the Keynesian multiplier effect that was observed with the availability of cheap electricity with the creation of the Tennessee Valley Authority as we show below. Likewise, electricity availability enables increases in economic productivity – from that at the household level (Ahmed, 2020a, p. 196) to enabling large-scale industrialisation which involves moving labour into higher productivity sectors as the cited literature below elucidates. The increased productivity drives economic growth. Kaldor's first law of growth posits that the higher the growth of manufacturing output, the more significant is the growth rate of the economy's product as a whole (Marconi, Reis and Araújo, 2016). Kaldor's second law, also known as the Kaldor-Verdoorn law (Marconi, Reis and Araújo, 2016) states that with increasing returns to scale and increasing skill and know-how, opportunities for easy communications of ideas, increasing opportunities for differentiation of processes and specialisation of activities increase such that productivity grows proportionally to the square root of output (Kaldor, 1970, p. 484).

[7] Dlamini et al found no causal relationship between the two variables using full-sample Granger causality tests (Dlamini *et al.*, 2016).

Figure 2 Relationship between electricity consumption and GDP, 2011



Source: Reproduced from Castellano et al (2015, fig. 1)

Szirmai and Verspagen (2015) found empirically that Kaldor's hypothesis that manufacturing is an engine of manufacturing growth held: manufacturing had a moderately positive impact on economic growth for a panel of 88 countries for the period 1950-2005. Cantore et al's (2017) regression analysis controlling for endogeneity bias using a sample of 80 countries for 1980-2010 similarly supported Kaldor's hypothesis.

Several theoretical arguments contribute to understanding why manufacturing has empirically been found to have historically propelled economic growth:

i. Manufacturing is more capital intensive than agriculture, and thus provides more opportunities for investment (Haraguchi, Martorano and Sanfilippo, 2019; Szirmai, 2012).
ii. Being capital intensive, manufacturing encourages investment into technological advance to reduce costs through achieving economies of scale. Technological advance is also driven to offer customers unique products, and thus provide the firm economic rents. Technological advance allows an economy's production capabilities to increase and hence its potential income, according to the neoclassical Solow model (Solow, 1956).
iii. These technological advances have a higher likelihood of spilling over into other sectors of the economy thanks to manufacturing's strong backward and forward linkages with other sectors. Manufacturing uses primary sector goods, and generates demand for tertiary sector services (Kaldor, 1984). Szirmai (2012) argues that advances in ICT hardware technologies produced in the manufacturing sector fuelled technological advance in the software producing service sector. (Thurlow and Wobst, 2007, pp. 232, 234) show that Zambia's services sectors grow more rapidly in the industry-led scenario. They note, however, that agriculture has more pro-poor growth linkages.
iv. Given manufacturing's superior use of technology and capital, a structural transfer of resources from the primary sectors to manufacturing results in a structural dividend due to increased productivity. A transfer of unskilled (Rodrik, 2016) labour from low-productivity

agriculture to high-productivity industry results in an immediate increase in overall productivity per capita and has been a major source of growth in developing countries (Szirmai, 2012). Rodrik (2016) finds that formal manufacturing exhibits unconditional labour productivity convergence. Cantore et al's (2017) research points to manufacturing productivity and manufacturing employment share as being responsible for observable effects on growth.

v. Given the higher productivity per worker, a burgeoning manufacturing sector not only absorbs labour, but also should be better able to compensate workers.

vi. As per capita income rises both as resulting from and resulting in increased manufacturing, demand for manufactured goods increases and the share of agricultural expenditures declines (Engel's law). Economies void of manufacturing will not profit from rises in per capita income, while economies with manufacturing sectors that can survive disruptive changes and international competition can benefit from the Keynesian multiplier.

vii. Manufacturing goods are easily tradable, as opposed to services, thus allowing a sector within a developing economy to escape the constraint of low-income domestic demand (Rodrik, 2016), and again allowing for the Keynesian multiplier to amplify the benefits of a thriving manufacturing sector.

viii. When trade opens up between a country that is more industrialised, it will be able to supply the needs of the more agricultural country on more favourable terms, and indeed will eliminate its competition for demand in the foreign market (Kaldor, 1970, p. 484).

In summary, electrification enables industrialisation which has historically led to economic development in industrialised economies. Since electricity consumption is not simply the result of individual preferences but connected to the way in which it is provided (Bayliss and Pollen, 2019), we will now interrogate and build upon Bayliss and Pollen's model of Zambia's energy system of provision which enunciates the agents and their roles in Zambia's supply of electricity.

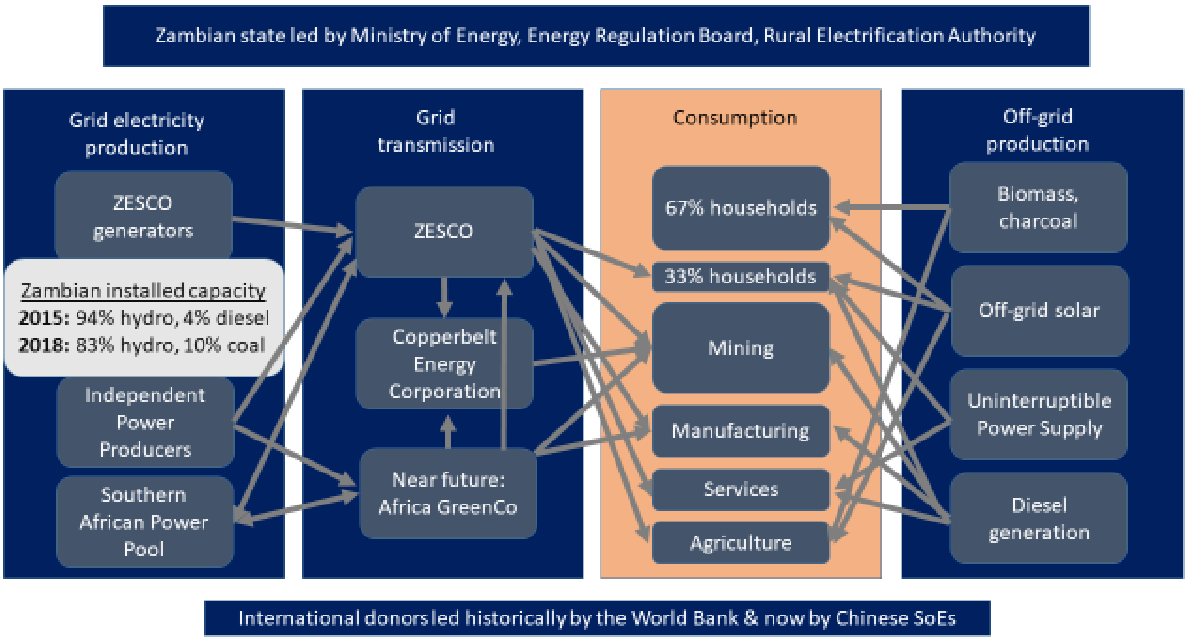
2.2 Zambian energy's system of provision

Bayliss and Pollen's "system of provision" approach to analysing Zambia's energy provision contends that consumption outcomes are not simply the result of individual preferences but are inherently linked to production, rooted in local context and emerge from the tensions among agents in the chain of provisioning (Bayliss and Pollen, 2019). The approach recognises the roles and significance of a diverse body of agents.

Figure 3 incorporates Bayliss and Pollen's system of provision (Bayliss and Pollen, 2019, fig. 1). The power utility ZESCO, independent power projects (IPPs) that sell energy to ZESCO through power purchase agreements, and the Southern African Power Pool (SAPP) generate power. This power is purchased by ZESCO, an autonomous corporation established in 1969 and wholly owned by the Government of the Republic of Zambia (IBRD and IDA, 1973, p. i) which then distributes energy to end-consumers (households, businesses and some mines) as well as to the Copperbelt Energy Corporation (CEC), an intermediate power utility which distributes solely to mining companies in the Copperbelt Region and also sources energy from the Southern African Power Pool. Overseeing energy policy is the Ministry of Energy. The Rural Electrification Authority is its agency to oversee and implement rural electrification policy. The Energy Regulation Board is responsible for licensing, tariff-setting and regulating quality of supply using a series of key performance indicators. Bayliss and Pollen (2019) assert that the tariffs paid by the Copperbelt Energy Corporation and mines are outside the remit of the Energy Regulation Board. In fact, the remit of the Energy Regulation Board is currently being litigated (personal interview with Alfred Mwila, Director of Economic Regulation at the Energy Regulation Board, 6 June, 2018, see Annex 3.1.3 for notes, and public statement made by Cletus

Sikwanda, Economist at the Energy Regulation Board on 4 September, 2019 at a public forum in Lusaka organised by the International Growth Centre to present some of this research's findings). Parliament has the power to resolve this ambiguity (personal interview with Alfred Mwila, Director of Economic Regulation at the Energy Regulation Board, 6 June, 2018), and so Parliament can also be considered an agent in the System of Provision missing from Bayliss and Pollen's map as illustrated in Figure 3.

Figure 3 Agents in the system of provision for electricity or electricity substitutes in Zambia



Source: Author

Figure 3 also builds upon Bayliss and Pollen's system of provision by including off-grid electricity provision, by taking into account the possible entry of a prospective private off-taker and by recognising the World Bank's pre-eminent role among donors and investors in financing Zambia's power generation assets.

The modified system in Figure 3 also includes the 67% of the population that live without grid connections (ZICTA and CSO, 2018) and who rely on off-grid solutions including solar products, charcoal and biomass (Tembo, 2018).[8] This situation persists 50 years after the World Bank's substantial energy investments into Zambia (World Bank, 2018b) to support mining (IBRD and IDA, 1970, 1973) in the vain hope that the benefits of hydropower would trickle down (Park, 1968). Agricultural firms can meet their electricity needs using biomass generation (Zambia Sugar, 2017, p. 15). Manufacturing firms use backup diesel generation to make up for lost ZESCO power (Ahmed, Baddeley, D. M. Coffman, *et al.*, 2019), as do mining companies (Mfula, 2010b, 2010a; Steel News, 2011; Syndigate, 2011). Grid-connected households' favourite mitigation strategy to power outages is rechargeable lights and solar products; the 10th and 11th favoured strategies are UPSs and diesel generators (Ahmed, 2020b).

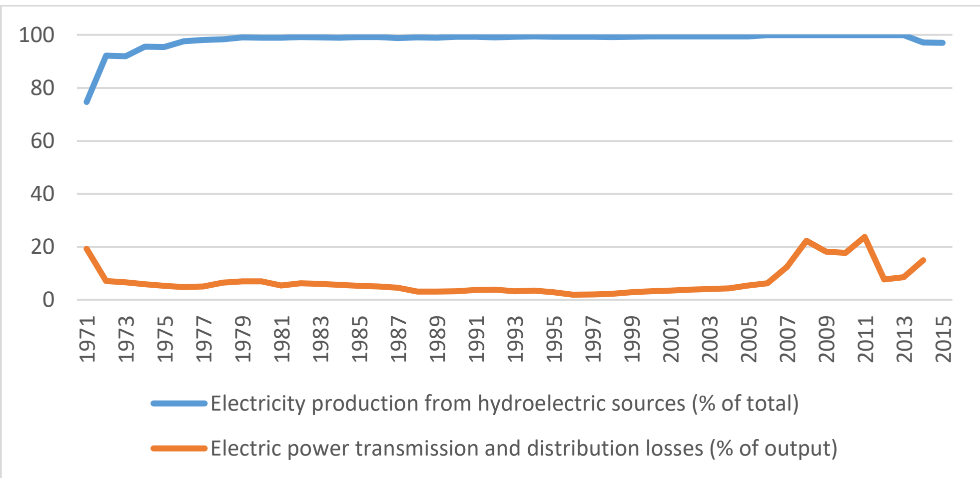
[8] In the context of rural China, Jiang et al (Jiang *et al.*, 2020) found that In low-income households, the main sources of energy increase, the consumption of energy increases, and the energy flows become more frequent.

Personal interviews with Africa GreenCo (4 June 2018, 23 April 2019, 3 September 2019) revealed that the company intends to facilitate investment into renewable Independent Power Projects by becoming a private credit-worthy off-taker that on-sells to ZESCO and clients on the Southern African Power Pool. Africa GreenCo's *raison d'etre* is to facilitate new renewable energy investment that would not otherwise take place because prospective independent power projects are afraid that ZESCO will not pay them because ZESCO is not credit-worthy (phone interview with a donor agency energy expert, 27 February 2019, see Annex 3.4.1). Africa GreenCo has raised capital from donors and development finance institutions to provide it 18 months working capital buffer in order to be able to provide this service (personal interviews with the CEO and CCO on 23 April 2019 and 1 August 2019; email received from CEO 30 October 2020; see annexes 3.2.2a and 3.2.2b for further details).

Without the World Bank and its regional counterpart, the African Development Bank, very little large-scale infrastructure would have existed in Africa because of the lack of established markets and lack of trust by private sector participants in both their governance as well as in commercial demand. The World Bank, AfDB and other development finance institutions both stand in place of as well as catalyse private investment by issuing guarantees. More recently, the Government of China has been investing heavily into African infrastructure as it joins the West's race for African resources (Moyo, 2013). Indeed, Chinese state owned enterprises are ZESCO's largest current debtor, with debts to Chinese institutions ranking first, second, seventh, 12th, 17th, 21st and 23rd, compared to the World Bank's loans ranking 9th, 14th, 24th and 29th largest debts as of 2018 (Zesco Ltd, 2018, p. 98).

Even though its most significant investments into Zambian power generation had taken place 40 years prior, the World Bank was still Zambia's most significant investor in Zambian power generation assets in use prior to the power outages of 2015 and 2016. Since these hydropower dams were completed, hydropower accounted for almost all of Zambia's power supply (see Figure 4 below). In 1971, as far back as World Bank panel data go back, hydropower accounted for 75% of Zambia's power generation. This increased to 92% in 1972 and to 98% by 1977. From 1982 to 2013 inclusive, this proportion did not fall below 99% (World Bank, 2020u). In 2014, the Energy Regulation Board observed more than 95% generation from hydropower (Energy Regulation Board of Zambia, 2015, p. 3), with the balance provided by diesel, heavy fuel oil and a minimal amount of solar photovoltaic plants.

Figure 4 Zambia's historic reliance on hydropower



Source of data: World Bank, 2018; graph: own

Just before the power outages of 2015 and 2016 in 2014, the Kariba and Kafue hydropower projects that the World Bank financed between 1956 and 1974 accounted for 81% of ZESCO generated electricity (Energy Regulation Board of Zambia, 2015, pp. 4, 5, 6, 7). Since that time and up until the power outages of 2015 and 2016, no significant investment had been made in Zambia's power generation capacity (Whitworth, 2014, p. 14). The World Bank not only financed the Kariba and Kafue hydropower projects, but, in the words of the former chairman of the British construction company selected to build the Kariba Dam, 'twisted' the Zambian government's arm to make it accept the Kariba north bank power station (Morrell, 1987, pp. 152–153).[9] Similarly, power generation was the World Bank's most significant destination for investment in Zambia, accounting for more than half the value of its investments up until 1974 (see Table 2 below). It therefore behoves us to understand the dynamics and the thinking that motivated and informed the Bank's investment prioritisation of energy.

Table 2 Zambia's first 18 executed World Bank-financed infrastructure projects

#	Project Title	Project ID	Commitment, USD M current	Status	Approval Date	US CPI-U	Power commitment, USD M constant 9/2018	Economic infrastructure, USD M constant 9/2018	Bottom of the pyramid focus, USD M constant 9/2018	
18	POWER KARIBA-NORTH(S	P003166	42.10	Closed	05/07/1974	49.4	215	215		
17	Lusaka Squatter Upgrading and Sites and Services Project	P003167	20.00	Closed	05/07/1974	49.4			102	
16	Kafue Hydroelectric Power/Second Stage Project	P003164	115.00	Closed	05/07/1973	44.3	655	655		
15	Program Loan Project	P003163	30.00	Closed	14/06/1973	44.2			171	
14	Education Project (03)	P003162	33.00	Closed	31/05/1973	43.9			190	
13	Integrated Family Farming Project	P003161	11.50	Closed	16/01/1973	42.6			68	
12	Kariba North Power Project	P003160	40.00	Closed	07/07/1970	39.0	259	259		
11	Agriculture / Tobacco Project	P003158	5.50	Closed	28/05/1970	38.6		36		
10	Education Project (02)	P003159	5.30	Closed	18/11/1969	37.0			36	
9	Livestock Project	P003154	2.50	Closed	17/06/1969	36.6		17		
8	Education Project (01)	P003156	17.40	Closed	08/04/1969	36.3			121	
7	Forestry Project	P003155	5.30	Closed	24/09/1968	35.1			38	
6	Highway Project (02)	P003157	10.70	Closed	24/09/1968	35.1		77		
5	Highway Project (01)	P003153	17.50	Closed	04/10/1966	32.7		135		
4	POWER II / Kariba Electric Power Development Project (02)	P003152 / P003267	3.80	Closed	02/10/1964	31.1	31	31		
3	Railway Improvement Project	P003151	9.50	Closed	16/06/1958	28.9		83		
2	POWER I / Kariba Electric Power Development Project (01)	P003150 / P003264	40.00	Closed	21/06/1956	27.2	371	371		
1	Railway Project (01)	P003149	14.00	Closed	11/03/1953	26.9		131		
						Total investments, 1953-74:	**1,531**	2,011	727	2,738
						% of total investments,1953-74:	56%	73%	27%	

Sources: World Bank, 2018 https://projects.worldbank.org/ and US Bureau of Labor Statistics, 2018 Table 24 for CPI-U values

Data sources: World Bank, 2018a; US Bureau of Labor Statistics, 2018; IBRD, 1956c, p. 6; IBRD and IDA, 1964, p. i; calculations own

2.3 The World Bank's support for energy investment around the world and in Zambia

The Bank's investment appraisal documents did not signal an intent for the power generation to extend to ordinary Zambians, and indeed, by 2018, only a third of the population had access to on-grid energy access is 33% (ZICTA and CSO, 2018). Instead, the appraisal documents showed that 85% of Zambia's electricity consumption at the time of appraisal of the Kafue hydroelectric project in 1973 was by Zambia's copper industry (IBRD and IDA, 1973, p. 1) and it was this industry whose 'electricity requirements' (IBRD and IDA, 1973, p. 1) were being assessed. Consistent with this neglect of electricity access for all as a priority, only a quarter of the World Bank's investments by real value were

[9] The twisting of the arm was not in the context of the Zambian power utility not wanting more hydropower – it did. The twisting of the arm was in the context of helping the World Bank finance the hydropower project for the benefit of the British colony Southern Rhodesia, which was facing sanctions, as well as Zambia, by channelling the money through Zambia (Morrell, 1987).

directly targeted at 'social infrastructure' to address poverty reduction in Zambia and the requirements of Zambians (see Table 2 above).[10]

The Bank's prioritisation of economic infrastructure, and moreover hydropower, reflected both the political instrumentalisation of the Bank within a geopolitical context, as well as its institutionalised economic thinking. To understand the Bank's political instrumentalisation as well as the investment principles underlying particular investments, we need to look at the original template of the hydropower project (the Tennessee Valley Authority), to the context which birthed the Bank, rhetoric that guided its purpose, as well as the writings and sayings of is most influential economists and executive leadership in respect of power generation versus investment in more welfare-focused projects.

2.3.1 The Tennessee Valley Authority template

The Tennessee Valley Authority was a federal hydropower agency that would by 1946 comprise nine 'huge' dams along a stretch of 600 miles of Tennessee River, and a further eleven dams on the tributaries. As well regulating the flow of water, the dams had the capacity to generate 2-2.5 gigawatts of power, ranking the TVA second among US electric systems (Huxley, 1946, pp. 12–13). As it started delivering electricity in 1937, the Tennessee Valley Authority offered electricity prices that were almost 60% lower than the national average (Finer, 1972, p. 205). Whether or not prices converged as a result of competitive pressure, that fell to 45% by 1941 (1972, p. 205). Where previously electric utilities had targeted one-fifth of households already modernised, the TVA focused on the four-fifths of households that utilities claimed were incapable of modernisation.[11]

Table 3 The Tennessee Valley Authority's tariffs compared to the national average

	Average rate per kWh/cents					
Electric system	**1933**	**1937**	**1938**	**1939**	**1940**	**1941**
Tennessee Valley Authority		1.83	1.95	2.16	2.06	2.05
US entire industry	5.49	4.39	4.14	4	3.84	3.73

Excerpted from Finer, [1944] 1972, p. 205

Prior to the New Deal, the average household consumed 30kWh monthly in the USA, just more than lights (11kWh/month) and a radio (7kWh/month). By the 1950s, that had increased by five times. Refrigerators – which spent on average 22kWh/month – went from being a luxury-appliance to a mass appliance (Tobey, 1996, pp. 157–162). Greater demand from the middle-class market meant that their unit cost of production fell in addition to the cost of running them thanks to the TVA. Within three years of connecting to the TVA's Wilson Dam, Tupelo, a town of 10,000 people in Mississippi, saw eight stores sell USD 500,000 worth of appliances. More broadly, between 1933-39, nominal retail and service receipts increased by 87% in the power area of the Tennessee Valley Authority according to census of business data (Finer, 1972, p. 213). A 1935 edition of *Electrical World* noted that the rise in sales of appliances was stimulated by the TVA's lower electricity rates (Tobey, 1996, p. 122). Electric cooking (123kWh/month) and water heating (168kWh/month) were the next items on the USA's energy ladder (Tobey, 1996, pp. 157–162).

[10] While the World Bank today no longer persists with the distinction between economic and social infrastructure (though the OECD does persist (OECD, 2019)), it is important to note the World Bank did make this distinction at the time that it financed most of Zambia's existing energy infrastructure. As late as 1995, the World Bank categorised water supply and sanitation as 'social' investments, separate from 'infrastructure' which were telecommunications, transportation, electric power and other energy (Kapur, Lewis and Webb, 1997, p. 6).

[11] This was the key difference between the balanced growth targeted by the TVA and the unbalanced growth which ZESCO targeted: the TVA was for those excluded; ZESCO was for those already included. We will return to this later.

Greater aggregate demand led to greater output and output per capita, and this was particularly pronounced in the TVA's catchment area. Per capita increased by 84% from 1933-40 in Alabama, Mississippi and Tennessee, compared with 57% for the USA (Finer, 1972, p. 212).

The increase in sales explains the increase of 17,000 jobs in the trade sector in the TVA power area from 1930 to 1940 (Finer, 1972, p. 211). The greater prosperity in this sector explains the expansion of other sectors. Value-added by manufacturing increased by 39% from 1935-1939 in the TVA public power area (compared with 31% across the United States), and manufacturing wages increased by 35% (compared with 25% across the United States) (Finer, 1972, p. 211). The textiles, food products and chemicals manufacturing sectors increased employment by 17,000 from 1930 to 1940 (Finer, 1972, p. 211). In turn, the expansion of these sectors explains the increase in employment of the construction industry by 16,000 for the same period. All this despite the inference that the TVA power area imported its manufactured electrical appliances from outside the area.

Additionally, electrification's intended aim to curtail urbanisation was somewhat successful. The rural non-farm population of the TVA power area increased by 22% from 1930 to 1940, compared with a 17% increase for the urban population (Finer, 1972, p. 211).

More broadly, mass electrification to stimulate the economy and reduce unemployment redefined the role of government by defying and rewriting textbook teaching (Barber, 1996, p. 1). It provided the template for the Keynesian multiplier linking consumption and output in a cyclical relationship, and gave rise to the economic theories of a number of other Western economists, including Keynes, Rosenstein-Rodan and Hirschman, Rostow and Kuznets.[12] The latter two approached the question of economic development as a teleological exercise with respect to US political interests.

2.3.2 The Bank's political instrumentalisation

US President Frank Delano Roosevelt's administration designed the World Bank ("the Bank"), or the International Bank for Reconstruction and Development (IBRD) as it was conceived, as part of a suite of Bretton Woods organisations to help maintain peace after the Second World War (Mason and Asher, 1973, p. 15; Sharma, 2010, p. 33, 2017, p. 7) by providing international public goods in the form of monetary stability, free flow of capital and free trade (Gilpin, 2001). In 1945, President Roosevelt shared with Congress a vision of establishing institutions that complemented his other legacy of electrification through the Tennessee Valley Authority: "expanded production, employment, exchange and consumption" to "ensure our own prosperity [. . .] as well as for a peace that will endure" (Roosevelt, 1945). Prosperity the world over meant deeper markets with which the US could trade, and fewer security threats. Roosevelt's vision would endure during the period in which the World Bank invested in Zambia's system of energy provision. Two decades later, US Secretary of Defence Robert McNamara who two years later would preside over the World Bank for the following 13 years, reiterated Roosevelt's vision by talking about the nexus between violence and 'economic backwardness', and that propelling developing nations from poverty was key to US security (McNamara, 1966).

[12] Perhaps the most neglected underlying theoretical commonality between the mainstream Anglo-American economists Keynes, Rosenstein-Rodan and Hirschman of the 1930s, '40s and '50s (the latter two of whom have latterly become known as development economists) was that their economic modelling based on the TVA experience was what Reinert (Reinert, 2019) characterises as '*Erfahrungswissenschaft'* – a science based on experience. Reinert is therefore not even-handed when he distinguishes German economics an Erfahrungswissenschaft' (Reinert, 2019).

With Roosevelt's successor's Truman Doctrine, the Bank and the Tennessee Valley Authority became instrumentalised to keep at bay the Soviet communist threat to US exports (Ahmed, 2020a). Providing cover to this mercantilism were the economic theories of British and American *Erfahrungswissenschaftler*[13] of the day whose work had been informed by the experience of the Tennessee Valley Authority – Keynes, Rosenstein-Rodan, Hirschman, Rostow, as well as of Kuznets. The latter two approached the question of economic development as a teleological exercise with respect to US political interests.

The Bank's push for electrification to fulfil US interests rather than the best interests of the recipient countries fits Gilpin's global hegemon model of the USA, where the hegemon 'created a liberal international economy primarily to promote its own interests' (Gilpin, 2001, p. 99). Voting power in the Bank would be decided by shares held – rather than one country one vote as in the United Nations – making the United States, which holds more than twice the shares than the next largest shareholder (IBRD, 2020), the most influential country at the World Bank. The US Secretary of the Treasury sits on the World Bank's Board of Governors, the World Bank's highest governing body (World Bank, 2017b). All World Bank presidents have been American. It was left to the newly established regional development banks – the Inter-American Development Bank established in 1959, the African Development Bank in 1964, and the Asian Development Bank in 1966 – to focus on poverty lending and water investments (Bakker, 2013, p. 288).

The political economy of Rostovian growth and the Tennessee Valley Authority template

Prime in intertwining development logic with the Truman Doctrine of containing Soviet expansion and influence was Walt Whitman Rostow's "The Stages of Economic Growth: A Non-Communist Manifesto", published in 1960. According to the popular and influential modernisation theory of the American economist Walt Whitman Rostow who advised the Kennedy and Johnson administrations, economic development was a linear path of five stages (Rostow, 1960).

Acknowledging that the 'Keynesian revolution' (Rostow, 1960, p. 155) had allowed Western governments to address unemployment in times of economic depression, and thus thwart Marxism, he set about merging a dynamic version of classical production theory with Keynesian income analysis. Since underdeveloped nations were 'the main focus of Communist hopes', their take-off would be the 'most important single item on the Western agenda' (1960, p. 134).

Rostow's theory of production focused on the composition of investment and on developments within particular sectors of the economy at particular stages (1960, pp. 13–14) – at a traditional stage; at a stage where it was getting ready for take-off and where 75% of the working force was in subsistence agriculture; at the stage of taking-off, by which end 40% of the work force might in agriculture; at a mature stage, where 20% of the work force would be in agriculture; and finally at a stage of high mass-consumption (1960, p. 71).

Given the varying elasticities of demand with each stage of growth, Rostow prescribed a 'sequence of optimum patterns of investment' (1960, p. 14). Investment to increase societal productivity would thus start in agriculture; then in 'social overhead capital'.[14] Together, agricultural and infrastructure investment provided a 'viable base' (1960, p. 25) for modern industry. To maintain industrialised

[13] Experiential scientists

[14] This was following Hirschman's use of the term in 1958 (p.63) which Hirschman said included 'all public services from law and order through education and public health to transportation, communications, power and water supply, as well as such agricultural overhead capital as irrigation and drainage systems. The hard core of the concept can probably be restricted to transportation and power'. For his part, Rostow emphasised transportation.

economies' growth, they should look towards 'underdeveloped' markets (1960, p. 156). Herein lies potential for a contradiction in the Rostovian development model: if industrialised nations are to continue growing by exporting to underdeveloped markets, how will underdeveloped markets advance to the stage of mass high-consumption? Do they too not need to industrialise? If imports hinder domestic industrial development, which country's development should take precedence?

This potential conflict of interests was borne out in the World Bank's first development investment, with US commercial interests profiting from the investment.[15] In step with the clamouring in the United States for the 'weaponisation' of the Tennessee Valley Authority, the Bank's first development (as opposed to reconstruction) investment loan was made in hydroelectric projects in Chile from an array of options that included forestry, a harbour and transport (IBRD, 1947; IBRD, 1948; Olivier, 1961b, p. 5; World Bank, 2016). Power supply was deemed insufficient in Chile, and hydro was favoured over coal and liquid fuels because they were high in cost and insufficient in supply (IBRD, 1948, p. 22). This investment was followed, in line with Rostovian alertness for the need to establish export markets in underdeveloped markets, with a loan to Chile for the importing of agricultural machinery (World Bank, 2016, p. 4). In 1948, 32% of Chile's workforce was employed in agriculture and fishing (Díaz, Lüders and Wagner, 2016, p. 666), rendering it at Rostow's "take-off stage" of development, or alternatively, ripe for flooding with US manufactured exports, required to sustain the final stage of growth in developed nations' high mass consumption. The ex-post data suggest that flooding with US manufactured exports is exactly what happened. UN (1962, p. 20) and World Bank (2016, p. 4) data show an 86% correlation between the value of Chile's manufactured imports and its increase in installed energy capacity between 1938 and 1960. Further analysis suggests that the bulk of these imports came from the United States.[16]

Besides the potential conflict between investment recipient countries and investor and export-oriented countries, replicating the Tennessee Valley Authority template in the Zambian context would have entirely different consequences for Zambia according to Rostow's theory. Whereas the United States was at the penultimate stage of five stages of Rostow's economic growth (1960, p. 71) with about just a fifth of its work force in agriculture (Rostow, 1960, p. 71; U.S. Census Bureau, 1999, table 1430), Zambia in 1968 was at the first traditional stage because close to three-fourths of its population worked in subsistence agriculture (Park, 1968). Where previously electric utilities had targeted one-fifth of households already modernised, the TVA focused on the four-fifths of households that utilities claimed were incapable of modernisation. Targeting hydropower for cheap electricity consumption in the United States propelled high mass consumption which drove demand across domestic and already established industries and drove rises in employment, wages and gross value added. Along with contributions from the Great Depression and the Second World War, this gave rise to the famous Kuznets Curve: the share of income of the two lowest quintiles rose from 13.5% in 1929 to 18% after the second world war, while the share of the top quintiles fell (Kuznets, 1955, p. 4). Inequality fell. This was the key difference between the balanced growth targeted by the TVA and the unbalanced growth which ZESCO targeted: the TVA was for those excluded; ZESCO was for those already included. 85% of

[15] It is important that the conflict of interests be noted as a potential one. To unequivocally state that this was a conflict in the case of Chile we would need to make the case that the rise in imports of manufactured goods from the USA diminished Chile's ability to industrialise. That is beyond the scope of this work. We also do not have data for Chile's manufacturing value added as a percentage of GDP prior to 1960. Post 1960, manufacturing value added grew from a fifth of GDP to a quarter by 1970 (World Bank, 2019b).

[16] 89% of Chilean merchandise imports were from high-income countries in 1960 (World Bank, 2019b, l. 216). There is an 89% correlation between the indexed value of Chilean manufactured imports and US manufactured exports from 1938-60. As Chile's imports increased, the USA's exports increased. By contrast, the correlation between Chile's manufactured imports and its largest neighbours' manufactured exports Argentina and Brazil for the same period is 11% and 4% respectively (United Nations, 1962, pp. 9, 17, 20, 52).

Zambian electricity consumption was by the export-facing copper mining industry (IBRD and IDA, 1973, p. 1) initiated by colonialists. Zambia's copper was valuable to developed market since Zambia was second only to the USA as a non-communist supplier of the commodity.[17] Export of raw metals and ores have continued to account for 70-80% of Zambia's exports (World Bank, 2020u). Targeting hydropower to benefit extractive mining industries in Zambia would benefit Western markets, those employed in mining, those serving mining companies and the customers of the mining products. The beneficiaries within Zambia would be limited, and inequality would rise.

Ironically, Kuznets' observation of reduced inequality from a time bound experience of one country's experience with a high degree of government intervention targeted at the bottom of the pyramid and hence with balanced growth had subsequently been used to justify development along a capitalist paradigm of unbalanced growth. Unlike Rostow's *Stages of Economic Growth: A Non-Communist Manifesto*, Kuznet's theory that 'income inequality would automatically decrease in advanced phases of capitalist development, regardless of economic policy choices or other differences between countries, until it stabilised at an acceptable level' (Piketty, 2014, p. 13) was not advertised as a political one.[18] But like Rostow's modernisation theory and like the many calls for the 'weaponisation' of the Tennessee Valley Authority, Kuznets' theory was a partisan one designed to further the USA's political interests and ideology in the context of the Cold War (Piketty, 2014, p. 13).

Accompanying Rostow's logic couched in economic terms was political pressure from the United States to export the USA's 'best-known, most highly appreciated institution' (Cooke, 1949; Ekbladh, 2002, p. 350) – the Tennessee Valley Authority. The historian Arthur Schlesinger called the Tennessee Valley Authority 'a weapon which, if properly employed, might outbid all the social ruthlessness of the Communists' (Schlesinger, 1949; Ekbladh, 2002, p. 350). Even a member of the judiciary was recorded making overtly political statements about the Tennessee Valley Authority. "The word "Tennessee" is well known all the way across from the Mediterranean to the Pacific," said US Supreme Court Justice William Douglas in 1951. "They know about Tennessee because they have heard of the Tennessee Valley Authority […] that fits their needs and will solve many of their basic problems. The TVA can also be utilised as one of the major influences to turn back the tide of communism which today threatens to engulf Asia" (Douglas, 1951; Ekbladh, 2002, p. 335). The political resilience and popularity of the TVA carried through into the 1960s as US president Lyndon Johnson's talked of replicating the Tennessee Valley Authority in Vietnam in his speech "Peace without conquest", delivered a month after he had dispatched 3,500 US Marines to South Vietnam to commence the USA's ground warfare in the Vietnam War.

> "Electrification of the countryside – […] that […] is impressive […] In the countryside where I was born, and where I live, I have seen the night illuminated, and the kitchens warmed, and the homes heated, where once the cheerless night and the ceaseless cold held sway. And all this happened because electricity came to our area along the humming wires of the REA [Rural Electrification Administration]." Vietnam's Mekong River could provide food, water and power, he told his audience, on a scale that would "dwarf even our own TVA" (Johnson, 1965).

[17] Prior to independence, mining was dominated by two companies, Anglo American and Roan Selection Trust, who paid royalties to the British South Africa Company in lieu of a local national government. The geographic area that would become to be known as Zambia was the world's third largest producer of copper in the world, trailing only the United States and USSR with 14% of global output (Barton, 2016, pp. 20–21). The Government of Zambia nationalised the mines in 1969 and reprivatised them in 2000 following protracted and failed negotiations for the Government of Zambia starting in 1992 (Barton, 2016, pp. 21, 141–144).

[18] Stated visually, the Kuznets' Curve was a statement of a universal 'n' shaped curve where the x-axis represented economic growth and the y-axis represented inequality.

Yet as the evidence of electrification in Zambia shows as well as investment appraisal documents for hydropower projects across 18 countries listed in Annex 1, Johnson's experience of and a vision of electrified rural homes from hydropower investments abroad was at odds with the reality of the Bank's focus on energy catering to mining and industry. This was because proponents of the TVA template within the Bank had forgotten the processes by which the TVA had achieved an increase in employment and stimulated the economy, and focused only on the outcomes.

The Tennessee Valley Authority (TVA) template came to be used as a universal supply-driven solution – to be referred to as the "granddaddy" of all regional development projects (Scott, 1998) and as "the marquee example of government-funded economic development" (Staples, 2006, p. 12).[19] By 1951, the Bank had extended 32 loans in 13 developing countries[20]. Energy accounted for 60% of the Bank's development finance portfolio (IBRD, 1951c, pp. 54–56).[21] In 1956, the Bank initiated the Economic Development Institute (Mason and Asher, 1973, p. 326) that would train future finance and prime ministers. The institute took students on outings. The Tennessee Valley Authority's network of dams, power plants, irrigation systems and fertiliser plant proved to be 'particularly popular […] as many Third World countries *[sic]*, as well as the World Bankers, saw it as a model of the type of large-scale economic development that could be produced by large infusions of outside development capital under close governmental supervision'.

The TVA would allow the World Bank 'the relative ease of transferring the technology of power generation from more developed to less developed countries' (Mason and Asher, 1973, p. 713). That it was very much a supply-driven solution is borne out in early World Bank country reports requesting water and sanitation investments that were rejected, crescendoing into the outcry by 1960 by developing countries that resulted in the creation of the International Development Association (Ahmed, 2020a).[22] The TVA itself was predicated on cheap electricity for all, but in the developing country contexts where it was introduced, it was used to supply those already with electricity access more. The TVA was an adaption of Henry Ford's model of mass production, applied to electrification (Tobey, 1996, pp. 93–96) to stimulate aggregate demand (Barber, 1996, pp. 128–131) and gave birth to the bottom-up Keynesian multiplier effect. As a supply-side solution offered by the World Bank, regard was not paid to how different the conditions were in Zambia versus what they had been in the United States.

2.3.3 The Bank's economic and financial rationale for investing in hydropower

[19] Staples continues: '[The TVA] became the model for similar river-development schemes throughout the United States and the world, as well as for the Rural Electrification Administration, which brought electricity to rural areas across the country in order to encourage their economic development and modernisation' (2006, p. 12).

[20] I have counted as developing countries Brazil, Chile, Colombia, El Salvador, Ethiopia, India, Iraq, Mexico, Nicaragua, South Africa, Thailand, Turkey, Uruguay, and excluded Australia, Belgium, Denmark, Finland, France, Iceland, Luxembourg, Netherlands, Yugoslavia.

[21] Using nominal values for 1948-51 loan agreements, electric power accounted for 61.5%, transport for 21.8%, agriculture for 9%, foreign exchange for finance for 4.6%, flood control for 2.8% and telecommunications for 0.3%.

[22] The International Bank for Reconstruction and Development's Cuba mission reported that were a water crisis allowed to occur, 'all employment in all industries would cease' (IBRD, 1951b, p. 328). The IBRD's Nicaragua report called investments in sanitation, education and public health 'without question' the first priority to combat high disease rates and low nutrition inhibiting productivity (IBRD, 1953b, p. 22). However, no loans were made to Cuba in the 1950s where requests were made for water projects (Alacevich, 2009, p. 129). Of the eleven loans to Nicaragua between 1951 and 1960, none was for water, sanitation, health or education (Kapur, Lewis and Webb, 1997, p. 111). With Paraguay, it was a similar story. Having accepted a US Eximbank loan in 1954 for a water supply system, the Bank 'arguing that the project was an unproductive amenity, and moved as well by its rivalry with the Eximbank, dropped plans for lending to that country, an interruption that lasted until 1962 (Kapur, Lewis and Webb, 1997, p. 111).

Having understood the context of the Tennessee Valley Authority, its successes within its context, the broader global political context underscoring its propagation and the creation and use of the World Bank by the United States, as well as Rostow's modernisation theory that married US interests with international development economic theory, we can now zoom back into the economic and financial rationale used by World Bank professionals – leading economists and executives – to justify investments into energy and in particular hydropower.

Broadly, the thinking was as follows:

a. Economic infrastructure would benefit the economy and generate taxes to pay for welfare assets (which, in the case of access to electricity in Zambia, it did not),
b. Social infrastructure was not also economic infrastructure, and that
c. In any case, it was not worth attempting to appraise the economic benefits of welfare assets either on an ex-ante or on an ex-post basis.

Economic infrastructure would benefit the economy more quickly than social infrastructure

While the World Bank today no longer persists with the distinction between economic and social infrastructure (though the OECD does persist (OECD, 2019)), it is important to note the World Bank did make this distinction at the time that it financed most of Zambia's existing energy infrastructure. As late as 1995, the World Bank categorised water supply and sanitation as 'social' investments, separate from 'infrastructure' which were telecommunications, transportation, electric power and other energy (Kapur, Lewis and Webb, 1997, p. 6).

The words of World Bank vice presidents lend insights into the rationale as to why the Bank as an institution thought there was a dichotomy between social and economic infrastructure.

In rejecting an investment for urban water in Colombia, World Bank vice president Robert Garner said that the Bank would only consider municipal projects if 'tangible evidence was provided that the projects were closely connected with the development of productive facilities' (Garner, 1952; Alacevich, 2009, p. 114).[23] Rejecting the project once again a year later in 1953 following a resubmission for the application of a loan for the municipality, Garner argued that the 'Bank should concentrate its efforts on projects which will yield the <u>greatest</u> and <u>quickest</u> increase in output and productivity'. Out of these new sources of income would come the means for member countries 'provide out of their own resources better municipal services, better housing, better health and education' (Garner, 1953; Alacevich, 2009, p. 117). Garner's sentiment would be reiterated by his successor almost a decade later. As World Bank vice president Burke Knapp (Olivier, 1961, p. 33) explained in 1961, "We can lean a little in the direction of taking those things which have come to be known as social projects rather than directly productive economic projects. My own definition of these is things that are less investment in future productivity and more satisfaction of current welfare requirements, like housing, water supply, other municipal services. Our sort of doctrine in the main in the past has been that those things were the fruits of economic development and that we would rather invest in the means of economic development and let countries develop the taxable capacity and the productivity that would enable these amenities to be provided."

Arguments that potable water, considered social infrastructure, was key to productivity fell on deaf ears. An IBRD mission to Cuba reported that were a water crisis allowed to occur, 'all employment in all industries would cease' (IBRD, 1951b, p. 328). The Nicaragua report called investments in sanitation, education and public health 'without question' the first priority to combat high disease

[23] The request accompanied requests for investment in other sectors, highlighting the importance of power: 'Electric power is perhaps the most single element in modern economic development' (Currie, 1950, p. 514).

rates and low nutrition inhibiting productivity (IBRD, 1953b, p. 22). However, no loans were made to Cuba in the 1950s where requests were made for water projects (Alacevich, 2009, p. 129). Of the eleven loans to Nicaragua between 1951 and 1960, none was for water, sanitation, health or education (Kapur, Lewis and Webb, 1997, p. 111). With Paraguay, it was a similar story. Having accepted a US Eximbank loan in 1954 for a water supply system, the Bank 'arguing that the project was an unproductive amenity, and moved as well by its rivalry with the Eximbank, dropped plans for lending to that country, an interruption that lasted until 1962 (Kapur, Lewis and Webb, 1997, p. 111). In relation to the rejected water investments, Currie (1979; Alacevich, 2009, p. 129) complained that the Bank "had the strange belief that water was social, not economic." The categorisation of water remains as such, with water and sanitation listed under 'Social Infrastructure and Services' and energy listed under 'Economic Infrastructure and Services' on the OECD's website (2019). It was not until a political uprising from developing members that the Bank made its first urban water supply loans in 1960 with the creation of the International Development Association, and even then, investments mainly privileged the urban middle-classes.

But lower marginal productivity could not be the reasoning for denying investment in water in Cuba and Nicaragua where clean water was seen as a prerequisite for productivity and industry. In truth, Garner's opposition to investing in water was informed by lived experience and emotive prejudice. Flippantly, in an interview in 1985, he said "Why should such and such a country have a water supply system in its town? When I was brought up in Mississippi [...] we didn't have any water in our house" (Kapur, Lewis and Webb, 1997, p. 110). Kapur, Lewis and Webb remark that 'one is left wondering [. . .] had Garner been born in a town with piped water in each home, he might have agreed to lend for municipal water services' (1997, p. 125). Clearly in addition to *Erfahrungwissenschaft* at play among the economic theories used to justify investment in power, *Erlebeniswissenschaft* was also at play in the preclusion of social infrastructure.[24]

Among the *Erfahrungwissenschaftler* at the World Bank were Paul Rosenstein-Rodan, for whom the TVA power area's growth provided a template for the importance of complementary knock-on effects between sectors of the economy, and Albert Hirschman, who propounded unbalanced growth. Both were economists who served at the World Bank.[25] Rosenstein-Rodan argued for a balanced growth approach (1943, pp. 205–206) illustrating with a toy example of a shoe factory employing 20,000 formerly agrarian workers in a more-or-less closed and self-sufficient domestic economy would be useless. The employees would require more than the shoes they were able to buy with their wages:

> If, instead, one million unemployed workers were taken from the land and put, not into one industry, but into a whole series of industries which produce the bulk of the goods on which the workers would spend their wages, what was not true in the case of one shoe factory would become true in the case of a whole system of industries: it would create its own additional market [...] The industries producing the bulk of the wage goods can therefore be said to be complementary.

By contrast, Hirschman argued that developing countries had an insufficient endowment of resources to enable them to invest simultaneously in all sectors to achieve balanced growth and take-off (Hirschman, 1959; Ncube, Lufumpa and Kararach, 2017, p. 3). According to his unbalanced theory of growth, therefore, governments had to invest strategically in infrastructure to raise the productivity of selected industries, not to the broad extent that Rosenstein-Rodan had imagined, to multiply new

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[24] *Erlebeniswissenschaft* is knowledge acquired from lived experience, as opposed to *Erfahrungwissenschaft* which is based more on observations (Fukuyama, 2018).

[25] Paul Rosenstein-Rodan, a University College London economist, became the IBRD's Economic Department Assistant Director. Albert Hirschman also consulted for the IBRD.

investment opportunities (Hirschman, 1959; Ncube, Lufumpa and Kararach, 2017). Availability of reliable power and transportation facilities were therefore prerequisites for economic development (Hirschman, 1959; Ncube, Lufumpa and Kararach, 2017). The argument for focus on selected industries seems to have prevailed in the US Department of Commerce's analysis of Zambia in 1968 (Park, 1968, p. vii): 'Zambia's bright prospects for continuing economic development arise largely from the country's strong financial base, consisting principally of revenues derived from abundant mineral resources.'

To preserve the IBRD's triple-A credit rating, the Bank established a separate International Development Association (IDA) in 1960 in response to the threat that frustrated governments of low-income countries would move their membership to a rival multilateral bank that would fund social infrastructure projects, and which would be housed by the UN, where each nation had one vote, undercutting the USA's influence. The funding of social infrastructure projects could have been an opportunity to test the hypothesis that so-called social infrastructure projects did not yield the same productivity returns as so-called economic infrastructure, but even as late as 1967, Hirschman argued against ex-post evaluations to rank infrastructure projects, citing the impossibility of using a single scale to amalgamate all the varied dimensions. And so it was that the IBRD continued to favour economic infrastructure projects without validating its assumptions.

This also meant that the IBRD could continue providing loans to sectors with which it was comfortable: hydropower helped it achieve a triple-A credit rating and allowed it to sell bonds on the private market (Sharma, 2017, p. 15). The Bank's credit rating affected its ability to raise funds. Its Wall Street leadership & project lending won it AAA credit rating by the mid-1950s (Sharma, 2017, p. 15), which reinforced for management that its conservative approach of sticking to lending what it knew was working. 'The first loans granted by the Bank […] proved to be successful, and in fact they were completely repaid,' notes Alacevich. 'According to those who urged and considered it inappropriate for the Bank to venture into higher-risk loans in an environment where it was difficult to raise funds, there was no reason to change policy. The Bank took pride in reorganising power companies to which it loaned so that they ran on sound financial lines (Mason and Asher, 1973, p. 716). The financial success of the first loans validated its position against alternative models of "impact" and "social loans" and contributed to perpetuating the model' (Alacevich, 2009, p. 136); the bank had not as of 1971 suffered a financial loss (Mason and Asher, 1973, p. 258).

Table 4 The IBRD's historic credit rating

Year	Bank credit rating
1947	AA – Fitch A – S&P
1950	A – Moody's AA – Fitch A1 – S&P
'soon after 1950'	AA – Moody's
'since the mid-1950s'	AAA – Moody's, Fitch, S&P

Source: Mason and Asher, 1973, p. 132

The Bank was thus able to continue using an appraisal methodology developed in the mid-1950s that assessed the need for power using market rather than shadow economic demand, in using market prices, and weighing the case for power in financial rather than economic terms (Mason and Asher, 1973, p. 716). This then explains why the Bank's investment appraisal for the Kafue hydropower project in 1973 assessed the electricity demand for Zambia's copper industry (IBRD and IDA, 1973, p. 1) rather than by Zambians. It also explains why industrial, mining or mineral processing demand and not residential demand was the Bank's primary target for its first hydropower investments in Brazil

(IBRD, 1950c, 1953a), Colombia (IBRD, 1950a, 1950b, 1951a; World Bank, 2020f), Ethiopia (IBRD, 1961c; World Bank, 2020i), Ghana (IBRD, 1961a, p. 2), Kenya (IBRD and IDA, 1971, p. 3) and Turkey (IBRD, 1952b; World Bank, 2020p). Investment in hydropower in Zambia was representative of the World Bank's institutional bias towards this type of development intervention. Where there were resources for hydropower, the World Bank went. It even went where it could not legally meet demand: the then chairman of the British construction company selected to build the Kariba Dam recalls that the Bank 'twisted' the Zambian government's arm to make it accept the Kariba north bank power station, to assist the Bank in circumventing investment sanctions on Southern Rhodesia (Morrell, 1987, pp. 152–153), referred to in the Bank's earlier investment appraisal documents as 'the Colony' (IBRD, 1952a).

Having understood the theoretical and empirical linkages between energy and industrialisation and the Bank's logic behind its significant support for the expansion of power generation in Zambia, we will now assess how power generation's target beneficiaries mining and industry fared, and how effectively investment into energy provision for them translated into the sort of welfare outcomes that World Bank executives Robert Garner and Burke Knapp suggested that they would.

2.4 A brief history of Zambia's industrialisation until 2015

This chapter has highlighted literature that shows that industrialisation has so far been a reliable path for economic development, and revealed the underlying assumptions of World Bank executives that the tax revenues earned from industry should pay for welfare amenities. This section now reviews how successfully investments into Zambia's power generation has resulted in industrialisation, and what that has meant for the welfare of Zambians in general. It also looks at other factors that have impacted Zambia's industrialisation, namely structural adjustment advocated for by the Bank and IMF, which saw deindustrialisation from 1991-2002.

Theory discussed at the beginning of this chapter would predict that investment into energy provision in Zambia for the purpose of industrialisation should have resulted in structural shifts in terms of sectoral employment from low-productivity agriculture to higher-productivity manufacturing, and an increase in the proportion of GDP generated by manufacturing. These shifts should have made the workforce more productive, and with manufacturing's backward and forward linkages and through the multiplier effect enabled by a more prosperous workforce, should generate further demand for goods and services. As these sectors grow and thrive, tax revenues for welfare services should increase. Measures of success that improvements in welfare are being distributed equitably would then be an increase in average expected life expectancy, increase in access to electricity, and increase in GDP per capita. Remembering that the World Bank's significant investments into power generation in Zambia were approved in 1956 and 1970-74 (Table 2), as well in 1964 for a smaller investment, we can assess whether Zambia's power generation achieved either of these predicted outputs or outcomes, before looking at other dynamics that affected Zambia's industrialisation.

An overview

Looking first at the World Bank and Energy Regulation Board's statistics to assess the relationship between energy consumption and manufacturing value-added and the relationship between manufacturing value-added and GDP we find that the energy consumption and manufacturing value-added are 94% correlated over the period 1971-2018 and that manufacturing value-added and GDP are 98% correlated over the same period. Over the observed period, 1% increase in energy consumption was associated with a 1.74% increase in manufacturing value-added, a statistically significant result with an 80% R-squared.[26]

Table 5 Regressing the log of manufacturing value-added on the log of total-electricity consumption in the economy

	(1)
VARIABLES	log_manuf
log_energy	1.741***
	(0.126)
Constant	6.782***
	(1.115)
Observations	48
R-squared	0.806

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

Analysis: Own

Looking second at structural changes in the economy, the broad trends do not neatly follow predictions: manufacturing's contribution to GDP increased eight times between 1960 and 1990, but the proportion of the population employed in agriculture barely changed. Manufacturing value-added's contribution to GDP did increase substantially in the period following the Bank's investments into power: from a base of 4% in 1960 to 10% in 1970 to 17% in 1980 and up to 32% in 1992 (World Bank, 2020u). It fell dramatically to 9% in 1994 (World Bank, 2020u) following structural adjustment, and has hovered at approximately that level since. On the other hand, investment in power generation did not apparently have the predicted effect on employment in agriculture. 75% of Zambia's population was assessed as being dependent on subsistence agriculture in 1968 (Park, 1968, p. 6). The sector accounted for 11% of GDP (Park, 1968, p. 6). The next datapoint available for employment in agriculture is 72% in 1991 (World Bank, 2020u). In the time between, the World Bank invested USD 1.13B (Table 2) in the early 1970s in Zambia's power generation. The investment seems to have had minimal impact on the structure of employment in Zambia. The decade since 2008, employment in agriculture fell by a quarter to 54% by 2018 (Table 2). This cannot be ascribed to investment in power generation forty years earlier. Likewise, investment in power generation did not have the predicted effect on agricultural contribution to GDP which hovered between 10-16% from 1960-1988 (World Bank, 2020u). It spiked to 21% in 1992 and 31% in 1992 (World Bank, 2020u) following structural adjustment (more on this later) before falling steady to 3% in 2018 (World Bank, 2020u).

The conflicting results for manufacturing and agriculture suggest that as Zambia's population grew, employment opportunities in Zambia's small manufacturing sector did not keep up. Quality of life would have improved for urban dwellers able to avail opportunities, but not for the rest of the rural population or the urban poor. This is borne out by the election of Michael Sata as president in 2011 who ended two decades of the incumbent Movement for Multiparty Democracy's rule that had overseen rapid growth in the 2000s. Not only did he overcome the incumbent, but also eight other opposition parties by tapping into the urban poor's disgruntlement with rising inequality (Resnick and Thurlow, 2014). It is also borne out in several sets of metrics measuring welfare. Zambia's GINI index of inequality has been very high – 0.61 in 1991 during structural adjustment (World Bank, 2020u) and

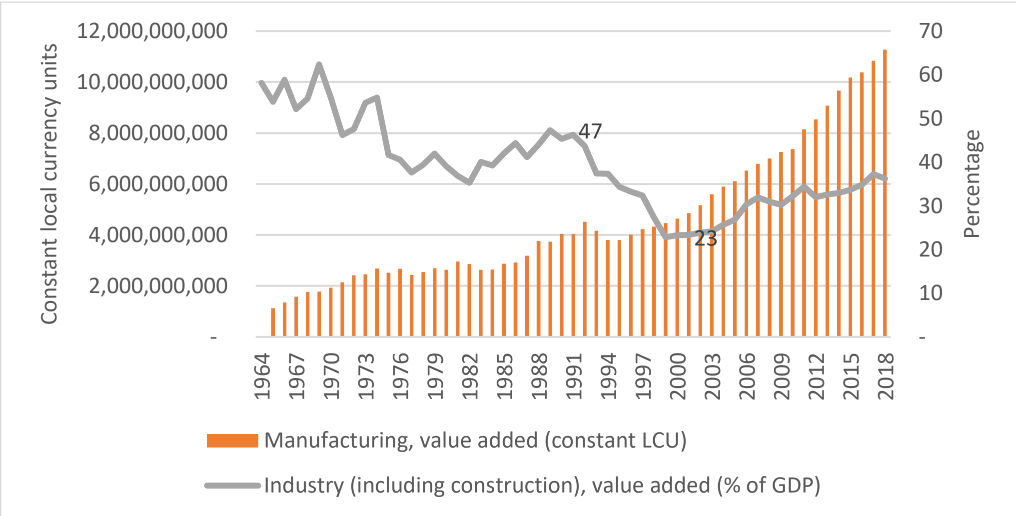
[26] The World Bank offers manufacturing value-added expressed in constant local currency (World Bank, 2020u). It also offers energy consumption per capita and total population statistics which enables us to compute results up to 2013. For 2014-2018, we used total energy consumption statistics offered by the Energy Regulation Board as outlined in Table 1. To calculate the effect of 1% changes in the explanatory variable on the dependent variable, I ran log-log regressions.

possibly 0.66 in 2006 (Resnick and Thurlow, 2014). Inflation-adjusted fell to two-thirds of its value by the end of Zambia's first president's presidency from the time of independence in 1964 over 27 years before rising to its present day level which is just 8% above its independence day level, compared to real GDP growth of 450% since independence (World Bank, 2020u).[27] Despite being categorised as a middle income country by the World Bank, 45% of the population lived on up to USD (2011 PPP) 3.20 per day in 2017 (World Bank, 2020u). Zambia's grid electricity access rate was just 33% as of 2017, with rural grid electricity access at just 6%, in contrast to 66% for urban access (ZICTA and CSO, 2018). 27% of households had no type of electricity at all (ZICTA and CSO, 2018). Just 18% of households had internet access (ZICTA and CSO, 2018).

A chronological view

Zambia's manufacturing sector grew quickly from a small base to service the mining sector from independence in 1964 until 1973 following a policy of import substitution and high copper prices (Gondwe and Pamu, 2014, p. 12), as well as following investments into Zambia's energy provision. Growth slowed over the next few decades as it was constrained by lack of infusion of new technology, the high cost of borrowing and foreign competition (Gondwe and Pamu, 2014, p. 12). The dip in the sector's value-added in the 1990s followed structural adjustment.

Figure 5 Zambia's manufacturing value added has generally been growing[28]



Data source: World Bank, 2020; graph: own

Post-independence Zambia was characterised by President Kenneth Kaunda's state-led 'humanist development' (Funder *et al.*, 2018, p. 34). Agriculture and state-subsidised manufacturing were

[27] This is not the perfect proxy for the income of the average member of society because on the one hand, it is skewed towards greater income by being calculated on a mean average rather than median average basis and thus overstates average income. On the other hand, inflation adjusted prices which form the basis of GDP calculations fail to account for the reducing price of technology over time as technologies become cheaper. Tracked over time, however, it still gives an idea of inequality when compared against GDP growth

[28] Industry corresponds to international sector industrial classification (ISIC) divisions 10-45 whereas manufacturing is a subsect, divisions ISIC 15-37 (World Bank, 2020c). ISICs 41-43 are construction, ISICS 36-39 are water supply, sewerage, waste management and remediation, p.43. However, the UN and this study counts ISICs 10-14 as manufacturing also: ISIC 10 is manufacture of good products, 11 is of beverages, 12 of tobacco products 13 of textiles, 14 of wearing apparel (UN, 2008, pp. 87–101) p87-101. ISICs 10-12 constitute Zambia's largest manufacturing subsectors and ISICs 13-14 were important subsectors until 1991.

responsible for much of Zambia's growth (Thurlow and Wobst, 2007, pp. 221–222); manufacturing growth has a 97% correlation with the growth of Zambia's GDP (World Bank, 2020u).[29]

However, on the back of rising debts and rising food prices which caused food riots in the wake of droughts, such that President Michael Sata later remarked in 2013 that, "Kaunda's government was overthrown because of food riots and I don't want food riots," multiparty elections were run in 1991 (Reuters, 2013; Funder *et al.*, 2018), ushering in a change of regime and political economic philosophy. Moving away from donor dependency and the old regime's emphasis on state-led development, the new government of Movement for Multiparty Democracy government adopted the Washington Consensus advocated by the Bretton Woods organisations (the International Monetary Fund and the World Bank), which was

> predicated on the belief that by eliminating "distortions" in the economy, Africa would grow faster by constructing an economy based on principles of free and unfettered markets. In reality, these structural adjustment policies foisted on developing countries have actually discouraged industrial development (Stiglitz, 2017, p. 12).

Per the Washington Consensus, the Movement for Multiparty Democracy government followed a programme of structural adjustment, which it largely achieved by 1998. This included privatisation of state owned enterprises and trade liberalisation by reducing trade protection, which left Zambia one of the most open economies in Africa (Thurlow and Wobst, 2007).

As the data across metrics above suggest, structural adjustment in 1991 wreaked havoc across the economy. Import tariffs fell by two-thirds on imported textiles, leading to increased cheap imports from Asia, against which Zambia's textiles subsector was unable to compete (Resnick and Thurlow, 2014). Compounding the problem was the import of second-hand clothes donated to foreign charities and sold at low prices (Resnick and Thurlow, 2014). Employment in textiles fell from 250,000 in the 1980s to less than 2,500 in 2002, and its contribution fell from 1.8% of GDP in 1991 to less than 0.3% in 2010 (Resnick and Thurlow, 2014). Manufacturing value-added's proportional contribution to GDP fell to a third of what it had been. Value-added per worker fell by 20% from 1991-2002, almost entirely due to negative structural change, as manufacturing job losses resulted in people seeking survival in low-skilled subsistence farming and in informal trading, resulting in a reduction of national labour productivity (Wobst and Thurlow, 2005; McMillan and Rodrik, 2011; Resnick and Thurlow, 2014; Mulanda and Punt, 2020). Life expectancy fell to its lowest since Zambia's independence, although the causality in increased inequality and mortality is confounded by an increase in the prevalence of HIV at the same time (World Bank, 2020u), as well as drought (Beilfuss, 2012).[30]

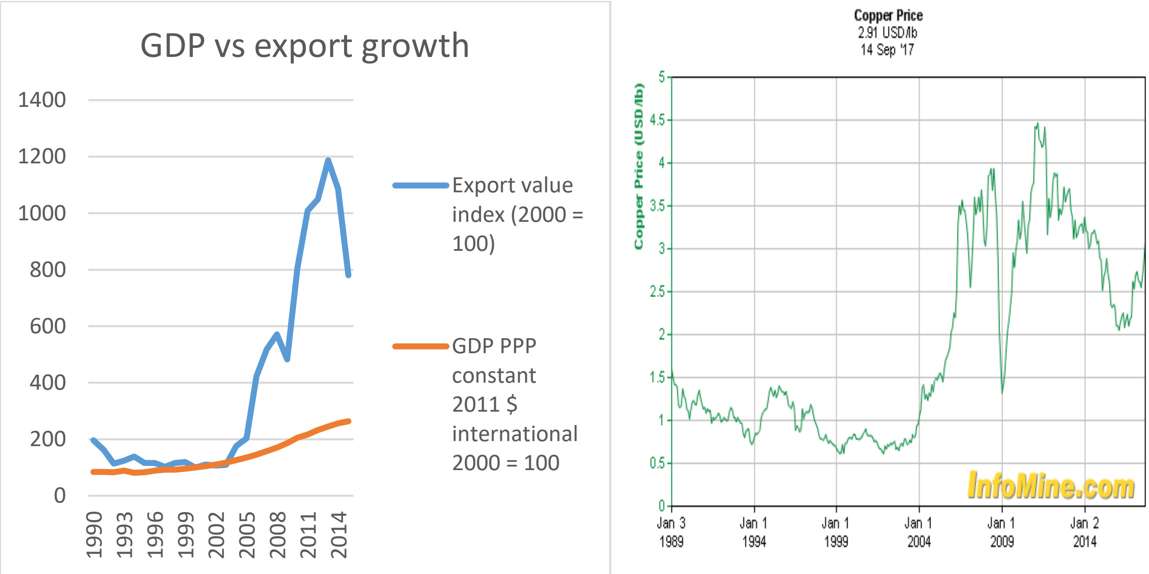
A couple of authors have blamed Dutch disease for the decline of textiles, but without comprehensive analysis. Resnick and Thurlow state that compounding the textiles subsector's woes was high copper prices, making Zambia's real exchange rate appreciate and thus making imports cheaper relative to

[29] According to the World Bank, GDP is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources and is calculated as the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products (World Bank, 2020u). The Central Statistical Office compiles Zambia's GDP statistics and has since 1994 been including the informal sector, which it caveats may exaggerate the total GDP figure relative to other countries (Jerven, 2013, p. 48).

[30] Life expectancy in 1960 was 45, increased to 49 by 1970 and then more or less plateaued at 51 from 1974 to 1982 (World Bank, 2020u) before steadily declining. It reached a nadir of 43 between 1993 to 1997 (World Bank, 2020u) following structural adjustment, but the timing may just have been a coincidence: life expectancy began its decline nine years earlier. The World Bank started recording the incidence of HIV for Zambia in 1990 when it was 2.4%, peaking in 1992 at 2.6% before declining. The coefficient of correlation between HIV incidence and life expectancy between 1990 and 2018 was -80%, with life expectancy reaching 62 years in 2018 (World Bank, 2020u)).

domestic production (Resnick and Thurlow, 2014, p. 9). This adverse impact on other sectors arising from the export of natural resources is known as Dutch disease. Where according to World Bank statistics, mineral rents in 1970 accounted for 35% of GDP, in 2017, they accounted for 12.5% (World Bank, 2019a). Nevertheless, Zambia's export value still follows the price of copper, the most commonly mined mineral in Zambia (see Figure 6 below); copper and copper products accounted for 72% of Zambia's exports (World Bank, 2020t).

Figure 6 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.



Sources of data for graphs: World Bank, 2017; Investment Mine, 2018

Cardozo et al. also suggest that with higher copper revenues resulting in the appreciation of the Kwacha, textile imports from China became more competitive (Cardozo *et al.*, 2014, p. 7) resulting in the shrinkage of Zambia's textile manufacturing subsector (Cardozo *et al.*, 2014, p. 10). There are weaknesses with how both sets of authors present the argument. With Resnick and Thurlow, they mention it as a confounding factor, but it may as well be a coincidental factor. The evidence Cardazo et al present is the fact that the textiles sector shrank. However, all of Zambia's other manufacturing subsectors grew over the same time period (Cardozo *et al.*, 2014, p. 10). Looking to the data, when one divides World Bank historic data for GDP per capita in current local currency by GDP per capita in current United States dollars (World Bank, 2020u), one gets average rates of exchange between the Zambian Kwacha and US dollar. If one uses 2000 or 2001 as the base year for looking at whether the Kwacha appreciated or depreciated over the 2000s, in no year did it appreciate beyond the base year. In 2006 it returned to the exchange rate at which it was in 2001. In that year, the Kwacha did appreciate by 19%, but then depreciated by 11% the following year and by 35% in 2009. Mining may well have been the cause of currency fluctuations in 2006, but the link is not definitive. Figure 6 above shows that global copper prices rose exponentially from 2006 to 2008, and that Zambia's export value continued to grow beyond then, but the annual average Kwacha-dollar exchange rate remained within a band of 3.6 to 4 Kwacha per dollar.

If 2006 was indeed the year in which Dutch disease harmed textiles, 2006 seems to be an aberration. Gondwe and Pamu argue that thanks to generous incentives and subsidies to the mining sector in Zambia, mining companies have little incentive to convert foreign exchange earnings into Kwacha to settle domestic obligations and that as a result, insufficient mineral rent gets absorbed into the domestic economy (Gondwe and Pamu, 2014). The depreciating trend of the Kwacha relative to the dollar suggests that Gondwe and Pamu are at least generally correct. In a case of Dutch disease, the Kwacha would appreciate. Instead, the Kwacha had half the US dollar value in 2018 that it had in 2012 (World Bank, 2020u).[31] Moreover, while metal and ores have accounted for between 70-80% of the country's exports since 2005, manufacturing exports have increased from 9% to 14% (World Bank, 2020u). Positive spill-over effects would be greater if this was the other way round since manufacturing has greater forward and backward linkages to the rest of Zambia's economy than mining does, which also has limited potential for direct employment and historically has not generated much tax revenue (Resnick and Thurlow, 2014, p. 8).

But for textiles, the 2000s saw a general rebound in Zambia's economic growth which Bhorat et al (2017) attribute in large part to a rebound in copper production, Bayliss and Pollen (2019) attribute to a boom in commodity prices, as well as favourable weather that supported agricultural production, and sustained macroeconomic stability,[32] and Barton attributes to greater institutional transparency in government and credible government commitment to investors (Barton, 2016). Resnick and Thurlow characterise the 2000s as a period of rapid economic recovery, marking a return to pre-crisis levels and middle-income status (2014). Value-added per worker increased by 3.6% per year from 2002-2010: about half of this increase was due to positive structural change driven by faster employment growth in services and a relative decline in farm employment (Resnick and Thurlow, 2014, p. 4).

During the 2000s, the largest contributors to growth were construction, transport, communication, finance and business services which collectively accounted for 56% of the increase in GDP (Resnick and Thurlow, 2014, p. 12). But because these sectors were driven mainly by rising value-added per worker rather than an increase in the number of workers – for example communications was capital intensive, while financial services required highly skilled workers – they generated only 14% growth in employment (Resnick and Thurlow, 2014, p. 12). From 2002-2010, manufacturing accounted for 4.5% of increase in national GDP per capita and 1.3% of employment growth (Resnick and Thurlow, 2014, p. 9) with food processing accounting for 70% of the manufacturing sector's contribution to GDP, up from 50% in 1991 (Resnick and Thurlow, 2014, p. 9). Vertical integration with South-Africa based supermarket chain helped Zambia's largest meat processor Zambeef expand (Resnick and Thurlow, 2014, p. 9). Wheat millers benefitted from liberalisation and an appreciating local currency because imported wheat was cheaper and expanded their production of flour and bread for urban consumers (Resnick and Thurlow, 2014). Food-processing was less labour intensive than the declining textiles subsector and contributed less to national job creation than it did to economic growth (Resnick and Thurlow, 2014). Overall, the sector continued to grow. Over 2002-2015, Zambia's real manufacturing value-added grew at a compounded annual growth rate of 5.4%.

Zambia started seeing greater institutional transparency with the presidency of Levy Mwanawasa, who was popularly credited with fighting corruption (BBC, 2008), and with his successor Rupiah Banda.

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[31] The only other relevant paper in the first 20 recommended articles that the search item "Dutch disease Zambia" yielded in UCL's online library was Boos and Holm-Müller's paper (Boos and Holm-Müller, 2016). The paper makes the case that patterns of Genuine Savings – the reinvestment of rents from the depletion of natural capital rents into physical or human capital – can be used to indicate whether a country is experiencing the "resource curse" of Dutch disease (Boos and Holm-Müller, 2016). However Boos and Holm-Müller overlook an alternative reason to that of the resource curse for why Genuine Savings do not materialise – the one pointed out by Gondwe and Pamu that substantial rents were not collected by the economy in the first place. Their analysis that the lack of Genuine Savings is indicative of a resource curse cannot therefore be sustained.

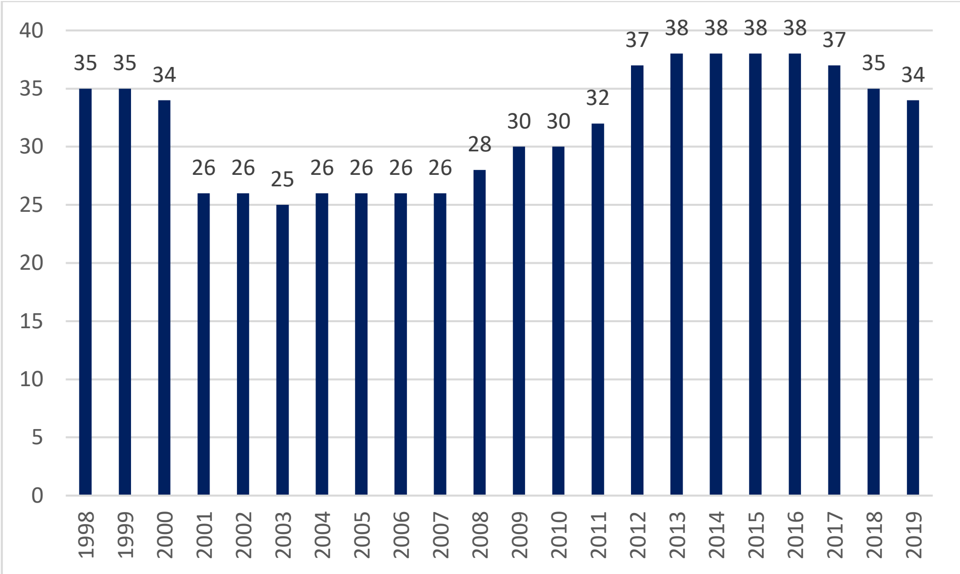
[32] Wamulume Kalabo, Chairman of the Zambia Chamber of Commerce and Industry (ZACCI) from 2004 to 2007 attributes growth in the 2000s to better governance (Kalabo, personal communication 4 June, 2018, see Annex 3.3.2 for interview notes).

Figure 7 shows that Zambia's corruption index score by Transparency International was 26 when Mwanawasa entered office in 2002 but improved to a score of 30 in 2009 months after he had left in September 2008 and continued improving until 2015. Barton has also characterised President Mwanawasa's reforms as reinforcing the Zambian state's 'credible commitment' to supporting a more inclusive institutional environment which helped lower investors' perceptions of future policy uncertainty (Barton, 2016, p. 157).[33] Net inflows of foreign direct investment picked up substantially with the passing of the Zambia Development Agency Act in 2006 and the creation of Zambia's first multi-facility economic zone in 2007 (Barton, 2016, pp. 157, 160) (see Figure 8). Like legislation passed in 1992 which only elicited a minor spike in growth of foreign direct investment (see Figure 8), the Zambia Development Agency Act prohibited expropriation of private property without prompt compensation of the property's fair market value less taxes, levies and duties, but it also offered tax incentives for new businesses, import duty waivers on raw materials and capital goods and deferment of VAT on machinery and equipment (Barton, 2016, pp. 158–163). Coupled with Zambia's first MFEZ, the Act that signalled the Zambian government's credible commitment. By 2008 following the announcement of Zambia's fourth MFEZ, the MFEZ initiative had attracted more than USD 3 billion of new investment pledges (Barton, 2016, p. 164). Investors saw goodwill on the president's part, and that he would not change policy without consulting the private sector (Kalabo, personal communication 4 June, 2018).[34] Consequently, manufacturing firms such as Trade Kings grew substantially under his presidency, and so too did the demand for energy (Kalabo, personal communication 4 June, 2018).

[33] New institutional economist and Nobel prize winner Douglass North and political scientist Barry Weingast pioneered this concept in assessing the five significant institutional changes that followed the triumph of the English parliament over the monarchy in the Glorious Revolution of 1688/89 (Coffman, Leonard and Neal, 2013). The institutional changes resulted in the 'credible commitment' that the government would not default on its future debt. The changes they observed removed the monarchy's underlying sources of expediency, increased parliament's agency and monitoring, introduced the credible threat of dethroning the sovereign and created a balance between parliament and the monarchy (North and Weingast, 1989; Coffman and Neal, 2013). Building upon this scholarship, modern commentators have added in the British case parliamentary supremacy over public finance, transparency in public accounting, accountability via direct creditor action and robust secondary markets, a stated commitment to maintaining the public faith, the use of the common-law procedure to adjudicate disputes between taxpayers and the regime as well as the perception of stability and permanence of a given regime (Coffman, 2013a). Beyond Zambia's structural change, the ZDA Act and signalling of credible commitment with the creation of MFEZs, new institutional political economists espousing the 'credible commitment' theory would observe the parallel between England with a strengthened parliament following the deposition of the monarch James II and Zambia's second decade of multiparty democracy following Kenneth Kaunda's 27-year long presidency.

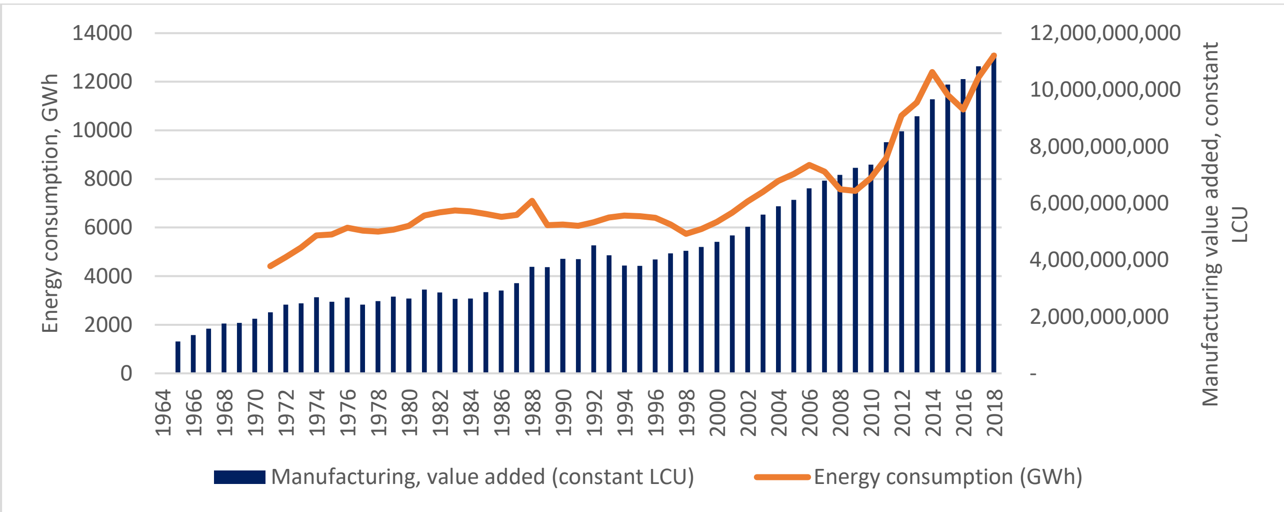
[34] Wamulume Kalabo, Chairman of the Zambia Chamber of Commerce and Industry (ZACCI) from 2004 to 2007. See Annex 3.3.2 for interview notes.

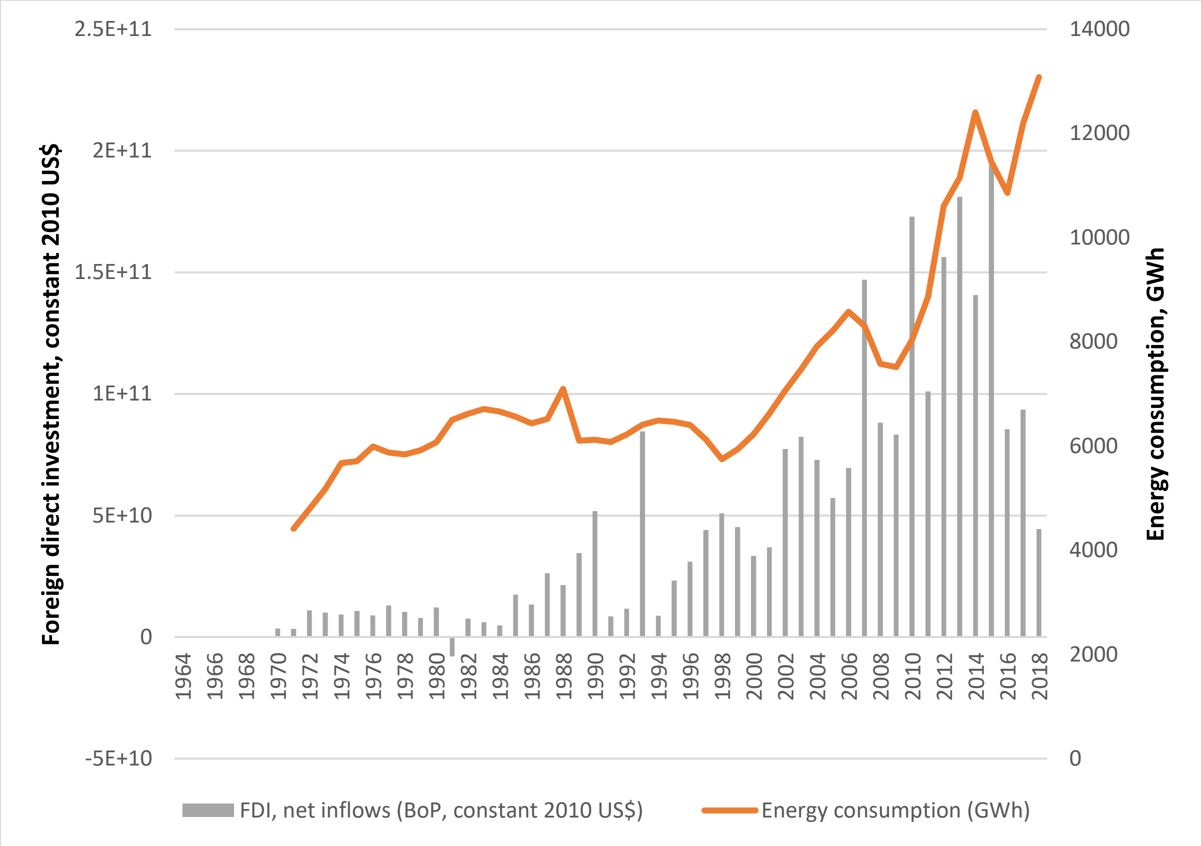
Figure 7 Transparency International Corruption Perceptions Index score out of 100 for perceived corruption within Zambia's public sector (100 = clean, 0 = highly corrupt)



Source: Transparency International, 2020

Figure 8 There is a 94% correlation between Zambia's energy consumption and manufacturing's value added; net inflows of foreign direct investment fell after the power outages of 2015





Data sources: World Bank, 2020; Energy Regulation Board of Zambia, 2016, p. 0, 2017a, p. 9, 2018, p. 36, 2019, p. 39

In spite of the growth overseen in the 2000s by the Movement for Multiparty Democracy under presidents Levy Mwanawasa and Rupiah Banda, in 2011, 43% of Zambians voted into power a new president from a new party, defeating the incumbents as well as eight other opposition parties that could have split the vote a lot more than they did. Michael Sata of the Patriotic Front came into power by tapping into the disgruntlement of the urban poor, highlighting their exclusion from the economic recovery (Resnick and Thurlow, 2014). Notably in rural areas, most of which he lost in,[35] he focused much less on articulating policies and instead relied on ethno-linguistic appeals in certain provinces (Resnick and Thurlow, 2014). Given Zambia's resurgent urbanisation, urban areas contained large concentrations of votes, and were his pathway to electoral victory. This neglect of rural voters even by the party that stood for more inclusive development explains in large part why by 2018, rural grid electricity access stood at just 6% in contrast to 66% in urban areas, and why 27% of households nationwide had no type of electricity at all (ZICTA and CSO, 2018).

More recently, neo-colonial criticisms have also been levelled recently at Chinese investments into Zambian multi-facility economic zones (MFEZs). Ostensibly designed to industrialise the economy and diversify away from mining,

> China's involvement in the zones has come under significant criticism from Zambians and Western commentators alike for allegedly having manipulated [Government of Zambia] policy to gain exploitative access to the country's mineral wealth (Barton, 2014, p. 91).

[35] Sata won two rural constituencies (Resnick and Thurlow, 2014).

Impressions that the MFEZs favour Chinese investors could be inferred from the fact that the first two MFEZs are part of the Zambia-China Economic & Trade Cooperation Zone (Zeng, 2016), were developed by a Chinese state owned enterprise, the China Nonferrous Metal Mining Group (CNMC) (Zeng, 2016; McKinney *et al.*, 2020), and that they are used for mining (Zeng, 2016; McKinney *et al.*, 2020). But for more recent investments into the new Lusaka South MFEZ, where there are seven manufacturing firms (Lusaka South Multi Facility Economic Zone, 2018), all previous MFEZ investments had been into the mining sector, according to the CEO of the Zambia Association of Manufactures (personal communication, 28th May, 2018, see A3.3.1 Interview with Chipego Zulu, CEO of Zambia Association of Manufacturers on 28 May, 2018The previous MFEZs had been difficult for Zambian manufacturing firms to enter, the Zambia Association of Manufactures CEO said, because of their high capital costs. Another respondent, a grants manager at the University of Zambia, felt that Chinese direct investment was crowding out access to capital for indigenous businesses and government policies were not geared at nurturing Zambian businesses (personal communication, 29th May, 2018, see A3.6.2 Meeting with Natty Chilundiki, Research Coordinator, on 29 May, 2018). In spite of Barton's impression that MFEZs created more institutional inclusivity, a third respondent, a retired director at the Central Bank of Zambia, observes that foreign direct investment has come only from China and suspects that Chinese investment and construction contracts are secured with corruption (personal communication, 28th May, 2018, see A3.6.1 Interview with Chibelushi Maxwell Musongole, Lecturer, retired Assistant Director at the Central Bank of Zambia and retired Director General at the Zambia Public Procurement Authority on 28 May, 2018 Chinese construction projects costs, he asserts, are inflated and commit the government to high debt levels. Whereas the respondents I interviewed believed that Chinese state enterprises had developed a competitive edge over indigenous businesses by ignoring good governance, Barton subscribes to the "wide open door" thesis that China has merely inserted itself into the neoliberal arrangements that the West opened up because, he argues, Chinese investment facilitates 'the [Government of Zambia]'s longer-term policy to align its economy with the dominant neo-liberal world order' (Barton, 2014, p. 91).

Whether one wants to characterise foreign direct investment in Zambia as neocolonial or neoliberal, it should not be surprising that while Zambia did see economic growth as a result of the investment and the accompanying infrastructure to facilitate it, the economic growth was highly concentrated in the hands of the few who had inherited control of the country's resources, and that its GINI coefficient by 2015 would be a highly unequal 57 (World Bank, 2020u).[36] While life expectancy improved substantially after hitting a nadir in the mid-1990s following World Bank and IMF-informed structural adjustment (Barton, 2016; Stiglitz, 2017) combined with a drop in copper prices (MacroTrends, 2020), the rise in life expectancy since the mid-1990s cannot be directly attributed to the World Bank's investments 20 years earlier. If anything, the investments taken together with the structural adjustment advocated by Bretton Woods organisations in the 1990s perpetuated a colonial legacy of Zambian economic dependence on copper and lack of resilience to fluctuation in raw material prices.

* * *

This chapter showed the salience of manufacturing in theory to economic development, the salience of cheap energy supply to economic recovery and industrialisation in the context of the Tennessee

[36] Stuart Barton characterises the presidency of Zambia's first president, spanning from independence in 1964 to 1991, as highly exclusionary both politically and economically (Barton, 2016, pp. 66–90). Real GDP per capita fell by 33% while real GDP had grown by 59% and life expectancy remained stagnant at 48 years of age (World Bank, 2020u). The UNDP notes that the flow into the state's budget from copper revenues has not been very different under either state or private ownership (Simpasa *et al.*, 2013, p. 18).. Weak revenue generation under state ownership is attributed to poor performance of the sector (Simpasa *et al.*, 2013, p. 18). Weak revenue generation under private ownership is attributed to contracts skewed in favour of the concessionaires, as well as illicit financial flows and transfer pricing schemes (Simpasa *et al.*, 2013, p. 18).

Valley Authority; the export of the Tennessee Valley Authority template by the World Bank to low-income countries with very different employment structures and the underlying politics and economic rationale for doing so; and how the links between energy supply, industrialisation and economic development played out in the Zambian context, where structural adjustment resulted in deindustrialisation, deurbanisation and increased inequality in the 1990s before a resurgence in industrialisation but continued inequality and voter discontent.

Almost half a century after the World Bank's investments in Zambian energy, only a third of Zambians had access to grid electricity (ZICTA and CSO, 2018). Because the World Bank invested in hydropower in Zambia when the initial conditions did not match those when the Tennessee Valley Authority was established, the results were also different. The Tennessee Valley Authority was built in the 1930s for those whom had been excluded. It democratised electricity and electrical appliances, stimulated the economy in a balanced manner from the bottom-up and contributed to a more equal society. By the mid-1950s, however, the World Bank's focus on its creditworthiness resulted in an appraisal methodology that assessed the need for power using markets rather than shadow economic demand, in using market prices, and weighing the case for power in financial rather than economic terms (Mason and Asher, 1973, p. 716). When the World Bank came to finance an expansion of ZESCO's energy generation capacity, it came to serve those already included. Unbalanced growth would be an understatement of what it promoted. It promoted an extremely stilted and highly unequal growth.

Rostow's own simple heuristics predicted a difference in outcomes: the United States was at the penultimate stage of five stages of Rostow's economic growth, whereas Zambia in 1968 was at the first traditional stage because close to three-fourths of its population worked in subsistence agriculture. But the differences in outcome also shows which argument out of balanced versus unbalanced growth ended up being more correct. Whereas the Tennessee Valley Authority fueled construction projects executed by domestic firms, fed into agriculture and tied up with other New Deal programmes that also promoted rural electrification to deliver balanced growth, foreign firms constructed Zambia's hydropower dams,[37] whose primary beneficiary was extractive export-forcing industries with few linkages to the domestic economy.[38] Broader electrification programmes for residential consumption were evidently not promoted so that even until today, two-thirds of the nation is without grid access. Power supply for industrialisation, on the other hand, does seem to have been successful: industrialisation grew rapidly following investment into power and expansion of Zambia's mining capacity. This industrialisation however was undone by the Bank and IMF's structural adjustment policies implemented by the Movement for Multiparty Democracy so that even today, upwards of 70% of the nation's exports are metals and ores. Unbalanced growth in Zambia failed to deliver an eventual balancing. Having interrogated the difference in context between the World Bank's template for hydropower and its investments in Zambia and the theory that guided distributional differences between the two, we now understood how inequality was baked into Zambia's energy infrastructure. Whereas balanced growth led to a deluge of benefits to Americans in the 1930s, a policy of unbalanced growth with hydropower have not resulted in a trickle down of material benefit to most Zambians.

Had the Washington Consensus never taken effect, manufacturing may have continued its upward trajectory and Zambia's economic growth may have been distributed more widely. With an improved environment of governance since the 2000s, manufacturing has been resurging and providing better employment and GDP returns per kWh of energy consumed than Zambia's largest consumer of

[37] For example Yugoslav firm Energoproject constructed the first stage of Kafue hydropower dam (Park, 1968, p. 16).
[38] The proof is in the export volume of Zambia's metal and ores, although the government does at least incentivise firms to process ores into blister copper (99.5% copper content) before exporting with high export tariffs on ores (Tembo, 2018, p. 42).

energy, mining. However, as we saw in the previous chapter, energy supply to manufacturing reduced in 2015 and 2016, and with it, growth in manufacturing value-added. Not only did ZESCO provide manufacturing firms schedules for load-shedding, but firms also experienced unannounced power outages. The next chapter will review the literature on the impact of power outages on manufacturing as well as analyse data related to Zambia to discern clues on how the power outages of 2015 and 2016 may have affected manufacturing that resulted in the reduced growth that we have observed.

3. The Impact of power outages in the literature

Microeconomic analysis of the impact of power outages do not suffer from the oversimplifying assumptions that macroeconomic analyses do, but microeconomic analyses relying on firm-level surveys are constrained by the accuracy of answers given by respondents. Research has found that power outages adversely impact productivity, but that the impact on manufacturing subsectors is not equal, and that neither is the downstream impact of an affected sector. Research has found that firms would be willing to shift their work timings if lower off-peak tariffs were offered, thus abating peak-demand. Fewer long-duration interruptions are less damaging than several very short outages. Firms have multiple coping mechanisms, of which using backup diesel generation is one. Characteristics that predict whether firms use backup diesel generation are firm size, age, export orientation and sector. With fewer outages, firms were less equipped to respond to them, and so the bigger the individual cost when they did occur. Zambia experienced power outages prior to 2015, but not to the same extent as demand caught up with Zambia's supply. Manufacturing growth slowed. Lafarge in Zambia attributed its reduced revenues and profits from 2014 to 2016 to outages. Backup diesel generation accounted for about 10% of Zambia's emissions in some months of 2019.

The previous chapter shows how Zambia's system of energy provision prioritised mining, beneficiation and manufacturing to kick-start the motor of Zamia's economy. This chapter examines the literature on the impact of power outages on manufacturing, and on Zambian sectors of the economy and manufacturing in particular. It also uses reports and statistics to supplement this understanding and identifies gaps in the literature that primary data collection can plug.

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

Macro vs micro analysis on the impact of power outages across sectors

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). 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. They also often fail to take into substitution away from electricity intensive activities (Bental and Ravid, 1982).

Andersen and Dalgaard returned to a macro analysis approach in 2013. Using outages as a binary variable in a logarithmic regression model, Andersen and Dalgaard estimated that a 1% increase in the average frequency of outages in a month reduces long-run GDP by almost 3% for a sample of 39 sub-Saharan countries, including Zambia (Andersen and Dalgaard, 2013). 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 problems with this macro analysis are several. Recognising that GDP is likely to be plagued by non-random measurement error in Africa, they produced "adjusted" real GDP per capita growth rates by looking at the growth in nightlights using satellite data. But non-growth of luminance is not necessarily representative of non-growth of GDP: it may be that unequal growth results in those who already had nightlights are getting richer, but have no more lights to shine, while those without nightlights previously are not and still do not have nightlights.

The weakness with micro studies is often that they rely on questionnaires prone to inaccuracies as respondents may have reason to overstate the damage done of power outages (Bental and Ravid, 1982) – 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 power utility. Another pitfall of subjectively answered surveys is that they could be prone to loss aversion.[39] This may explain why a number of studies such as Pasha, Ghaus and Malik's in Pakistan (1989) and Beenstock, Goldin and Haitovsky's in Israel (1997) concluded that firms overstated their losses. Similarly, perceived losses do not necessarily match actual losses if framed in a particular way, contrary to rational expectation.

In reviewing the literature on whether individuals' willingness to abandon electricity is greater than their between willingness to pay for it, however, Plott and Zeiler (2005) point out that there is not a consensus.[40] They themselves used procedures which resulted in no difference between willingness to accept and willingness to pay, calling into question the applicability of prospect theory.[41] The key, they wrote, is to avoid misconceptions in willingness to pay questions and provide some sort of incentive for truthful revelation of valuations. Willingness to pay an additional premium for reliable electricity could still therefore be potentially useful for gauging the marginal cost of back-up power. The loss caused by outages is converted into a positive extra price that they would have to pay. Where respondents are firms and not individuals, the "house money effect" should not come into play since respondents themselves would not be paying the higher tariffs. Additionally, while willingness to pay could be used to gauge the marginal cost of backup generation, to avoid the problem of subjectivity associated with micro studies, observations can be used to ascertain the marginal cost of power outages.

Steinbuks and Foster (2010) took a micro analysis approach to investigating the impact of power outages across 25 African countries, Zambia among them. Using World Bank enterprise survey data from 2002-2006, the surveys drew on information collected across the manufacturing and services sectors. One of their identification methods used results of reported loss of sales due to power outages. This is open to both the loss aversion and protest critiques, and is not resolved by seeking how much more respondents would have been willing to pay for more reliable energy.

One noteworthy finding of theirs is their calculation of Zambia's weighted average cost of electricity for firms using backup generators. Adding the variable cost of backup energy to the average capital cost of backup energy, and weighting that by 100% of the time of power outages in relation to non-outage hours, which they ascertained from the World Bank enterprise survey data, they calculated Zambia's weighted average cost of electricity to be USD 0.02/kWh greater than the cost of ZESCO

[39] Behavioural economist Richard Thaler (1980) observed that 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.

[40] Thaler's loss aversion theory, also known as "endowment effect theory", would predict that individuals would state a minimum amount for which they would be willing to abandon electricity as greater than the maximum amount they would be willing to pay for it (Plott and Zeiler, 2005, pp. 530–531). This runs contrary to orthodox economic 'expected utility theory' which predicts that under conditions of sufficiently smooth preferences and the absence of wealth effects, the magnitudes of willingness to buy and willingness to forgo the electricity should be the same (Plott and Zeiler, 2005, pp. 530–531; Baddeley, 2013, p. 15).

[41] Thaler's loss aversion theory builds upon Kahneman and Tversky's prospect theory which explains why utility theory does not explain real-world choices made by people which are inconsistent and intransitive (Baddeley, 2013, p. 139). In prospect theory, value is assigned to gains and losses rather than to final outcomes, and probabilities are replaced by decision weights (Kahneman and Tversky, 1979).

energy (Steinbuks and Foster, 2010). Their method has one apparent weakness and rests on an assumption that requires further examination. The weakness is that it is incorrect to divide the capital cost of backup generation by the hours of use each year, since generators last longer than a year. If anything, they should have divided the capital cost by the expected lifespan of the generator in terms of hours. The assumption that requires further examination is that firms with backup generators use backup generators 100% of the time and to capacity during power outages, an assumption shared by earlier literature such as that by Bental and Ravid (1982). The problem with this is that this may not even have been rational behaviour for the profit-maximising firm: the variable gross profit of production may have become negative with the use of backup generation. Firms may also have lacked the working capital necessary to run generators due to higher running costs, especially fuel costs. It may also not have been a policy followed because the firms' management suffered from heuristic behavioural biases, miscalculated the costs involved or misjudged the length of anticipated outages *ex ante*.

Across Africa, 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. Seventy-fine percent 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 (a subjective estimate subject to loss aversion and protesting). Fifty-three percent of firms owned or shared generators. When generators were used, the average proportion of energy generated was 28% (World Bank, 2018a).

The impact of power outages on large manufacturing firms

The literature on the impact of power outages to the manufacturing sector in general is rich – studies have been carried out since at least 1948, in Sweden (Bental and Ravid, 1982) – and there are a number of studies that hone in on the impact of outages on Zambia's manufacturing sector in particular. None of these studies on Zamia, however, study the impact of the severe outages of 2015 and 2016 on large manufacturing firms, including those published after 2015.

Reduced productivity

Using World Bank Enterprise Survey data collected from 2001-2005 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. While the regression result which pitted days with power outages against total factor productivity that gave rise to this conclusion was only significant at the 10% level using ordinary least squares, and the R-squared for the ordinary least squares model was only 30%, this result was significant at the 1% level using the semi-parametrically estimated firm productivities per Olley and Pakes (Olley and Pakes, 1996) with a 48% R-squared for the model. Moreover, the coefficient on the share of firms that own a generator to be significant and positive at the 5% level in both models.

Similar in aim to Arnold et al's study, Escribano et al (2010) used World Bank investment climate surveys of 26 African countries carried out 2002–2006 to consider the impact of poor quality of power, as measured by number and average duration of power outages and the use of a generator on total factor productivity. They calculated the contribution of the average duration of power outages to average log total factor productivity as 9%, though the level of significance of this result was not shared (their publication was a World Bank working paper and not a peer-reviewed journal).

Pre 2015/16 power outages in Zambia accounted for 5.5% of sales value for the World Bank's surveyed firms. The loss was felt mostly greatly by medium-sized firms employing 20-99 people, which lost 6.9% of value and felt least by large firms employing more than 100 people (accounting for only 4.7% of sales). This was the case 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.

Also using World Bank data (enterprise survey data of 720 firms collected between 2012-2014) for Zambia, Sichone et al (2016) found that load shedding had a statistically significant (at the 5% level) and negative impact on manufacturing output in Lusaka. His model had an R-square of over 97%.

Generally, the mechanism by which productivity reduces with power outages is that electronically operated capital ceases to be operational without power. Worker productivity falls. 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 – particularly for export oriented firms, such as reduced rankings on export markets' reliability criteria (Beenstock, Goldin and Haitovsky, 1997; Steinbuks and Foster, 2010). Even when making up for lost load, firms lose with higher wear and tear as they use their machinery more intensely and with higher staff costs associated with over-time shifts. There are thus welfare losses (Kessides, 1993) and economic growth dampens (Eberhard *et al.*, 2008; IMF, 2008, chap. IV). However, Allcott et al (2015) noted 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 itself may be causing loss in productivity because of the increase in electricity demand that leads to shortages, and poor institutions could lead to insufficient power supply and reduce productivity.

Subsector impact and multiplier effects

Pasha, Ghaus and Malik (1989) first considered the idea that the impact of power outages on an industry could have a downstream effect. Using values calculated by others (Naqvi and Ahmed, 1986) for the coefficients of variables in a truncated[42] formula for aggregate demand, they calculated a static multiplier of 1.34 for all industries. This implied that industrial outage costs could increase as much as 34% when one considered the downstream impact, regardless of manufacturing subsector. Given different manufacturing subsectors' different outputs, a static multiplier value is unlikely to be a good measure for any given subsector.

Chen and Vella (1994) went further by disaggregating multipliers by manufacturing subsectors, to assess the impact of power outages on a particular subsector on the rest of the economy (Chen and Vella, 1994) (see Table 6 below). Their research provided the calculations to be performed and stating that a FORTRAN programme was written for computing the input-output framework in its application for the Taiwanese economy. It was unclear how they ascertained the required data, how rich it was, and what problems they faced with it. The value of the analysis for informing policy is limited by the fact that it does not consider the volume of value-added by industries. It is useful to know that for every Taiwanese dollar the steel and iron industry supplied its products, downstream value-added was NT$0.917, but it would also have been good to know what total value the steel and iron industry added to the Taiwanese economy, not to mention the total employment it brought. At least Pasha et al considered the variation in outage cost per kilowatt hour by industry, and the knock-on effects for Pakistan's exports. Continuous-process industries and those more vulnerable to spoilage experience

[42] Government expenditure and net exports were omitted

greater losses, they found. To minimise loss, therefore, power-feeders should prioritise these industries (Pasha, Ghaus and Malik, 1989). Chen and Vella, on the other hand, saw their methodology as a possibly useful one for figuring out the electricity customers to cut first (Chen and Vella, 1994, pp. 1064–1065), which, given its incompleteness, makes their suggestion a dangerous one.

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.

Table 6 Chen and Vella's table (1994) of Taiwanese industries' multiplier effects on the rest of the economy using in-put-output analysis

Chen & Vella's value multipliers of non-electrical sectors in Taiwan

#	Sector name	Value multiplier
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 fertilizer	0.921
7	Artificial fibres	0.926
8	Iron and steel products	0.939
9	Non-ironic metals and products	0.941
10	Paper, paper products, printing and publishing	0.942
11	Miscellaneous non-metallic mineral products	0.942
12	Garments, miscellaneous fabric products and dyeing	0.944
13	Rubber products	0.945
14	Coal and coal products	0.945
15	Plastics and plastic products	0.948
16	Electrical machinery and apparatus	0.949
17	Gas and city water	0.951
18	Petrochemical intermediate materials	0.951
19	Machinery	0.954
20	Miscellaneous manufactures	0.955
21	Miscellaneous chemical manufactures	0.956
22	Other minerals	0.957
23	Electronic products	0.957
24	Transport equipments	0.957
25	Household electrical appliance	0.959
26	Construction	0.963
27	Products of wood, bamboo and rattan	0.963
28	Lumber and plywood	0.963
29	Leather and leather products	0.965
30	Miscellaneous food products	0.966
31	Livestock	0.97
32	Canned foods	0.971
33	Slaughtering and by-products	0.971
34	Fisheries	0.976
35	Petroleum refining products	0.977
36	Beverages	0.98
37	Rice and grain milled products	0.983
38	Crude oil and natural gas	0.983
39	Transportation and warehousing	0.983
40	Commmunications	0.983
41	Miscellaneous services	0.984
42	Sugar	0.984
43	Sugarcane	0.985
44	Trade	0.986
45	Paddy rice	0.989
46	Other crops	0.99
47	Tobacco	0.992
48	Forestry	0.997

For Zambia, using World Bank enterprise survey data with 720 observations, 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. They posit that the insignificant impact of self-generation on wood processing, garments and leather and non-metallic minerals subsectors is because they are less dependent on electricity for production (Sichone *et al.*, 2016).

For the food subsector and metal fabrication, when production starts, Sichone said (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. He also told us that ZESCO would not always keep to its load-shedding schedules.

Running along the theme of discerning the impact of power outages on different customers, Allcott et al (2015) suggested that offering interruptible electricity contracts at a discount could substantially reduce the impact of shortages. This bottom-up approach, rather like the purchase of generators, would allow for customers to determine for themselves their value of reliable electricity. Unlike Chen and Vella's suggestion, which aspires for a central decision-making body to figure out how to maximise social economic benefit (Chen and Vella, 1994, p. 1067), it relies on the "invisible hand" to figure out how to reduce the costs of shortages – if not achieve the socially optimal result.

Peak versus off-peak tariffs

Pasha et al found that 28% of firms surveyed not operating 24 hours per 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 (Pasha, Ghaus and Malik, 1989). Pasha et al also suggested seasonal variation in the level of tariffs generally, because hydropower dependent Pakistan in 1989, like Zambia today, saw a difference in the incidence of outages between winter and the early summer months (Pasha, Ghaus and Malik, 1989).

Duration of outages

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).

Coping mechanisms used by manufacturing firms to mitigate against power outages

The literature identifies myriad ways in which firms can respond to unreliable electric supply:

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 (2015) 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.

Use of backup generators to calculate observed floors for marginal costs of power outages

To avoid the problem of subjectivity associated with micro studies discussed above, observations can be used to ascertain the marginal cost of power outages.

Bental and Ravid (1982) and others subsequently, such as Adenikinju (2003) and Steinbuks and Foster (Steinbuks and Foster, 2010) argued that because acquiring backup generation is not costless (Adenikinju, 2003), the formulation of marginal cost of outages should include in addition to the variable cost the capital expenditure of purchasing a given capacity, divided by the hours of use in a year. This, it is submitted, is an incorrect formulation. Marginal cost is the cost of added by producing one additional unit of a product or service. The acquisition of backup generation is only relevant at the time of acquisition, and is thereafter a sunk cost. For this reason, the time of acquisition of generators would be interesting to know for Zambia, as it would inform when power outages were bad enough to justify the capital expense of a backup generator, an apparent gap in the literature.

Farquharson et al (2018) took the correct approach to calculating the marginal cost of backup generation, although they called it 'premium cost', and they likely calculated the wrong value as a result of using the wrong input value. They calculated that consumers in Zambia pay a cost premium for backup generation of USD 0.53/kWh. They calculated this as the difference between diesel backup generation and the price of grid electricity. This is the correct formulation of marginal cost – the additive cost, necessarily considering the cost of electricity that would have otherwise been paid. However, Farquharson et al base their calculation on a 2014 cost of USD 0.59/kWh for diesel generation exclusive of capital expenditure, operating and maintenance expenses, which is far higher than what would have been expected. Steinbuks and Foster found that the average variable cost of self-generated electricity in Zambia was USD 0.27/kWh in 2010 (Steinbuks and Foster, 2010), personal experience negotiating power purchase agreements in Rwanda suggested that the cost was circa USD 0.29-0.34/kWh (personal experience in Rwanda, 2012-16).

Predictors of possession of generators

Sichone's research (remarked on above) suggests that certain subsectors are more impacted than others because of their greater dependence on energy and vulnerability to power outages. Based on this, the subsector of manufacturing that a firm falls into could be a predictor of whether it owns a generator.

Steinbuks and Foster (2010) investigated what drives firms to generate their own power using data from the World Bank's Enterprise Survey Database comprising 8,483 operating firms sampled between 2002-2006 across 25 African countries, including Zambia. Using the binary choice model of Reinikka and Svensson (2002), they looked at the probability that firms invested in generators by firm characteristics, using the probit method. They found that the probability of finding a generator on the premises increases by nearly 50% as one moves from firms employing less than 10 employees to firms employing over 500 employees; and that the probability of having a generator remains high even where power supply is reliable. They found statistically significant relationships for several firm characteristics: days of power outages, size in terms of employees, age, export orientation and sector. The following is a rank of magnitude of coefficient for statistically significant sector variables for most likely to own a generator: hotels and restaurants, food and beverages, chemicals and pharmaceutics, non-metallic and plastic materials, metals and machinery, wood and furniture – mining did not have a statistically significant coefficient. For all the 8,483 observations that Steinbuks and Foster had to draw broad trends for 'Africa' from disparate countries ranging from middle income countries such as Egypt, Algeria and Mauritius to lower middle income countries such as Zambia to least developing countries such as Burundi and Mauritania, the pseudo R-squared of their regression model was only 26%.

Oseni and Pollitt (2015) also attempted to identify predictors of firms' decision to invest in self-generation. Their pseudo-R-squared was only slightly higher, at 34%, using 2,665 observations from 2012 World Bank Enterprise Survey data. Unlike Steinbuks and Foster, they did not find either days of power outages or age to be statistically significant predictors even at the 10% level. They did find size in terms of employment and various sectors to be statistically significant. In terms of statistically significant sectors, they ranked as follows in terms of magnitude of coefficient: other services, food and beverages, electronics, chemical and pharmaceuticals, non-metals, retail, garment and textiles. Besides adding electricity consumption to their model that Steinbuks and Fuchs did not (and hence had a lower R-squared), they also added countries, further contributing to their R-squared. With their data coming from a dataset that was published in 2012, they found that Zambia had a statistically significant result at the 5% level, but with a negative coefficient, meaning that as of 2012, one would predict that Zambian firms were generally not equipped with generators.

Extent of use of backup generation

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 backup facilities purchased by the firm. Steinbuks and Foster (2010) also casually observed that the capital cost of generators tends to be higher in countries with more reliable energy.

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 (Sichone *et al.*, 2016). This implies that self-generation does not fully cover loss in energy.

Oseni and Pollitt posited and then showed that a firm that has invested in backup generation may still suffer a higher unmitigated outage loss relative to a non-backup firm if its operations are more vulnerable to power outages and its investment in self-generation capacity is not large enough to significantly reduce the potential outage loss (Oseni and Pollitt, 2015).

To test this theory on 2012 data collected by the World Bank with outage losses as the dependent variable, rather than using a pooled regression for firms that had generators and those that did not, Oseni and Pollitt ran separate regressions to account for the possibility that the generator variable may interact with other explanatory variables. The adjusted R-squares using this approach for the outage loss given backup generation or given no backup generation was 42% and 52% respectively for 1,648 and 1,017 observations across Africa.

A remarkable result that comes out of their regressions is that firms with backup generation were slightly more (4% more) vulnerable to outage losses than firms without backup generation capacity when the electricity consumption of the firm is greater.[43] This could possibly mean that there are two types of large consumers of energy: those that need to mitigate the losses with backup generation but

[43] For the other non-country statistically significant variables for both firms that had generators and firms that did not have generators – days of power outages, employment, the chemical and pharmaceuticals subsector at the 10% level of significance – the outage losses were smaller for firms with generators than those without.

cannot afford to mitigate the loss entirely, and there are those for which the costs of backup generation do not equal the marginal benefit of self-generation. This may reflect the differences in the energy intensity of the two types of firms' operations, as Oseni and Pollitt note (2015).

An alternative explanation for this result could be that the underlying data is unsafe: it comes from questions asking the value and percentage of losses due to power outages. Responses could have been affected by the biases discussed above such as protests or loss aversion. The implication would be that respondents at firms with generators would protest more about their losses or feel their unmitigated losses even more than respondents at firms without generators. However, given that for the other non-country statistically significant variables the costs of outages were smaller for firms with generators than those without, this is unlikely to be the case. This was the expected result, and Oseni and Pollitt found that despite the substantial amounts of unmitigated outage losses suffered by firms with generators, their counterfactual estimates showed that firms engaging in self-generation were better off than if they did not invest in self-generation (Oseni and Pollitt, 2015).[44] In fact, their results showed that the actual unmitigated outage loss per kWh was considerably higher for backup firms than for non-backup firms in countries with frequent power outages.

In spite of the existing commentary on backup generation failing to fully make up for lost energy, research published as recently as 2018 in a *Nature* publication used the assumption that firms with generators used them to mitigate all outage losses (Farquharson, Jaramillo and Samaras, 2018).

The impact of power outages in Zambia prior to 2015

Before 2015, Zambia's power capacity theoretically should have allowed electricity supply to exceed industrial and mining demand, but news reports and multilateral surveys suggest that poor maintenance and corruption were responsible for power outages nonetheless.

While Zambia's electricity was amongst the cheapest in the world (Jourdan, 1990, p. 182), an accountant assigned to a consulting project in Zambia 1992 and 1993 recalls (email from Michael Mainelli dated 17 February 2019 see annex 3.6.4) that power quality was an issue in Zambia for private investors even then. 'One of the points we failed to get the government to take seriously enough,' he writes,

> was that variability in the electricity supply was leading to production problems and thus variability in the output. In turn, these production problems were impeding the sales potential for Zambian copper as buyers were concerned about irregularity of supply. Clearly Zambia had significant hydropower production potential, but it was often out of action, or diverted elsewhere for political purposes […] A small feedback problem related to this was that because Zambia's intermittent supply caused sub-optimal contracts, it in turn caused significant [foreign exchange] problems in turn, a second-order effect.

An example of a reason for the power stations being out of action was in 1989 when there was a fire at the Kafue station (Jourdan, 1990, p. 182). Power outages continued to be reported in the 2000s and mining companies (both open pit and underground mines) responded by installing diesel generators to make up for the shortfall of delivered grid electricity to prevent ZESCO power outages from resulting in loss of production (Mfula, 2010b, 2010a; Steel News, 2011; Syndigate, 2011), although underground mines are more electricity intense (Tembo, 2018, p. 41).

[44] They calculated the outage loss per kWh unsupplied assuming that a firm would have consumed the same amount of electricity per hour during outages as they did during uninterrupted hours, and assumed firms operated 12 hours per day.

Although mining is by far the largest of Zambia's electricity users, its energy consumption patterns do not appear to be diverse. Most of Zambia's mining is for copper, and 80% of Zambia's copper comes from just four mines (Zambia Chamber of Mines, 2016). [45] Line 3 of Table 7 shows that for each of 2013, 2016, 2017 and 2018, the mining grid electricity consumption in gigawatt hours per copper production in thousands of tonnes ratio was the same to two significant figures, 7.8.

Table 7 Zambian copper mining production 2013-2018e

Imputing diesel-generated electricity by the mining sector

Line	Year	2013	2014	2015	2016	2017	2018
1	Mining grid electrcity consumption, GWh	5,929	5,871	6,246	5,918	6,202	6,682
2	Copper (Cu) production, '000s tonnes	760	708	712	763	794	854
3	Grid electricity/Cu produced, GWh/'000 tonnes	7.8	8.3	8.8	7.8	7.8	7.8
4	Median average electricity/Cu producted, GWh/'000 tonnes	7.8					
5	Predicted grid electricity consumption given Cu produced, GWh	5,941	5,535	5,566	5,965	6,207	6,676
6	Variance where predicted grid electricity consumption > actual grid electricity consumed, GWh	12			47	5	

Sources: Energy Regulation Board of Zambia, 2015, p. 8, 2016, p. 0, 2017, p. 9, 2018, p. 36, 2019, p. 39 and U.S. Geological Survey, 2015, 2016, 2017, 2018, 2019, 2020 and own computations

Using this ratio, we can calculate how much grid electricity consumption mining would have required where we have the copper output figures in Line 5 of Table 7. Where this calculated figure exceeds the Energy Regulation Board's reported figure of energy consumption by the mining sector, the difference is what we can estimate as the amount of energy mining companies self-generated, so 12 GWh in 2013, 47 GWh in 2016 and 5 GWh in 2017. Note that the prediction shows that in 2015, they did not have to self-generate. The mining sector was somewhat more insulated in the beginning (ZESCO Ltd, 2017a). Indeed, in 2015, mining's share of ZESCO energy grew from 47% in 2014 to 55%. But then ZESCO requested the mining sector to reduce its load by 30% (Energy Regulation Board of Zambia, 2016, p. 1), and mining consumption data of ZESCO energy indicate that the period of worst load shedding for the mining sector was from December 2015 to November 2016.

In spite of that, Zambia's copper mining production did not fall either from 2014 to 2015 nor from 2015 to 2016 (U.S. Geological Survey, 2015, 2016, 2017, 2018, 2019), but instead grew in 2016 to its 4 year peak (see Table 7 above). That copper production grew in spite of heavy power outages of December 2015 to November 2016 implies that it was still economic to extract copper and supports Tembo's findings that the key decision variables for Zambia's mining sector are copper price, grade and type of ore, and not energy price (Tembo, 2018). Given that 60% of Zambia's mines are open pit (Tembo, 2018, p. 50) and less electricity intense, it is probable that the proportion of production from less electricity-intense open pit mines increased.

Moving on to manufacturing, Steinbuks and Foster (2010) provide one of the earlier studies on the impact of power outages on Zambia's manufacturing sector using the World Bank's Enterprise Survey data collected from 2002 to 2006. Providing their assumed cost of self-generating electricity (variable and capital charge for generators) and the grid-cost of electricity, they provided their output average cost of energy. Working their calculation backwards (Steinbuks and Foster, 2010, table 2),[46] we find that Zambian manufacturing firms experienced 5% of their operating hours.

[45] Copper and copper products accounted for 92% of Zambia's exported metals by value in 2018 and 72% of all exports (World Bank, 2020t). The Lumwana and Kansanshi mines are open pit (Barrick Gold Corporation, 2019; First Quantum Minerals Ltd, 2019), whereas Mopani and Konkola Copper are a mix of underground and open pit mines (Konkola Copper Mines Plc, 2019; ZCCM Investment Holdings Plc, 2019).

[46] Using the Goal Seek function in MS Excel for USD 0.45/kWh * x% of the time + USD 0.04/kWh * (1-x%) of the time = USD 0.06/kWh

They also found that firms experienced a 7.3x difference in losses between having a generator and not having a generator (Steinbuks and Foster, 2010, table 3). The value they used to ascribed to having a generator was the capital and variable cost of a generator. The weakness associated with how they calculated the capital cost has been discussed above. The value they ascribed to not having a generator was the average loss of sales over the course of an hour. The weaknesses with this are that manufacturing is a heterogeneous sector, with diverse subsectors, and that firms tend to overstate their losses, as noted above. Nonetheless, because power outages occurred with such infrequency, they found that the costs of having a generator exceeded the benefits (Steinbuks and Foster, 2010, table 5a), and that only 38% of firms owned generators (Steinbuks and Foster, 2010, table 1).

Further research by Sichone et al, discussed above, used the World Bank's Enterprise Surveys of 2013. The critical juncture came in 2015, however, as Figure 1 illustrates, when power outages resulted systematically and frequently from severe droughts, causing growth of manufacturing to decline The drop in growth of the manufacturing was followed by a steep decline in net inflows of foreign direct investment in 2016, as illustrated in
Figure 8 above.

The impact of the 2015 and 2016 power outages in Zambia

Headline statistics suggest that the power outages of 2015 and 2016 adversely affected manufacturing firms, and annual reports from listed companies confirm this impression. Between the power outages of 2015 and 2016, Zambian manufacturing's share of electricity consumption fell from third biggest sectoral consumer to fourth biggest sectoral consumer behind finance and property (see Table 1), and manufacturing value-added growth fell (Figure 1). Table 8 below shows how the annual reports of eight listed Zambian manufacturing firms reported the impact of power outages on their operations. Six out of seven firms whose annual reports for 2016 were obtained mentioned the power outages, and of them, four mentioned them in the context of adversely affecting firm performance or production processes.

The power outages seem to have affected firms differently depending on their subsector. Cement manufacturer LaFarge experienced reduced revenues and profits year on year from 2014 to 2016, attributing the decline in performance to power shortages which adversely impacted production. In contrast, Zambia Sugar Plc saw increased revenues year on year from 2014 to 2016. Because Zambia Sugar Plc was sourcing energy from the fibrous residue remaining after the extraction of sucrose from sugar cane, it was not heavily dependent on ZESCO for energy: ZESCO energy was a supplementary source during the factory off-crop maintenance period when the factory was not operational (Zambia Sugar, 2017, p. 15). The impact of power outages for this agricultural firm, therefore, were negative primarily through the lack of irrigation, rather than through the impact on the firm's operating factory.

Table 8 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 (National Breweries, 2018)			IP IE
Analysis			
Power outages mentioned	5/7	6/7	
Power outages mentioned as adversely affecting firm performance or production processes (PF, PP)	3/7	4/7	
Improvement in on-grid power mentioned			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' (Lafarge Zambia, 2016).
- 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' (Zambia Bata, 2017).

While power shortages were one key feature of 2015 and 2016 that adversely affected their operations, the annual reports for the food processing companies also mentioned 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). There were other factors besides power outages that were contributing to the fall of manufacturing value-added.

For a further idea of how the power outages impacted businesses in Zambia in 2015 and 2016, we need to broaden our review of the literature to research carried out by Mwila et al (2017) who surveyed the impact of power outages on micro, small and medium sized businesses, which focused mainly on services since the percentage of the MSME population engaged in manufacturing was only 9.3% (Mwila *et al.*, 2017, fig. 21).[47] Similarly, 93% of Batidzirai et al (2018)'s sample was micro and small enterprises. The one finding they found germane to large-scale manufacturing was that a manufacturing firm with 400 employees was willing to pay ZMK 0.32 more for reliable electricity, although whether this was per kWh is not clear (Batidzirai, Moyo and Kapembwa, 2018, p. 18). They also found that overall manufacturing firms were more willing to pay for reliable electricity services than other sectors, followed by financial services.

Small businesses were less resilient than larger firms because of limited resources to invest in alternative energy sources and most lacked insurance (Mwila *et al.*, 2017, p. v).

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

- Electricity featured as the most popularly reported 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 whereas the latter also included the mining sector. 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

[47] According to the MSME policy of the Ministry of Commerce, Trade and Industry (Zambia Development Agency, 2019), micro, small and medium enterprises are those registered with the Patents and Companies Registration Agency (PACRA) with the following characteristics (Kwacha converted to USD at a rate of 13 per USD as of 27 September, 2019):

Category	Micro enterprise	Small enterprise	Medium enterprise
Investment in equipment, $	77-6,153	6,154-15,384	15,385-38,461
Annual sales, $	77-11,538	11,539-23,076	23,077-61,538
Workers	≤ 10	11-50	51-100

Mwila et al estimated 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 involved in trade (2017, p. vi). Of MSMEs falling within the manufacturing sector, they only contributed to 1.5% the manufacturing sector's contribution to GDP (Ministry of Commerce Trade and Industry, 2014, p. x), even though small and medium businesses accounted for 56% of the manufacturing sector population in 2011-12 (Ministry of Commerce Trade and Industry, 2014, p. x).

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.

- In terms of average load-shedding hours per day, Lusaka was hit the worst (2017, p. 24), but in terms of the cost per kilowatt hour cost, Kitwe was had the highest loss (2017, p. viii);
- 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 (p. 28). 8% of firms reported reducing on labour hours (p. 36);
- Load shedding resulted in purchases and hiring costs for alternative energy sources (p. 31). Among the surviving firms that were interviewed, 42% reported to have used generators in 2015 (p. 33), whereas just 2% reported having used a UPS (p. 34) and just 2% reported having used surge protectors (p. 34);
- Only 0.2% of businesses reported moving (p. 32). However, the total number that did was 21 businesses, all in Lusaka (p. 37).
- 7% of businesses reported switching working hours (p. 38). The report also says that no businesses reported shutting down their operations (p. 37), but this result would be heavily affected by survival bias;
- 7% of small and medium sized businesses reported backing up data systems (p. 34);
- 7% of sampled firms used enhanced security (p. 35), while 21% of firms reported facing theft during load shedding (p. 39).

Batidzirai et al (2018) surveyed 224 mostly micro and small enterprises (this constituted 93% of their sample, pp. 8, 14) on their willingness to pay a higher electricity tariff for reliable service. They 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).

They found that hotels, restaurants and businesses paying a commercial tariff (i.e. other service-sector companies) as well as operating hours per day were statistically significant independent variables in a regression where willingness to pay more was the dependent variable (Batidzirai, Moyo and Kapembwa, 2018, p. 23). Variables that did not seem to have an impact were the number of years a firm 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 Batidzirai et al's findings were relevant even at the time of publication.

Table 9 ZESCO revised its tariffs twice upwards in 2017

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

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

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

While finance and property seem to have fared better through the power outages of 2015 and 2016 than manufacturing firms as suggested by their increase in share of energy consumption, the services sector in general and SMEs did rank power outages as the most popular constraint to their operations.

The impact of power outages on the climate

Beyond looking at the impact of power outages on ZESCO's largest customers, it is relevant to consider their climate impact, since global warming is what caused the power outages in the first place. Farquharson et al (Farquharson, Jaramillo and Samaras, 2018) based their top-down analysis of generator emissions for Zambia, at least, using out of date because that was collected by the World Bank from December 2012-February 2014 (World Bank and International Finance Corporation, 2014), i.e. before the power outages of 2015 and 2016 and before, as the next chapter shows, most manufacturing firms purchased their first diesel generators.

For Zambia, they estimated that a typical month saw 5.2 outages for an average of 2.8 months; that the installed grid capacity was 2.3 GW and that generator availability was 3% of the grid. This would imply that they estimated that generators on average produced 1 GWh of energy in a month, the equivalent of 3.6TJ, resulting in just 74 tonnes of CO_2 in a month.

Their analysis also ignored the possibility that backup generation capacity may not be used at all times of power outages.

In the absence of data for load lost and replaced by backup generation (even proportion of generator ownership), Farquharson et al used Monte Carlo Analysis in which the load replaced during outages was bounded by a distribution of backup capacity available. This was judged as 1-25% in the case of Zambia. Explanation was not provided for why 1%. The upper bound was the maximum observed regional value as a percentage of grid capacity. The region used for Zambia is not provided, nor the source of the value 25%. Farquharson claim that the mode was the current estimate of the installed backup capacity 3%, but do not explain mode of what. That their estimate in 2018 is therefore made using outdated data and that their calculations lack transparency leaves the impression that their findings on the estimated annual electricity replaced by diesel backup generators, and subsequent findings reliant on that estimate, are frail.

Addressing this issue with a top-down estimate, Ahmed et al took a bottom-up sectoral approach to estimate the emission from backup diesel generator use by ZESCO, the mining sector, manufacturing sector and households. They estimated the emissions from power diesel generation use by ZESCO using the Energy Regulation Board's reports of diesel generation use. They estimated diesel generation for the relatively homogenous mining sector using secondary data on mining output, data on grid-electricity consumed and assuming a constant ratio of electricity intensity for output to impute electricity that would have been generated by backup diesel generators. They estimated diesel generation use for manufacturing firms and households using primary collected survey data. In the months of worst outages for 2019, they estimated emissions to be north of 27,000 tonnes of carbon dioxide per month (Ahmed *et al.*, 2020). This represents about 10% of Zambia's total greenhouse gas emissions in 2012 (World Bank, 2020t).

Ahmed et al's estimate is not of the same order of magnitude of Farquharson et al's estimate. To triangulate their results, they took 2018 as a base year of electricity consumption, since 2018 was not according to their household survey a bad year for power outages. Given that in the worst months of 2019, outages were lasting 15 hours, they estimated that if mining, industry and households generated 15% of grid capacity that they would have consumed in 2018, CO_2 emissions would have been 22,000 tonnes, so of the same order of magnitude as their bottom-up estimate.

Beyond estimating the volume of the greenhouse gas CO_2 emitted by diesel backup generators, Farquharson et al also estimated the generated volume fine particulate matter, carbon monoxide, sulphur oxides and nitrogen oxides. Less important than the estimates that they calculated (founded on frail assumptions) is the attention that they brought to the fact that diesel backup generators increase greenhouse gases in the atmosphere and adversely impact health.

Gaps in the literature

Several gaps have been identified in the literature relating to the impact of power outages. These inform the objectives of this research emanating from primary data collection in the next chapter.

Research has been conducted on the impact of power outages on Zambia's large manufacturing firms. However, since these contribute to 98.5% of the manufacturing sector's contribution to GDP (Ministry of Commerce Trade and Industry, 2014, p. x) and since industrialisation has historically been the catalyst for economic development, the gaps in this domain of literature merit a closer examination.

Research has been conducted by Batidzirai et al (2018) on firms' willingness to pay for more reliable energy in Zambia, but this seems to be out of date and also was not addressed to large manufacturing firms. There is therefore a gap for knowing the willingness of large Zambian manufacturing firms to pay a premium on the latest tariff revisions of 1 September 2017. Framing the question as willingness to pay for reliable energy overcomes the loss aversion bias, but not necessarily the bias induced from protests, nor from miscalculations by respondents. In addition to this, it would be useful to know what types of manufacturing firms by subsector would be willing to pay higher prices for reliable electricity.

The literature seems to have neglected an analysis of whether managing Zambia's peak versus off-peak demand could alleviate the cause of power shortages during times of peak demand. An investigation therefore of firms' peak versus off-peak energy consumption is warranted, together with a look at how consumption is tariffed at these various times.

In light of the two tariff increases in 2017, data collected on energy consumption can be used to figure out elasticity of demand for energy for Zambia's manufacturing firms.

A hypothesis that can be tested is whether most firms bought their first generators in the years of the worst outages.

Studies as recent as 2018 (Farquharson, Jaramillo and Samaras, 2018) assessing the use of backup generation as a coping mechanism seem to assume two things: i. that they are used 100% of the time that there are power outages and ii. that the generators are capable of replacing 100% of the capacity lost. While research shows that there are unmitigated losses for firms that use self-generate energy (Oseni and Pollitt, 2015; Sichone *et al.*, 2016), it would be worth explicitly demonstrating that firms with backup generation do not fulfil one, the other or both assumptions. The reason for them not fulfilling either of these assumptions could be for a number of reasons:

- Factors such as fuel costs and constraints on working capital may limit the extent to which firms are able to use their backup generators;
- The marginal revenues earned from certain activities using energy may not be worth the marginal cost of running the backup generators, and so capacity may not have been installed to support those activities;[48]
- Availability of credit may also constrain the purchase of an adequate capacity of backup generation;
- It may be thought that power outages are not going to be a frequent enough occurrence to justify the large capital outlay to mitigate against their occurrence in the first place.

A step can be taken beyond Steinbuks and Fuchs' (2010) investigation into the predictors of whether or not firms had generators on their premises, by looking into the predictors of the extent to which backup generation is used. Answering the question whether firms that own generators use them, and if so, what costs these help abate, will also help address three further questions – i. are the losses to firms using backup generation underestimated, ii. are the emissions that Farquharson et al calculated overestimated, and iii. were the import waivers on generators in 2008 justified?

It is not clear that the literature acknowledges the correct working definition of marginal cost of using backup generation. This needs to be rectified.

This thesis also investigates several dimensions that have not previously been addressed in the literature:

- the months that Zambia's manufacturing firms identified as the worst in which they experienced power outages;
- ranking the different costs of outages on a scale of 0-4;
- ranking the use of coping strategies on a scale of 0-4;
- finding correlations between the score of coping strategies with the score for particular costs of outages to learn what coping mechanisms may be effective;

[48] Oseni and Pollitt have expressed this slightly differently: the marginal productivity of a backup generator (i.e. the marginal reduction in the potential outage loss) must be greater than or equal to the user cost of self-generation (Oseni and Pollitt, 2015).

- finding correlations between firm characteristics and the score for costs of power outages experienced as well as the score for the extent to which different coping mechanisms were used.

This chapter reviewed the literature for how power outages have impacted economies and Zambia's in particular. It has reviewed how power outages impact different sectors of consumers, in particular large manufacturing firms, industrialised economies' vehicles for increased productivity and economic growth. It has reviewed different methodologies. It has identified significant gaps in the literature. The next section offers a methodology for how to fill the gaps.

4. Primary data collection methodology to address gaps in the literature

The previous chapter critically evaluated and identified the gaps in the literature for how power outages affect various segments of the economy. Building on that work, this chapter will define the objectives of, theoretical approaches to and propose methodologies for how to collect primary data to address those gaps in the literature. It will conclude with an evaluation of the success of sampling achieved by the primary data collection executed.

Quantitative data collected through the surveys will be analysed using descriptive statistics and appropriate regression analyses in chapters 6, 8 and 10. Qualitative data collected through unstructured interviews with key informants have been cited in the preceding and concluding chapters. The interviews have been included in the annexes with permissions granted by the interviewees whom have been named.

Primary data collection objectives and theoretical approaches

Given the gaps identified above as well as the research's orientation in helping Zambia industrialise, the objectives of this research using primary data collection seek to fill these insofar as they relate to the impact of power outages on Zambia's manufacturing sector. These objectives are:

1. Ranking the costs of power outages;
2. Ranking the use of coping strategies;
3. Seeing how the costs of power outages differ for firms using certain coping strategies against those not using those strategies;
4. Identifying firm characteristics that can be used to predict different coping strategies;
5. Testing the assumption that firms with generators substitute on-grid power perfectly with backup generation:
    a. Figuring out whether firms with generators have enough capacity to cover all their operations as normal;
    b. Figuring out the extent to which firms with generators use them when facing power outages;
6. Discovering manufacturing firms' willingness to pay for a premium service for reliable energy in Zambia on top of the tariffs as of 1 September, 2017;
7. Assessing how firms' energy consumption changed after the two tariff hikes of 2017;
8. Analysis of Zambian manufacturing firms' consumption of energy during peak versus off-peak hours;
9. Discovering which months are as identified as the worst for power outages;
10. Testing the hypothesis that 2015 and 2016 were the years of worst outages in the last 5 years;
11. Testing the hypothesis that most firms bought their first generators in the years of worst outages;
12. Identifying the characteristics associated with the extent to which backup generation is used;
13. Given 3, 4 and 12, figuring out whether the import waiver on generators of 2008 was justified;
14. Using 12, where data is lacking for generator use in 2016, extrapolating what the fuel usage in generators would be in years of low rainfall in Zambia and where supply for energy exceeds demand;
15. Using 14, extrapolating the emissions from backup generation in years of low rainfall and where supply for energy exceeds demand;
16. Correctly working out Zambian firms' marginal cost of using backup generation.

The literature in the domain of impact of power outages on Zambia's residential sector is wide open. The primary objective of this research is to understand the impact of power outages on the environment that come from the use of backup diesel generation in households with internet connections.[49] The secondary objectives are:

1. Ranking the costs of power outages;
2. Ranking the use of coping strategies;
3. Seeing how the costs of power outages differ for households using certain coping strategies against those not using those strategies;
4. Identifying household characteristics that can be used to predict different coping strategies;
5. Discovering households' maximum willingness to pay for reliable energy;
6. Understanding how households rank the years 2014-2018 for power outages.

The analysis is founded on four theoretical approaches to assess the impact of power outages on Zambia's manufacturing and residential sectors and to assess diesel generator emissions.

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

ii. by observing extent of use of self-generation. 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). Marginal cost has to therefore be greater than the cost of self-generated energy less the cost of energy 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 electricity consumers lack the capital to purchase self-generation capacity or working capital to finance self-generation;

iii. 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.

B. 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 client losses. Oseni and Pollitt (2015) noted that ownership of a generator may interact with other variables, so while doing this analysis, the results for firms with certain interventions should not be pooled with those without.

C. The third is a double-hurdle approach that will examine whether there are significant differences between predictors of backup generation ownership, a capital expenditure decision, and of use, an operational expense decision. This builds on the work of Steinbuks and Foster (2010) who looked at the predictors of generator ownership and 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.

D. A ground-up approach to estimating total fuel consumption by the manufacturing and residential sectors for the purpose of estimating emissions. Based on data collected on fuel consumption, and where this is lacking, extrapolation from other data collected that indicates capacity of installed backup generation and extent of generation used, a more accurate picture of emissions from backup generation can be drawn than by assuming, as Farquharson et al have (2018), that firms with backup generation capacity fully mitigate their power outages.

[49] The assumption is that people who cannot afford internet on their phones cannot afford diesel generators.

Research design

Research design for the manufacturing survey

Primary data was collected using a structured survey questionnaire (the last iteration of which is included as Annex 2a). 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.

Sampling frame for the manufacturing sector

To get representative results for Zambia's manufacturing sector, it was necessary to sample Zambia's population of large manufacturing firms as representatively as possible. Sampling was therefore done on a stratified basis by subsector according to the Zambian Ministry of Commerce Trade and Industry's categorisations and, to the extent feasible, by geography.

As of 2014, 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 therefore made sense to concentrate limited surveying resources in these two provinces which together accounted for 84% of large manufacturing firms.[50] See Annex 2b for the geographic and sub-sectoral breakdown of large Zambian manufacturing firms.

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).[51] However, the universe of interest (i.e. the population from which the sample was taken) was the 196 large manufacturing firms in Lusaka Province and 133 large manufacturing firms in the Copperbelt Province.

To get the names and contact information of manufacturing firms in Lusaka Province and the Copperbelt Region, two lists were used, obtained by the Research Field Manager from the Zambia

[50] The research grant from the International Growth Centre for the project was £58,000 inclusive of flights to and from Zambia to scope, pilot surveys and train enumerators, and present findings. It was less when one accounts for the wasted expenses on the first trip by three researchers who produced no written output of value.

[51] This is likely because some manufacturing firms did not meet the minimum demand thresholds that ZESCO defined for manufacturing tariffs.

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 the focus was on large manufacturing firms, this self-selection was appropriate for the purpose of the sampling attempted. 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.

Execution of the data collection

Results were collected for 123 respondents – mostly large firms (which we gauged by the number of people they employed, their revenues or the nature of their business activity).

On a geographical basis, the aim was to have 59% of the sample come from Lusaka and the remaining from the Copperbelt (since 50% of large manufacturing firms are in Lusaka and 84% of large firms are in both Lusaka and the Copperbelt; 50/84.1 = 59%). In fact, 71% of the sample came from Lusaka, representing an overweight for Lusaka, even though the time enumerators in the Copperbelt were deployed was longer than the time they were deployed in Lusaka. The enumerators seemed to hit a limit as to how many firms they could interview in those two towns. This may or may not have been the result of fewer firms in the Copperbelt, particularly in Kitwe, surviving power outages.[52] The number of surveys in Ndola and Kitwe, the two major towns in the Copperbelt, was almost equal. Only one interview came from the seven manufacturing firms in the LSMFEZ and only one firm in Kafue, in Lusaka Province.

On a subsector basis, no subsector was over or underrepresented by more than 9%.

Table 10 Sampling achieved by subsector vs national population of large manufacturing firms by subsector

Large manufacturing firms by subsector and province

Subsector	Lusaka & Copperbelt	Central	Eastern	Luapula	Muchinga	Northern	NW	Southern	Western	Total	National	Achieved sample	Delta
Food and food products	96	7	6	2	1	7	3	15	2	139	36%	39%	-3%
Textiles and garments	15	0	2	0	0	0	0	1	0	18	5%	9%	-4%
Wood and wood products	21	0	0	0	0	0	1	2	1	25	6%	3%	3%
Chemicals	48	2	0	0	0	0	0	1	0	51	13%	16%	-3%
Plastics and rubber	25	1	0	0	0	0	0	0	0	26	7%	16%	-9%
Non-metallic mineral products	30	1	0	0	0	0	0	0	0	31	8%	1%	7%
Basic metals	19	2	0	0	0	0	0	1	0	22	6%	8%	-2%
Fabricated metal products	27	2	0	0	0	0	0	0	0	29	7%	12%	-5%
Machinery and equipment	28	0	0	0	0	0	2	0	0	30	8%	1%	7%
Electronics	10	0	0	0	0	0	0	0	0	10	3%	0%	3%
Other manufacturing	10	0	0	0	0	0	0	0	0	10	3%	0%	3%
Total	**329**	**15**	**8**	**2**	**1**	**7**	**6**	**20**	**3**	**391**			

See Annex 2c for details on how the team was built and incentivised, iterations for the manufacturing survey and challenges and how these were overcome.

Weaknesses of the manufacturing survey

The first firm visited as a 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 possible that the same people who responded to our

[52] Kitwe seemed the hardest hit town of Lusaka, Ndola and Kitwe by power outages both according to Mwila et al (Mwila *et al.*, 2017) and according to the collected data. The Ministry of Trade and Industry's information may therefore have been more out of date for Kitwe than for other towns insofar as more firms may have gone out of business there because of the power outages.

questions could have responded differently on different days, in different seasons. This also highlights the weakness of prior research dependent on the World Bank's enterprise survey data.

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

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.

A further weakness with the surveys was their susceptibility to the honesty of the enumerators. Dishonesty in terms of fabricated surveys was largely kept to a minimum by having the Field Manager write a thank you email as a follow-up to enumerators' visits. This follow-up was missed in the last few weeks, and based on two sets of data analysis, it became apparent that one of the enumerators was likely dishonest. First, she was found to be a statistically significant variable for whether firms were willing to pay more for reliable energy, at the 1% level. Second, the bounce-back ratio of her respondents' email addresses after the initial results were shared in a working paper (Ahmed, Baddeley, D. M. Coffman, *et al.*, 2019) was much higher than her counterparts'. For this reason, all of Enumerator A's surveys were expunged from the data since the publication of the working paper.

Table 11 Clue 1: Enumerator A was a statistically significant predictor of whether firms would report that they would be willing to pay

VARIABLES	(1) WTP
Exports	0.903**
	(0.395)
Enumerator A	1.761***
	(0.555)
food & bev	0.370
	(0.416)
basic metals	0.450
	(0.777)
constant	-1.577***
	(0.355)
Pseudo R2	11%
Observations	140

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

Table 12 Clue 2: Enumerator A's respondents' emails bounced back far more frequently than her colleagues'

	Beauty	Johanna	Tapiwa	Nandi	Mundia	Enumerator A	w/o A
successful contacts after 1y	8	31	27	12	5	9	83
contacts provided	12	37	35	16	6	20	106
% successful contact after 1y	67%	84%	77%	75%	83%	45%	78%

Triangulation and contextualisation: conversations with key informants

In addition to the primary data collection, unstructured interviews were held with the key informants listed in Annex 2e to help triangulate survey findings and improve understanding of the context of Zambia's outages.

This chapter set the objectives of primary data collection in addressing the literature's gaps on the impact of power outages, the design of processes to collect the required data, and an evaluation of the execution of the surveys to collect data. The next chapters present and interpret the mostly quantitative results of the primary data collected through descriptive statistics and regression analysis.

5. Results of the manufacturing surveys, interpretations and discussions

The greatest costs of power outages are extra staff payments, damage to equipment and damage to reputation. Firms that use generators evidently experience a marginal cost of greater than USD 0.25/kWh of grid-energy loss. The most popular interventions to mitigating damages are the use of surge protectors, voltage regulators, capacitors, delaying production and using diesel generators. Following the frequent and severe power outages of 2015 and 2016, most Zambian manufacturing firms purchased generators for the first time. The use of diesel generators are associated with reduced delay in meeting customer orders. Delays are associated with a loss in clients. Predictors of the installed capacity of generators are different from predictors of the extent to which they are used. Whereas firm size in employees predicts generator capacity, subsector and perhaps other factors such as whether a firm exports or is foreign-owned predict the extent of self-reported use. The data suggest that basic metals firms purchase generator capacity but might not have the working capital required to run them to the extent that they would like. ZESCO's several tariff hikes in 2017 had no apparent effect on electricity consumption by firms, the largest consumers of which were paying the lowest tariffs. Low tariffs may in fact be more uneconomical for firms if they result in greater power losses due to lack of funds for additional power generation infrastructure. The (minimal) difference between peak and off-peak tariffs seemed not to be having an effect on consumption. A quarter of firms did not receive reliable or any communication from ZESCO, resulting in distrust and unwillingness to commit to paying higher tariffs for apparently more reliable electricity.

Having designed a method for collecting data to respond to the objectives of a survey aimed at understanding the impact of power outages on Zambia's manufacturing sector, this chapter presents and interprets the results of the manufacturing survey, and discuss their value-add to the literature on the impact of power outages on Zambian manufacturing firms and on manufacturing in general.

Because of the several iterations that the survey underwent, all the 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 elicited, thus resulting in, for example, 122 responses to the question about whether firms reduce output as a response to power outages, versus just 34 responses to the question about whether firms use back-up data systems. This is why there are a different numbers of responses to different questions. All of Enumerator A's results have been expunged, resulting in a sample of 123 firms.

5.1 General characteristics of the manufacturing sample

The geographical breakdown of the survey was as follows:

- 90% of 113 respondents were located in industrial zones or a Multi-Facility Economic Zone;
- 71% of respondents were based in Lusaka, 15% in Kitwe and 14% in Ndola.

The international characteristics of the sample were such that

- 35% of 123 respondents reported that they export;

- Of these, only 4 exported or had exported outside of Africa (QA3 of questionnaire in Annex 2a). 3 of these firms exported to China.[53] One firm exported to India previously but no longer exported anywhere. One firm exported to India in addition to China.
- 58% of 42 questioned firms were majority foreign owned (QA5 of questionnaire in Annex 2a).

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

Personnel at companies were asked for the number of years of that their firms had been manufacturing. Their responses were not counter-checked with official documents in most instances, so their responses should be taken as approximations and quoting the maximum number of years of experience may therefore be misleading. The median years of manufacturing experience was 15, and the interquartile range was 7-34. The least experienced firm whose staff were interviewed was less than a year old. The firm with the longest experience was older than Zambia having been formed before independence.

Table 13 Years of manufacturing experience in the sample of manufacturing firms

Measure	Years of manufacturing experience
median	15
standard deviation	19
mean	22
upper quartile	34
lower quartile	7
min	1
max	Before independence

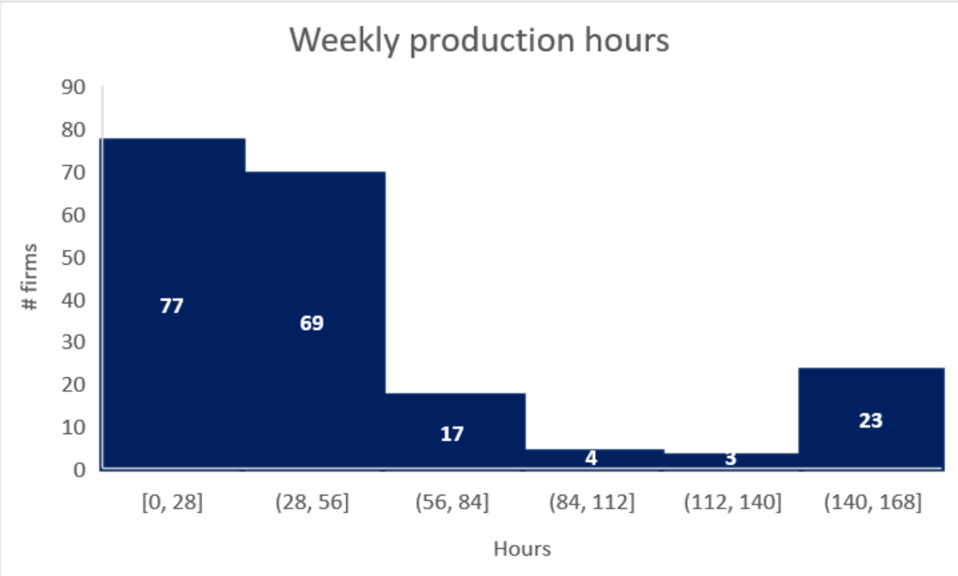
Source: Manufacturing survey

14 of 119 companies (i.e. 12% of the sample) for which production hour data was collected manufactured 24 hours 7 days of the week. However, the interquartile range of production hours was 48-89 hours. The distribution of production hours is represented by the below histogram.

Figure 9 Histogram and averages of production hours of the sample

Weekly hours worked	
119	Sample
168	Mode
75	Mean
48	Lower quartile
53	Median
89	Upper quartile

[53] Since this information is largely irrelevant to this study, this will not be discussed further, except to note that this tallies with the findings of Sutormina et al (2019) who found that flows of official finance from China resulted in exports of manufactured goods from Africa to China.



Source: Manufacturing survey

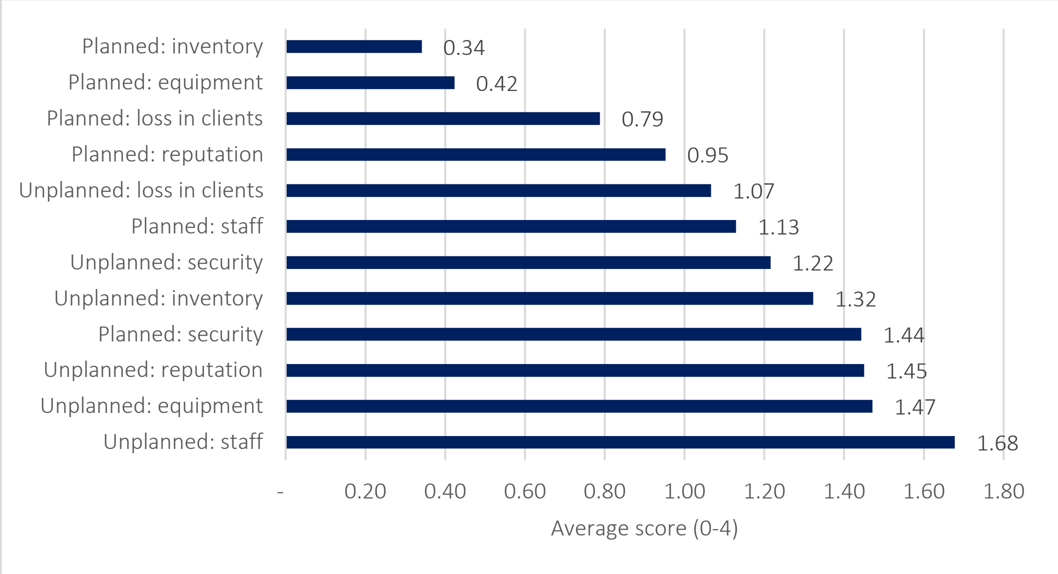
5.2 Ranking the damages incurred to large manufacturing firms from ZESCO's outages

Respondents were asked to rank the various ways in which power outages imposed costs to them on a scale of 0-4, with 0 ranking as "does not cause", 1 as "causes to a minor degree", 2 as "causes to a moderate degree", 3 as "causes to a major degree" and 4 as "causes all the time".

With the exception of outages related to lapses in security, unplanned outages did more damage than planned damages for all types of damage recorded. However, 35 (24% of) firms surveyed 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: they could not plan for outages.

Besides extra security costs from, 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 8th of the 6 types of damage across planned and unplanned outages.

Figure 10 Most common & severe costs of power outages for manufacturing firms April-August 2018



Source: Manufacturing survey

Discussion

Figure 10 adds to an understanding of how large Zambian manufacturing firms rank the various costs of power outages.

Given the high number of responses elicited for Figure 10, ranging from 79-121 for any given variable, the average cost values and relative values are credible. The findings support the thesis and findings of others (Pasha, Ghaus and Malik, 1989; Diboma and Tamo Tatietse, 2013) that planned outages considerably reduce costs when they come with notification. Unplanned outages resulted in additional costs due primarily to extra staff costs, secondly due to damage to equipment, thirdly due to damage to firm reputation and fourthly due to damage to inventory. By contrast, for planned outages, damage to equipment was on average considered to be 3.5x less costly, and damage to inventory was considered to be 4.7x less costly. For planned outages, extra staff costs again ranked higher, but so too did damage to firm reputation and loss in clients.

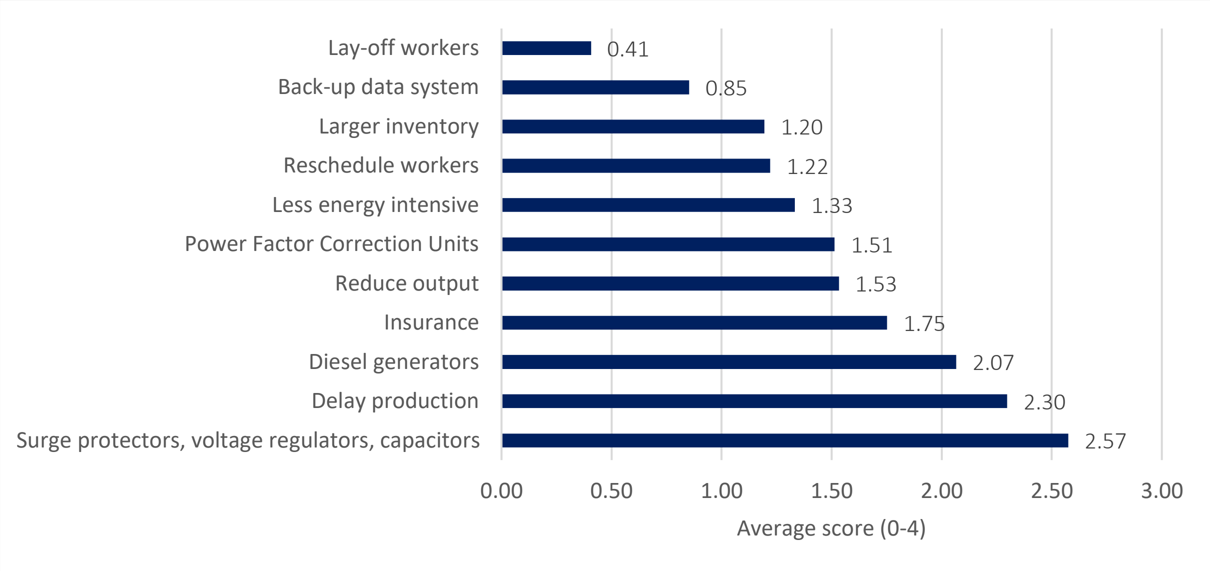
The only cost for planned outages which exceeded the same cost for unplanned outages was for security. This was presumably because it allowed firms to prevision for human personnel to secure premises when firms could expect security lights to go out.

This study also found that a quarter of ZESCO clients said that they never received notifications or accurate notifications for planned outages, meaning that in effect, ZESCO's failure to relay information accurately was costing its clients more. This impacted their decision to say 'no' to paying ZESCO for more reliable energy.

5.3 Ranking the use of mitigation strategies used by large manufacturing firms

The number of responses for each type of coping strategy varies because additional coping strategies were added to the survey when they were first elicited from firms (see QB2 of the survey in Annex 2a). Self-generation appeared as the third most popular intervention if the use of surge protectors, voltage regulators and capacitors were collapsed into one type of mitigation strategy.

Figure 11 Popularity of mitigation interventions for manufacturing firms April-August 2018



Source: Manufacturing survey

Discussion

Figure 11 adds to an understanding of popularity of interventions by large Zambian manufacturing firms to mitigate against power outages. The table's weakness, however, is that some of the interventions, such as delay in production, reduction in output, rescheduling workers and laying off workers, may have been understood by respondents to have been results of power outages, as opposed to coping mechanisms. Still, it tells us that interventions to mitigate against damages to equipment and inventory are the most popular. Self-generation is behind that. Larger inventory is behind that.

Generator records showed that firms used their backup diesel generators more in 2015 and 2016 than in 2017 and 2018.

Generator records also showed that firms were still using backup diesel generation as recently as June, July and August 2018, which did not accord with what ZESCO's economists said (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, 2017d).

If data had been collected in 2019, it is thought self-generation patterns would have been closer to 2015 and 2016 patterns than to 2017 and 2018. Although 300MW of coal energy had been added to the grid, most of ZESCO's power capacity continued to be vulnerable to low rainfall.

5.4 How the costs of power outages differ for firms using differing coping strategies

In addition to the damages incurred from ZESCO's outages looked at in section 5.2 and the use of mitigation strategies looked at in section 5.3, this section looks at the association between the use of mitigation strategies and extent of damages incurred.

In chapter 4 Weaknesses of the manufacturing survey, the weakness of asking respondents to rank costs and the extent of use of coping mechanisms on a scale of 0-4 was both discussed theoretically and shown to be evident with a return to the pilot survey company. For this reason, responses were collapsed into narrower bands: 0 remained 0, but 1 and 2 were re-categorised as 1 and 3 and 4 were re-categorised as 2.

Below is a table of these re-categorised variables in various Tobit regressions, with the extent of damages incurred listed as the dependent variables and the mitigation strategies listed as independent variables.

Table 14 Tobit regressions for costs of power outages against mitigating strategies

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Consequences →	Loss in clients		Use of	Damage to equipment		Damage to inventory		Use of capacitors,
Coping mechanisms ↓	Planned outage	Unplanned outage	delay	Unplanned	Planned	Unplanned	Planned	VR, PFCUs
Capacitors, voltage regulators,	0.135	0.381	0.0505	0.291**	0.0827	0.360**	0.170	
power factor correction units	(0.126)	(0.283)	(0.0795)	(0.138)	(0.0749)	(0.173)	(0.117)	
Delay recat	0.516***	1.145***		0.0265	-0.0278	0.383*	0.122	0.0253
	(0.148)	(0.389)		(0.164)	(0.0892)	(0.204)	(0.140)	(0.110)
Self-generation recat	-0.151	-0.228	-0.357***	0.0402	-0.0341	0.148	-0.0391	0.110
	(0.137)	(0.290)	(0.0788)	(0.151)	(0.0821)	(0.189)	(0.129)	(0.0997)
Larger inventory recat	0.0341	0.218	0.110	0.0516	-0.115	-0.0228	-0.123	-0.0502
	(0.136)	(0.283)	(0.0855)	(0.150)	(0.0788)	(0.187)	(0.123)	(0.0988)
Resch workers recat	0.0820	0.00800	0.261***	-0.108	-0.0159	0.0771	0.166	-0.171*
	(0.141)	(0.281)	(0.0864)	(0.156)	(0.0810)	(0.194)	(0.127)	(0.102)
Damage to inventory during								0.101**
unplanned outages								(0.0485)
Constant	0.326	0.115	1.321***	1.027***	0.384*	0.206	0.0311	1.224***
	(0.351)	(0.367)	(0.178)	(0.387)	(0.206)	(0.483)	(0.323)	(0.230)
Pseudo R2	6%	6%	13%	2%	3%	2%	3%	4%
Observations	115	81	117	115	81	115	81	115
regression run	tobit	tobit	tobit	tobit	tobit	tobit	tobit	tobit

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

Model	(9)	(10)	(11)	(12)
Consequences →	Firing staff		Damage to reputation	
Coping mechanisms ↓	Unplanned	Planned	Unplanned	Planned
Capacitors, voltage regulators,	-0.202	-0.0750	0.0887	0.111
power factor correction units	(0.160)	(0.162)	(0.0772)	(0.0808)
Delay recat	0.283	0.0651	0.219**	0.181*
	(0.189)	(0.193)	(0.0905)	(0.0954)
Self-generation recat	0.170	-0.120	-0.0686	-0.173*
	(0.174)	(0.178)	(0.0838)	(0.0881)
Larger inventory recat	-0.00817	-0.0492	-0.153*	-0.0282
	(0.173)	(0.171)	(0.0827)	(0.0841)
Resch workers recat	0.453**	0.379**	0.0954	0.00931
	(0.180)	(0.175)	(0.0862)	(0.0865)
Damage to inventory during				
unplanned outages				
Constant	1.046**	0.976**	0.639***	0.482**
	(0.447)	(0.447)	(0.215)	(0.222)
Pseudo R2	3%	3%	3%	3%
Observations	115	81	114	80
regression run	tobit	tobit	tobit	tobit

Standard errors in parentheses;

Source: Manufacturing survey

Models 1, 2 and 3

Where the extent to which clients were lost was reported due to unplanned outages as the dependent variable on a re-categorised scale of 0-2, delay in manufacturing as an independent variable was statistically significant at the 1% level, with a positive relationship between the two, suggesting that delays in production may not in fact have been interpreted by respondents to mean a coping mechanism but rather a symptom. Although self-generation is not a statistically significant variable, increase in its use correlates with a decrease in loss of clients. The model likely suffers from endogeneity between use of delaying production and loss of clients, and interaction between the independent variables self-generation and delayed production. To test this, model 3 has been introduced with use of delay as a mitigating strategy as the dependent variable.

Model 3 shows two statistically significant independent variables with a pseudo R-squared result of 13% – the highest reading from among all the models. An increase in the use of self-generation is associated with a decrease in delayed production. An increase in rescheduling workers is associated with an increase in delayed production.

In terms of descriptive statistics, 61 firms that reported use of self-generated energy at levels 3 and 4 (on a scale of 0-4) reported an aggregate score of 65 for total loss of output, where one respondent could score loss of output between 0-4. On average, the score of loss of output was 1.07. By contrast, those that did not use self-generation at all, or at levels 1 or 2 on the scale of 0-4 reported an aggregate score of 120 for loss of output. On average, the score of loss of output was 2.00. Hence using generators at least to a major extent resulted in firms reporting loss of output by almost a half of what firms that did not use generators to a major extent.

Similarly, 61 firms that reported use of self-generated energy as a coping mechanism at levels 3 and 4 on a scale of 0-4 reported an aggregate score of 44 for rescheduling workers, where one respondent could score rescheduling workers between 0-4. On average, the score of rescheduling workers was 0.72. By contrast, those that did not use self-generation at all, or at levels 1 or 2 on the scale of 0-4 reported an aggregate score of 103 for rescheduling of workers; an average score of 1.72 for rescheduling workers. Hence using generators at least to a major extent resulted in firms reporting rescheduling workers by 2.4x less.

Models 4, 5, 6, 7, 8

Models 4, 5, 6 and 7 look at the effect recorded coping strategies have on damage to equipment and to inventory.

There are no statistically significant predictors of damage to equipment or inventory for planned outages (models 5 and 7). The use of voltage regulators, capacitors, or power factor correction units are a statistically significant and positive predictor of damage to equipment and inventory for unplanned outages (models 4 and 6). This result is the opposite of what would have been expected and suggests endogeneity. For this reason, model 8 has been created, where voltage regulators, capacitors and power factor correction units are the output variable as a mitigation strategy, and damage to inventory has been found to be a statistically significant predictor at the 5% level.

Delay in production as a mitigation strategy was also a statistically significant predictor at the 10% level for damage to inventory caused by unplanned outages. The positive correlation also suggests endogeneity.

Whether a firm rescheduled its workers was found to be a statistically significant negative predictor of whether it used voltage regulators, capacitors or power factor correction units.

Models 9 and 10

Models 9 and 10 look at the downsizing of staff as a cost (the dependent variable). The only statistically significant predictor from those investigated is rescheduling of workers, but this is positively rather than negatively associated with the downsizing of staff. Again, this could be the result of respondents understanding 'rescheduling of workers' as a symptom rather than as a coping mechanism. Whether or not it is a symptom or coping mechanism, the rescheduling of staff seems to be an intermediate step before they are let go.

The survey's results for subsectors did not predict the downsizing of staff when these were included as independent variables (not shown in the above table).

Models 11 and 12

With damage to firm reputation set as the dependent variable in models 11 and 12, several coping mechanisms appear to be associated. For unplanned outages, delays in production are positively associated and statistically significant at the 10% level. Again, delays in production may have been understood by respondents as a symptom rather than as a coping mechanism.

Larger inventories, a statistically significant coping mechanism at the 10% level for unplanned outages, seem to be an effective mitigation strategy.

Self-generation is a statistically significant mitigation strategy for planned outages, reducing damage to reputation.

Capacitors, voltage regulators and power factor correction units are positively associated with damage to firm reputation. The positive association does not make sense in terms of causality; rather the relationship probably indicates that firms which suffer from power outages to the extent that they suffer reputational damage are also firms that use these technologies to mitigate against damage to their equipment and inventory.

Discussion: efficacy of firm interventions in mitigating the costs of power outages

Table 14 adds to an understanding of the efficacy of various interventions in mitigating the costs of power outages to large Zambian manufacturing firms. The use of larger inventories was negatively and statistically significantly correlated with damage to firm reputation for unplanned outages.

The use of capacitors, voltage regulators and power factor correction units is statistically significantly positively correlated with damage to inventory for unplanned outages and damage to firm reputation for planned outages. However, this probably indicates reverse causality, as an alternative regression shows: damage to inventory is a positive and statistically significant predictor of use of capacitors, voltage regulators and power factor correction units. It is also useful to look at descriptive statistics to make sense of the results. 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%. A follow-up study with semi-structured interviews could confirm the flow of cause and effect.

Self-generation marginally misses out being a statistically significant negative predictor at the 10% level for loss in clients for unplanned outages. It is, however, statistically significant at the 1% level as a negative predictor of delay, which in turn is a statistically significant predictor at the 1% level as a positive predictor of loss in clients for both unplanned and planned outages. Self-generation is also a negative predictor at the 10% level of statistical significance for damage to firm reputation resulting from planned outages. 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.

That more than 95% of firms that have access to a generator use their generators in spite of its high running cost of circa USD 0.29/kWh shows that they see value in using them. That there was a spike in acquisition of generators in 2008 suggests that there was latent demand for them prior to the duty waiver introduced in 2008 (Government of Zambia, 2008) for their import. They help mitigate against loss of welfare. From a public policy perspective, then, their import into the country should continue unimpeded.

5.5 Identifying firm characteristics that can be used to predict differing coping strategies

Section 5.4 looked at the associations between coping strategies and costs of outages. This section looks at predictors of coping mechanisms.

5.5.1 Predictors of whether firms keep more inventory as a coping strategy and reschedule workers

Tobit regressions were run to find the predictors of the last two independent variables identified as coping mechanisms in Table 14. The below models in Table 15 are the best fit.

For keeping larger inventory, two variables were found to be statistically significant predictors: the number of hours was statistically significant at the 5% level, and whether a firm rescheduled workers was statistically significant at the 1% level. The greater the number of hours a firm manufactured per week, the more likely it was to use keeping larger inventories as a coping strategy to power outages.

If a firm rescheduled its workers, it was likely to also keep a larger inventory. The same is also true for firms that rescheduled workers: if a firm keeps a larger inventory as a coping mechanism for power outages, it is more likely to reschedule workers, and this association also holds at the 1% level of statistical significance.

There were two other statistically significant predictors of whether a firm would reschedule its workers, both at the 5% level of significance and both as negative predictors. Use of self-generation reduced the need for rescheduling workers, and the number of hours a firm manufactured was also associated with a reduced need for relying on rescheduling workers. Together, these predictors suggest that less well-resourced firms resorted to rescheduling their workers. The intuition is that rescheduling is an easier option for smaller firms without backup generation capacity.

Table 15 Variables associated with firms keeping larger inventories and rescheduling workers

Coping strategies → Predictors ↓	Larger inventory recat	Reschedule workers recat
reschrecat	0.353***	
	(0.0861)	
selfgenrecat	0.00213	-0.199**
	(0.0879)	(0.0827)
employees	0.000151	8.92e-05
	(0.000510)	(0.000491)
exports	0.00361	
	(0.161)	
hoursweek	0.00428**	-0.00403**
	(0.00176)	(0.00177)
basicmetals	-0.126	
	(0.276)	
invrecat		0.362***
		(0.0872)
Constant	0.0957	0.997***
	(0.187)	(0.159)
Pseudo R2	7%	9%
Observations	117	117
Regression	tobit	tobit

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

Source: Manufacturing survey

5.5.2 Predictors of a firm's scale of investment in self-generation and predictors of on-going use of back-up generation

5.5.2.1 Time as a relevant factor in the purchase decision – descriptive observations

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%.

Table 16 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	47	66	92	73	40
Number of responses for year	42	42	38	32	25
Average score for year	1.12	1.57	2.42	2.28	1.60
Ranked in terms of worst year	5	4	1	2	3

Source: Manufacturing survey

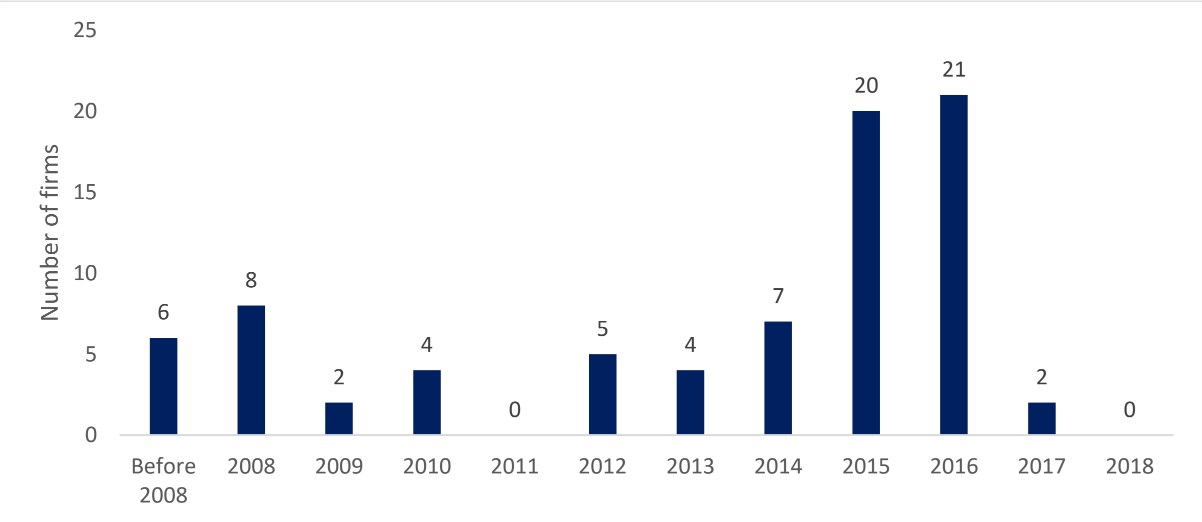
To ensure robustness of results, the average of results obtained for a year was used rather than the aggregate score, which would have been skewed towards the more recent years for which more respondents remembered their experiences, or for which respondents were able to talk about their experience at the firm they were serving at when interviewed (more responses were received for more recent years). 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. To account for the greater number of responses for the most recent years, the aggregate score for a given year was divided by the number of responses for that year. With this, 2016 and 2015 ranked as worse years than the most recent years, meaning that even after discounting for what happened in the further past, respondents still rated these years as the worst for power outages.

Purchase year of firms' oldest generators was data that was collected because it was directly observable by enumerators looking at the year written on generators. In this way, it is not a piece of datum that can be mistakenly reported by a respondent. It may possibly be a good proxy for the year in which first generators bought by firms if firms were not replacing damaged generators. This rests on the assumption that generators are resilient and have long lifespans. Whereas 3 firms reported damaged generators that they had not replaced, 6 firms purchased their oldest generators in use before 2008, with the oldest generator in use having been purchased in 1994. 36 out of 79 firms (45% of firms) bought their oldest running generators before the power outages of 2015. This would seem to support the notion that at least a large portion of generators still in use in 2018 were resilient.

2008 was the year in which the Zambian government waived duties on imported generators (Government of Zambia, 2008). This could explain why 2008 is a modal year for the purchase of generators in the years up to 2013.

If the year of purchase of firms' oldest generators is a good proxy for the year of purchase of firms' oldest generators, then the modal year for first-time purchases of generators was 2016. Of 79 responses, 21 (27%) of firms bought their first generator in 2016, while 20 (25%) of firms bought their first generator in 2015. Together, 2015 and 2016 accounted for 52% of first-time generator purchases.

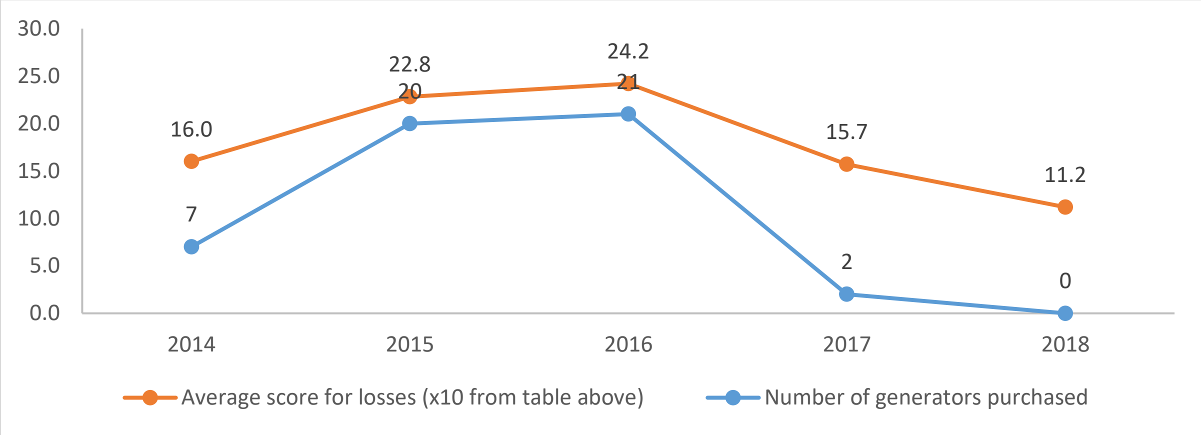
Figure 12 Year in which first generator in use was purchased



Source: Manufacturing survey

The correlation between the scores for how bad each year between 2014-2018 was in Table 16 above and the number of generators that were purchased in 2014-2018 is 97% - see Figure 13.

Figure 13 Number of first generators bought by year; average score for losses by year (x10 from Table 16)

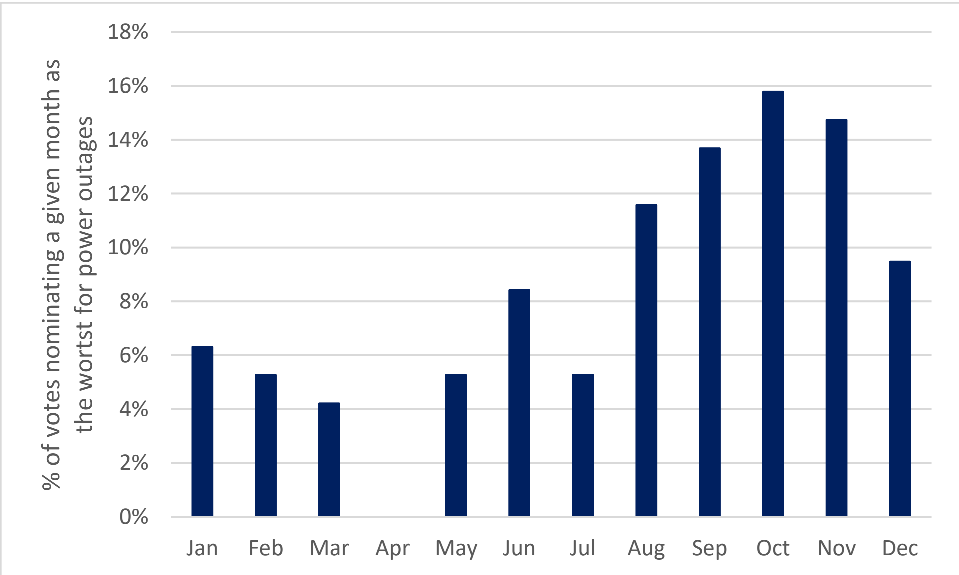


Source: Manufacturing survey

5.5.2.1.1 Worst months generally for outages

Enumerators were asked to explore the seasonality of outages. This is relevant knowledge for manufacturing firms to be better prepared for when to expect power outages. Ninety-five votes were cast in response to the question of what months were worst for power outages by 31 distinct respondents. October was noted as the worst month for outages, followed by November and September. The month least reported for worst outages was April, which is in the dry season and when ZESCO produces less than average energy.

Figure 14 Months rated as the worst for power outages

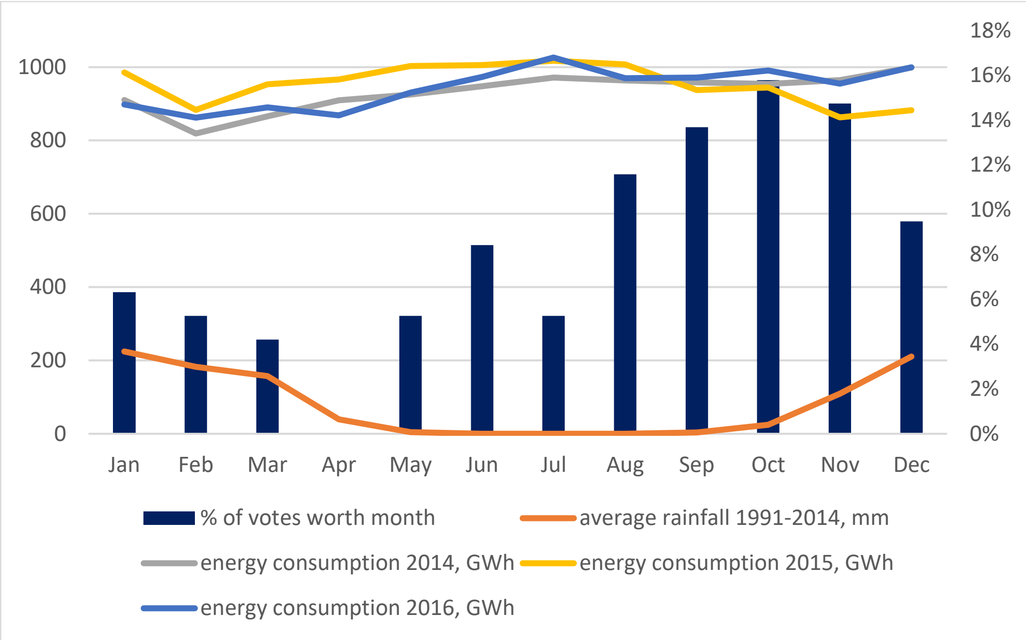


Source: Manufacturing survey

Discussion: How worst months for power outages can be explained

Figure 14 illustrated how firms ranked months for worst power outages, reproduced as the navy columns in Figure 15 below. Juxtaposed with average precipitation data as well as for energy consumption in 2014 to 2016, it becomes apparent why October ranks as the worst month: it follows months of no rainfall. Hydropower reservoir levels will be at their lowest.

Figure 15 October follows months of no rainfall is the worst month for power outages

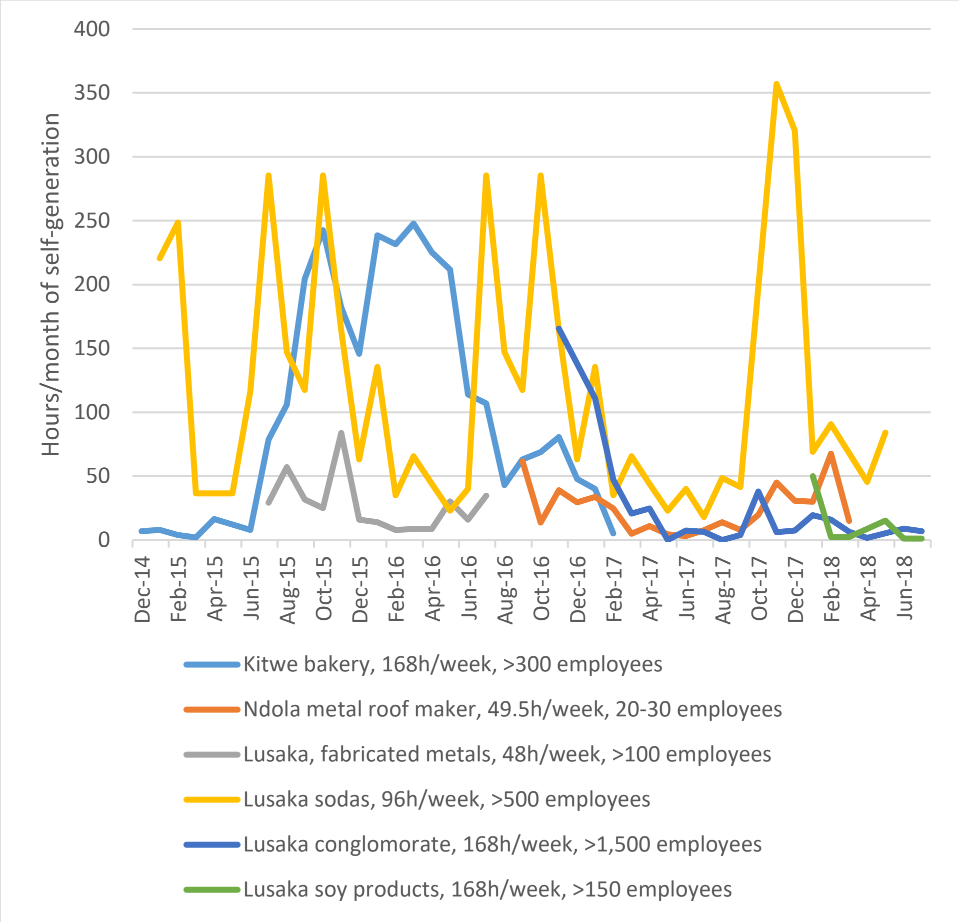


Sources: Manufacturing survey; ZESCO Ltd, 2017d; World Bank, 2018d

5.5.2.1.2 Observed generator usage

Six large manufacturing firms shared their generation hours per month for varying periods. As the graphs show, the most concentrated period of outages was between June 2015 and October 2016. There was 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.

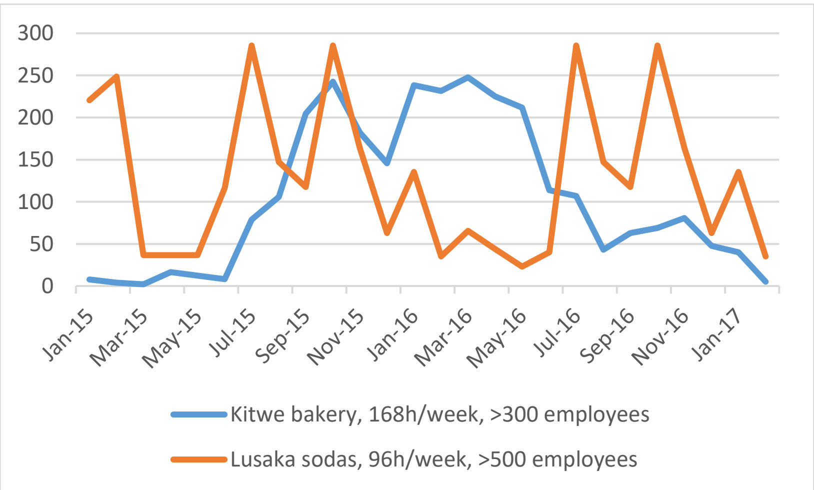
Figure 16 The self-generation hours/month profiles of 6 large manufacturing firms, Dec 2014-July 2018. Note: empty bars do not necessarily mean no generation hours that month



Source: Manufacturing survey

In focusing 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, it becomes apparent that the self-generation patterns are an almost perfect inflection of one another, suggesting that outages between the two cities could have been alternating.

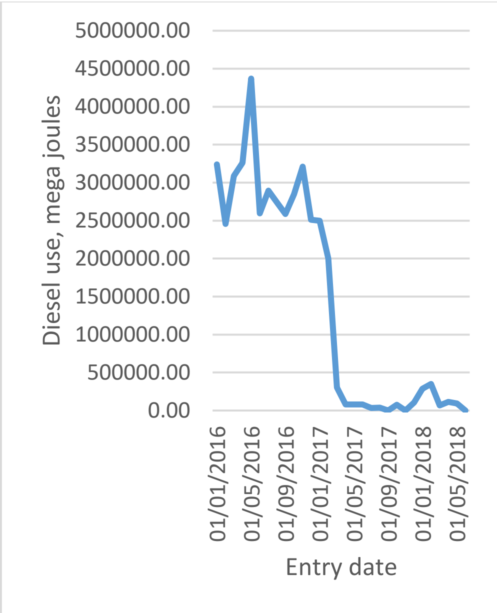
Figure 17 Self-generation hours/month profiles of one large manufacturing firm in Kitwe and one large manufacturing firm in Lusaka, Dec 2014-July 2018. Note: empty bars do not necessarily mean no generation hours that month



Source: Manufacturing survey

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

Figure 18 Diesel use by a large beverages company in Lusaka, Jan 2016-Jun 2018



Source: Manufacturing survey

5.5.2.2 Ownership rate versus usage rate – descriptive observations

Of 123 firms asked, 90 (i.e. 73%) 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, 81 out of 122 firms (66%) said that they used their generator, i.e. 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, 81 out of 87 firms (93% of firms) that had had access to a generator and whose generator did not break down continued to use their generator.

5.5.2.3 Econometric observations

Two different types of regression model were run to investigate the predictors of scale of investment in self-generation and extent of use of self-generation, to see how they differed. An ordinary least squares regression model was used to predict the kVA of installed generator capacity that firms invested in by various characteristics, since the dependent variable of kVA installed capacity was continuous. Since ordinal logistic regression analysis did not return Brant tests, Tobit regressions were run identify which firm-level variables impacted the extent to which self-generation was used since the dependent variable came in the form of ordinal outputs 0 for no use, 1, 2, 3 and 4 for use all the time.

Because an OLS regression model was used to predict installed capacity and a Tobit regression was used to predict extent to which the generator was used, , a direct comparison of the predictors of backup generation and predictors of backup usage cannot be provided. This does not mean a comparison is impossible. Statistically significant predictors for regressions can be compared, and whether the impact they have has the same direction of impact.

Regressions were run against at most seven independent variables at a time, because of the limited number of observations.. Below is a table with those variables that were found to have statistically significant associations with the dependant variables, and the models of best fit.

According to the R-squared and pseudo R-squared scores of the two models, the explanatory value of the regression models for predicting self-generation capacity is greater than the models for predicting extent of generator use. This may be a function of richer output data for the former: the installed capacity had a larger range and more diverse output, whereas for the ordinal logistic model, it was just five different outputs, ranging from 0-4.

R-squared on its own is not the only metric for determining how good a model is. The probability that the joint null hypothesis that all regression coefficients are zero, denoted by the prob > chi 2 statistic, tells how statistically significant the models are. So in the case of models 6-9, whereas models 7 and 8 with the independent variable 'not Zambian owned' have higher explanatory power, they are also less statistically significant than models 6 and 9 which have wood as a variable. In regressions where 'not Zambian owned' was inserted as an independent variable with wood, wood was automatically omitted by Stata.

Table 17 Comparison of ownership of backup generation capacity versus extent to which self-generation is used

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Installed generator capacity, kVA					Extent to which self-generate, 0-4			
employees	3.617***	3.639***	6.045***	5.795***	3.432***	0.00176*	0.00151	0.00237	-0.000150
	(0.509)	(0.517)	(1.295)	(1.282)	(0.509)	(0.00104)	(0.00179)	(0.00167)	(0.00124)
exports	229.2	238.1	438.8	318.8	150.1	0.773**	0.720		0.622*
	(157.9)	(159.1)	(431.3)	(430.9)	(158.3)	(0.321)	(0.596)		(0.320)
hoursweek	3.036*	2.891	0.369	-0.375	2.702	0.00274	0.00487	0.00618	8.67e-05
	(1.751)	(1.786)	(3.658)	(3.625)	(1.740)	(0.00354)	(0.00487)	(0.00482)	(0.00360)
notzambian			417.9	243.5			1.080**	1.184***	
			(309.4)	(324.8)			(0.420)	(0.418)	
basicmetals		-56.15	-808.4	-532.4	105.0	-1.347**	-1.657*	-1.728*	-1.339**
		(328.6)	(640.3)	(654.5)	(325.4)	(0.558)	(0.884)	(0.896)	(0.655)
o.wood			-	-			-		
wood		-353.6			-142.9	-1.751**			-1.604**
		(394.5)			(391.9)	(0.803)			(0.789)
selfgen				164.9	117.7***				
				(108.3)	(44.30)				
var(e.selfgen)									
kva									0.000526***
									(0.000192)
Constant	-254.0*	-233.5	-354.7	-415.3	-420.2***	1.462***	0.320	0.241	1.708***
	(142.3)	(147.6)	(367.0)	(362.7)	(159.9)	(0.287)	(0.474)	(0.477)	(0.298)
Observations	114	114	42	42	114	119	43	43	114
R-squared/Pseudo R-squared	45%	45%	55%	58%	49%	5%	10%	9%	6%
Prob > chi2						0.05%	0.68%	0.56%	0.02%
Regression model	linear	linear	linear	linear	linear	tobit	tobit	tobit	tobit

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

Source: Manufacturing survey

Similarly, the inclusion of the 'not Zambian owned' independent variable seemed to have an impact on other variables: in OLS model 4, it seems to have been responsible for the negative coefficient sign of hours of production per week, which otherwise had a positive sign and was statistically significant at the 10% level in model 1. It also might have been responsible in model 4 for making extent of self-generation a non-statistically significant predictor, whereas in model 5, self-generation extent was statistically significant at the 1% level.

The one definitive result from the OLS models 1-5 is that firm size in terms of employees is a statistically significant predictor of the amount of installed kVA of self-generation capacity.

Despite their lower R-squareds, models 6-9 yield more predictors of the extent to which firms self-generate.

Whether a firm belongs to the basic metals subsector is a statistically significant negative predictor of the extent to which firms self-generate. Wood is similarly a statistically significant negative predictor when not omitted by the inclusion of the 'not Zambian owned' variable.

The variable 'not Zambian owned' is a statistically significant positive predictor of extent to which firms self-generate. Inclusion of this variable seems to dampen the statistical significance of the basic metals variable, as well as of exports, which is otherwise a statistically significant predictor. It increases the Tobit regression models' R-squared scores, but also makes the overall models less statistically significant.

Extent to which self-generation is used and installed capacity are statistically significant predictors for one another, although extent to which a firm self-generates is not a sensible predictor for installed capacity since the extent to which a firm can generate electricity would only happen once generation capacity had been installed.

These results are at great variance to the results in the working paper (Ahmed, Baddeley, D. M. Coffman, *et al.*, 2019), due to the impact of expunging Enumerator A's results from the analysis.

Finding that basic metals and wood were predictors of less use of self-generation, I wanted to see what the effect would be on workers. Basic metals subsector was statistically significantly and positively correlated with delays in production (model 2 in Table 18) and also with a loss of clients when unplanned outages occurred (model 4), but not with rescheduling workers (model 1) or firing staff (models 5 and 6). The wood subsector was not a predictor for any of these outcomes.

Table 18 Tobit regressions of various dependent variables run on the basic metals and wood subsectors and on self-generation use and rescheduling workers

	(1)	(2)	(3)	(4)	(5)	(6)
Consequences →			planned outages	unplanned outages	planned outages	unplanned outages
Coping mechanisms ↓	resch workers recat	delay	loss of clients	loss of clients	firing staff	firing staff
basicmetals	-0.0422	1.084**	0.118	0.845**	0.461	0.0765
	(0.291)	(0.500)	(0.444)	(0.418)	(0.522)	(0.505)
wood	0.1382	0.189	-0.0355	0.503	-0.264	0.489
	(0.425)	(0.733)	(0.669)	(0.611)	(0.764)	(0.760)
selfgenrecat	-0.251***	-0.712***	-0.286*	-0.297**	0.0396	-0.143
	(0.085)	(0.153)	(0.145)	(0.129)	(0.160)	(0.165)
reschrecat		0.494***	0.0411	0.191	0.541***	0.381**
		(0.156)	(0.146)	(0.131)	(0.164)	(0.166)
Constant	0.987***	2.673***	1.104***	1.204***	1.203***	0.971***
	(0.131)	(0.274)	(0.269)	(0.233)	(0.290)	(0.306)
Prob > Chi2	2.9%	0.0%	30%	0.3%	2.0%	9.1%
Pseudo R2	2.9%	9.4%	1.8%	4.1%	2.6%	2.8%
Observations	122	120	86	119	120	86
regression run		tobit	tobit	tobit	tobit	tobit

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Manufacturing survey

5.5.3 Discussion on the predictors of coping mechanisms

The number of hours a large Zambian manufacturing firm operates is a positive predictor of whether it will keep larger inventories and use capacitors, voltage regulators or power factor correction units. For the former, whether a firm reschedules its workers is also a statistically significant predictor. For the latter, as was discussed already above, damage to inventory was also a predictor.

Timing of acquisition of the use of a self-generator was 92% correlated with when firms reported to have experienced their worst power outages. Tellingly, age – a proxy for a firm's level of experience and business acumen, and one that Steinbuks and Foster found to be a statistically significant predictor of backup generation ownership (Steinbuks and Foster, 2010) – was not a statistically significant predictor of backup generation ownership. This suggests that many large manufacturing Zambian firms did not perceive power outages to be a threat to their operations prior to the outages of 2015 and 2016 – indeed this is borne out by the increase in ownership of generators from 38% of firms owning a generator observed from the World Bank's 2002 to 2006 Enterprise Surveys (Steinbuks and Foster, 2010, table 1) to 73% in 2018 from this thesis' primary data collection. For the period 2002 to 2006, Steinbuks and Foster had calculated a negative average cost-benefit figure for owning a generator given the infrequency of power outages and the high capital cost of buying one (Steinbuks and Foster, 2010) But during the power crisis of 2015 and 2016, both old and new firms saw the need for backup generators. Timing of crisis took precedent over age of firm.

Like Steinbuks and Foster (2010), the survey found firm size, export orientation and whether a firm was owned by Zambian or not to be statistically significant predictors of generator ownership. My survey analysis in Table 17 shows firms with more employees had statistically significantly more installed capacity. It does not show statistical significance for export facing firms or Zambian ownership in this regard, but where it goes beyond Steinbuks and Foster is that it examines predictors of the extent to which firms report self-generation. Firms that exported were likely to report statistically significantly more self-generation use. Firms that were not owned by Zambians, or that were in the basic metals or wood subsectors were likely to report statistically significantly less self-generation use.

Regarding subsectors, the study had different findings than Steinbuks and Foster (2010), perhaps partly due to the lower number of observations, but also more nuanced findings because it went a step beyond.

Like Steinbuks and Foster, the study found that food and beverages were a statistically significant positive predictor of installed backup generation capacity. A former production manager at a milk factory gave a qualitative explanation for why self-generation was important for milk production, which falls within the food and beverages subsector. He said (personal communication, 25th May, 2018) 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.

Steinbuks and Foster were able to rank in order of magnitude of coefficient for statistically significant subsectors for most likely to own a generator –

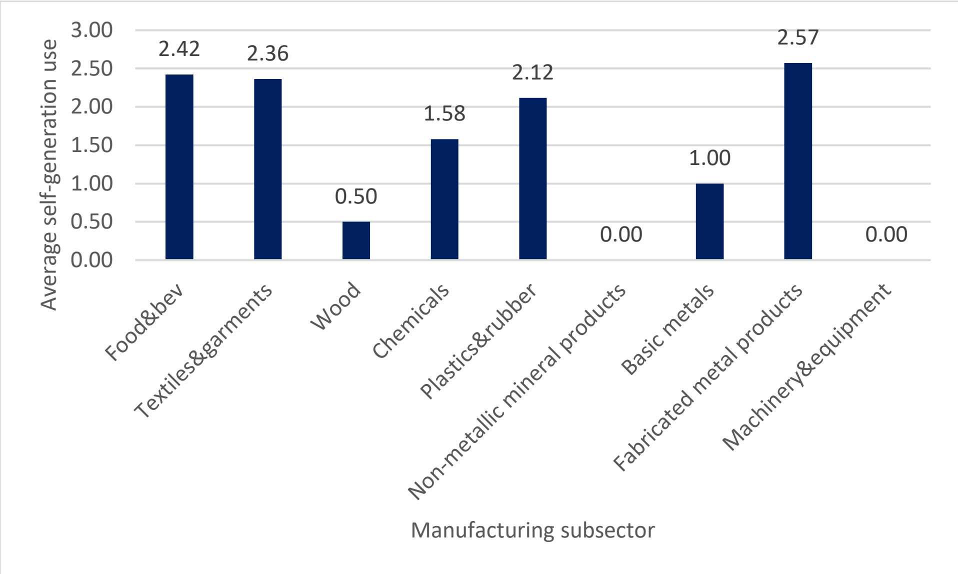
1. hotels and restaurants,
2. food and beverages,
3. chemicals and pharmaceutics,
4. non-metallic and plastic materials,
5. metals and machinery,
6. wood and furniture.

The survey and analysis showed a similar ranking among subsectors for which there were more than 5 firms, when ranking subsectors by how frequently their firms marked the use of self-generation by '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
7. wood and wood products.

Figure 19 How generation use differs between subsectors



Source: Manufacturing survey

Analysis of variance showed the difference in self-generation use between subsectors from the manufacturing survey is statistically different at the 10% level of significance (see Table 19 below).[54]

[54] To carry out this analysis, I:

1. Calculated the mean for all self-generation scores
2. Calculated the mean self-generation for each subsector
3. Calculated for each value within each subsector the sum of squares difference with the mean for its subsector, and aggregated the 'sum of squares within'
4. Calculated for each value within each subsector the sum of squares difference between the subsector mean and the overall mean, and aggregated the 'sum of squares between'
5. Found there to be 8 degrees of freedom for sum of squares between and 115 degrees of freedom for sum of squares within
6. Calculated the F-statistic by dividing the sum of squares between by 8 degrees of freedom and dividing this by the sum of squares within and by its 115 degrees of freedom
7. Used an F-statistic table (UCLA Statistics, 2019) to find the F-statistic at the 10% level of statistical relating to 8 degrees of freedom in the numerator and 115 degrees of freedom in the denominator
8. Compared this 10% statistical significance F-statistic with the F-statistic that I calculated.

Table 19 How differently firms use self-generation by subsector

	Food& bev	Textiles& garments	Wood	Chemicals	Plastics& rubber	Non-metallic mineral products	Basic metals	Fabricated metal products	Machinery& equipment	Mean	SSW	SSB	df
# firms that self-generate levels 3 or	28	6	0	7	9	0	2	9	0				
% subsector that self-generates leve	61%	55%	0%	37%	47%	0%	22%	64%	0%				
Average self-generation for subsecto	2.42	2.36	0.50	1.58	2.12	0.00	1.00	2.57	0.00	**2.07**			
# firms surveyed in subsector	46	11	4	19	19	1	9	14	1				
Square of sums within subsector, SS	139	29	1	57	51	0	18	39	0		**333**		
n-1 degrees of freedom	45	10	3	18	18	0	8	13	0				**115**
Square of sums between subsectors	5.85	0.98	9.80	4.50	0.05	4.27	10.22	3.58	4.27			**44**	**8**
H0: subsectors averages are equal													
H1: subsectors are different													
F-statistic = (SSB/8) / SSW/(115)	1.8776												
Test for alpha = 10%													
For 10% and 8, 120 df, F statistic is	=1.77483-(1.77483-		1.72										
Therefore H0 is disproved at the 10% level and H1 is correct													

Source: Manufacturing survey

Like Steinbuks and Foster (2010), food ranked high, basic metals and wood and wood products at the bottom and the other subsectors ranked in the middle. This study found food and beverages to be a statistically significant predictor of generator capacity, and that the basic metals and wood subsectors were statistically significant predictors that firms categorised as such would *not* self-generate to a great extent.

This study was unable like Steinbuks and Foster (2010)'s to show statistically significant p-values for all subsectors. It was unable like their study to list all subsectors on the right hand side at the same time, because of a budget constraint. Whereas Steinbuks and Foster (2010) relied upon the World Bank's 2010 enterprise survey data for 4,246 observations, this study was limited to the 114 observations stated in Table 17. But in spite of this, this study yields some richer results. Whereas Steinbuks and Foster's observations came from all over Africa in diverse stages of development, this study focused on Zambia and covered a third of Zambia's large manufacturing firms. Moreover, because this study collected kVA of installed generator capacity – a continuous dependent variable – rather than a binary variable for generator ownership, this study's regression analysis was richer, and so whereas Model 4 in Table 17 has an R-squared of 58% for installed generator capacity, Steinbuks and Foster's model had an R-squared of 24% (Steinbuks and Foster, 2010, Table 2). The three ordinal categorical variables (0, 1, 2) used for measuring extent of self-generation use in models 6-9 in Table 17, though, did, not improve on Steinbuks and Foster's R-squared score.

The study builds upon Steinbuks and Foster (2010) by

- Using richer data
- Updating our understanding of the impact of outages on Zambia's manufacturing sector post-El Niño when outages lasted 8 hours a day, as opposed to when outages occurred only 5% of the time
- Considering as Oseni and Pollitt did (Oseni and Pollitt, 2015), that there are still outage losses that are unmitigated by ownership of backup generation. By taking a ground-up approach to asking firms how much capacity they invest in and then to what extent they use their generators to make up for power outage losses, this study allows for the possibility that firms with generators do not completely cover the power losses both because they cannot in terms of capacity and because the firms do not employ them to, because of working capital issues.

By illustrating differences between the statistically significant predictors of installed capacity in Models 1-5 of Table 17 and the statistically significant predictors of the extent to which generators are used in Models 6-9, Table 17 illuminates stories that may have otherwise been missed. On a subsector level, both wood and basic metals were statistically significant negative predictors of the extent to which firms used their generators. While neither wood nor basic metals were statistically significant predictors of installed capacity of backup generation in this study, a firm belonging to the basic metals subsector was a non-statistically significant predictor of greater installed capacity whereas belonging to the wood subsector was a non-statistically significant predictor of less installed capacity. These results suggest different reasons, therefore, for reporting that their use of backup generation was less. The wood and woodwork subsector is not energy intensive (Steinbuks and Foster, 2010), whereas the basic metals subsector is, hence the different directional impact on installed backup capacity. The marginal revenues earned from intensive generator use for the wood and wood products subsector are lower than the marginal costs of self-generating, whereas with basic metals, the issue is perhaps a case of insufficient working capital. Further semi-structured interviews would confirm this. This would be a credible explanation, given Steinbuks and Foster's observation that belonging to the metals and machinery subsector, like belonging to the food and beverages subsector, has a statistically significant benefit-cost margin of owning a generator (Steinbuks and Foster, 2010, table 5c). (The other subsectors do not have statistically significant cost benefit margins of owning a generator.)

Beyond subsectors, the regression analysis of the extent to which firms used backup generation revealed another statistically significant predictor that was not statistically significant for predicting installed capacity of backup generation: whether a firm was based in Kitwe or not had an impact on the extent to which firms reported self-generation. Because only one enumerator surveyed firms in Kitwe, the statistically significant result could have been due to the particular enumerator's influence on the survey. The result therefore required further investigation. Out of the 18 firms which the particular enumerator interviewed in Kitwe, 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 the 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.

When this result was discussed in a public forum (4 September 2019), an economist at the Energy Regulation Board said it accorded with his own research (Sikwanda, 2019). His research indicates that small firms in Kitwe bore a higher cost of power outages than firms in Ndola, Lusaka and Livingstone (Mwila *et al.*, 2017, p. viii), which would explain why firms in Kitwe might have used self-generation more. The self-generation pattern use of the firm in Kitwe shown in Figure 17, compared with a firm in Lusaka could possibly support this assertion by the Energy Regulation Board (Mwila *et al.*, 2017, p. viii).

Given that there is variance in the extent to which firms use their generators – and some of the factors that impact this are shared by the predictors of installed capacity (i.e. number of employees, whether a firm is export-oriented) – this shows that studies that assume that backup generation mitigates completely against losses have overestimated generation's capability to mitigate against losses, underestimated those losses and would have overestimated emissions associated with backup generation.

The same ranking of subsectors for use of self-generation (where there were more than five firms in the sample) held for highest proportion of firms that used capacitors, voltage regulators or surge protectors all 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.

Analysis of variance (see Table 20), however, showed that the difference in the use of capacitors, voltage regulators and/or surge protectors between subsectors from the manufacturing survey to not be statistically different at the 10% level of significance.[55]

Table 20 To a major extent or all the time and whether they use capacitors, voltage regulators and/or surge protectors all of the time

	Food &bev	Textiles& garments	Wood	Chemicals	Plastics& rubber	Non-metallic mineral products	Basic metals	Fabricated metal products	Machinery& equipment	Mean	SS W	SS B	df
# firms that protect against power surges al	30	6	2	12	10	1	4	9	0				
% subsector that use protection all the time	65%	55%	50%	63%	53%	100%	44%	64%	0%				
Average CVS for subsector, 0-4	2.84	2.27	2.25	2.74	2.67	4.00	2.71	2.77	0.00	**2.69**			
# firms surveyed in subsector	46	11	4	19	19	1	9	14	1				
Square of sums within subsector, SSW	130	40	13	60	48	0	21	44	0		**356**		
n-1 degrees of freedom	45	10	3	18	18	0	8	13	0				**115**
Square of sums between subsectors, SSB	1.05	1.93	0.78	0.04	0.01	1.71	0.00	0.08	7.25			**13**	**8**
H0: subsectors averages are equal													
H1: subsectors are different													
F-statistic = (SSB/8) / SSW/(115)	0.518												
Test for alpha = 10%													
For 10% and 8, 120 df, F statistic is	=1.77483-(1.7748		1.72										
Therefore H0 is not disproven at the 10% level													

Source: Manufacturing survey

The same ranking did not hold for willingness to pay more for more reliable electricity (see section 5.6.1.1 below for results):

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 this should not be looked at too deeply.

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 both have

[55] Using the same methodology as for the above variance of analysis.

the resources for both the required capital expenditure, for the working capital to run their generators as well as benefit from any economies of scale associated with capital costs and generation capacity (Allcott, Collard-Wexler and O'Connell, 2015).

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, 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. These results accord with the World Bank's, 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).
Exports was a statistically significant predictor of both installed self-generation capacity (if a firm exported, it would on average have approximately 600 kVA of additional 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 were a statistically significant predictor of a firm's installed capacity; for every additional hour of work, a firm would have on average approximately 5 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.

The results 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, of 36 firms that were foreign-owned, 26 (72%) had self-generation capability. Of 27 domestically 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 perhaps explains why years of experience was not a factor.

5.6 Costing the damages for firms

Section 5.2 showed the most common costs of outages. Section 5.3 showed that using self-generation was the fourth most favoured means of mitigating these costs. This section costs the damages by working out marginal costs of outages by:

i. Asking firms' production managers and accountants to cost the premium on top of the tariff that their firms paid that they would be willing to recommend their firms pay for a reliable supply of electricity, and
ii. Observing firms' use of self-generation.

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

30 (25% of respondents) at 119 firms said that their firms would be willing to pay a higher electricity tariff for more reliable energy. Of the 89 (75%) firms whose representatives said that they were not willing to pay a premium, they fell into broadly four categories:

1. Those that were satisfied with their arrangements –
    a. 2 responses were that they had secured a bilateral agreement with ZESCO to give them secure energy,
    b. 1 response was that the firm now received good communication from ZESCO about outages,
    c. 3 responses were that there was either no problem with power outages now (during the period in which the interviews were taken, April-August 2018);

2. Those that opposed tariff hikes on the basis that they were too high for the business (12 firms said that the tariff was already too high or would affect profits);

3. Those that opposed tariff hikes because there had already been two tariff increases in 2017 (2 firms);

4. And those that opposed tariff hikes because they did not trust ZESCO to deliver more reliable energy if they paid a higher tariff. More than a quarter of respondents (32/123) 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.)

52 of 89 negative responses can be attributed to these four broad reasons for not wanting to pay a premium.

Of the 30 firm's representatives that said that they would be willing to pay a higher tariff for more reliable electricity supply, 20 quantified the extra they would be willing to pay. The mean extra, when expunging outlier responses that implied higher tariffs than the cost of self-generation, was 0.61 K/kWh, which at the time of the survey was equivalent to 0.04 USD/kWh. Of 21 firms without a generator, 21% were willing to pay more for electricity, versus of 90 firms with a generator, 26% were willing to pay more.

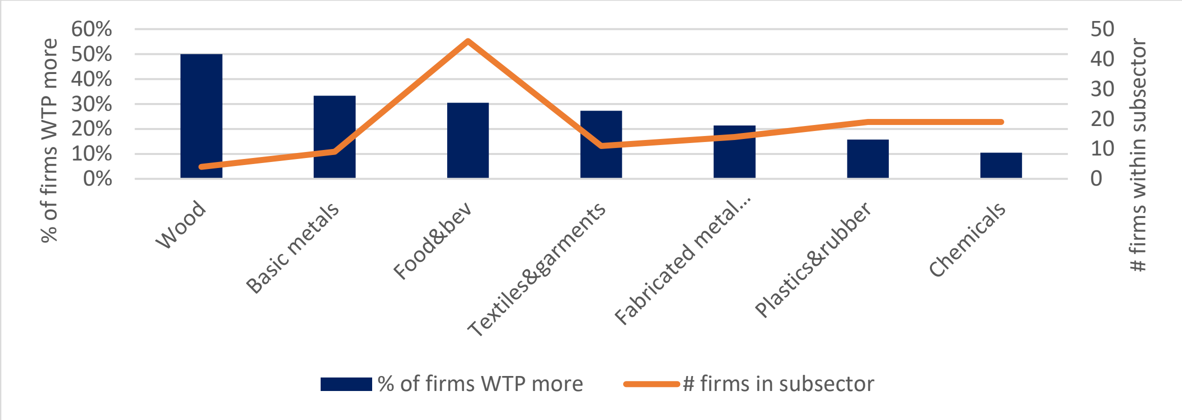
Because not all firms were willing to pay a higher tariff, predictors of whether a firm would be willing to see an increase in tariff were investigated, and amongst those who would be willing to see an increase in tariff, what increase they would be willing to pay.

5.6.1.1 Willingness to pay by firm characteristics

Respondents at 25% of firms said that they would be willing to pay a higher tariff for more electricity. 50% of wood and wood products firms' respondents said they would be willing to pay more, but the sample of just 4 firms is too small to reach a strong conclusion. Next most likely was respondents at basic metals firms at 33%, followed by food and beverages at 30% followed by respondents at textiles and garments firms at 27%. These all represented average response rates marginally higher than the overall average. Lower than the average were respondents at fabricated metal products, where 21%

said they would be willing to pay more. Respondents at plastics and rubber and chemicals firms were a lot less likely to respond positively to a higher tariff, with 16% and 11% answering in the affirmative.

Figure 20 Percentage of respondents willing to pay a higher tariff by manufacturing subsector



Source: Manufacturing survey

When whether a firm was willing to pay for more reliable energy was used as a binary dependent variable in logistic regressions, several independent variables were investigated. 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 independent variable that was consistently statistically significant and disproved the null hypothesis was whether a firm exported. More than eight variables could not be modelled at the same time because of the limited number of observations. The food and beverages subsector appeared as statistically significant at the 10% level in a couple of regressions. The basic metals and wood subsectors added to the regression model's R-squared and reduced the model's chi-squared probability score, whereas other subsectors had the reverse impacts.

Table 21 Variables tested for their statistically significant impact on willingness to pay for more reliable grid electricity

VARIABLES	wtp
foodbev	0.975*
	(0.580)
basicmetals	1.312
	(1.006)
wood	1.779
	(1.124)
exports	1.442***
	(0.550)
years	0.0196
	(0.0132)
hoursweek	0.00681
	(0.00560)
kva	0.000179
	(0.000269)
employees	-0.00244
	(0.00206)
Constant	-3.109***
	(0.763)
Prob>chi2	8.2%
Pseudo R2	11.4%
Observations	111
Model	logit

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

Source: Manufacturing survey

Firm that exports were shown to be willing to pay more for reliable energy at the 1% level of statistical significance. One would expect exporters' clients to be more demanding and less tolerant of failure, especially those with a large pool of potential suppliers.

5.6.1.2 Peak and off-peak usage indicating firms' elasticity of demand

The enumerators collected ZESCO bills for 48 companies whose respondents said that their firms 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.

The enumerators collected the ZESCO bills for 23 companies whose respondents said that their firms 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 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 per 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)
4. 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, it is not possible 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.

5.6.1.3 Energy consumption post tariff hikes indicating firms' elasticity of demand

ZESCO increased its tariffs to commercial manufacturing firms twice in 2017 – once on 15 May, and once on 1 September. The tariff increases are shown in columns 3-5 of the table below for firms with Maximum Demand 1, 2 and 3 kVA connections to the ZESCO grid.

ZESCO April and June 2017 bills were shared by 8 MD1 firms, 4 MD2 firms and 1 MD3 firm and ZESCO August and October 2017 bills were shared by 8 MD1 firms, 8 MD2 firms and 2 MD3 firms. While these are not large numbers when split into the three categories, they aggregate to 18 observations for August – October, 2017. Except for a decrease in energy consumption observed from April-June, 2017 for energy charged at the standard rate to MD2 firms, an increase in energy consumption is observed for all other types of firm by grid connection size, period and tariff rate. Demand elasticity would be expected to be negative, but this is the case only once in the table below in columns 10 and 11.

This shows that ZESCO is not charging tariffs high enough to the clients that shared their ZESCO bills tariffs even at the September rate which are impacting their energy consumption. Indeed, energy consumption can be seen to be increasing even more at the peak rate than for the standard rate, especially for the higher Maximum Demand firms, presumably because they are already near their full capacity utilisation rates during standard tariff hours.

Table 22 The non-effect of tariff hikes on 8 MD1 firms, 4 MD2 firms and 1 MD3 firm

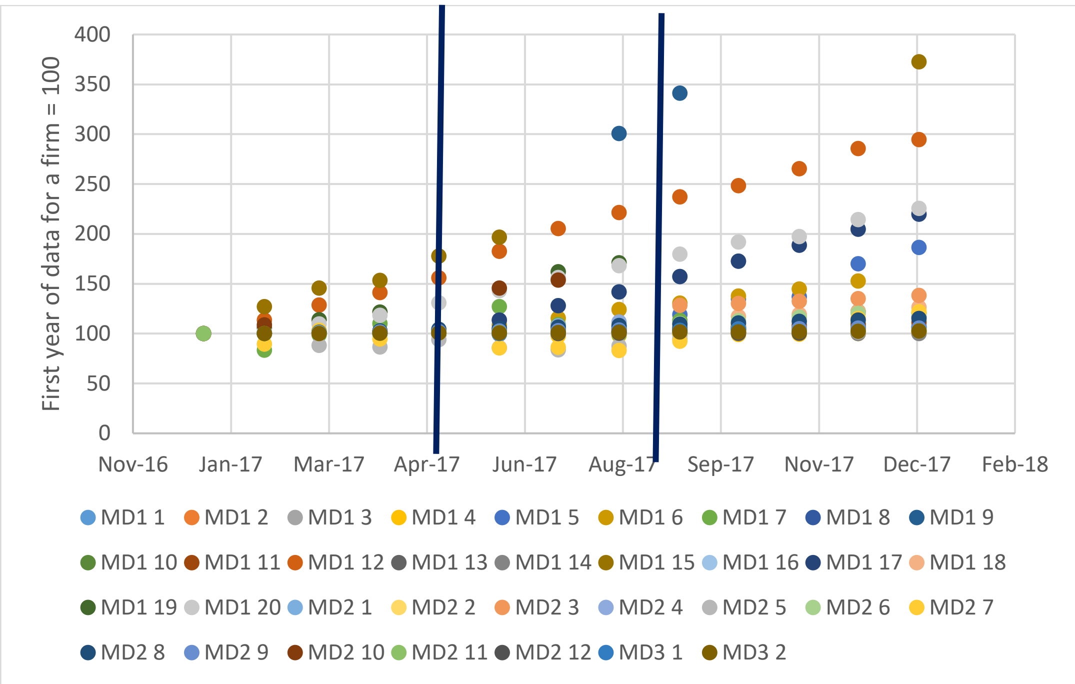
1	2	3	4	5	6	7	8	9	10	11
Maximum demand category	**Charge for time of day**	**Tariffs before**	**Tariffs as of 15 May, 2017**	**Tariffs as of 1 Sept, 2017**	**% price increase in May**	**% price increase May-Sept**	**average % consumption increase April-June**	**average % consumption increase Aug-Oct**	**implied price elasticity, April-June**	**implied price elasticity, Aug-Oct**
MD1-Capacity between 16 - 300kVA	Energy Charge(K/kWh)	0.2	0.3	0.35	50%	17%	14%	8.5%	0.28	0.51
	Off Peak Energy Charge(K/kWh)	0.15	0.23	0.26	53%	13%	35%	13%	0.66	0.98
	Peak Energy Charge(K/kWh)	0.25	0.38	0.44	52%	16%	49%	12%	0.95	0.75
MD2-Capacity between 301-2,000kVA	Energy Charge(K/kWh)	0.17	0.26	0.3	53%	15%	-1%	11%	- 0.02	0.71
	Off Peak Energy Charge(K/kWh)	0.13	0.2	0.23	54%	15%	16%	15%	0.29	1.02
	Peak Energy Charge(K/kWh)	0.21	0.32	0.37	52%	16%	6%	16%	0.12	1.03
MD3-Capacity between 2,001-7,500kVA	Energy Charge(K/kWh)	0.14	0.21	0.25	50%	19%	1%	1.4%	0.01	0.07
	Off Peak Energy Charge(K/kWh)	0.1	0.15	0.18	50%	20%	18%	12.9%	0.36	0.65
	Peak Energy Charge(K/kWh)	0.17	0.26	0.3	53%	15%	42%	23.6%	0.79	1.53

Source: Manufacturing survey

These observations and interpretations are matched and supported by Figure 21 to Figure 24 below, which show the trends in energy consumption for a total of 34 firms that shared their ZESCO bills for the period January 2017 to January 2018.

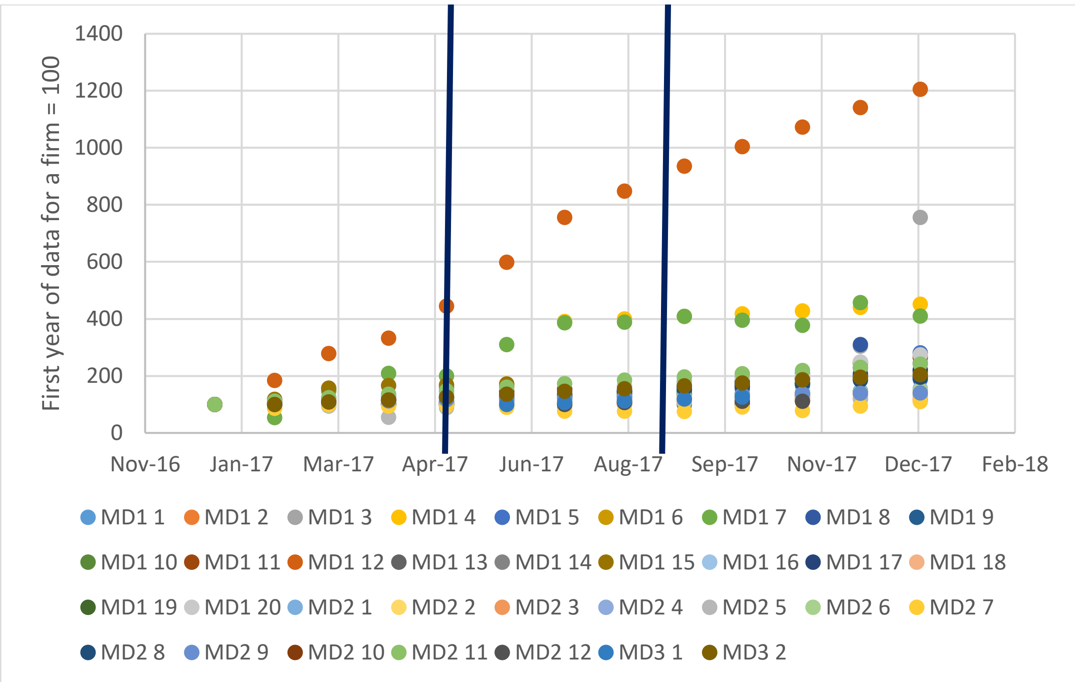
Each figure shows a general increase in energy consumption over the period in spite of the tariff increases. In spite of the higher tariffs charged during peak hours, the highest increases in energy use are during off-peak and peak hours.

Figure 21 Standard energy consumption for by 34 MD1, MD2 & M3 firms before & after the tariff hikes of 15 May 2017 & 1 September 2017



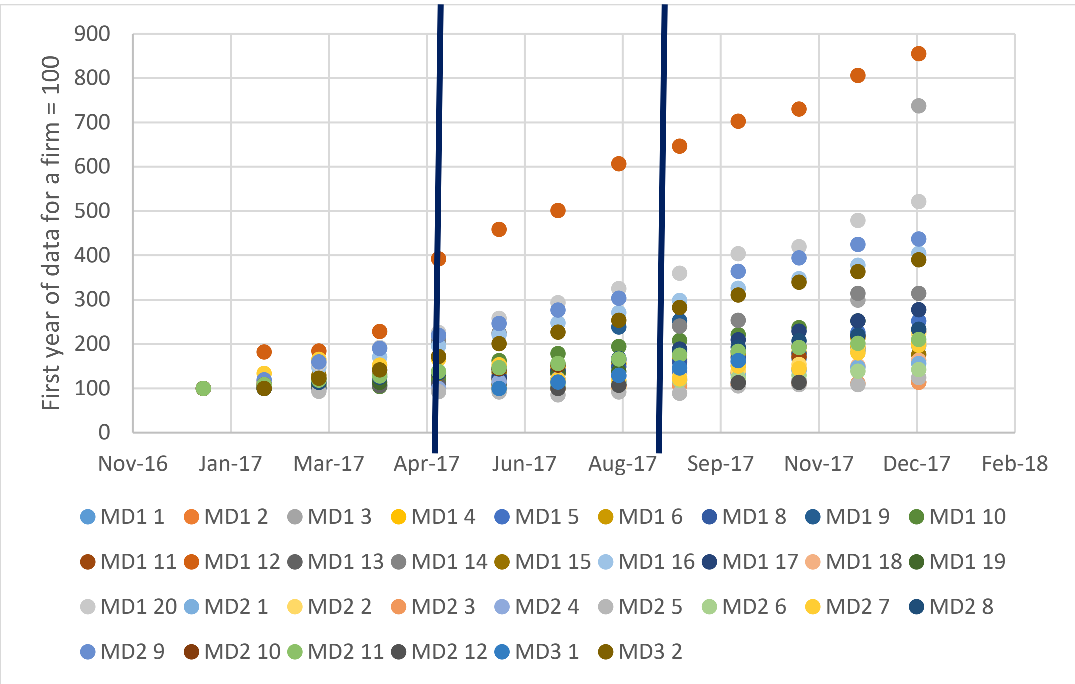
Source: Manufacturing survey

Figure 22 Off-peak energy consumption for by 34 MD1, MD2 & M3 firms before & after the tariff hikes of 15 May 2017 & 1 September 2017



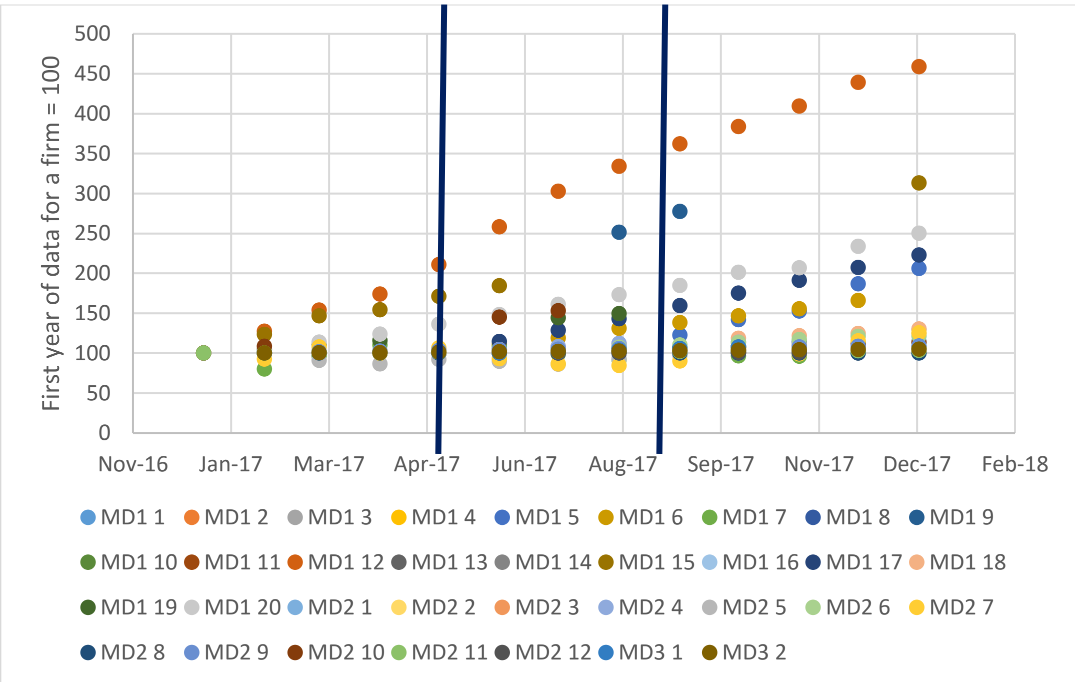
Source: Manufacturing survey

Figure 23 Peak energy consumption for by 34 MD1, MD2 & M3 firms before & after the tariff hikes of 15 May 2017 & 1 September 2017



Source: Manufacturing survey

Figure 24 Total energy consumption for by 34 MD1, MD2 & M3 firms before & after the tariff hikes of 15 May 2017 & 1 September 2017



Source: Manufacturing survey

5.6.1.4 Discussion on willingness to pay

Figure 21, Figure 22, Figure 23, Figure 24 show that firms did not reduce their electricity consumption in spite of tariff hikes. The increase in consumption suggests that that firms would have been willing to pay more for grid electricity. The same can be inferred of the current slightly higher tariff levels for peak energy – they do not seem to deter energy use at peak energy hours.

At the time that the surveys were conducted, the average of what respondents said on behalf of firms that would be willing to incur higher tariffs for more reliable energy was USD 0.04/kWh more than they currently did. This is the latest figure offered by research on Zambia, updating the findings of Batizdirai et al which were made before the most recent tariff hikes (Batidzirai, Moyo and Kapembwa, 2018).

USD 0.04/kWh would not likely get ZESCO to its cost recovery levels in order to be able to invest in new installed energy capacity if those cost-recovery levels were USD 0.10/kWh. It needs to be borne in mind that the surveys were conducted in a period of relatively low power outages, but that without an increase in energy supply and Zambia's continued reliance on hydropower, power outages will become a cyclical issue dependent on rainfall and reservoir levels. Firms would likely therefore have expressed higher willingness to pay for more reliable energy during periods of acute power outages. Respondents would also have been inclined to understate their actual willingness to pay in order to protect their firms' profitability. In a separate household survey I carried out online in December 2019 prior to ZESCO's tariff hikes of 1st January 2020 (which were still unlikely to have reached the cost-recovery threshold), 63% of respondents said that they would be willing to pay more for reliable energy – more than double the proportion of respondents on the behalf of manufacturing firms. The average that all respondents said that they would be willing to pay was circa USD 0.095/kWh. The difference between the household and manufacturing survey were

1. The timing of the survey: December 2019 was in the midst of even more severe power outages when respondents were experiencing up to 15 hours of official load shedding (ZESCO, 2019), up from eight hours in 2015 and 2016. The timing of the manufacturing survey was April-August 2018, when some manufacturing respondents thought that the power outages were a thing of the past.
2. The way in which I framed the question: For the household survey, I explained to the cost of self-generating energy from diesel generators, explained that a system-sustainable tariff would allow for more reliability and anchored their responses around a cost-recovery mark (see Box 2).

Box 2 How the household survey question relating to willingness to pay was phrased

15. Households currently pay K 0.15/kWh for the first 200kWh/month and K 0.89/kWh on energy consumed after the first 200kWh/month.

Zesco is not charging any customer a cost-recovery tariff, which means it does not have the money to supply more energy.

Bearing in mind that it costs about K 4.2/kWh to run a diesel-generator, if it meant more reliable energy, what is the maximum you would pay:

- K 1.2/kWh on all your household energy consumption?
- K 1.5/kWh on all your household energy consumption?
- K 1.7/kWh on all your household energy consumption?
- Other, K/kWh (state how much in comments)

Comments:

Firms most likely to pay for a premium service are those that are export oriented. ZESCO would therefore have more latitude to invest in increased dependable installed energy capacity on those firms' behalf.

In terms of firms refusing to accept higher tariffs, distrust of ZESCO's competence seemed to be the most important reason, stemming largely from its inability or unwillingness to communicate correct information about outages. Receiving correct information was the exception rather than the norm. Given that 92% of respondents were either located in industrial zones or an MFEZ, this doesn't speak well to ZESCO's ability to support manufacturing firms well.

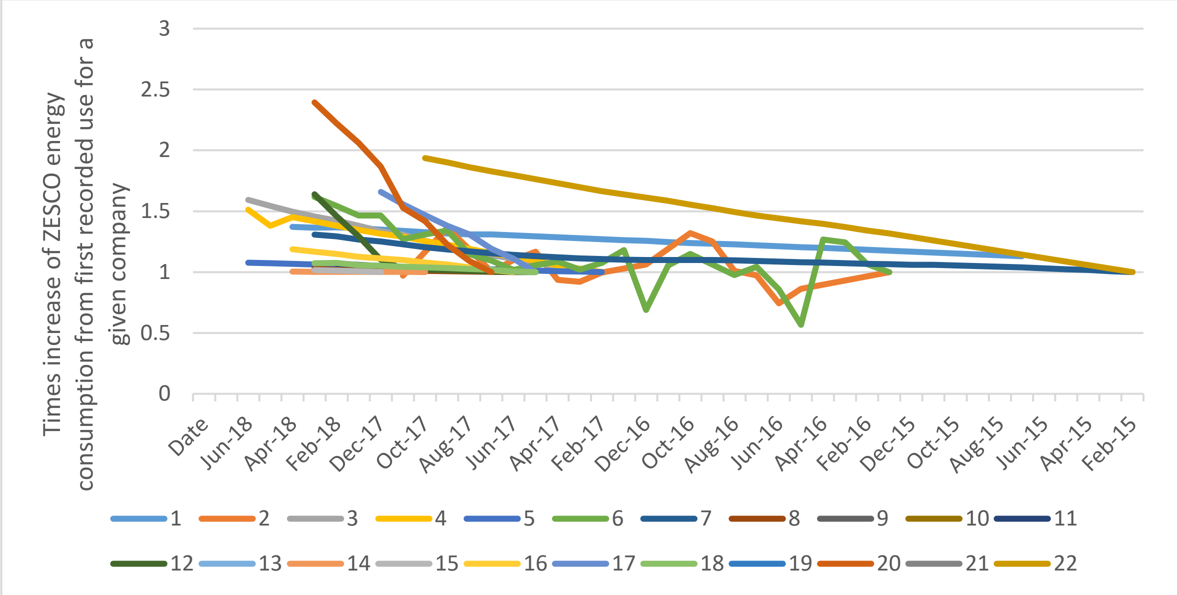
Manufacturing firms felt they were subsidising the mining sector (interview with the CEO of the Zambia Association of Manufacturers on 28th May, 2018). The Director of Economic Regulation at the Energy Regulation Board (interviewed on 6th June, 2018) said that the Energy Regulation Board was endeavouring to regulate ZESCO's tariff to the Copperbelt Energy Corporation, which was low, by pushing through legislation enabling it to do so. A director of customer affairs said that ZESCO was charging subsidised tariffs to all customers (personal communication, 4th September, 2019).

The second most popular reason cited by 12 firms for not wanting to pay higher tariffs was that it would affect profitability, but judging by the energy consumption rise in peak-hour energy following the two tariff hikes, they could probably afford a further reduction in profitability.

5.6.1.5 Discussion on pattern of ZESCO energy consumption

Figure 21, Figure 22, Figure 23 and Figure 24 show that generally for a sample of more than 30 large Zambian manufacturing firms, energy consumption has been increasing month by month in spite of tariff increases. The same pattern can be seen for 22 firms in Figure 25 from February 2015 until May 2018.

Figure 25 The ZESCO-grid electricity consumption patterns of 22 Zambian manufacturing firms



Source: Manufacturing survey; manufacturing firms' ZESCO bills

These patterns go against the pattern shown in Table 1 where aggregate manufacturing demand dropped in 2016 and had not recovered to its 2015 level by 2016. This might be explained by the possibility that not all manufacturing firms survived the outages, as suggested by Sichone et al (2016) – thus the aggregate amount consumed decreased while the per capita consumption did not.

The 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 25 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 (2015) predict: rapid economic growth could cause an increase in electricity demand that leads to shortages, which then reduces productivity.

The perpetual and recent growth 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. Indeed expectations have been shown to impact energy use as shown in section 9.6 – with an increase in rainfall comes an expectation that more energy can be consumed, which is accompanied with an increase in power outages.

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

The lowest marginal cost of outages that can be inferred for firms that use backup generation is the difference between the cost per kilowatt hour of energy of running the generator and the cost that the firm would have paid ZESCO. The rational firm will only self-generate electricity if the cost to do so is lower than the benefit gained from doing so.

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 31st August 2018, when collection of data was finished, the ZMK/USD varied around 13. (It was 18.25 as of 3rd August 2020 according to Google.com.) The table below shows what firms' marginal cost/kWh would have had to exceed for them to self-generate:

Table 23 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%

Source: Manufacturing survey

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. Thirty-seven percent (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.

In section 5.5.2.2, it was noted that 95% of firms that had access to a generator used them, meaning most firms with generators incurred a marginal cost of backup generation of at least USD 0.25/kWh.

In section 5.5.2, the most popular years of purchase for generators were identified as 2016 and 2015, when power outages were at their worst. Export-facing firms, firms with more employees, firms with greater production hours and firms in the food and beverages subsector invested in greater capacity; firms which were based in Kitwe, which had more employees, which were export-facing used their generation capacity more, whereas firms in the basic metals subsector and wood subsector used their generators less, but most likely for different reasons. Given that basic metals firms were likely to invest in more generation capacity but were less likely to use their installed capacity, the marginal cost of outages of circa USD 0.25/kWh might be a huge underestimation for the sector, because it is unable to use the capacity it would want to because of lack of cash flows; firms in the subsector therefore probably suffer more greatly from unmitigated power outages.

Discussion

Interviews with key informants and firms indicated that the cost of self-generating electricity is approximately USD 0.29/kWh, not dissimilar to the USD 0.27/kWh figure that Steinbuks and Foster found as the average variable cost of self-generated electricity in Zambia in 2010 (Steinbuks and Foster, 2010). The value of USD 0.59/kWh that Farquharson et al used (2018), exclusive of capital expenditure, operating and maintenance expenses was likely incorrect.

The minimum marginal cost of outages would be equal to the observed difference between the higher cost of self-generating an extra kilowatt hour of energy and the lost opportunity of paying the lower cost per kilowatt hour of on-grid energy. Previous literature (Bental and Ravid, 1982; Adenikinju, 2003; Steinbuks and Foster, 2010) has got this wrong by including a portion of the sunk capital cost of a generator. Table 23 shows that the minimum marginal cost of power outages is north of USD 0.25/kWh, with the largest firms that pay the lowest cost for on-grid energy paying the highest marginal cost of power outages of USD 0.278/kWh for off-peak energy.[56]

While it appears to be industrial policy to subsidise Zambia's largest manufacturing firms through the lowest electricity tariffs, the perverse effect is that they could end up paying more on backup generation caused by power outages that could have been avoided had they been charged a tariff that would have enabled the purchase of additional power generation. Consider, for example, the scenario where a large manufacturing firm operating 24 hours per day incurs 8 hours of outages per day, as depicted in Table 244 below. The cost of running backup generation for 100% of its power needs for a third of the day would result in energy costs exceeding those were the firm to pay a cost-recovery tariff to the grid. Beyond the extra energy costs, it would also incur the non-monetised costs highlighted in Figure 10, i.e. damage to equipment, reputation, inventory, extra staff costs, loss in clients. In this scenario, the implication is that large manufacturing firms would benefit more from system-sustainable tariffs than lower tariffs.

Table 24 Hypothetical scenario in which a large manufacturing firm pays more for energy because it is not paying a cost-recovery tariff that would pay for new installed dependable power supply

	Cost, $/kWh	Hours	Cost, $
Backup generation	0.29	8	2.32
Standard on-grid energy currently MD3	0.016	16	0.26
			2.58
Hypothetical cost-recovery on-grid energy	0.1	24	2.4

[56] As of 31 August, 2018, when the data was finished being collected, the ZMK/USD varied around 13.

Besides the issue of costs, there is the issue of affordability. Larger manufacturing firms would be best placed to pay for tariffs that allow ZESCO to deliver reliable electricity. Table 17 shows that size in terms of employees is a predictor for both the capacity of installed power as well as the extent to which generators are used. And yet they pay even less than small manufacturers. Large manufacturers are charged as little as USD 0.01/kWh for off-peak hours while lower maximum demand category commercial customers are charged up to USD 0.03/kWh for peak hour use (ZESCO Ltd, 2017b).

This is not the case 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). Zimbabwe is not known for being a paragon of financial prudency, and yet Zambia's public utility makes it look thus by charging lower tariffs based on the marginal operating costs of fully-amortised power generation assets, with no accounting for future construction costs. This issue seems to be recognised by ZESCO in its recent application for tariff increases (African Energy, 2019; Phiri, 2019).

Another area for restructuring tariffs is the differential between peak and off-peak charges. Reducing peak hour demand would reduce the pressure on ZESCO to increase its installed power capacity. For example, 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. The collected ZESCO bills for these firms show that they consume energy in a 16%:9% ratio for off-peak to peak hour energy. Had they been operating 168 hours a week (the maximum number of hours in a week), they would have consumed 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. There is therefore 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. Figure 21, Figure 22, Figure 23 and Figure 24 further highlight the point that peak hour tariffs are doing little to discourage energy during peak hours. Energy use saw its greatest growth in 2017 during both off-peak and peak hours, in spite of two tariff hikes in 2017.[57]

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 between standard and off-peak energy and USD 0.06/kWh between standard and peak-hour energy. Hearing two of three respondents say they pay higher wages for workers working off-peak hours, and hearing one of them state that they pay twice the wages that they do during normal business hours, the difference in cost between off-peak and standard energy would have to off-set this.

5.6.3 Summary

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. This is to be expected. Running diesel-generators

[57] Presumably energy consumption growth was greatest during non-standard hours because firms were already manufacturing at capacity during standard hours. To increase energy consumption during standard hours, they would have to install extra capital. It would seem that it is either cheaper or more affordable to increase the capacity utilisation rate during non-standard hours than to install extra capacity for use just during standard tariff hours.

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. The discussion above also explored how the cost of backup generation inhibits the extent to which the basic metals subsector use electricity.

A cost recovery tariff that allows ZESCO to build extra power generation capacity would be better industrial policy than low tariffs that prevent ZESCO from delivering its customers reliable electricity delivery.

To reduce the peak demand it has to meet, ZESCO should charge a much higher differential in tariffs at times of peak demand that will alter firm behaviour.

5.7 Special energy provision for important clients

ZESCO's economists (ZESCO economists, personal communication, 10 November, 2017) said 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. Enumerators 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 the expectation that multi-facility economic zone (MFEZ) clients would have reliable energy, the one manufacturing firm with which enumerators 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 the interview by an enumerator with their assistant supervisor of production.

5.8 Willingness to sell energy back to the grid

While prospecting, the Field Manager discovered a cement manufacturer in the Copperbelt that used entirely self-generated energy from its own purpose-built power plant. The firm 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.

Discussion

If 29% respondents said that their firm would be willing to sell energy back to the grid, a mechanism should exist for them to do so, especially when ZESCO is forced into enact load shedding.

The team of enumerators did not witness the use of self-generation of energy using solar panels, biomass (although this has been reported in the introduction from the annual report of one listed agro-processing firm) or industrial waste. This represents an opportunity.

A conversation with an EPC contractor and developer of energy solutions for manufacturing firms (2 November, 2018 – see annex 3.2.3 for further details) revealed that they construct 5MW to 40MW independent power projects that are fuelled by industrial waste such as paper mill pulp (biomass) or such as steel mill blast furnace gas, or excess wood into biomass, or waste into fuel. They are interested in opportunities in Zambia. They said they are one of about ten players operating in a niche space.

An environmental benefit of using biomass, sawdust, tree stumps, papermill sludge, laminated wood residues, deinking sludge, grain, blast furnace gas, and coke oven gas as fuel is that rather than end up landfills, make their way into waterways or be released directly into the atmosphere, these waste products can be used productively to generate energy for the companies that produce them (Martalla, personal communication, 2 November, 2018).

This chapter assessed the results of the manufacturing survey and discussed its contribution to knowledge. Given its industry-orientation, the next chapter will investigate why ZESCO had not prepared to prevent the outages that caused such disruptions to the manufacturing sector.

6. Why Zambia's system of energy provision did not prevent the power outages of 2015 and 2016

Several reasons contributed to the power outages of 2015 and 2016. Increasing transmission and distribution losses was one of them. Another was Zambia's almost complete lack of resilience to droughts, as well increased demand and little change in supply since the World Bank had invested in Zambia's hydropower. Path dependence explains why Zambia's system of energy provision did not heed to warnings that severe drought was becoming increasingly likely, and act with greater urgency to ensure diversification from hydropower in the Zambezi River Basin. Path dependence explains why Zambia's system of energy provision did not charge a tariff to end-consumers that would allow for the funding of additional and climate-resilient baseload power generation assets.

In chapter 2 we saw the nexus between industrialisation and economic growth. We were introduced to Zambia's system of energy provision, saw that the World Bank was a significant financier of Zambia's power generation assets in use in 2015, and saw that mineral extraction, beneficiation and industrialisation motivated the World Bank's funding of Zambia's hydropower generation assets, besides its other political interests. In chapters 3 and 5 we saw what power outages mean for manufacturing and what they have meant for Zambian manufacturing firms experiencing outages of up to 8 hours a day following El Niño-induced droughts. In this chapter we will explain why Zambia's system of energy provision did not prevent the outages of 2015 and 2016, or, indeed, 2019 which saw outages of up to 15 hours (ZESCO, 2019).

Before anything else, we will note the rising incidence of transmission and distribution losses which the literature seems to have neglected. It appears as though these losses surpassed the difference in energy consumption between that in 2014 and the years of the outages in 2015 and 2016. These losses are the first issue to which Zambia's system of energy provision should attend, together with looking at releasing inefficiencies in existing infrastructure through maintenance prior to looking at adding and diversifying power generation assets.

Having assessed the latent additional power generation that can be released without constructing new power generation assets, we will then diligence the system of provision's demand projections to appreciate to what extent additional power generation is required. Next, we will investigate how climate change and droughts are expected to impact hydropower assets, the Zambian system of provision's favoured mode of generating energy. After that we will consider alternatives sources of energy before finally attempt to explain why Zambia's system of provision did not diversify from hydropower in the Zambezi River Basin in a timely manner. In doing so, we will rely heavily on the historical institutional path dependent framework.

6.1 Transmission and distribution losses and other inefficiencies

Besides low rainfall which caused a 40% reduction in energy generated at Kariba North hydropower dam – which accounted for 45% of Zambia's installed power capacity in 2016 (Energy Regulation Board of Zambia, 2017a, p. 57) – path dependence and the other factors discussed above, rising transmission and distribution losses since 2007 played a role in Zambia's power outages.

ZESCO's transmission and distribution losses were recorded as 10% (Energy Regulation Board of Zambia, 2017a, p. 63) according to self-reported data by ZESCO. An Energy Regulation Board official noted that this was too good for the kind of data his agency was able to extract from what they were given by ZESCO. The implied losses of generated energy grew to almost a fifth of energy generated in 2016, calculated by subtracting from the output generated the net exports and domestic consumption and dividing that by the output generated (see Table 25 below) – well above the 12% threshold below which ZESCO is required to maintain distribution losses. This could be the result of both transmission losses and non-technical losses, such as pilfering and unmetred use. ZESCO economists said that these calculations in line 6 of the below table were credible calculations (personal communication, 3 September, 2019, ZESCO Ltd, Lusaka). The transmission and distribution losses in 2015 and 2016 were greater than the difference in domestic energy consumption between 2014 and 2015 and 2014 and 2016 respectively.

Table 25 Energy lost in transmission and distribution compared with the energy deficit in 2015 and 2016

Zambia's energy crisis in 2015 and 2016 - decrease in production, increase in energy losses resulting in increased imports

	2013	2014	2015	2016	2017	% drop in 2016 from 2014
1 - Energy output from all sources, GWh	13,299	14,453	13,440	11,696	15,195	*19%*
a - Kariba North	4,507	4,999	4,316	2,964	2,689	*41%*
b - Kafue Gorge	7,463	6,666	6,417	5,853	7,363	*12%*
c - Kariba North Bank Extension		1,162	1,179	672	599	*42%*
d - Victoria Falls	810	811	785	754	684	*7%*
2 - Net exports, GWh	1,010	1,243	391	- 1,391	310	
a - Imports, GWh	73	13	785	2,185	753	*-16708%*
b - Exports, GWh	1,083	1,256	1,176	794	1,063	*37%*
3 - Domestic energy consumption, GWh	10,846	12,405	11,450	10,858	12,192	
Annual growth in energy consumption		*14%*	*-8%*	*-5%*	*12%*	
4 - Output - (exports + domestic consumption), GWh	1,370	792	814	44	1,940	
5 - Output - (net exports + domestic consumption), GWh	1,443	805	1,599	2,229	2,693	
6 - Implied unused generated energy, % = 5/1	11%	6%	12%	19%	18%	
7 - lost energy, GWh	1,443	805	1,599	2,229	2,693	
8 - Difference in energy consumption between 2014 and 2015/2016			955	1,547		

Sources: Energy Regulation Board of Zambia, 2015, 2016a, 2017a, 2018

The literature points to other inefficiencies that can be released. Before investing in additional power capacity, Beilfuss suggests investing in rehabilitation, refurbishment and renovation to increase hydropower capacity (Beilfuss, 2012, p. 36). Yamba et al advocate for pumped storage schemes to accompany select hydropower stations to ensure continuous energy (Yamba, Walimwipi and Mzezewa, 2011). So far in Africa no hydropower plant has been coupled with solar-pumped storage (Ncube and Lufumpa, 2017). Plans are underway in Zimbabwe to change this. Swedish-owned Ngonyezi Projects has entered a non-consumptive water use agreement with the Zimbabwe National Water Authority to install a 2,000MWh pumped storage hydro facility and 300MW floating solar photovoltaic plant so that 30% of the solar PV is supported by storage. The solar panels are anticipated to float on 500 hectares of reservoir surface. This will cool the solar panels, reduce algae growth and reduce evaporation (ESI-Africa, 2019).

6.2 Zambia's future grid-electricity demand

Zambia's energy demand can be forecast by applying the elasticity between GDP and energy consumption to forecast GDP. A log-log regression of Zambian energy consumption (Energy Regulation Board of Zambia, 2016a, 2017a, p. 9, 2018, p. 36, 2019a, p. 39; World Bank, 2020d) against Zambia's real GDP (World Bank, 2020u) and Zambia's population from 1990-2018 (World Bank, 2020u) shows that GDP has been a statistically significant predictor at the 1% level in a model (see Table 26) with 89% explanatory power. A 1% increase in GDP has represented a 0.52% increase in energy consumption. The reason for the model having only an 89% explanatory power is because 2015 and 2016 represented years in which energy consumption dropped but GDP increased, albeit at a slower rate, meaning that the model does not perfectly predict historic results; the model has, after all been constructed on just 29 observations, making it a weak regression model. The model also shows that population does not have a significant impact on Zambia's energy on-grid consumption. This makes sense given Zambia's low grid-access.

Table 26 Log-log regression of the relationship between energy consumption, GDP and population on Zambia's energy consumption

VARIABLES	1990-2018 lnenergy
lngdp	0.516***
	(0.182)
lnpopulation	0.0260
	(0.356)
Constant	-4.305**
	(1.617)
Observations	29
Prob>F	0.00%
R-squared	89.1%

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

Source of underlying data: Energy Regulation Board of Zambia, 2016a, 2017a, p. 9, 2018, p. 36, 2019a, p. 39; World Bank, 2020d

Data points for on-grid electricity access are unreliable. Data in the World Bank's indicators for electricity access go up one year and down the other (World Bank, 2020u), which is not likely even with moderate population growth. Beyond the World Bank, government agencies provided electricity access data. It was apparently 22% in 2008 (Ministry of Energy and Water Development, 2008) for all forms of access and 32.9% in 2018 (ZICTA and CSO, 2018). It is difficult to pinpoint when off-grid solar home systems became prevalent in Zambia, but it is probably safe to assume that most electricity accessed in Zambia in 2008 would have been via the grid.[58] Interpolating the 2009-17 access rate using

[58] The Ministry of Energy and Water Development's 305 page Power System Development Master Plan for Zambia published in 2011 mentions solar home systems only once on page 6, and then only in terms of knowledge of demand for them (Ministry of Energy and Water Development, 2011, p. 6). As of 2010, off-grid solar devices were serving only 1 million households worldwide, compared with 73 million households by 2017 (Dalberg Advisors, Lighting Global and World Bank, 2018, p. 28), when 86% of off-grid suppliers were concentrated in East Africa, compared with just one supplier (Fenix International) in Zambia (Dalberg Advisors, Lighting Global and World Bank, 2018, p. 95). At the turn of the century, off-grid

the compounded annual growth rate from 2008-2018, a log-log regression between energy consumption on the left hand side and GDP, population and electricity access on the right hand side, the regression model comes out with a 94.5% R-square and 3 right hand side statistically significant variables. Unfortunately, the coefficient for the log of electricity access variable does not prima facie make sense: it is negative. Energy consumption should not be decreasing as electricity access increases. Possible explanations could be that when grid expansion occurs, connecting infrastructure for other customers is disrupted; or that when load-shedding occurs ZESCO does not prioritise high-consumption customers – when energy is diverted towards low-consumption customers, aggregate consumption decreases. This is an area for further examination.

The IMF's World Economic Outlook used statistics from Zambia's National Statistics Office, which provided last actual[59] data from 2017 (IMF, 2019). The pre-COVID-19 and pre-power outages of 2019 and 2020 forecast the IMF published was that Zambia's real GDP in 2024 would be 115% of its real GDP in 2017, a real compounded annual growth rate (CAGR) of 2%. A 15% increase in GDP would therefore, according to the elasticity between GDP and energy consumption shown in Table 26, correspond to a 7.5% growth of energy consumption. This would imply energy consumption of 13,100 GWh by 2024-2028. In fact, this was achieved by 2018, implying that there was latent unmet demand in 2017. If one were to assume that 13,100 GWh was unconstrained demand for existing grid users in 2018, then a sustained 2% CAGR GDP growth from 2018 to 2030 would imply energy demand of 14,800 GWh by 2020 by applying the elasticity in Table 26. This is before accounting for greater electricity connectivity (for what is the point in worrying about Zambia's economic growth if it does not result in better living standards for the majority of the country's population?) but also before accounting for greater energy efficiency.

Greater on-grid connectivity can be driven by market forces, by political will or both, which in turn can be driven by international donors or the domestic electorate. Neither market forces nor political will seem theoretically to support greater expansion in on-grid connectivity.

In terms of international donor political will, the United Nations Sustainable Development Goal 7 for affordable, reliable, sustainable and modern energy for all by 2030 does not need to be met by on-grid energy; it can be met by off-grid solar products (Lighting Global *et al.*, 2020). Off-grid solar solutions overcome the lumpy, indivisible and irreversible barriers to private investment in generation and distribution (Ahmed, 2017). In fact, Lighting Global, a World Bank institution, and Vivid Economics consider Zambia to be the world's eighth most attractive market for pay-as-you-go solar energy products (Lighting Global and Vivid Economics, 2019). It seems that the donor community's comfort with off-grid solutions absolves the Government of Zambia of the responsibility to connect its population to the grid.

In terms of domestic political will, Zambia's last National Energy Policy was written in May 2008 (Ministry of Energy and Water Development, 2008) (emailed to me by an economist at the Energy Regulation Board on 9 September 2019) and its latest Power System Development Master Plan for Zambia was released in 2011 (Ministry of Energy and Water Development, 2011). As of 2008, 22% of the population had access to electricity (Ministry of Energy and Water Development, 2008), and the objective to increase it was vague, only 'to increase access to electricity' (Ministry of Energy and Water Development, 2011, p. 19). There was no specific, measurable or time-bound target. This seems to

solar systems were not yet technologically developed to be cost-effective without governments subsidies in Argentina and Sri Lanka (World Bank, 1999; Gunaratne and LGA Consultants, 2002). By 2012 in India, though, they were proving cheaper than kerosene for household lighting (Buragohain, 2012).

[59] As opposed to estimated.

indicate political inertia on the matter of expanding on-grid energy access. In terms of market forces, Zambia's growth trajectory has favoured the elite, as illustrated by a whole swathe of metrics in chapter 2.4, and the election of Michael Sata in 2011 on a platform against inequality.

Yet Zambia did see an increase in access to on-grid electricity with probably electoral pressure on Michael Sata's administration to deliver. From electricity access to 2.8 million people in 2008,[60] Zambia's access to on-grid electricity access increased to 5.6 million people by 2018,[61] representing an increase of on-grid electricity access for at least[62] 2.7 million people over 10 years.

If ZESCO were to extend on-grid electricity to 2.7 million additional Zambians, or 530,000 households (there are on average 5.1 Zambians per household (United Nations, 2017)) over a period of 12 years by 2030, and each household used on average 11kWh/day,[63] energy consumption would increase by 2,100 GWh per annum. This would make on-grid energy demand 16,900 GWh by 2030, assuming an ability of new users to pay ZESCO's tariffs.

By contrast, the Japan International Cooperation Agency, a donor agency, forecast that by 2025, Zambia's energy demand would be 18,000 GWh and would reach 21,000 GWh by 2030 (Japan International Cooperation Agency (JICA) and JERA Co. Inc., 2017, table 5.1-9). This 4% CAGR growth in energy consumption from 2018 to 2030 would imply annual GDP growth of 7.8% sustained over 12 years – high for any country. Only 3% of countries on the World Bank's database (World Bank, 2020b) sustained real GDP CAGR growth of 7.8% or more over the past 12 years.

In fact, JICA's forecast was based on an erroneous base of 14,370 GWh consumed in 2016 – 3,500 GWh more than what was consumed according to the Energy Regulation Board (2017a, table 2–1). JICA's forecast energy growth from the incorrect 2016 value to 2030 was 2.7% CAGR, implying a sustained CAGR growth of 5.3% for GDP using the elasticity shown in Table 26, something achieved by 16% of countries in the World Bank's database (World Bank, 2020b) over the past dozen years, i.e. much more feasible than 7.8% year-on-year growth. On the basis of 5.3% sustained GDP growth for a dozen years, Zambia's energy demand in 2030 would be 18,100 GWh.

Between these two demand energy scenarios based on an assumption of unconstrained energy demand in 2018 and the IMF/National Statistics Office's growth extrapolated, and JICA's adjusted growth scenario, demand for energy in Zambia could be between 17-18,000 GWh by 2030.

Taking into consideration the excessive losses in transmission and distribution, if ZESCO were to reduce implied energy loss from 18% in 2017 (line 6 in Table 26) to 10%, it would regain 1,200GWh of energy.[64] 15,195GWh output in 2017 from the Energy Regulation Board's counted power generation assets less 10% of transmission and distribution losses is 13,700GWh. This means Zambia's system of energy provision would need to generate an additional 3,300-4,300GWh energy by 2030 relative to what it generated in 2017.

6.3 Droughts in Zambia – forecasts, historical occurrences and competition for water

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60 22% access (Ministry of Energy and Water Development, 2008) x 12.8 million people (World Bank, 2020u)
61 33% (ZICTA and CSO, 2018) of 16.9 million people (ZICTA and CSO, 2018)
62 Since some of those with electricity access in 2008 may have had off-grid electricity access.
63 I was unable to find a statistic for average Zambian off-grid energy consumption. 10.75kWh was the average of summer and winter off-grid energy consumption in Uttar Pradesh (Sandwell *et al.*, 2016).
64 15,195 GWh in 2017 * (18% – 10%) = 1,174 GWh

Having assessed how much additional energy Zambia needs from new power generation assets, we will diligence the suitability of hydropower as a continued source.

Whereas political opposition argued that the power crisis was caused by the government's poor water and energy mismanagement, the government blamed climate change (Mfula, 2016; Funder *et al.*, 2018).[65] The two explanations are not mutually exclusive, nor even co-causations, but in fact go hand-in-hand if one extends the meaning of government from the political party which forms the executive to government institutions, and the period over which these institutions are scrutinised from an election cycle to a longer time horizon. We will use the historical institutional path dependent framework to explain why Zambia's system of energy provision did not respond to the changing realities of climate change.

Forecasts since 2002 have been indicating that as global temperatures rise, the frequency and intensity of drought and low reservoir levels would reduce Zambia's hydropower capacity factors (Harrison and Whittington, 2002; Beilfuss, 2012; Spalding-Fecher, 2012). The power outages of 2015 and 2016 bore this out. In 2016, the average capacity utilisation rate across Zambia's four large hydropower dams feel from 71% in 2014 to 54% in 2016 (see Table 27).

Table 27 In 2016, Zambia's large hydropower dams' average capacity utilisation rate was 54%

Average capacity utilisation rates of Zambia's large dams in 2015 and 2016

	Kafue Gorge Dam	Kariba North Dam	Kariba North Ext Dam	Victoria Falls Dam	Weighted average capacity utilisation rate
Installed capacity as of 2014, MW	990	720	360	108	
Energy generated in a year at 100% capacity utilisation, MWh = capacity x time	8,672,400	6,307,200	3,153,600	946,080	
Hours/y	8,760				
Generated energy, 2014, MWh	6,666,000	4,999,000	1,162,000	811,000	
2014 capacity utilisation, %	77%	79%	37%	86%	71%
Generated energy, 2015, MWh	6,417,000	4,316,000	1,179,000	785,000	
2015 capacity utilisation, %	74%	68%	37%	83%	**67%**
Generated energy, 2016, MWh	5,853,000	2,964,000	672,000	754,000	
2016 capacity utilisation, %	67%	47%	21%	80%	**54%**
Generated energy, 2017, MWh	7,363,000	2,689,000	599,000	684,000	
2017 capacity utilisation, %	85%	43%	19%	72%	59%

Data sourced from Energy Regulation Board of Zambia (2015, 2017a)

Yet instead of heeding the warnings, as well as the Intergovernmental Panel on Climate Change's forecasts (IPCC, 2018) for a 1.5°C and 2°C above pre-industrial levels scenarios, ZESCO neither pursued with urgency the diversification from hydropower with the commissioning of the Maamba Collieries coal-fired power plant in the half decade prior to 2015, nor had it changed its plans to not commission additional hydropower after 2015. Table 28 shows that as late as November 2017, ZESCO was planning to commission more than 70% of additional installed power capacity to come from hydropower (Zesco Ltd, 2017d).

65 The Energy and Water Development minister said "The situation is not only affecting Zambia alone but the entire southern African region due to Climate Change" (Mfula, 2016).

Table 28 Zesco's power generation expansion plan as of 2017

Zesco's power generation expansion plans, as of 10 November, 2017

Power plant	Developer	Energy source	Capacity, MW	Project status	Commissioning year
Maamba I	Nava Barat	Thermal (coal)	300	Construction	2016
Maamba II	Nava Barat	Thermal (coal)	300	Feasibility	2021
EMCO I	EMCO Energy	Thermal (coal)	300	Feasibility	2022
EMCO II	EMCO Energy	Thermal (coal)	300	Feasibility	2022
Lunsemfwa/Mkushi	LHPC	Hydro	190	Feasibility	2023
Kabompo Gorge	CEC	Hydro	40	Construction	2022
Mulungushi	LHPC	Hydro	50	Feasibility	2018
Lusiwasi Upper	Zesco	Hydro	15	EPC contractor mobilisation	2019
Lusiwasi Lower	Zesco	Hydro	86	EPC contract awarded	2021
Kafue Gorge Lower	Zesco	Hydro	750	Construction in progress	2020
Musonda Falls	Zesco	Hydro	10	Construction in progress	2017
Chishimba Falls	Zesco	Hydro	15	Construction in progress	2018
Batoka Gorge	Zesco	Hydro	1,200	Financing	2023
Lusaka	Ngonye	Solar	74	Financing	2019
Kitwe	IPP	Solar	100	Pre-feasibility	2019
Other Towns	TBA	Solar	100	Pre-feasibility	2019
Mutinondo	IPP	Hydro	43	Feasibility completed	2021
Luchenene	IPP	Hydro	34	Feasibility completed	2022
Kabwelume Falls	LPA	Hydro	96	Feasibility completed	2023
Kumdabwika Falls	LPA	Hydro	151	Feasibility completed	2023
Luapula-CX-Mombututa	Zesco/SNEL	Hydro	301	Feasibility in progress	2022
Luapula-Mambilima-2	Zesco/SNEL	Hydro	206	Feasibility in progress	2024
Luapula-1-Mambilima	Zesco/SNEL	Hydro	120	Feasibility in progress	2025
Wind power	Zesco/MASEN	Wind	150	Pre-feasibility in progress	2022
Solar rpower	Zesco/MASEN	Solar	200	Pre-feasibility in progress	2020
GETFIT	IPP	Solar	50	Pre-feasibility in progress	2020
Kalepela	Zesco	Hydro	4	Feasibility in progress	2023
Kapamba	Zesco	Hydro	12	Feasibility in progress	2024
Namundela	Zesco	Hydro	5	Pre-feasibility in progress	2024
Mumburuma	Zesco	Hydro	8	Pre-feasibility in progress	2024
Devil's Gorge	Zesco/ZRA	Hydro	543	Pre-feasibility planned	2030
Mpata Gorge	Zesco/ZRA	Hydro	1,000	Pre-feasibility planned	2035
Total			**6,753**		

Summary of planned projects by energy source by 2035	Capacity, MW	% share
Hydro	4,879	72%
Thermal (coal)	1,200	18%
Solar	524	8%
Wind	150	2%
	6,753	100%

Source: Zesco, 2017d

Additionally, while ZESCO did increase electricity tariffs to end consumers, it did not do so to a level that would allow it to finance the commissioning of additional assets (Haria and Ahmed, 2020).

- The remainder of this chapter will build out the details of this argument. It will show historic rainfall patterns across Zambia, show the historic analysis that was available to ZESCO when it was making its decisions viz. Maamba, and show the IPCC's projected climate outlook for Zambia. It will introduce the nexus approach for evaluating the use of water for drinking, agriculture and power generation. It will then introduce alternative sources of energy at ZESCO's disposal. Following this context, the remaining chapter will introduce and incrementally build upon the historical institutional path dependent framework to explain how early decisions have disproportionate consequences for the evolution of later decisions (Coffman, 2013b). The remaining chapter will then apply the historical institutional path dependent framework to explain why ZESCO did not diversify away from hydropower energy as domestic demand was catching up with supply and as the threat of drought was starting to be discussed; and

- explain how the pursuit of supporting Zambia's sectors driving economic and industrial development through subsidies and complacency for decades in not having to recover capital costs for fully depreciated generation assets resulted in ZESCO's inability to directly fund new power generation projects, or credibly pay independent power projects (IPPs) cost-recovery tariffs.

Separate from droughts and historical institutionalism, the remaining chapter will end by noting the recent rise in transmission losses.

* * *

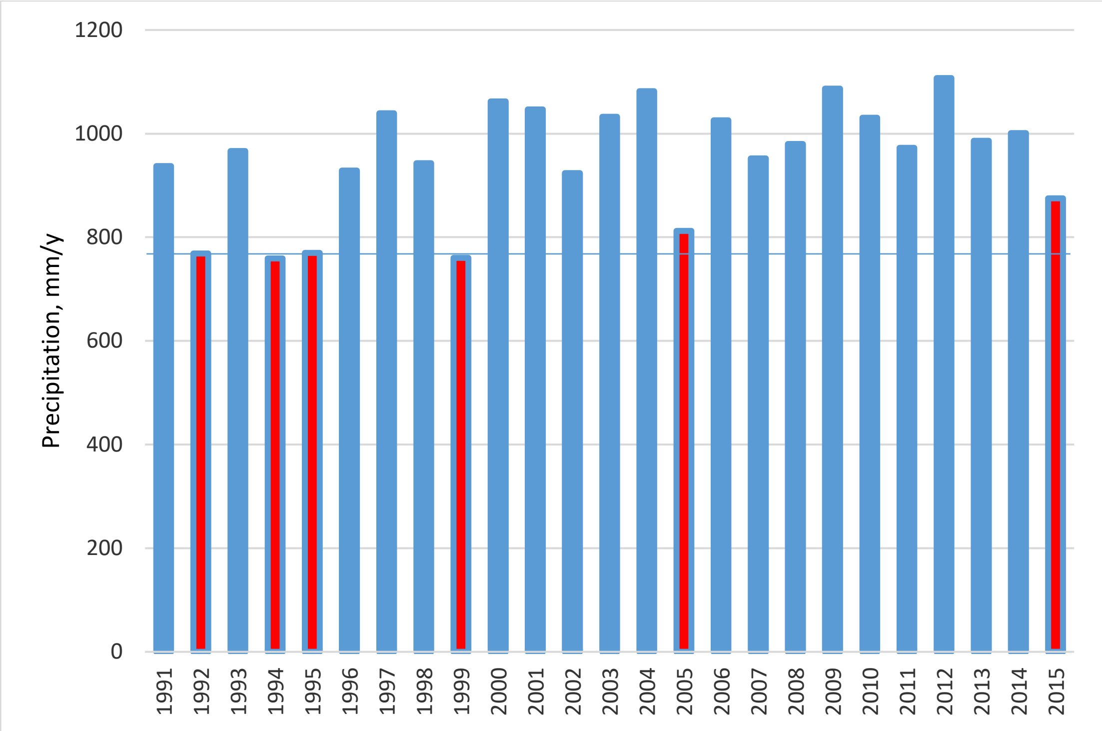
The IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels states that there is high confidence that human-induced global warming has resulted in an increase in the frequency and duration of marine heatwaves, and that further, there is medium confidence that it has led to an increase in the frequency and intensity of heavy precipitation events and increased risk of drought at a global scale (IPCC, 2018, p. 177). The former are known as La Niña events whereas the latter are known as El Niño events. Southern Africa is one of the regions associated with increased drought (IPCC, 2018, p. 178). With global temperatures rising, the El Niño effect is predicted to increase in frequency (Wang *et al.*, 2017). Models agree that for southern Africa, temperatures will rise faster at a range of 1.5°C-2.5°C as compared to the global warming average of 0.5°C-1.5°C (IPCC, 2018, p. 197). At a 1.5°C temperature rise, 'a robust signal precipitation reduction is found over […] areas of the Zambezi basin in Zambia' as well as in other parts of southern Africa (IPCC, 2018, p. 197). At a 2°C temperature rise, the region is projected to face 'robust precipitation decreases of 10-20% and increases in the number of [consecutive dry days]' (IPCC, 2018, p. 197). Further, reductions in streamflow of 5-10% in the Zambezi River basin have been associated with increased evaporation and transpiration events resulting from a rise in temperature, wish issues for hydroelectric power across southern Africa (IPCC, 2018, p. 197).

If IPCC forecasts were not enough to make future reliance on hydropower seem unattractive, even the historical base of evidence shows that

a. the reduction in rainfall in 2015 and 2016 was not unprecedented: 20% of years between 1991-2014 had seen less precipitation, and the level of precipitation in 2015 was less than a standard deviation from the mean precipitation for 1991-2014 (see Figure 26). World Bank data on precipitation for an unspecified location in Zambia for 1991-2015 (World Bank, 2018d) showed that 2015 was worse than average years for precipitation, but not unforeseeably bad.[66] Compounding the low reservoir levels for 2016 would have been the low levels from the year prior, but again, there was precedence for this (and the low rainfall in 2019 – three times in five years) in the past 25 years: 1994 and 1995 had been two consecutive years when rainfall had been lower than it was in 2015, and counting 1992 made three years of low rainfall in five years. The power outages of 2015 and 2016 were therefore a function of two things happening simultaneously: low-rainfall constrained supply from hydropower in 2015, and demand for energy at its highest level yet.

[66] As Zambia Meteorological Department data presented later in this thesis show, precipitation results do not vary greatly across Zambia, and nor does it vary much across the Southern African Power Pool. Zambia lies in the middle of the Zambezi River Basin, which also covers Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania and Zimbabwe.

Figure 26 Zambia's precipitation levels for an unspecified location. Almost a quarter of the 25 years 1991-2015 saw rainfall equal to or less than in 2015



Source: World Bank, 2018d; graph: own

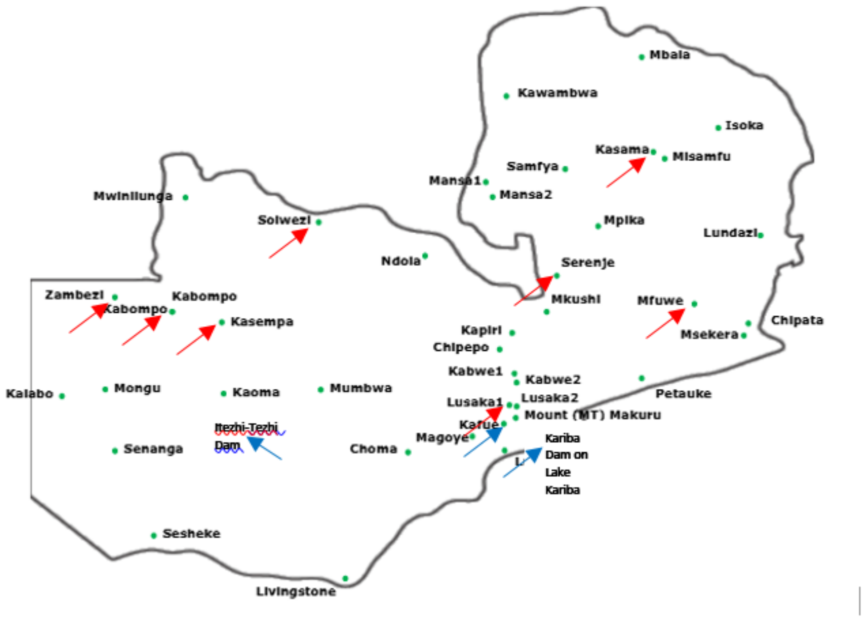
b. Zambia's geography is largely not resilient to drought: of 39 sites for which the Zambia Meteorological Department has rainfall data, only 9 have data for recent precipitation patterns, the sites for which are indicated on the map below. In general rainfall patterns have at least a 70% correlation (Zambia Meteorological Department, 2018) (see Table 29**Error! Reference source not found.**), the only exception being the Kabompo site which saw correlation as low as 65% with the Solwezi site and 69% with the Kasepma site. It should be noted, however, that these sites largely fall (perhaps with the exception of Kasama) within the Zambezi River Basin.

   Besides the Zambezi River Basin, northern Zambia falls within the Lake Mweru Basin, from which Luapula River, the upper section of the Congo River (formerly known as Zaire River) runs along the Zambian-DR Congo border. The Lake Mweru Basin lies between two well-established regions of opposing 'poles' of hydroclimatic response to phases of El Niño-Southern Oscillation and the Indian Ocean Dipole – southeast Africa and equatorial East Africa (Waylen, Annear and Bunting, 2019, p. 11). Attempting to deduce that El Niño and the Indian Ocean Dipole induced opposing effects on annual precipitation and Lake Mweru levels, Waylen et al noted that the varying numbers and locations of stations used to estimate basin input were a weakness and made their results tenuous (Waylen, Annear and Bunting, 2019, p. 10). Whereas the IPCC has consistently forecast reduced precipitation and water availability levels in 2001 and 2018 for the Zambezi River Basin, it has produced contradictory forecasts for the Congo River Basin.

Table 29 Highly correlated rainfall across sites in Zambia. Correlations of more than 80% highlighted in pink; of 70-79% highlighted in yellow.

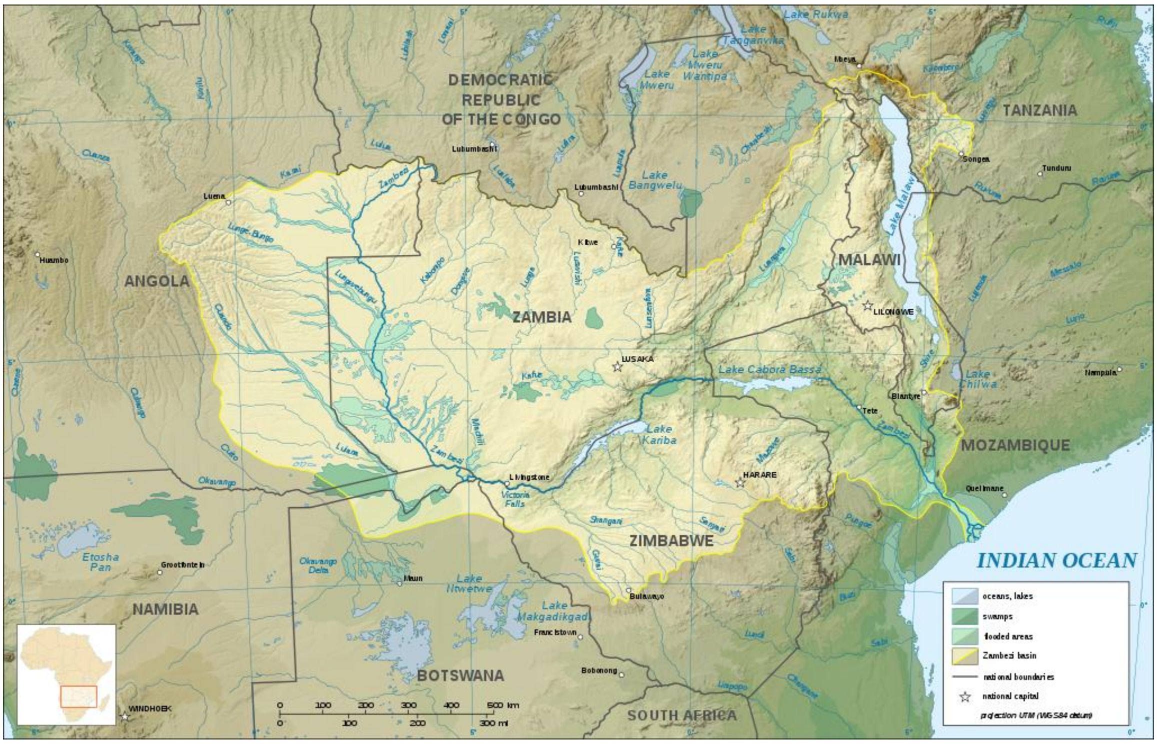
Correlation in rainfall patterns between Zambia Metereological Department sites, 2000-2018

Observations	Zambezi	Kabompo	Kasempa	Solwezi	Lusaka 1	Lusaka 2	Serenje	Mfuwe	Kasama
Zambezi	202	76%	75%	79%	82%	81%	79%	82%	76%
Kabompo	76%	80	69%	65%	73%	71%	74%	76%	76%
Kasempa	75%	69%	88	87%	80%	81%	83%	71%	85%
Solwezi	79%	65%	87%	191	79%	76%	86%	73%	83%
Lusaka 1	82%	73%	80%	79%	197	91%	80%	82%	74%
Lusaka 2	81%	71%	81%	76%	91%	191	79%	79%	71%
Serenje	79%	74%	83%	86%	80%	79%	182	78%	83%
Mfuwe	82%	76%	71%	73%	82%	79%	78%	197	73%
Kasama	76%	76%	85%	83%	74%	71%	83%	73%	197



Data sourced from Zambia Meteorological Department (2018). Map made with the assistance of Graham Sianjase.

Figure 27 The Zambezi River Basin covers most of Zambia



Source: By Eric Gaba – Wikimedia Commons user, https://commons.wikimedia.org/w/index.php?curid=41919543

As early as 2001, the IPCC had categorised the Zambezi as the 'worst' of 11 major African river basins in terms of exhibiting potential effects of climate change, with rainfall expected to decrease by 10-20%, increases in temperature expected to result in increased evaporation by 10-25%, resulting in 26-40% reduced average annual streamflow (IPCC, 2001, table 10–1) by 2050 (Beilfuss, 2012, p. 3). In 2002, Harrison and Whittington had sounded the alarm bells for the proposed scheme for a hydropower station at Batoka Gorge's susceptibility to climate change – a scheme that Zambia's system of provision was making progress on preparations for in 2018, and had in fact extended from an envisioned 1,200MW in 2017 (Table 28) to 2,400MW for an approximate cost of USD 5 billion (Energy Regulation Board of Zambia, 2019). Paradoxically, Harrison and Whittington noted, as hydropower was being seen as a key strategy to limit impact on climate change, its availability itself may be limited by climate change (Harrison and Whittington, 2002). Their model illustrated that the Batoka Gorge hydropower scheme would be sensitive to reductions in river flows (Harrison and Whittington, 2002). In 2011, Yamba et al used General Circulation Models (GCMs) to generate projected precipitation along the Zambezi River Basin. They found that hydropower potential will reduce for all existing and proposed schemes across sub basins, and therefore recommended regional integration of hydropower infrastructure to include natural gas and biomass sources and for pumped storage schemes to accompany select hydropower stations to ensure continuous energy (Yamba, Walimwipi and Mzezewa, 2011). In 2012, Beilfuss highlighted that the Zambezi River Basin had one of the most variable climates of any major river basin in the world, and that the severe 1991/92 drought reduced hydropower generation and resulted of GDP and jobs (Beilfuss, 2012). He recommended prioritising investments that increased climate resilience, rather than investments into hydropower which reduced it (Beilfuss, 2012, p. 4), and investing in rehabilitation, refurbishment and renovation before investing in new infrastructure (Beilfuss, 2012, p. 36). In 2014, Spalding-Fecher et al added to the literature on the Batoka Gorge hydropower scheme their doubts online (and in print in 2016) that it would reach its anticipated production levels from its original feasibility study (Spalding-Fecher *et al.*, 2016).

Contrasting these highly pessimistic outlooks were the more muted results of Beck and Bernauer in 2011. One of the two supply side scenarios they derived from the 2000 IPCC Special Report Emissions Scenarios A2 scenario projected slightly increased precipitation by 11% (Beck and Bernauer, 2011), while the other projected a basin-wide decrease in annual precipitation of 28%.[67] However, when combining these supply side scenarios with minor, moderate and major changes in demand scenarios, not even in their minor changes in demand scenario did water availability at the end of each sub basin in the Zambezi River Basin's 13 sub basins increase in 2050 relative to 2000. In the minor changes in demand and supply scenario, water availability remained the same in three sub basins – Luanginga, Lungue Bungo and Kabompo sub basins (Beck and Bernauer, 2011, table 1) and decreased by less than 1% in the Luangwa and Barotse sub basins. Under their moderate demand and supply side changes scenario, water availability in the Kabompo sub basin decreased by 15%. Under their strong demand and supply side changes scenarios, water availability in Kabompo sub basin decreased by 90%.

Figure 28 Location of the drainage basin feeding Lake Mweru, Zambia

Source: Waylen, Annear and Bunting, 2019

The IPCC offers different forecasts for the Zaire/Congo River Basin in 2001 and 2018. In contrast to its projections of decreased precipitation and runoff for the Zambezi River Basin, the 2001 IPCC Summary for Policymakers forecast a 10% increase in precipitation and a 10-15% increase in runoff for the Zaire River Basin (IPCC, 2001, table 10–1) by 2050. The reason for this difference would be the effect that the Indian Ocean Dipole has on the river basin, which it similarly has on equatorial East Africa. By contrast, the IPCC in 2018 limited forecasts related to the Congo Basin (of which Lake Mweru is a part), citing only one study projecting a 10% decrease in a 1.5̊C scenario (IPCC, 2018, p. 203).[68]

Beyond the potential for climate change to reduce energy production, climate change also had the potential to exacerbate competition between energy and food production. The interaction creates a so-called food, water, climate and energy nexus (Spalding-Fecher *et al.*, 2016), bringing forth the threat of the Malthusian trap (Beck and Bernauer, 2011).

The construction of the Kafue and Kariba dams has been associated with a decline in fish production and fish biodiversity, and been associated with the rise of tilapia and kapenta fisheries in the Kariba

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[67] The A2 scenario is a high population growth scenario in which the population is 15 billion by 2100 (IPCC, 2000, p. 5). It assumes a significant decline in fertility for most regions and stabilisation at above replacement levels. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other scenarios (IPCC, 2000, p. 5). Net anthropogenic CO2 emissions from land-use change remain positive through 2100 (IPCC, 2000, p. 6). Final energy intensity in 2050 is 9.5MJ/US$ and share of coal in primary energy by 2050 is 30% (IPCC, 2000, p. 15).

[68] It is unclear to what this time horizon applies (Döll *et al.*, 2018; IPCC, 2018).

reservoir (SADC, 2008, p. 12). The Kariba reservoir has resulted in damage to freshwater and marine shrimp fisheries downstream in the Zambezi Delta in Mozambique (SADC, 2008, p. 12).

Consumptive water use on the Zambezi River Basin was estimated at around 15-20% of runoff in 2007, and the Southern African Development Community (SADC) estimated that this might increase to 40% by 2025 (SADC, 2008, p. xiii; Beck and Bernauer, 2011). The largest consumptive water users of the Zambezi River Basin were dams at circa 13 km^3 per annum from evaporation impoundment (16% of consumption), followed by irrigated agriculture at circa 1.5 13 km^3 per annum (1.4% of consumption) (SADC, 2008, p. xiii; Beck and Bernauer, 2011). By 2025, SADC's consultants forecast that under a mega growth scenario for hydropower, hydropower would account for almost a quarter of consumptive water use, and irrigated agriculture for 6% of total use (SADC, 2008, table 2.3). Livestock would account for less than 0.2%, mining for 0.4%, industrial consumption for less than 0.1%, and urban domestic consumption for 0.65% (SADC, 2008, table 2.3) – 16 times more than rural domestic consumption, in spite of being less than slightly less than half the population (World Bank, 2020u). Flood releases would account for more than 6% of consumptive use (SADC, 2008, table 2.3).

Beck and Bernauer predicted that national shares of consumptive water demand would be driven mainly by population growth, which was highest in Malawi, but that Zambia would remain the biggest water user of the system and its consumption would also grow as a result of massive growth of irrigated agriculture from 34% in 2000 to up to 42% by 2050 (Beck and Bernauer, 2011, p. 1070). To provide context, according to the FAO Aquastat's database, 30% of Zambia's agricultural area had potential for irrigation by 2002, and 100% of land equipped for irrigation actually irrigated (FAO, 2020) – most Zambian farming, which accounts for 54% of the workforce (World Bank, 2020u) on subsistence farms, is rainfed (Resnick and Thurlow, 2014). This means that Zambia had substantial potential for irrigation expansion. Other countries sharing in the Zambezi River Basin's water are Angola, Botswana, Mozambique, Namibia, Tanzania and Zimbabwe. In their projections, they foresee Mozambique (downstream) and Zimbabwe (contiguous) will challenge Zambia for water consumption as all three countries are likely to experience a large decrease in water availability (Beck and Bernauer, 2011, pp. 1070–1071).

Spalding-Fecher et al found that accelerating economic growth was increasing the potential for competition for water between hydropower and irrigated agriculture in the Zambezi River Basin, and that climate change would add additional stress to the system. Using the Water Evaluation and Planning (WEAP) tool, they assessed the Kariba hydropower dam to be vulnerable to increases in upstream irrigation demand as well as to climate change. They found that electricity generation could reduce by 12% and that expansion of the Kariba hydropower dam would unlikely deliver increases in power production even under a favourable climate (Spalding-Fecher *et al.*, 2016). They concluded in their paper first published online in 2014 (i.e. before the power outages of 2015 and 2016) that an intense El Niño drought that affects the whole of Zambezi River Basin would result in a corresponding decline in generating capacity across the basin. Because Global Circulation Models could not model the frequency and intensity of future El Niño events, they recommended policy makers and project developers must plan for a wide variety of potential climate futures. To coordinate investment and operational decisions as effectively as possible, they recommended a water modelling approach to an energy system model for the region that would model the energy, water and agriculture economic trade-offs (Spalding-Fecher *et al.*, 2016) and incorporate projections from Global Circulation Models that are better at simulating the frequency and intensity of El Niño droughts.[69]

[69] In terms of forecasting future forecasts, Jury found that the most influential predictor of maize yield, river flows and GDP in South Africa was cloud depth in the tropical Indian Ocean in the preceding spring (September-November). Reduced monsoon convention is related to enhanced rain fall over South Africa the following summer and greater economic prosperity during the subsequent year (Jury, 2002).

For some farms that were irrigated but did not power their irrigation using biomass, industrial farming was doubly impacted by the El Niño events: both directly from lack of rainfed water and by lack of power for irrigation. Zambia Sugar Plc and Zambeef reported reduced crop yields in 2016 due to power interruptions which affected irrigation (Zambeef Products, 2017, p. 23; Zambia Sugar, 2017, p. 36).

The above review of data and literature shows that Zambia's system of energy provision had access to an abundant wealth of information as to why it should seek to diversify from hydropower prior to the power outages to 2015 and 2016. Experience of power outages should not have been required to make the system of provision react, and yet that is what happened, as illustrated by President Edgar Lungu's comment, "The difficult realities of climate change have taught us over-reliance on hydropower won't just do" (Mfula, 2016). The next section will delve into what alternatives Zambia's system of provision has.

6.4 Alternative energy sources

With the capacity utilisation of hydropower under threat by El Niño events, particularly in the Zambezi River Basin, Zambia's system of energy provision needs to consider alternatives and complements not just to hydropower in the Zambezi River Basin, but hydropower per se.

In the preceding section, we saw constructive suggestions emerge: pumped storage electricity generation for hydropower; a water modelling approach to an energy system model for the region that would model the energy, water and agriculture economic trade-offs; incorporating projections from Global Circulation Models that are better at simulating the frequency and intensity of El Niño droughts; coordination with the Southern African Development Community, the Southern African Power Pool and trade of agricultural products be used to enhance water, energy and food security in southern Africa (Yamba, Walimwipi and Mzezewa, 2011; Conway *et al.*, 2015; Spalding-Fecher *et al.*, 2016).

Linking regional Power Pools could achieve greater operational efficiency and hazard mitigation. Research published subsequent to the power outages of 2015 and 2016 additionally suggests further research to explore the implications for hydropower reliability in eastern Africa (Conway *et al.*, 2017), whose hydropower generation may prove to be sufficient diversification from El Niño affected southern Africa. Building on this research, if interannual rainfall variability is different enough between eastern, southern and central Africa, trading across regional Power Pools (but not within) could offset the tendency at regional scales for coincident surplus supply or demand due to high reliance on hydropower production in single river basins or clusters of shared hydropower production (Conway *et al.*, 2017). Zambia, for instance, is not diversified with respect to rainfall through its membership of the power-sharing Southern African Power Pool. According to data collected by the Southern African Power Pool, Angola, Botswana, the DRC, Malawi, South Africa, Tanzania and Zimbabwe all had installed capacities greater than their peak demand, and yet they all experienced capacity shortfalls in 2016 (Energy Regulation Board of Zambia, 2017a, p. 24). The Southern African Power Pool experienced a shortfall of 7,857MW in 2015 (Energy Regulation Board of Zambia, 2016, p. 28) and a shortfall of 5,583MW in 2016 (Energy Regulation Board of Zambia, 2017a, p. 24). With significant drying across Africa's major basins (Niger, Nile, Sanaga and Volta), however, Falchetta et al seem to suggest a diversification away from hydropower technology altogether (Falchetta *et al.*, 2019).

Power can be generated in three main ways: i. through thermal generation, i.e. fossil fuel-fired plants and nuclear units, but also geothermal and biomass power generation, or concentrated solar power; ii. kinetically, including hydropower and pumped storage, wind turbines, or tidal energy; and iii.

through solar photovoltaic units (Falchetta *et al.*, 2019). All three of these main ways and several of these sub-means appear to be available to some degree in Zambia. Table 28 based on ZESCO's power generation expansion plan as of 2017 shows coal, hydro, solar (PV) and wind were sources for planned new power plants. Diesel and high fuel oil power plants have also been contributing to ZESCO's recent power generation (Energy Regulation Board of Zambia, 2019, p. 34). Nuclear power is another option considered (Ministry of National Development Planning, 2017), as are waste to energy and geothermal power (Ministry of Energy, 2018).

As discussed earlier, when ZESCO and the World Bank evaluated alternatives to the Kariba and Kafue hydropower plants, the only apparent criteria that they considered was cost (IBRD and IDA, 1970, 1973). Since then, consultancies have formulated frameworks for evaluating the sustainability of infrastructure projects from multiple perspectives. Two that are affiliated with the UK's Institution of Civil Engineers (ICE) are Arup's SpeAR and ASPIRE and Building Research Establishment's CEEQUAL that bring together a number of indicators to assess the total environmental and socioeconomic impact of a project (Arup, 2017). CEEQUAL goes further than Arup's appraisal tools by also assessing the resilience of new infrastructure projects (BRE Global, 2019).[70]

Box 3 Criteria by which Arup's ASPIRE and the Building Research Establishment's CEEQUAL ass infrastructure projects

Arup's ASPIRE –

- Institutions
    - Structures, skills, policies, reporting
- Environment
    - Air, land, water, biodiversity, energy, materials
- Economics
    - Equity, livelihoods, macro, viability
- Society
    - Population, culture, stakeholders, services, health, vulnerability

Building Research Establishment's CEEQUAL –

1. Management
2. Resilience
3. Communities and stakeholders
4. Land use and ecology
5. Landscape and historic environment
6. Pollution
7. Resources
8. Materials, including waste
9. Energy and carbon (operational)
10. Energy and carbon (construction)
11. Water use
12. Transport

[70] Other broad criteria are management; communities and stakeholders (including consultation and engagement, wider social benefits, wider economic benefits); land use and ecology (land use and value, land contamination and remediation, protection of biodiversity, change and enhancement); landscape and historic environment; pollution; resource efficiency; and transport.

While both approaches would make for comprehensive feasibility studies, creating detailed feasibility studies goes beyond the scope of this study. Moreover evaluating energy sources by 20 Arup or 12 BRE criteria dilutes the foci of this study. The Zambian system of energy provision also did not make available its feasibility studies for this study. Accordingly, we will have had to make do with using a more heuristic approach using the Pareto principle to construct a "least regret approach" to make a very preliminary evaluation of Zambia's power generation options.[71]

In 2015, the UK National Grid introduced the concept of a "least regret approach" with the aim of minimising the cost implications of any decision made when there is uncertainty over the future (National Grid, 2015, p. 86). I suggest giving the following five criteria at least 80% weight for the appraisal of Zambia's possible power generation sources:

1. **Domestic availability of source.** ZESCO's first preference for an energy source would be within the boundaries of Zambia to a. minimise financial costs and b. to minimise the risks associated with power systems outside of Zambia's sovereign control, such as hold-up for political or financial reasons from parties outside of Zambia. Within Zambia, it can leverage its status as a wholly-government owned entity to get power generated where it is physically possible.

2. **Availability of the resource within the Southern African Power Pool (SAPP).** If the resource is not available in Zambia then it must be available within the Southern African Power Pool with which ZESCO has power interconnections until the SAPP or Zambia directly connect with power pools outside the El Niño region affected region.

   Sourcing a significant portion of energy from a power pool comes with its risks but offers opportunities. Of West Africa, it has been estimated that USD 32 billion of investment and 23 million tonnes of fuel oil (and the commensurate amount of CO2 equivalent emissions) (USAID, Tony Blair Institute for Global Change and Power Africa, 2019, p. 39) could be saved over 2020 to 2030 if the West African Power Pool traded efficiently (Gareth Walsh, introduction to Tony Blair Institute for Global Change's work in energy in Africa, 16 December 2019). The same principle of emissions and financial cost savings should hold for southern Africa as energy is traded between energy surplus and deficit countries to achieve operational efficiency and hazard mitigation (Conway *et al.*, 2017). To ensure that the benefits of trade are maximised, national power utilities and governments would have to coordinate in their planning and disclose their expected surpluses and deficits accordingly. But there would also have to exist a mechanism whereby energy suppliers would not be able to exploit the energy deficiencies of net energy consumers, either at the stage of contractual negotiations or in the operating stages, so as not to threaten net consumers' energy security. Multilateral bodies and international courts would likely need to be involved to regulate tariffs and resolve disputes in order for nationally owned utilities such as ZESCO and governments such as the Government of Zambia to become comfortable with outsourcing their energy generation needs. Alternatively, ZESCO or the Government of Zambia would need to be able to hold something of value to its supplier(s) hostage as collateral against default.

3. **Climate resilient and reliable baseload.** As chapters 1-10 have demonstrated, hydropower's climate vulnerability has threatened the growth of Zambia's manufacturing sector, adversely affected individual users and contributed to additional diesel-generated greenhouse gas emissions.

[71] Named after the Italian economist Vilfredo Pareto, the Pareto principle states that for many outcomes, roughly 80% of consequences come from 20% of the causes. It has also been called the 80/20 rule and the law of the vital few. Here, we effectively assume that 20% of the criteria considered by Arup and BRE will account for 80% of weighting.

4. **Lifecycle greenhouse gas emissions.** If ZESCO does not want to contribute to its hydropower infrastructure becoming even more redundant than it is during El Niño events, it will want to minimise greenhouse gas emissions into the atmosphere to minimise the increase in temperatures that lead to the increase in frequency of El Niño events. Even if Zambia's direct contribution to a prospective increase in emissions is minimal, maintaining climate leadership theoretically provides the government more leverage in international negotiations with high emitting nations to reduce their emissions: the Government of Zambia has committed to reduce its emissions by 47% from its emissions in 2010 by 2030 (Government of Zambia, 2016). To take emissions into account will mean internalising to the investment appraisal process the negative externalities of lifecycle greenhouse gas emissions emanating from hydropower which, if excluded, would otherwise have represented a market failure (Coffman *et al.*, 2020, p. 162). In a lifecycle assessment of greenhouse gas emissions emanating from hydropower, embedded carbon, the loss of carbon sinks in perpetuity, emissions from the reservoir lake as well as the emissions of backup diesel generation when dependence on hydropower does not deliver sufficiently against a changing energy context (Ahmed *et al.*, 2020) must be counted.[72][73][74]

   While lifecycle emissions should be the criteria used, these values would only be known with the execution of bespoke feasibility studies, especially in the case of hydropower projects. I have therefore used operating emissions in Table 30 A least regret framework for assessing Zambia's potential energy sources
   below.

5. **Effects of waste on human health and the environment.** CEEQUAL considers the effects of pollution (BRE Global, 2019), ASPIRE considers the effects of projects on the environment and health (Arup, 2017). Farquharson et al considered not only the greenhouse gas emissions from diesel generation but also the nitrogen oxides (NOx), sulphur oxides (SOx) and carbon monoxide (CO) which both harm human health and also contribute to acid rain and the destruction of carbon sinks in the form of forests (US EPA, 2020b). To proxy for NOx, SOx and CO emissions in Table 30 A least regret framework for assessing Zambia's potential energy sources
6. below, I used kilogrammes of N2O emissions per TJ of energy release for fossil fuels in Table 2.2 of the IPCC Guidelines for National Greenhouse Gases (Gómez *et al.*, 2006). For nuclear power, I considered nuclear waste.

7. **Lifecycle financial cost.** This is the one appraisal criterion ZESCO and the World Bank seem to have assessed Zambian power projects by in 1970 and 1973 (IBRD and IDA, 1970, p. 12, 1973, p. 12).

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[72] Looking at proposed hydropower dams and the associated distribution infrastructure required in Chilean Patagonia, Mar (Mar, 2009) forecast that the carbon impact of construction equipment and machinery, transport of labour, material embedded energy, and land-use change would be 48x the impact of natural gas plants that would deliver an equivalent amount of energy.

[73] Reservoirs themselves contribute to 1.5% of global anthropogenic emissions from carbon dioxide, methane, and nitrous oxide reported by the UN Intergovernmental Panel on Climate Change (Deemer *et al.*, 2016).

[74] Coffman, Cardinale, Meng and Zhifu (2020, p. 164) suggest, beneficiaries should bear the responsibility for embedded carbon emissions (category 2 Scope 3 emissions according to the Greenhouse Gas Protocol (2013)). For hydropower, this would mean the substantial emissions associated with the manufacture of cement in concrete reservoir walls. For hydropower, the emissions associated with lake emissions should also be counted as Scope 1 operating emissions. Another type of emission should also be counted which is not captured within any of the Greenhouse Gas Protocol Scopes of emissions: foregone carbon sinks lost in perpetuity, as is the case with hydropower when swamps and forests are lost to make for hydropower reservoirs.

8. **Other considerations particular to the energy source.** This criterion picks up the nexus-approach for hydropower and the particular hazards of nuclear energy.

Table 30 A least regret framework for assessing Zambia's potential energy sources presents Zambia's energy sources assessed by these five criteria to the extent that data coverage allows, in a least regret framework.

Table 30 A least regret framework for assessing Zambia's potential energy sources

Source of energy	Domestic availability of resource	SAPP availability of resource	Climate resilient and reliable base load	Operating GHG emissions – kg CO2e/TJ v WTT CO2e/GJ[75]	Harmless to health, environment? kg N2O/TJ	Low financial cost	Other considerations particular to the energy source
Hydropower	× Not with El Niño events	× Not with El Niño events	× Not with El Niño events	o mg 450 CO2e /sq. m/d (Deemer *et al.*, 2016, table 1)	× Loss of carbon sinks, loss of homes	✓ If capacity utilisation is high	Competition for water with agriculture
Coal	✓	✓	✓	× 95,100 v 14.55	× 1.5	✓	
Natural gas	×	✓	✓	o 56,200 v 14.1	o 0.1	✓	
Nuclear	×	✓	✓	✓	× Hazardous waste	✓	Magnitude of impact of mismanagement Required scale
Heavy fuel oil	Imported	Imported	✓	× N/A v 17.4	×	×	
Diesel	Imported	Imported	✓	× 74,400 v 14.55	× 0.6	×	
Biomass	Untested quantity	Cannot be easily authenticated	Depends on availability	× 54,700-114,000 v N/A	× 0.1-4	Depends on resource	
Industrial waste	Untested quantity		Depends on availability	× 145,000 v N/A	× 1.5	?	
Solar	✓	✓	×	✓	✓	✓	
Wind	×	×	×	✓	✓	×	

[75] Carbon dioxide emission factors for CO2, CH4 and N2O sourced from the IPCC Guidelines (Gómez *et al.*, 2006, table 2.2) and converted to CO2e using a value of 25 global warming potential for methane and 298 for N2O, versus "Well to Tank" lifecycle carbon dioxide equivalent emission factors sourced from the UK Department for Business, Energy and Industrial Strategy (BEIS, 2019, Table. 4)

Geothermal	?	?	✓ if available	✓	Possible seismic activity	✓	

Key: ✓ = yes, x = no, o = intermediate. Source: original analysis

The drawbacks of hydropower reliability particularly in the Zambezi River Basin in the face of increasingly frequent El Niño events as global temperatures rise has already been discussed extensively in in the previous section, as has the necessity for considering how it competes with food production domestically as well as the needs of neighbouring countries, with challenges from Zimbabwe and Mozambique forecast. Large hydropower is also not quite as green as popularly perceived. First, there is the embedded carbon that goes into their concrete walls. Second, the flooding required to fill their large reservoir lakes destroy biodiversity and destroy carbon sinks such as forests and swamps whose ability to decarbonise has been lost in perpetuity. Deforestation has also been linked with the rise in global pandemics arising from zoonotic disease such as Ebola (Olivero *et al.*, 2017) as wildlife such as bats lose their natural habitat and move closer to human populations. Dam reservoirs destroy communities' homes, livelihoods and sacred lands, as they have in Zambia (Serpell, 2019). Reservoirs themselves contribute to 1.5% of global anthropogenic emissions from carbon dioxide, methane and nitrous oxide reported by the UN Intergovernmental Panel on Climate Change (Deemer *et al.*, 2016). Ahmed et al referenced above in Chapter 6 show how complete reliance on hydropower also increases greenhouse gas emissions by inducing electricity consumers to self-generate electricity using back-up diesel generators (Ahmed *et al.*, 2020).

Coal in Zambia so far costs USD 0.1035/kWh (Mabumba, 2017). However, because coal's capacity factor can be reliably assumed as 93% (Lazard, 2018, p. 18), compared with hydropower's capacity utilisation of 54% in 2016 (see Table 25), its effective tariff would be USD 0.06/kWh.[76] Coal, however, emits even more carbon dioxide than diesel generation does (see Table 30 A least regret framework for assessing Zambia's potential energy sources
above) and so would contribute to the global warming that is contributing to the increased frequency in El Niño events that are impacting the efficacy of Zambia's hydropower plants. On its own as the largest producer of coal in Zambia, Maamba Collieries Ltd had coal reserves of 103M tonnes of high grade coal and 70M tonnes of low grade coal as of 2012 (Maamba Collieries, 2012). This is enough to generate almost 1,400 TWh of energy. Even if only half of the high grade coal was now available, this would be enough to meet Zambia's projected on-grid 2030 electricity demand of 18,000MWh per annum for 23 millennia.[77]

Table 31 Average capacity utilisation over 2016 of Zambia's largest hydropower dams

Average capacity utilisation of Zambia's largest hydrodams over 2016

	Kafue Gorge	Kariba North	Kariba North Ext	Victoria Falls	Aggregate	Source
Energy output in 2016, GWh	5,853	2,964	672	754	10,243	ERB 2017, p32
Installed capacity in 2016, MW	990	720	360	108	2,178	ERB 2016, p57
MW/GW | h/y	1,000	8,760				
Energy output at 100% capacity utilisation, GWh	8,672	6,307	3,154	946	19,079	
Average capacity utilisation over 2016	67%	47%	21%	80%	54%	

Data source: Energy Regulation Board of Zambia, 2016a, p. 57, 2017a, p. 32; original analysis

Natural gas can seem at first to be a more environmentally friendly solution than coal as a dispatchable and dependable energy source, emitting c.60% of the level of CO_2 emissions that coal does. With major gas discoveries made in Tanzania and Mozambique, the resource is accessible through the Southern African Power Pool as both nations are members of the power pool. Indeed, 40% of global gas discoveries have been made in Africa between 2011 and 2018 (IEA, 2020), and Tanzania and Mozambique have 57 and 180 trillion cubic feet of proven resources (Ford, 2016). However, major methane leakages are associated with the supply chain of natural gas (Marchese and Zimmerle, 2018), the global warming potential of which is 28-36 carbon dioxide equivalents (CO_2e) (US EPA, 2020a). On a well-to-tank CO_2e basis, therefore, the UK government's research finds that that natural gas is only 3% less harmful than coal – a margin of error not high enough to justify ZESCO displacing domestically

[76] USc 10.35 / (93%/54%)
[77] 1kg coal generates approximately 8kWh of energy (Ovo Energy, 2018)

available coal with natural gas available from the Southern African Power Pool. When one considers the effect of other noxious gases on human health and forests, however, choosing natural gas over coal is justified: coal emits 15 times more nitrous dioxide (Gómez *et al.*, 2006, table 2.2).

Like natural gas, nuclear power generation is theoretically available through the Southern African Power Pool. The 1,940MW Koelberg nuclear power station in South Africa is the only nuclear power plant in Africa. Nuclear power plants produce no emissions during operation. Nuclear power once installed is cheap and a reliable source of peak demand energy. Uranium is available in South Africa, Namibia and Niger (Teljeur, Chetty and Hendriksz, 2017, p. 205).

However, nuclear power is complicated. First, it requires a relatively large scale power plant, above 900MW of installed capacity, technical expertise and significant upfront cost (Teljeur, Chetty and Hendriksz, 2017, p. 205). Second, it can be dangerous. Within three decades, a superpower and an OECD country failed to prevent accidents at nuclear power plants due to incompetence (Chernobyl) and due to a natural disaster (Fukushima). To be more resilient to natural disasters, it seems, nuclear power needs to be located away from tectonic fault-lines and away from the ocean. Further, Pravalie and Bandoc (2018) assert that there is apparent global lack of interest in hazardous waste management, considering that underground facilities for relatively safe storage have yet to be built. Given the health and safety risks associated with managing nuclear power and waste safely and the requisite strong systems of governance, Zambians that I talked with[78] did not feel comfortable with the idea of nuclear power being managed by ZESCO, which has proven unreliable in communicating accurate load shedding schedules. That would make reliance on South Africa's power utility Eskom for nuclear power necessary if nuclear power is to be an option, given that Eskom is the only African utility with nuclear expertise. Even with its relatively positive track record, however, Eskom and South Africa in general do not exist in a stable institutional environment with good governance. Radio France International reports that plans to procure a new nuclear power plant made between former president Jacob Zuma and agents of Russia were "secured with hefty bribes" (Cornish, 2019). Given that Zambia requires additional energy and the prospect of procuring additional nuclear power through good governance and with a stable institutional environment through the SAPP looks currently unlikely, nuclear power does not seem to an option at this point.

Neither diesel nor heavy fuel oil are low cost nor low in greenhouse gas or harmful to health emissions. This perhaps explains why ZESCO does not plan to expand its energy generation capacity with these fuels.

The annual reports of Zambia Sugar revealed that the company has been generating electricity to reduce its grid electricity demand and increase its resilience through periods of load shedding (2016, pp. 1, 11–12, 20, 2017, pp. 24, 41, 2018, pp. 8, 31). Biomass is technically renewable so long as the fuel source is replenished as quickly as it is consumed, but when this ceases to be the case, it is no longer renewable. From an environmental perspective, it may be challenging for the national utility to source enough renewable resources for nationally owned power plants, in a way that an agricultural company that supplements its on-grid electricity demand with its own waste product does not find it so challenging. And though renewable, unlike intermittent renewable sources, biomass emits greenhouse gases as well as gases harmful to health, particularly when solid fuels are burnt (Gómez *et al.*, 2006, table 2.2). The volume of emissions associated with biomass can be worse than those by diesel generators. When operators run out of biomass, they can resort to petrochemicals, such as used tyres. For these reasons, biomass is not an environmentally attractive solution (Gibbs, 2019).

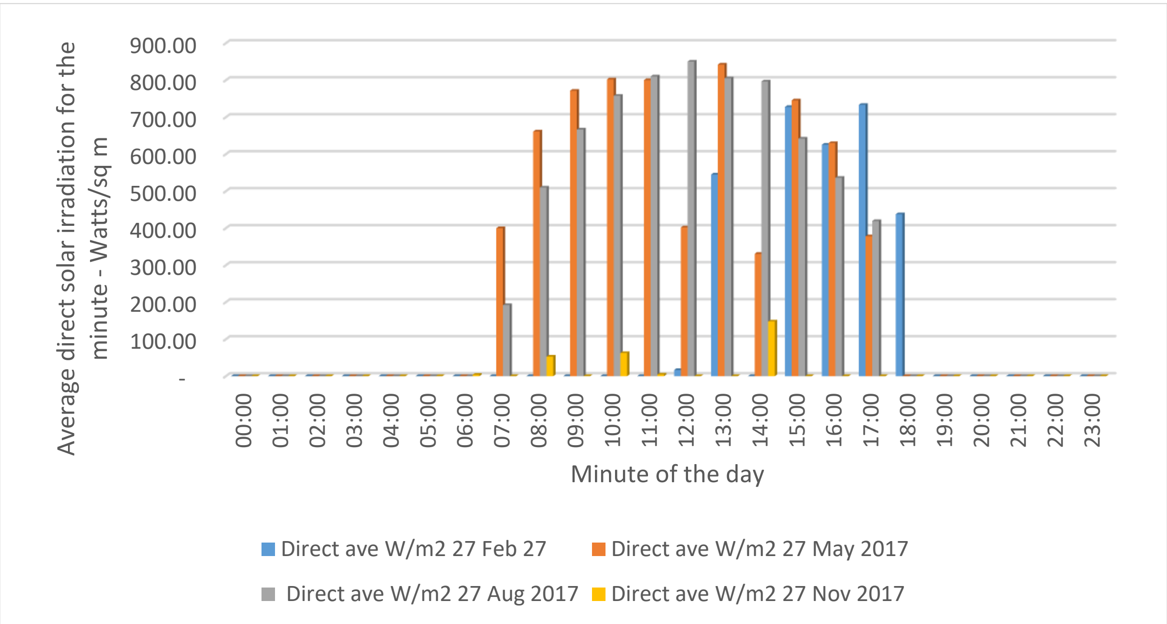
[78] Interview with Chipego Zulu, CEO of Zambia Association of Manufacturers on 28 May, 2018

Industrial waste is another possible source of energy, but again more at the company level than at a national utility scale given the unpredictable supply of fuel. Companies such as KPA Unicon construct 5 to 40MW independent power plants for manufacturing firms, fuelled by those firms' waste, such as steel mill blast furnace gas or paper mill pulp (personal interview on 2 November 2018 – see Annex 3.2.). The high level of GHG and harmful to health emissions also do not make them attractive for nationally-scaled projects.

Solar power is intermittent and therefore is not a reliable and dispatchable source of energy without batteries. It should not account for more than 15% of grid energy according to an energy expert with three decades of gird experience (personal communication with an energy expert at a donor agency, 27 February, 2019, see Annex 3.4.1). Department of Energy officers said (personal communication, 6 June, 2018, see Annex 3.1.3) that ZESCO's planned solar plants would not have batteries to store the energy they generated, nor would be used to recharge the hydropower reservoirs by powering pumps. Instead, they would be used to feed directly into ZESCO's grid. In times of high cloud cover, pollution or ash cover from volcanic activity, the sun's rays would only faintly reach the solar panels for a few hours, and in times of total solar eclipses, not at all. The average irradiation would vary by season. It cannot therefore be relied upon for baseload energy, even if it can substitute away from a small portion of coal or hydropower during baseload hours. There is also a mismatch between the time when solar irradiation peaks and the time when demand for energy peaks in Zambia.

ZESCO charges peak tariffs between 18:00-22:00 (Energy Regulation Board of Zambia, 2017b, p. 6). Peak tariffs occur when there is peak demand for power, as people return home from work and turn on their house lights as the evening begins and switch on their electrical appliances. As the graph below shows, however, solar irradiation peaks at about midday. In a sample of four days four months apart, there was only solar irradiation on 27 February, 2017 at 18:00, and none on the other three days. There was no solar irradiation any of these days at 19:00, 20:00, 21:00 or 22:00, which is when ZESCO's peak tariff ends.

Figure 29 Average solar irradiation for a minute every hour of four days each four months apart at Lusaka



Source: Generated from data from the World Bank, 2017b; graph own

Given all these plans and limitations, solar would be most useful for ZESCO in decreasing the variable charge it pays for thermal power, or, when hydropower reservoirs are low, conserve on hydropower during daylight hours. To maximise its usefulness, however, Zambia's system of energy provision would do well to change their plan to not use solar to recharge hydropower reservoirs.

In the medium-term, repurposed second-life electric vehicle batteries offer a low-cost storage solution that can be paired with solar power plants. Electric vehicle batteries stop being usable in vehicles when they reach circa 70-80% of their initial rechargeable capacity, but can be used for stationery storage. The global supply of electric vehicles for second-life stationery use by 2030 will reach 60GW, circa twice the amount of power supply Africa requires to achieve universal electricity access (Vivid Economics and Oeko-Institut, 2020). Repurposed batteries are anticipated to cost about half of first life lithium-ion batteries, and so the potential for solar PV with low-cost batteries should increase exponentially as electric buses, two and three wheelers approach their end of life by 2030. Even if ZESCO deprioritises solar for the first half of the 2020s, therefore, it should be prepared in the event that the forecasts for the potential of repurposed electric vehicle batteries prove prescient to scale-up solar power generation rapidly in the later 2020s so as to prevent a path dependence of exclusion of solar PV.

Wind energy potential in Zambia is 'relatively limited' and not expected to attain high capacity factors (Africa Power Ventures, 2018, p. 7).

At present it appears that geothermal energy is not a serious contender for providing a significant portion of Zambia's energy needs. Geothermal energy is physically reliable because it is consistent, efficient, and can easily accommodate changes in electricity demand (Lofthouse, Simmons and Yonk, 2015, p. 1). Geothermal plants produce few emissions and are more environmentally friendly than traditional fossil fuel plants (Lofthouse, Simmons and Yonk, 2015, p. 1). However, the question of availability of geothermal power in Zambia is yet unproven. The costs of exploration involve high capital expenditures for drilling and plant installation and the returns are uncertain. As of 8th August 2020, the latest news on exploration for geothermal power in Zambia is that the developer Kalahari GeoEnergy Ltd has raised USD 3.2 million in the form of a convertible loan to drill wells at Bweengwa. While the ultimate goal is to construct a 15 MW steam power plant, the second part of the loan is conditioned on one of the wells demonstrating a deep reservoir temperature of at least 130°C (Richter, 2020; Takouleu, 2020). An environmental and health downside of geothermal drilling is that it can induce earthquakes (Harmon, 2009).

From this preliminary analysis of Zambia's alternative sources of energy, it seems apparent that gas-fired power will be Zambia's least regret source of energy in the short-term in terms of resource availability, dispatchability, greenhouse gas emissions and financial cost, if ZESCO and the Government of Zambia can become comfortable with relying upon neighbouring TANESCO and Electricidade de Moçambique as suppliers. If the governments and energy regulators of Tanzania andMozambique allow, ZESCO could even contract directly with independent power producers in those countries for power, and pay wheeling charges to the utilities for using their distribution infrastructure. On top of this, Zambia's system of energy provision should work to connect with utilities and power projects beyond those in southern Africa which do not share its weather patterns. In the medium-term, the prospect of dispatchable solar power with the use of affordable battery storage if not recharged hydropower looks like it could deliver an emission-free and reliable source of energy. The high embedded cost of carbon in photovoltaic cells (Gibbs, 2019) and the issues of energy intensive recycling or toxic landfills would be new environmental challenges to overcome with end-of-life batteries (Boyden, Kie and Doolan, 2016).

Having seen that Zambia has alternatives to hydropower, we can now grapple with why Zambia's system of energy provision did not seek a balanced energy portfolio mix.

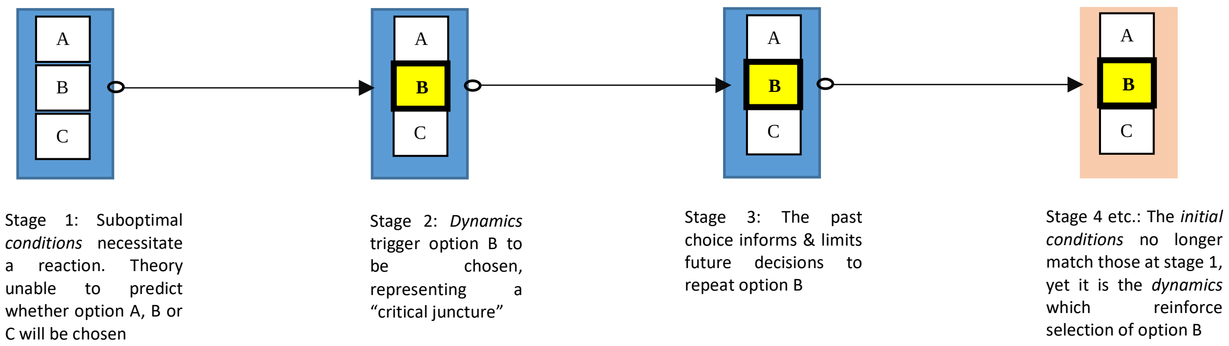
6.5 The historical institutional path dependence framework

Path dependence refers to institutional norms that become ossified at a point in time – a critical juncture – through positive feedback. It is the 'notion that, for any given sequence of practices and events, past choices and temporally remote events can help explain subsequent paths of institutionalised practices and contemporary outcomes' (Colignon, 1997, p. 39). Mahoney explains (2000, pp. 513–14) that in a path-dependent pattern, selection will happen in an otherwise unpredictable manner other than what has been tried and tested before.

Adapting and expanding on Mahoney's explanation, at Stage 1, there exists a set of suboptimal initial conditions at which point a universe of interventions A, B and C could be adopted.[79] Theory is unable to predict which will be chosen (2000, p. 538). Option B is chosen at Stage 2. Stage 2 is described as a "critical juncture" – a particular point in time where a decision is made. At Stage 3, the past choice triggers the feedback mechanism that informs and hence limits future decisions to repeat the same decision taken at Stage 4 and beyond.

At Stage 4, Pierson and Skocpol (2002, p700, with reference to Stinchcombe, 1968) would argue that it is the *dynamics* triggered at the critical juncture, rather than the initial conditions themselves, that cause reproduction of those same dynamics. Selection of Options A and C becomes increasingly unlikely, although not impossible.

Figure 30 Path dependence illustrated



Source: Ahmed, 2020

In this work, we adapt the institutional path dependence framework to organisations within Zambian energy's system of provision.[80] Douglass North wrote that organisations are created to take advantage of the opportunities that institutions determine. 'The resultant path of institutional change is shaped by the lock-in that comes from the symbiotic relationship between institutions and organisations that have evolved as a consequence of the incentive structure provided by those institutions and the feedback process by which human beings perceive and react to changes in the opportunity set' (North, 1990, 5%). Institutionalisation occurs, according to Colignon (1997, p. 39), 'when organisational structure and practices – which maintain relationships and upon which policies are derived, rest upon, and sustained – are themselves, maintained through embeddedness in path-dependent relations.'

[79] In his illustration of contingency of a self-reinforcing sequence, Mahoney (2000, fig. 1) shows three distinct times, as opposed to stages. He does not give reflection of Time 2 its own distinct time period, as I do.

[80] The next section discusses Zambian energy's system of provision.

Taking forward the concept of lock-in in an organisational theory context, or 'structural inertia' (Cecere *et al.*, 2014, p. 1042), Cecere et al.'s broad literature review of multiple academics (Dosi, 1982; Nelson and Winter, 1982; Tushman and Anderson, 1986; Levitt and March, 1988; Hannan and Freeman, 1989; Henderson and Clark, 1990; Dosi, Teece and Al., 1992; Christensen, 1997; Tripsas and Gavetti, 2000; Davies and Brady, 2000; Sinclair-Desgagné and Soubeyran, 2000; Becker *et al.*, 2005) concludes the following narrative, with some additional insights added where indicated with citations of the original works. Organisations are endowed with routines and competences that define and bound their behaviour and strategies, limiting their adaptive intelligence. Individual agents use routines, which can be considered 'organisational memory', to economise on cognitive resources and to make up for their bounded rationality. Routinisation entails satisficing behaviour and constitutes a rational defence against time scarcity (Sinclair-Desgagné and Soubeyran, 2000). Routines are a crucial part of any account of how organisations accomplish their tasks in society (Becker *et al.*, 2005). For an aspect of organisational behaviour to emerge and persist as a 'routine', there must be a certain amount of stability to the conditions moulding behaviour: broad policies set by management, the conditions must be consistent with organisational goals and policies (Becker *et al.*, 2005). Routines are thought to be the repository of organisational capabilities but also pave the way for deliberate learning (Becker *et al.*, 2005) inside organisations – in the Zambian energy system of provision's case, these would have resulted in increasing returns to specialised knowledge in building and operating hydropower. Developed over time along a specific technological trajectory, routines become a source of lock-in which in the face of radical and disruptive change (in this context of this study, the disruptive change is the increasing frequency of El Niño droughts) become a constraining force to adaption to the new context. Core competencies turn into core rigidities.

Adding to this analysis on increasing returns of lock-in to learning, Douglass North has argued that lock-in will attempt to reduce uncertainty and minimise transaction costs by shaping the direction of the acquisition of knowledge and skills. This direction will determine long-term development (North, 1990, pp. 42-44%). 'The way in which knowledge develops influences the perceptions people have […] and hence the way in which they rationalise, explain and justify (North, 1990, p. 43%).' This does not, however, result in adaptive efficiency, concerned with inducing innovation, undertaking risk and resolving problems and bottlenecks – it is adaptively efficient institutional frameworks that permit the maximum generation of trials that will most likely solve problems (North, 1990, pp. 45-46%).

Many rationale-choice theorising approaches fall short in explaining organisational rigidities because they assume that institutions are patterns of regularised behaviour that reflect Pareto-optimal equilibria to collective actions that are stable because the actors cannot improve their positions by defecting from the pattern of behaviour (Hall, 2010). Even in a world of voluntary decisions and individual maximising behaviour, the rigid 'lock-in' that path dependence creates results in inefficiencies (Liebowitz and Margolis, 1995).

Liebowitz and Margolis (Liebowitz and Margolis, 1995) distinguished three types of path dependence by the type of inefficiency they create or do not create:

1. 'First-degree path dependence', where sensitivity to starting points exist but does not result in inefficiency;
2. 'Second-degree path dependence', where the inferiority of a chosen path is unknowable at the time a choice was made, and which leads to outcomes that are regrettable and costly to change; and
3. 'Third-degree path dependence', where sensitive dependence on initial conditions leads to an outcome that is inefficient and was avoidable but is also remediable.

In the context of Zambia, the World Bank's energy investments in the 1950s to 1970s solely in Zambian hydropower would be second-degree path dependence whereas ZESCO's investment decisions regarding the Maamba Collieries coal-fired power plant, its current investment plans dominated by hydropower and its subsidisied tariffs as part of industrial policy but which prevent it from expanding power generation are third-degree path dependence. It is this third-degree path dependence to which we will now turn.

6.6 ZESCO's third-degree path dependence

When ZESCO evaluated both the Kariba North project and the Kafue hydroelectric projects, it compared them against the thermal alternative, a coal-fired power plant at Maamba Collieries (IBRD and IDA, 1970, p. 12, 1973, p. 12). However it considered the thermal alternative on only one criterion: lifecycle cost. Maamba was evaluated to be more expensive on both a capital and operational expenditures basis (IBRD and IDA, 1970, p. 12, 1973, p. 12). Given that the effect of El Niño Southern Oscillation events on an unbalanced energy portfolio mix four decades hence would have been unknowable in the 1970s, evaluation of the options on just this one criterion was a case of second-degree path dependence stemming from the Bank's established investment appraisal process discussed in chapter 2.3.3 The Bank's economic and financial rationale for investing in hydropower. However, it seems that little changed in ZESCO's evaluation processes from the 1970s to the 2000s such that when the inferiority of a chosen path was knowable, an inefficient outcome that was avoidable arose because of third-degree path dependence.

By 2007, ZESCO's energy supply was not far exceeding demand, as Figure 31 below shows. Additionally, Zambia had seen lower precipitation levels in 1992, 1994, 1995, 1999 and in 2005 than what it was to experience in 2015, as Figure 26 illustrates. Additionally, IPCC pessimistic projections of rainfall in the Zambezi River Basin and Harrison and Whittington's pessimistic evaluation of the Batoka Gorge hydropower project had been published (IPCC, 2001; Harrison and Whittington, 2002) as noted in chapter

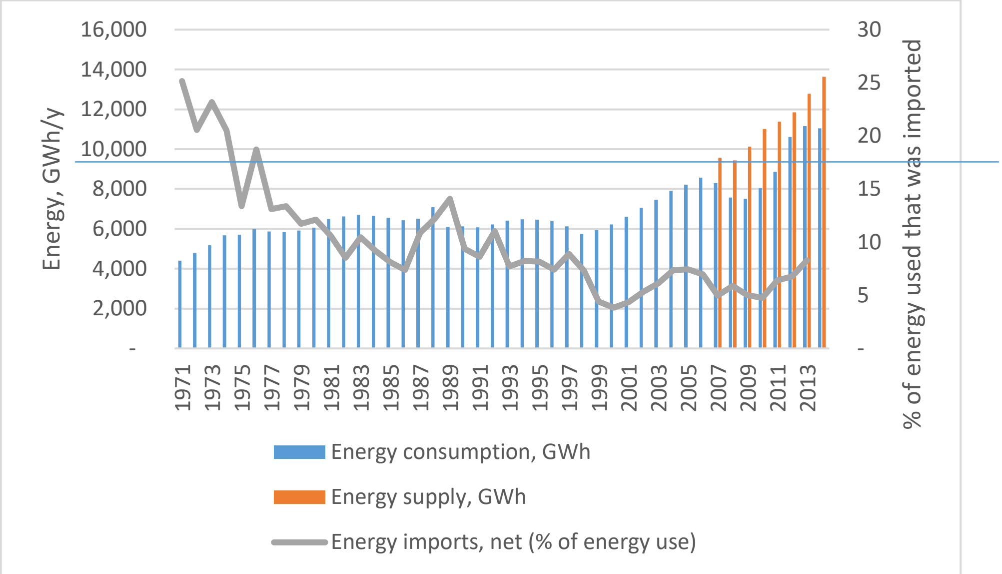
Taking into consideration the excessive losses in transmission and distribution, if ZESCO were to reduce implied energy loss from 18% in 2017 (line 6 in Table 26) to 10%, it would regain 1,200GWh of energy. 15,195GWh output in 2017 from the Energy Regulation Board's counted power generation assets less 10% of transmission and distribution losses is 13,700GWh. This means Zambia's system of energy provision would need to generate an additional 3,300-4,300GWh energy by 2030 relative to what it generated in 2017.

6.3 Droughts in Zambia – forecasts, historical occurrences and competition above. At the same time, the coal dumps, which were the by-product of mining at the Maamba collieries, were at risk of spontaneous combustion (African Energy, 2014). If Maamba Collieries had been considered since 1970 as an option for power generation, given that rainfall patterns were not reliable even in the 1990s, and given that demand was catching up with power supply, why was the Maamba Collieries coal fire power plant only fully commissioned to sell energy to ZESCO in 2017 (Patil, 2017), after the power outages of 2015 and 2016? Had Maamba Collieries come online by 2015, it could have theoretically delivered more than 2,400GWh in 2015 and 2,120GWh more energy than it did 2016, which would have been more than the difference in energy consumption by ZESCO's domestic customers in 2014 and 2015 and 2014 and 2016.[81] Why did ZESCO not act with urgency to ensure that Maamba was

[81] Assuming 93% capacity utilisation and generation for 24 hours every day, to relieve ZESCO's hydropower dams running low on stored water. In 2016, Maamba delivered 326GWh of energy (Energy Regulation Board of Zambia, 2017a, p. 8). The difference in domestic energy consumption between 2014 and 2015 was 955GWh. The difference in domestic energy consumption between 2014 and 216 was 1,548GWh (see Table 1).

delivering to the grid as soon as was possible, and why did Zambia's system of energy provision continue to plan for greater hydropower generation capacity?

Figure 31 Domestic energy consumption in Zambia vs percentage of energy imported into Zambia, 1971-2014



Sources: Energy Regulation Board, 2011; Energy Regulation Board of Zambia, 2015; World Bank, 2019a. The energy consumption was calculated from the energy consumption per capita and population figures given.

Maamba was again on Zambia's energy system of provision's list of prospective generation projects in 2008 (JICA, 2008), was included in the Ministry of Energy and Water Development's Power System Development Master Plan and was expected to be delivered by 2014 (Ministry of Energy and Water Development, 2011) and was approved for USD 150 million of loan from the African Development Bank in 2013 (Power Technology, 2013). A director at ZESCO explained that ZESCO could not agree to the tariff being offered by the independent power project for Maamba Collieries coal-fired power plant (personal interview, 4 September, 2019), and that originally, the IPP was meant to deliver energy directly to a mining company. When that negotiation failed, the Government of Zambia "imposed" agreement for the power plant upon ZESCO (see Annex 3.1.4 for more notes of the interview).[82] Even so, the reported timeline of negotiations and financing arrangements suggest that Maamba Collieries could have delivered power to ZESCO's grid before the 2015 power outages had ZESCO delivered the transmission infrastructure on time to make use of power plant's output.

The Energy Regulation Board approved ZESCO's Power Purchase Agreement with Maamba Collieries in September 2011 (Sinkamba, 2011) and the Ministry of Energy and Water Development signed an Implementation Agreement with Maamba Collieries on 16 September 2011 (Maamba Collieries, 2013, p. 6). Financing for the 300MW plant was approved two years later by the African Development Bank in October 2013 (AfDB, 2013). The first 150MW was projected to come online by October 2014 (Power Technology, 2013), but commissioning was delayed by a hold-up on the transmission line to link the plant to the ZESCO grid (African Energy, 2014). A statement by the Resident Director of Maamba Collieries suggests that the delay stemmed from ZESCO's end: 'We have made substantial progress in in ensuring that ZESCO would [*sic*] put in place certain important facilities to ensure that the power we will produce will be transported on the national grid' (Maamba Collieries, 2015b, p. 3). In fact, a report by Maamba Collieries indicates that ZESCO only started to prepare for its power in 2015.

[82] ZCCM Investment Holdings, a successor to Zambia Consolidated Copper Mines Ltd, owned by the Government of Zambia and also publicly listed (JICA, 2008, p. 109)

Entitled ‘ZESCO starts power line upgrades to prepare for MCL power’, the report states that ZESCO had only just signed a memorandum of understanding with a private contractor to upgrade substations and transmission lines to be able to receive the power plant’s energy (Maama Collieries, 2015, p. 7) – well after it was meant to accept Maamba’s energy. The project was expected to be completed within 15 months (Maama Collieries, 2015, p. 7). Maamba Collieries’ subsequent quarterly newsletter announced that ZESCO was providing a temporary arrangement for power evacuation to be completed within 5 months (Maamba Collieries, 2015a, p. 13).

ZESCO’s resistance to pursuing a power purchase agreement with Maamba Collieries and its lack of determination to deliver transmission infrastructure to receive the power plant’s generated energy as soon as possible raises yet more questions about the constraints on ZESCO to act on better judgment:

1. ZESCO should have independently seen the imperative of adding Maamba Collieries’ energy to the grid quickly. By 2015, electricity demand was 1,959MW, compared with installed capacity of 2,411MW (email sent by an energy officer at the Ministry of Energy on 30 April 2020, see Annex 3.1.2); average capacity utilisation of Zambia’s hydropower dams only needed to fall below 81% for Zambia to experience power shortages. Why did ZESCO not see the imperative of diversifying its energy generation portfolio with Maamba Collieries?
2. Why was there disagreement on the tariff?

The next two subsections will answer this two-part question that taken together explores why ZESCO failed its existing customers.

ZESCO did not treat diversification from hydropower with urgency

Institutional path dependence explains why ZESCO did not see the urgency of commissioning the Maamba Collieries coal-fired power plant to diversify its energy portfolio from climate risks.

Stage 1 of the path dependent model represents ZESCO in 1973. The Zambian copper mining industry required more energy supply to meet its demand (IBRD and IDA, 1973, p. 1). ZESCO did not yet know whether extension of the Kafue hydroelectric power project or construction of the Maamba Collieries coal-fired power plant was the most suitable choice for energy generation, where suitability is a function of reliability and dispatchability, cost, availability, environmental impact, climate impact, human health impact and impact on water availability for food.

Stage 2 is when ZESCO carried out ex-ante investment appraisal analysis and found that the extension of the Kafue hydroelectric power project would be less costly than the Maamba Collieries coal-fired power plant. Investment appraisal based on just one criterion – least cost (IBRD and IDA, 1973, pp. 12-13) – triggered hydropower to be chosen, representing a “critical juncture”. Other criteria were not considered. Even had they been, it is not clear that the result would have been different, thus benign first-degree path dependence could have emerged from this critical juncture had climate conditions not changed.[83]

Stage 3 is ZESCO in the late 2000s and early 2010s when the past limits and informs the present. As Zambia’s demand from existing customers catches up with supply (see Figure 31 above), the Ministry of Energy plans for and approves the Maamba coal-fired power plant, but alongside much more installed hydropower capacity. ZESCO, meanwhile, slows the process of commissioning the coal-fired power plant.

[83] The El Niño effect would come decades later, so excessive supply of hydropower would have been dispatchable. It is not clear how hydropower and coal fire would have compared on environmental impact when the effects of flooding were taken into consideration.

By 2015 electricity demand was 1,959MW, compared with installed capacity of 2,411MW (email sent by an energy officer at the Ministry of Energy on 30 April 2020, see Annex 3.1.2), meaning that average capacity utilisation needed to fall below only 81% for Zambia to experience power outages. Zambia had seen lower precipitation levels in 1992, 1994, 1995, 1999 and in 2005 than what it was to experience in 2015, as Figure 26 illustrates. A growing body of literature was accompanying the IPCC's pessimistic projections of rainfall in the Zambezi River Basin and Harrison and Whittington's pessimistic evaluation of the Batoka Gorge hydropower project (IPCC, 2001; Harrison and Whittington, 2002) as noted in chapter

Taking into consideration the excessive losses in transmission and distribution, if ZESCO were to reduce implied energy loss from 18% in 2017 (line 6 in Table 26) to 10%, it would regain 1,200GWh of energy. 15,195GWh output in 2017 from the Energy Regulation Board's counted power generation assets less 10% of transmission and distribution losses is 13,700GWh. This means Zambia's system of energy provision would need to generate an additional 3,300-4,300GWh energy by 2030 relative to what it generated in 2017.

6.3 Droughts in Zambia – forecasts, historical occurrences and competition above. Yamba et al, Beck and Bernauer, Beilfuss and Spalding-Fecher et al were all to add their voices online by 2014 (Beck and Bernauer, 2011; Yamba, Walimwipi and Mzezewa, 2011; Beilfuss, 2012; Spalding-Fecher *et al.*, 2016), with Spalding-Fecher et al concluding that climate change and upstream development must be incorporated into both project and system expansion planning (Spalding-Fecher *et al.*, 2016). At the same time, the coal dumps, which were the by-product of mining at the Maamba collieries, were at risk of spontaneous combustion (African Energy, 2014).

To its credit, the Zambian energy provision commissioned the Maamba coal fired project. But it also commissioned more hydropower (Itezhi Tezhi, Kafue Gorge Lower, Kariba North Bank Extension and Kabompo), and slated for the future three more large hydropower projects (Batoka Gorge, Devil's Gorge, Kalungwishi) and smaller hydropower projects (Ministry of Energy and Water Development, 2011; Tembo and Merven, 2013).

Within Zambia's system of energy provision, the Ministry of Energy, Energy Regulation Board and international donors in the form of the African Development Bank, had agreed to contract and finance the Maamba coal-fired power plant (Sinkamba, 2011; AfDB, 2013; Maamba Collieries, 2013, p. 6). It seems though that ZESCO was not on board. A director at ZESCO reported that the government (the Ministry of Energy and Energy Regulation Board) had "imposed" the agreement on ZESCO because ZESCO found the cost-recovery tariff to be too high (personal interview, 4 September, 2019 – see Annex 3.1.4 for more notes of the interview). ZESCO's 2016 Integrated Report gives an insight into how ZESCO sceptically views the non-zero variable cost of thermal energy: 'we remain focused on embracing cost cutting measures such as switching from costly diesel generation to cheaper and renewable energy sources' (Zesco Ltd, 2017a, p. 7). Even with the agreement imposed, it took ZESCO until 2015 to sign a memorandum of understanding with a private contractor to upgrade substations and transmission lines to transmit power from Maamba onto the national grid, causing transmission delays after the completion of construction of the power plant, as discussed above in greater detail (African Energy, 2014; Maamba Collieries, 2015b, 2015a).

ZESCO did not see climate resilience as an important investment appraisal criterion to consider historically before 2015 and therefore did not see the need to diversify its portfolio of energy generation sources. ZESCO failed to give urgency to first the development of Maamba coal fired plant and then the required infrastructure needed to off-take power from its coal-fired power plant. ZESCO prioritised new hydropower projects. Past choices informed ZESCO's investment appraisal criteria which precluded climate resilience.

Stage 4 is ZESCO in 2017. The El Niño effect brought drought to southern Africa in 2015 and 2016 (FAO, 2015b, 2018; Vidal, 2016; Hao *et al.*, 2018), rendering ZESCO's hydropower plants ineffective in meeting demand.[84] The Kariba North Bank Extension, commissioned in May 2014, produced energy in 2015 at only 37% capacity utilisation in its first full calendar year and 21% in its second year due to the drought; average capacity utilisation of Zambia's largest hydropower dams falls well below 81% in both 2015 and 2016 (see Table 27). The 300MW Maamba Collieries coal-fired plant came fully online in July 2017 (Patil, 2017), after the power outages of 2015 and 2016, outages that it could have prevented had it come fully online sooner. Four more power plants, one hydropower, two solar and one fossil-fuel based, also came online soon – Itezhi-Tezhi 120MW hydropower plant in 2015/16, a 105MW heavy fuel oil fired thermal power plant in Ndola in 2017, and 54MW and 34MW solar power PV power plants in 2019 (correspondence with a Ministry of Energy officer on 30 April 2020, see Annex 3.1.2).

ZESCO's economists (interview on 10 November 2017) believed that they had figured out how to resolve the power outages as they presented their plan to expand power capacity, but not entirely with hydropower, as they handed me Table 28. Some more nuanced thinking emerged in ZESCO's 2016 Integrated Report (Zesco Ltd, 2017a, p. 7) about differentiating between hydropower projects in the Zambezi River Basin and in the Lake Mweru Basin/Congo River Basin:

> We also continue to shift our dependence from water bodies in the southern part of the country which have been hardly hit by low rainfall and water levels in the past few years. To this end a number of projects are being explored in the northern part of Zambia such as the Luapula River Basin and Kalungwishi Hydro Power Projects.

The call to diversify ZESCO's water catchment areas as a main source for hydropower (Zesco Ltd, 2017a, p. 7, 2018, p. 21) demonstrates that individual minds as well as at an institutional level, ZESCO had recognised that the initial conditions for investment in hydropower in the Zambezi River Basin no longer matched those at Stage 1. Yet path dependence at the institutional level ensured that Zambezi River Basin hydropower projects including the 2,400MW Batoka Gorge Project remained in ZESCO's next annual Integrated Report (2017, the most recent one available) and even in the Energy Regulation Board's 2018 Energy Sector Report (the most recent one available) (Zesco Ltd, 2018, p. 45; Energy Regulation Board of Zambia, 2019, p. 56).

Path dependence explains ZESCO's and more broadly Zambia's system of energy provision's continued proclivity for hydropower in spite of the evidence that hydropower in an El Niño-vulnerable southern Africa is no longer the dependable, dispatchable source of hydropower that it once was capable of being when capacity for supply far exceeded demand. Having explained why Zambia's system of provision failed to diversify Zambia's power generation capabilities from Zambia's climate vulnerability, the next subsection will supplement this explanation with Zambia's system of provision's failure to achieve system sustainability.

ZESCO's tariff structure failed to achieve system sustainability

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[84] Also to north South America, and south and south east Asia, making this case study applicable to other hydropower dependent countries beyond southern Africa.

The previous subsection mentioned that a director at ZESCO stated that ZESCO had difficulty agreeing to the tariff being offered by the independent power project for Maamba Collieries coal-fired power plant (personal interview, 4 September, 2019), and it took imposition by Government of Zambia for the tariff negotiations to not breakdown. This subsection explains why it is likelier that out of the negotiating parties on tariff, ZESCO is the likelier to have held a position misaligned with the interests of its customers. It then attempts to explain why that would have been the case through two mechanisms. First, why inherently unequal distributional policy between residential customers and residential non-customers never became a cause for voter mobilisation. Second, why policy aimed at allocating low tariffs to industries that would spur the economy would result in a lock-in of low tariffs even when the system of provision required additional funds to ensure reliability of electricity delivery.

Economic theory would model the developers of Maamba Collieries, Nava Bharat, as profit-maximising investors, seeking a minimum risk-adjusted return given their options to invest elsewhere. While Nava Bharat would have been incentivised to negotiate to maximise profit by seeking to gain returns in excess of the norm for the risk of their investment, they would not have been incentivised to draw out negotiations over a long period, since this would incur extra running costs before they could hope to be compensated, because their chances of winning the commission would diminish and because the opportunity cost associated with pursuing this venture would have increased. JICA documents their interest and involvement with Maamba Collieries back to 2008 (JICA, 2008). The resulting negotiated tariff between Nava Bharat and ZESCO should not therefore have been excessive from the perspective of returns Nava Bharat could expect by investing elsewhere for a similar level of risk. Based on my own experience with a peat-fired power plant in another landlocked African country (I was a Transactions Advisor to the Rwandan power utility through the Rwanda Development Board from 2012 to 2016), the tariff of USc 10.35/kWh (Mabumba, 2017) does not seem excessive on the basis of a 15% post-tax equity internal rate of return.[85]

To answer the question from ZESCO's perspective, further context is required. In a ministerial statement to Parliament, the Minister of Energy revealed that ZESCO charges on average USc 5.47/kWh to its residential, industrial and mining customers, while it pays Maamba Collieries USc 10.35/kWh (Mabumba, 2017). This is approximately the tariff that ZESCO would need to charge to cover the cost of asset maintenance and new energy infrastructure (confidential document viewed). And yet as of 2014, ZESCO offered the lowest tariffs in sub-Saharan Africa, with the average Zambian tariff only 38% of the median one (Trimble et al. 2016). Even as far back as 1973, the World Bank noted (IBRD and IDA, 1973, p. ii):

> ZESCO's past financial position has not been satisfactory. This was largely due to low tariffs both for its retail power supplies to its consumers and for its bulk supplies of power from its generating stations to the [Central African Power Corporation] and on account of liabilities inherited from predecessor companies.

In that instance, the World Bank agreed to support ZESCO on the condition that it raised its tariffs by 25%. More recently, the World Bank estimated that the Zambian power sector lost USD 300-400 million in 2016 due to under-pricing (World Bank, 2017a, p. 5), while a Zambian newspaper published that ZESCO owed Maamba Collieries USD 149 million as of November 2019 (Diggers Editor, 2019).[86] Clearly, ZESCO's tariff policy did not make sense from a system sustainability perspective. This is why

[85] On a prima facie basis, without knowing the associated costs and without knowing the structure of the tariff and therefore what proportion is escalated with inflation.

[86] I heard similarly from a private developer on 4 September 2019 in Lusaka. I was informed that ZESCO was only paying Maamba Collieries the debt service payment portion of the capacity charge and the variable fuel cost.

a company like Africa GreenCo sees a gap in the market for a credit-worthy off-taker in Zambia to encourage new investment by independent power producers (see interviews with their CCO and CEO in Annex 3.2.2 as well as with an energy expert at a donor agency on 27 February 2019 in Annex 3.4.1).

ZESCO's tariff policy did not make sense from a distributional equity perspective either. Two-thirds of Zambia's population is without ZESCO electricity (ZICTA and CSO, 2018) and ZESCO's ability to expand its electrification access is compromised by subsidising existing users. This makes it unfair to those without any electricity for ZESCO to subsidise even their poorest customers. Cost-recovery tariffs across the board would enable ZESCO to invest more in on-grid electrification. This would help achieve universal access, to the extent that on-grid electrification is more cost-effective than privately offered or subsidised off-grid electrification.

Sabatier's Advocacy Coalition Framework (Sabatier, 1998) or alternatively even corruption might explain the low tariffs. However, the evidence does not support either interpretation.

First, the Minister of Energy's parliamentary address disclosed that the largest mining companies are ZESCO's highest tariff payers, paying USc 9.3/kWh (Mabumba, 2017). Given that mining companies consume more than half of ZESCO's generated electricity and that 80% of Zambia's mining output is generated by just four companies, advocacy should result in the largest, most consolidated industries benefiting the most instead of the least. Even if the Minister's statement about mining companies was inaccurate or only temporarily true (he was talking of an 'interim' tariff), my conversations with the Director of Economic Regulation at the Energy Regulation Board (personal interview, 6 June 2018, see Annex 3.1.3) and an energy expert at a donor agency (phone interview, 27 February 2019, see Annex 3.4.1) indicated that mining companies receiving ZESCO energy through the Copperbelt Energy Corporation would still be paying more than residential and industrial customers, and close to the value that the Minister had stated.

There also does not seem to be an intersectoral coalition between manufacturers and mining companies, and it seems manufacturers would be open to paying higher tariffs. An interview with the CEO of the Zambia Association of Manufacturers (personal interview, 28 May 2018, see Annex 3.3.1) indicated that the manufacturing sector perceives an unfair tariff distribution between sectors and would like to see a rise in tariffs for the mining sector: they would be willing to pay more if first the perceived unfairness of the mining sector not paying enough was solved. She also said that the manufacturing sector would consider agreement to further tariff increases pending the publication of the government's much delayed and awaited Cost of Service Study for the electricity sector.

Third, residential customers are not organised to the extent that the consolidated mining sector is. Yet the third of the population that is privileged enough to have grid electricity at home enjoy even lower tariffs than the manufacturing and mining sectors.

Voter concentration in urban areas can partially explain the lack of distributional equity in ZESCO's tariff structure. When Michael Sata ran to end the Movement for Multiparty Democracy's two decade rule on a campaign against inequality, he meant urban inequality (Resnick and Thurlow, 2014). In rural areas, he relied on ethno-linguistic appeals to the Bemba populations (Resnick and Thurlow, 2014). His non-ethnic constituency was the urban poor, opening and closing his campaign in Lusaka's informal market and shanty compound, rather than the rural poor (Resnick and Thurlow, 2014). In 2011 he won 63% and 68% of the vote in urban Lusaka and Copperbelt Provinces, and 64% and 73% of votes in Bembaphone Northern and Luapula Provinces. This helped him amass 43% of the Zambian national vote against the incumbents and eight other opposition parties to be declared winner of the presidential elections (Al Jazeera, 2011). His Patriotic Front party also emerged the most represented in the National Assembly with 40% seats in a first-past-the-post system. Two-thirds of urbanites now have grid access as opposed to 6% of rural households (ZICTA and CSO, 2018). Since the year of his election in 2011, urban access to electricity (both on and off-grid) increased from 59% to 75% in 2017, while in rural areas it increased from 5% to 14% (World Bank, 2020u). An issue-based, needs-based appeal to electrify the two-thirds of the rural population without grid electricity would prove more difficult for the same reason that infrastructure access to rural areas proves more difficult to justify: fewer people are reached with the same fixed costs.

Having explained why unequal distributional policy between residential customers and residential non-customers has not yet become a cause for voter mobilisation, we can now examine the industrial policy that informed the choice of low tariffs in the first place that were to become locked-in and prevent ZESCO from imagining paying USc 10.35/kWh for thermal energy.

A path dependent belief in the allocative efficiency of charging subsidised tariffs offers a credible explanation for why ZESCO became married to under-pricing tariffs and used to not paying capital recovery and variable operational charges. Here is the logic:

At Stage 1 in 1968, the time of ZESCO's creation, 75% of Zambia's population is dependent on primarily subsistence agriculture, yet mining, which provides employment to c.15% of the country's wage earners, contributes to 45-49% of Zambia's GDP (Park, 1968, pp. viii, 11). Light manufacturing contributes to c.9% of GDP (Park, 1968, p. vii). The Government of Zambia, owners of ZESCO, seek a strategy to develop Zambia's economy and improve quality of life. Hirschman's argument for unbalanced growth and focus on selected industries seems to have prevailed in the US Department of Commerce's analysis of Zambia in 1968 (Park, 1968, p. vii):

> Zambia's bright prospects for continuing economic development arise largely from the country's strong financial base, consisting principally of revenues derived from abundant mineral resources.

This thinking influenced the Government of Zambia's development strategy at Stage 2. It elected a strategy of unbalanced growth. It used its state-owned electricity utility ZESCO to subsidise productive sectors of the economy that would drive economic growth, with the hope that improved quality of life for all would follow. This explains why the World Bank found that ZESCO's tariffs in 1973 were low, and conditioned its loan on an increase of tariffs by 25% (IBRD and IDA, 1973, p. ii).

The past choice of subsidised tariffs informed and limited future decisions so that by Stage 3, Zambia offered tariffs that were 38% of the median sub-Saharan African electricity tariff (Trimble *et al.*, 2016), whether to industry or to residential consumers.

By stage 4 when ZESCO was negotiating tariffs with Nava Bharat, the premise of allocative efficiency for subsidised tariffs no longer held, because to support its customers' productivity, it needed to deliver reliable electricity. But low user tariffs had become an ossified norm (per Mahoney's prediction, 2000, pp. 513–14), and ZESCO had become unaccustomed to paying a capital recovery charge for new power generation assets, because the majority of its power supply came from assets that were constructed in the 1970s or earlier, and had therefore fully depreciated by the late 2000s. ZESCO had also become unaccustomed to paying a variable operating charge for fossil fuel, given that it was almost fully reliant on fuel-free hydropower. This is eluded to in its intention to return to cheaper, renewable energy sources from diesel generation (Zesco Ltd, 2017a, p. 7).[87] ZESCO's history of low user tariffs now prevented it from delivering on the promise of allocative efficiency because it was no longer able to finance the construction of new power generation and service delivery to its base of mining and manufacturing companies. Chapters 3 and 5 illustrated the costs to manufacturing firms of the power outages caused by this.

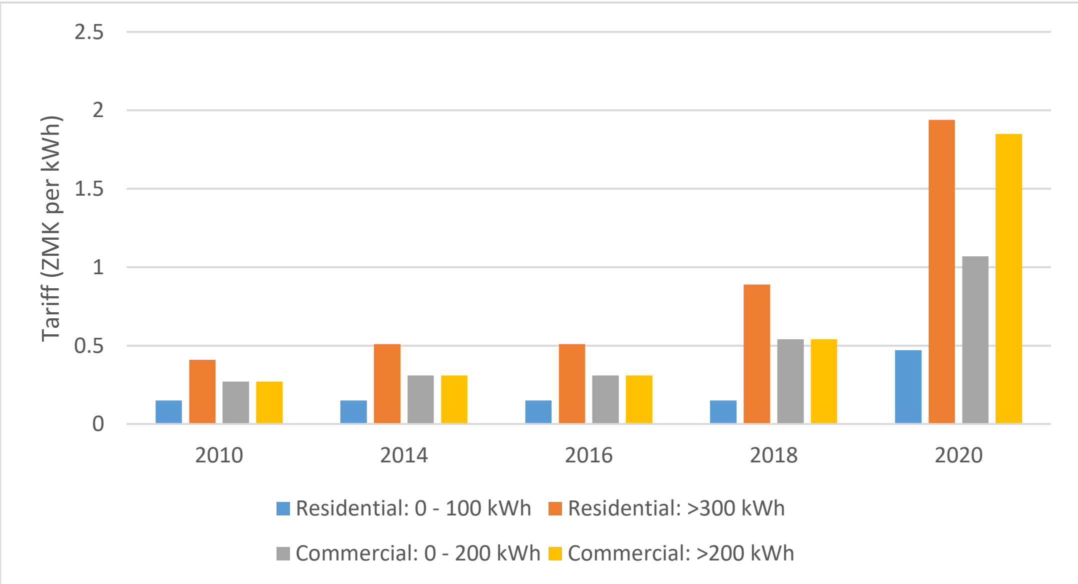
The critical juncture of the power outages of 2015 and 2016 resulted in two tariff increases in 2017. However, the large percentage increases on very small values meant that the increases were not substantial. They were not increased to be cost reflective (see phone interview with an energy expert at a donor organisation on 27 February 2019 in Annex 3.4.1). As the results of the manufacturing survey below show, the tariff increases did not affect manufacturing demand.

The critical juncture of a second wave of severe power outages, this time lasting 15 hours per day (Zesco, 2019), prompted the Energy Regulation Board to accept ZESCO's application to raise tariffs yet again on 1st January 2020 (see Figure 32 below). Still, Haria and Ahmed (2020) note:

> The Energy Regulation Board commissioned a Cost of Service Study in 2016 with the findings on a cost-reflective electricity tariff due in 2017 (Energy Regulation Board of Zambia, 2016b). This remains outstanding, so those outside ZESCO and the ERB do not know whether the new tariffs are cost reflective. Still, their increase can only mean better system sustainability.

Resolving the issue of a system sustainable tariff would also ensure better creditworthiness for ZESCO vis-à-vis other power utilities and power projects on the SAPP, and ensure that ZESCO was better financially situated to pay for emergency power.

Figure 32 Evolution of ZESCO tariffs, 2010-2020



Source: Haria and Ahmed, 2020

[87] There are three elements of a tariff that a power utility would pay an independent power project: the capital recovery charge, the fixed operations and maintenance charge and the variable operations and maintenance charge. The first includes the returns paid to equity and debt investors for their investment into the capital assets. The second covers salaries and other fixed operating costs. The third includes the cost of non-renewable fuels and other variable operating costs.

This chapter examined why Zambia's system of energy provision did not prevent the power outages of 2015, 2016 or even 2019. Warnings of climate change's effects on water availability for hydropower were available as early as the turn of the millennium so that as Zambia's system of energy provision planned to meet increasing demand, it should have taken into consideration a variety of climate futures. Even after the power outages of 2015 and 2016, even when the system recognises the need for technology or basin diversification, the system continues to look at the Batoka Gorge hydropower dam in the Zambezi River Basin whose potential was negatively assessed by Harrison and Whittington in 2002. The historical institutional path dependence explains this phenomenon. It also explains why a low tariff to end-consumers which had its beginnings in industrial policy persists to inform tariff policy that has hamstringed the system's ability to deliver reliable energy to Zambia's industrial base.

7. Recommendations

First, ZESCO and the Energy Regulation Board should investigate why distribution and transmission losses have been increasing and seek to address these. Second, ZESCO should ensure that existing infrastructure is refurbished and rehabilitated to the extent that it can be economically. Next, ZESCO needs to improve its communication to customers on when they can expect power outages and what tariffs mining companies are paying. This will improve customer confidence in and comfort with paying higher tariffs that will allow for the financing of additional and climate-resilient power generation, or imported power. ZESCO and the ERB should consider offering premium services at premium prices to the food and beverage subsector and to export-facing manufacturing firms since these are most willing to pay higher tariffs for more reliable energy. In evaluating its options for sourcing extra power supply, ZESCO needs to look beyond the financial costs of generation under scenarios which do not include drought: it should also be low-carbon and carbon resilient and minimally impact human health and nature. A more balanced portfolio of power generation assets will include gas-fired power from Zambia's SAPP partners. To make renewable energy more viable, the regional power pool should seek to expand into other regions of Africa. Beyond charging system-sustainable tariffs, ZESCO should increase the differential between peak and off-peak tariffs so that the peak demand it needs to meet is reduced. It should also penalise consumers for reactive power, and incentivise the use of power self-generated by rooftop solar PV.

Chapter 2 reviewed the historic role that industrialisation has played in the economic development of nations. It has observed that manufacturing grew in Zambia following investments into power generation until 1991, but that its growth had minimal impact on structural changes in employment shifts away from agriculture and in fact GDP per capita was lower by 1991 than it was at the time of independence in 1964, with average life expectancy at about the same level. Since the 2000s, manufacturing has been growing again, with higher employment and GDP returns per kWh of energy consumed than Zambia's largest consumer of energy, mining. Chapter 5 investigated the ways in which power outages harm Zambian manufacturing firms, and investigated manufacturing firms' interventions to lessen the costs of power outages and investigated the efficacy of their interventions. Chapter 6 explained the reasons why Zambia's system of energy provision did not prevent these power outages. Chapter 6 assessed distribution and transmission losses, diligences forecast demand and considers viable alternatives to hydropower. This chapter will offer recommendations on how to overcome Zambia's power outages in the future in the hope that they offer a more equitable development pathway.

Some recommendations were provided earlier in written format (Ahmed, Baddeley, D. Coffman, *et al.*, 2019; Ahmed, Baddeley, D. M. Coffman, *et al.*, 2019) in a closed-door presentation at the Ministry of National Development Planning to key representatives from Zambia's Ministry of Finance, Ministry of Energy, Energy Regulation Board, ZESCO and Central Statistical Office (4 September, 2019), in the keynote presentation of a public forum hosted by the International Growth Centre (Ahmed, 2019) and aired on prime time TV news by ZNBC (ZNBC, 2019). Some of these recommendations have been updated here because the Energy Regulation Board subsequently accepted ZESCO's application for a further tariff escalation on 1st January 2020. To systematically approach the problems that can be solved, this chapter will offer solutions to address supply, and then offer solutions to dampen demand.

Supply-side solutions

ZESCO and the Energy Regulation Board should investigate ZESCO's increasing sources of distribution and transmission losses and work to address these before commissioning extra power supply. Additionally, before investing in or committing to purchase additional power supply, ZESCO should work to improve existing hydropower capacity through rehabilitation, refurbishment and renovation.

Delivering a more reliable energy supply while achieving sustainability is an example of a wicked problem: because of complex interdependencies, the effort to solve one aspect of a wicked problem may reveal or create other problems. Addressing Zambia's issue of power supply reliability by recommending full reliance going forward on coal-fired power plants adds to the accumulation of greenhouse gases in the atmosphere that have exacerbated the El Niño effect which is causing ZESCO's existing hydropower infrastructure to become less effective. It would also acidify rain, which would damage vegetation and thus limit transpiration, interrupting a necessary process of putting water vapour into the atmosphere for rainfall to occur, as well as harm human health. To overcome the problem, we categorised possible sources of energy by a number of essential factors to consider: availability, dependability, climate impact, impact on health and the environment and financial costs in Table 30 A least regret framework for assessing Zambia's potential energy sources
. The analysis shows that a more balanced portfolio is required, and that ZESCO will need to supply approximately 17-18,000 GWh of power by 2030. Realistically, gas-fired power imported from Zambia's SAPP neighbours Tanzania and Mozambique seem to be the most viable short-term options if ZESCO is able to charge its customers the costs of importing energy. For the medium-term, ZESCO should look into the feasibility of pairing hydroelectricity reservoirs with solar-powered pumps for recharging, and investigate the potential of cheap solar PV energy storage as repurposed electric vehicle lithium-ion batteries come onto the global market. ZESCO should also spear-head expanding the SAPP beyond southern Africa so that weather patterns affecting one river basin can be offset by alternative weather patterns in other parts of Africa. Diversifying across time zones will also make solar without storage more viable.

ZESCO will need to charge a cost-recovery tariff. The Government of Zambia does not have the resources to subsidise ZESCO and ZESCO does not have the resources to subsidise its customers and additionally increase on-grid electricity access. It should not have taken more than four years for the Energy Regulation Board's 2016 commission of the Cost of Service Study to be completed. It is likely that when it is completed, it will find that the cost-recovery tariff for ZESCO exceeds the average tariff ZESCO charges since the Energy Regulation Board approved the revised set of tariffs on 1st January 2020. Raising the tariff to the cost-recovery level will allow ZESCO to procure the additional energy it needs to serve its customers reliably, whether domestically or from the power pool, and achieve system sustainability. The manufacturing survey, which monetised the minimum impact of power outages for diesel-generators in 2016 as USD 0.25/kWh, shows that low tariffs to the manufacturing sector are not achieving the goal of allocative efficiency. The same goes for the mining sector which also employs diesel generators for backup energy. With access to on-grid electricity only available to a third of the population, subsidised tariffs are inherently regressive against those without grid-electricity since they financially disable ZESCO from expanding its distribution network. Until all poor and rural communities in Zambia have access to grid-electricity, subsidised tariffs do not make sense from a distributional equity perspective. Parliament should ensure that the Energy Regulation Board is able to set tariffs for the mining sector.

For ZESCO to charge yet higher tariffs that will enable it to achieve system sustainability, it will need to build trust with its clients. A quarter of manufacturing firms reported not receiving accurate load shedding notifications during the period April – August 2018. ZESCO must ensure therefore to the extent that it can that its communications to its clients are correct. To facilitate accurate communication about load shedding schedules, perhaps it will need to take more conservative estimates of the reservoir levels of its hydropower dams and their capacity utilisation rates. To dispel notions that other sectors subsidise mining, ZESCO should also make public on its website the tariffs that its mining clients and the Copperbelt Energy Corporation receive; the Copperbelt Energy Corporation in turn should disclose what tariffs it charges to its clients.

Given that they self-generate electricity more, food and beverages and export-facing firms within the manufacturing sector incur greater financial costs in running their businesses normally. They also emit more greenhouse gases with that self-generation (Ahmed *et al.*, 2020). ZESCO should consider offering these firms a premium service solution, and link these firms' energy supply to nuclear power in South Africa. Alternatively, to offset the prioritisation of steady Zambian coal-fired power, ZESCO could require manufacturing firms to install solar panels (notably absent on manufacturing firms' warehouse and factory rooftops), or to finance renewable energy interventions.

Solutions that can dampen demand for electricity or improve self-sufficiency

The Ministry of Finance's tax waiver of generators seems to have been responsible for increased investment in generators. These help sectors of the economy limit the damages caused by power outages. Until ZESCO can ensure that the food and beverage manufacturing subsector and that export-facing manufacturing firms have uninterrupted power supply, the Ministry of Finance should retain these waivers to ensure smoother business operations. Similarly, other interventions should be introduced to encourage firms to generate their own energy, especially if it leads to a net reduction in harm the environment (such as some forms of waste-to-energy which are less greenhouse gas emitting and whose disposal processes would otherwise be greatly harmful), or a reduction in emissions (such as solar panels on rooftops). Feed-in-tariffs seem to have been a popular and successful mechanism for encouraging such investment.[88]

The differential between ZESCO's new peak and off-peak tariffs continues to be minimal. The peak tariff should be increased further to dampen demand during peak hours, so that ZESCO does not have to procure additional power capacity that will only be used a few hours of the day. Similarly, to reduce wastage, ZESCO should impose a surcharge on reactive power, the power that flows back from a destination towards the grid in an alternating current scenario. Increasing tariffs beyond cost-recovery will additionally have the effect of incentivising greater energy efficiency which the household survey has shown has been lacking.

[88] The South African utility Eskom does not seem to cater a feed-in-tariff for households (Strydom and Morar, 2018). However, nine municipalities in the Western Cape are piloting feed-in-tariffs for households. This is perhaps responsible for the Western Cape having the most solar rooftop installations (301) in South Africa (Strydom and Morar, 2018). The Eastern Cape has one municipality with an approved feed-in-tariff and has the second most installations (154) (Strydom and Morar, 2018). In the provinces without feed-in-tariffs, no PV installations have been recorded (Strydom and Morar, 2018).

8. Conclusions

By building power generation assets for the benefit of Zambia's mining, the World Bank pursued a strategy of unbalanced growth in Zambia. Unbalanced development outcomes followed. Path dependence within Zambia's system of energy provision both in terms of homogenous power generation assets as well as in terms of subsidised tariffs for existing electricity consumers led to its failure in delivering the value that it had envisioned to for its existing customer base when droughts – that had been predicted by the IPCC as early as 2001 – struck. Up to a fifth of humanity live in nations heavily dependent on hydropower that is vulnerable to drought due to increases in average global temperatures. This case study holds lessons for them.

Hydropower dependence makes countries vulnerable to climate change. As the El Niño effect increases in frequency as global temperatures rise it causes an increase in droughts in southern Africa, north South America, and southeast Asia. Whereas system of provisions previously took for granted that hydropower could be a dispatchable source of power when supply of capacity exceeded demand, they should no longer take it for granted in climate vulnerable geographies.

Donor funded energy from the 1970s primarily targeted energy for mineral extraction in Zambia, perpetuating a colonial trend of meeting Western market needs. It was premised on the argument that unbalanced growth would pay for so-called social infrastructure and benefit the rest of the population in the long term. Metrics evaluating Zambia's development since the 1970s do not support this premise. Most Zambians still cannot access the power supply that the World Bank financed in the 1960s and 1970s that still accounts for the majority of Zambia's installed power capacity. Zambia's real GDP has grown, but GDP per capita, for all its faults as a metric, has grown only 8% since 1964. Income inequality has grown. Life expectancy has finally increased, but only after reaching a nadir in the mid-1990s; it is not directly attributable to the World Bank's investments.

Path dependence within Zambia's energy system of provision resulted in ZESCO being insufficiently prepared for the climate events of 2015, 2016, and 2019 which rendered low hydropower reservoir levels. Further investment in hydropower failed to build its climate resilience. Low user tariffs precluded it from being able to finance sufficient additional power generation capacity or source it from abroad – thus harming the very users it was subsidising – by being unable to avert power outages.

The harm for manufacturing firms included increased staff costs, damage to their equipment, damage to their reputation, increased costs of security in the expectation that there could be insufficient lighting, as well as damage to inventory. Many firms incurred additional costs of USD 0.25/kWh to generate the backup energy through diesel generators that they required. Larger firms invested in greater installed power capacity of diesel generators; export-facing firms not owned by Zambians used their generators more intensely. The wood and basic metals manufacturing subsectors used their generators least intensively but were most willing to pay ZESCO higher tariffs for more reliable energy; the food and beverages manufacturing subsector and export facing firms were also willing to pay higher tariffs for more reliable ZESCO energy.

To mitigate against the harm, mining companies, manufacturing firms and households, and even ZESCO itself have resorted to generating energy by burning diesel. This increases Zambia's emissions by up to a tenth in months of severe power outages. It incrementally contributes to a rise in global temperatures and the increased likelihood of El Niño droughts that further undermine the utility of Zambia's existing hydropower infrastructure, and also undermines the government's effort to reduce the nation's emissions per its Nationally Determined Contributions commitment.

ZESCO, the Energy Regulation Board, Ministry of Energy, donor agencies and financial institutions should broaden their criteria for selecting and supporting new energy sources. These should include the lifecycle environmental, health and climate impact, availability, dependability and climate resilience and financial lifecycle costs in a "least regret" framework. This broader framework for energy investment appraisal would help solve Zambia's climate vulnerability. With the right governance structures in place to prevent hold-ups and renegotiations, Zambia's best chance at achieving least regret energy is likely through the import of nuclear power from South Africa and then through the import of natural gas fired-power from Tanzania and Mozambique, until second life lithium-ion electric vehicle batteries become available and makes intermittent solar energy viable as a dispatchable energy source.

The case of reduced hydropower capacity in Zambia is unfortunately not a unique one. Up to a fifth of the global population live in nations heavily dependent on hydropower that is vulnerable to drought due to increases in average global temperatures. As droughts and El Niño events increase in frequency in across parts of Africa, north Latin America and in southeast Asia, the case study of and recommendations for Zambia have significant implications for the formulation of low carbon transition energy policy in these other countries.

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Annex 1 – Hydropower dependent countries that like Zambia experienced El Niño droughts

Country/territory	Column A Conditions applied to World Bank Data (2020s): Not "High Income" AND >25% electricity production comes from hydropower sources = 1; >25% and High Income = 0	Column B Source that says that countries that score 1 in column A experiences El Niño droughts	Column C If Column A = 1 AND affected by El Niño droughts, evidence of similar political economy dynamics viz. early World Bank focus on hydropower?	Column D Population (World Bank, 2020s) if not >25% hydropower AND are not High Income AND experience El Nino droughts
Total countries that meet condition	45	32	17	1,357,770,729
Angola	1			
Albania	1			
Argentina	1	Rojas et al (Rojas, Li and Cumani, 2014)		43,590,368
Armenia	1			
Austria	0			
Bosnia and Herzegovina	1			
Bolivia	1	FAO (FAO, 2016)	The World Bank's first investments into Bolivia were into hydropower plants (IDA, 1964; World Bank, 2020d)	11,031,813
Brazil	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's second investment into Brazil in 1950 was in hydropower followed by investment in another hydropower station in 1953 to meet industrial demand (IBRD, 1950c, 1953a; World Bank, 2020e).	206,163,058
Canada	0			
Cambodia	1	Rojas et al (Rojas, Li and Cumani, 2014)		15,766,293

Cameroon	1	European Commission (European Commission, 2015)		23,926,539
Chile	0	Cai et al (Cai, W., McPhaden, M.J., Grimm, 2020)		18,209,068
Congo, Dem. Rep.	1	WFP, Isango (WFP, 2016; Isango, 2017)		78,789,127
Congo, Rep.	1			
Colombia	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's first investments in Colombia were in hydropower, starting from its second investment, to meet industrial demand (IBRD, 1950a, 1950b, 1951a; World Bank, 2020f). The World Bank's choice of investment in power over 'social' investment in water has been discussed in greater length in footnote 12.	48,171,392
Costa Rica	1	Costa Rica Guide (Costa Rica Guide, 2020)	The World Bank's fourth investment in Costa Rica was in hydropower (IBRD, 1961b; World Bank, 2020g).	4,899,345
Croatia	0			
Ecuador	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's second investment in Ecuador was in 3MW thermal and 14.5MW hydropower plants (IBRD, 1956a; World Bank, 2020h) to meet industrial and residential demand.	16,491,115

Ethiopia	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's eighth investment in Ethiopia was in power to meet expanding industrial demand (IBRD, 1961c; World Bank, 2020i).	103,603,501
Gabon	1			
Georgia	1			
Ghana	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's first investments in Ghana were into the Volta Power Project (World Bank, 2020j) for the purpose of 'the aluminum smelter, various mining companies and the Electricity Division which would distribute power to the general consumers in southern Ghana' (IBRD, 1961a, p. 2).	28,481,946
Guatemala	1	Lakhani (Lakhani, 2019)	The World Bank's second and third investments in Guatemala were in hydropower, with the Bank noting that industrial electricity sales accounted for 42% of electricity in 1966 (IBRD, 1967; IBRD and IDA, 1968, p. 4; World Bank, 2020k)	15,827,690
Honduras	1	Moloney (Moloney, 2019)	The World Bank's third investment in Honduras was	9,270,795

			for an interim power project consisting of the installation of additional diesel capacity and the preliminary costs for survey work for the Rio Lindo hydroelectric scheme. The Bank's fourth investment in Honduras was in the first stage of the Lake Yojoa-Rio Lindo hydroelectric power project (IBRD, 1959, 1960b; World Bank, 2020l). The target customers were mines, residential communities, a railroad company and a cement factory (IBRD, 1960b, p. 2).	
Iceland	0			
Kenya	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's first investment into energy was in hydropower (IBRD and IDA, 1971, p. ii). Coming as it did in 1971, it lagged many other Bank investments in Kenya. This was because electricity demand was driven by industrial growth which was slow prior to 1971, but 1971 represented an inflection point in Kenya's	49,051,686

			industrialisation (IBRD and IDA, 1971, p. 3). No fossil fuels had been discovered in Kenya as of the time of investment, while hydropower was assessed as abundant (IBRD and IDA, 1971, p. 2).	
Kyrgyz Republic	1			
Latvia	0			
North Macedonia	1			
Montenegro	1			
Mozambique	1	Rojas et al (Rojas, Li and Cumani, 2014)		27,829,942
Myanmar	1	Sutton et al (Sutton *et al.*, 2019)		53,045,226
Namibia	1	Rojas et al (Rojas, Li and Cumani, 2014)		2,358,041
Norway	0			
Nepal	1			
Nauru				
New Zealand	0			
Oman				
Pakistan	1	Rojas et al (Rojas, Li and Cumani, 2014)		203,627,284
Panama	0	Fountain (Fountain, 2019)	The World Bank's fifth investment in Panama was in hydropower (World Bank, 2020m). Unlike other early power investments, this was for rural electrification to	4,037,078

			stem depopulation of rural areas (IBRD, 1962). The World Bank's 12th investment, its first in power, was in hydropower (World Bank, 2020n). The power was intended to meet demand in	
Peru	1	Rojas et al (Rojas, Li and Cumani, 2014)	Lima (IBRD, 1960a)	30,926,032
Korea, Dem. People's Rep.	1	FAO (FAO, 2015a)		25,307,744
Portugal				
Paraguay	1	Rojas et al (Rojas, Li and Cumani, 2014)		6,777,872
Romania	1			
Slovenia	0			
Sri Lanka	1			
Sudan	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's fifth investment into Sudan was in power generation and transmission (World Bank, 2020o). Two thirds of the installed capacity was in hydropower and a third was in a thermal power plant (IBRD and IDA, 1961).	39,847,440
Suriname	1	FAO (FAO, 2016)		564,888
Sweden	0			
Switzerland	0			
Tajikistan	1			
Tanzania	1	Rojas et al (Rojas, Li and Cumani, 2014)		53,050,790
Togo	1			

Turkey	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's fourth investment in Turkey was in a multi-purpose dam which helped control floods, expanded irrigation and provided power for expanding industries (IBRD, 1952b; World Bank, 2020p).	79,821,724
Uruguay	0	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's third investment in Uruguay was in hydropower, but this was also the Bank's third investment in power – the first and its extension being in thermal energy (IBRD, 1956b; World Bank, 2020q).	3,424,132
Venezuela, RB	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's first investment in Venezuela was in hydropower (World Bank, 2020r).	29,846,179
Vietnam	1	FAO (FAO, 2015a)		93,638,724
Zambia	1	Rojas et al (Rojas, Li and Cumani, 2014)	See chapter 3.	16,363,507
Zimbabwe	1	Rojas et al (Rojas, Li and Cumani, 2014)	The World Bank's first investments in what was then a British colony, Rhodesia, also referred to as "the Colony", were in hydropower in the Kariba hydropower project (IBRD, 1952a, 1956c; IBRD and IDA, 1964).	14,030,390

Annex 2a – Last iteration of manufacturing questionnaire used, July 2018

POWER OUTAGES AND MANUFACTURING FIRMS' PERFORMANCE IN ZAMBIA

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.

Responses to this questionnaire will be anonymised and will remain confidential

Table for 5a and b.

	Do not cause (0)	Cause to a minor degree (1)	Cause to a moderate degree (2)	Cause to a major degree (3)	Cause every time (4)
i.Damage to equipment Unplanned: Planned:					
ii.Damage to inventory Unplanned: Planned: *Please explain how*					
iii.Extra pay to staff to make up for lost productive hours after work hours Unplanned: Planned:					
iv.Damage to firm reputation Unplanned: Planned:					
v.Loss in clients Unplanned: Planned:					
vi.Additional security costs Unplanned: Planned:					
vii. Other 1 Unplanned: Planned:					
viii. Other 2 Unplanned: Planned:					
ix. Other 3 Unplanned: Planned:					

Annex 2b – Sampling frame for the manufacturing sector

Table 32 Eighty-four percent (84%) of large manufacturing firms are located in Lusaka Province and Copperbelt Region

Table: Distribution of manufacturing firms by size and province, 2011-12 for Zambia

	Small	Medium	Large	Total	*% of all firms*	*% of large firms*
Central Province	283	18	15	316	*8.3%*	*3.8%*
Copperbelt Region	531	56	133	720	*18.9%*	*34.1%*
Eastern Province	318	10	8	336	*8.8%*	*2.1%*
Luapula Province	143	2	2	147	*3.9%*	*0.5%*
Lusaka Province	1,163	93	195	1,451	*38.1%*	*50.0%*
Muchinga Province	34	3	1	38	*1.0%*	*0.3%*
Northern Province	163	4	7	174	*4.6%*	*1.8%*
NW Province	134	1	6	141	*3.7%*	*1.5%*
Southern Province	328	8	20	356	*9.3%*	*5.1%*
Western Province	125	4	3	132	*3.5%*	*0.8%*
Total firms	3,222	199	390	3,811		

Adopted from Annex 7 of Zambian Ministry of Commerce, Trade & Industry Central Statistics Office, 2011-12 Manufacturing Sector Study Report published August 2014

Appendix 7 of the Ministry of Commerce, Trade and Industry's 2014 report provided the breakdown of manufacturing firms by subsector. More up-to-date breakdowns were unavailable, 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.

Table 33 Breakdown of the Copperbelt's manufacturing sector into the Ministry of Commerce's categorisations of subsectors

Table: Copperbelt firms by size and sector, 2012

	Small	Medium	Large	Total	large as % of total sector	large % of total large
1 Food and food products	147	19	30	196	15%	23%
2 Textiles and garments	190	6	10	206	5%	8%
3 Wood and wood products	52	8.5	8	68.5	12%	6%
4 Chemicals	31	7	15	53	28%	11%
5 Plastics and rubber	3	0	9	12	75%	7%
6 Non-metallic mineral products	8	1	7	16	44%	5%
7 Basic metals	2	1	13	16	81%	10%
8 Fabricated metal products	70	4.5	14	88.5	16%	11%
9 Machinery and equipment	17	6	17	40	43%	13%
10 Electronics	10	2	7	19	37%	5%
11 Other manufacturing	1	1	3	5	60%	2%
Total	531	56	133	720		

Adopted from Annex 7 of Zambian Ministry of Commerce, Trade & Industry Central Statistics Office, 2011-12 Manufacturing Sector Study Report published August 2014

What is included in the taxonomy for Copperbelt province (in ***bold*** *are businesses not in Lusaka):*

1. Processing & preserving of meat; manufacture of vegetable & animal oils & fats; dairy products; grain mill products, bakery products; cocoa, chocolate & sugar confectionery; other food products; prepared animal feeds; distilling, rectifying & blending of spirits; wines; malt liquors; Soft drinks, mineral waters

2. Preparation & spinning of textile fibres; weaving of textiles; finishing of textiles; manufacture of made-up textile articles, except apparel; manufacture of wearing apparel, except fur apparel; knitted & crocheted apparel; tanning, dressing of leather, dressing & dyeing of fur; footwear

3. Sawmilling & planing of wood; manufacture of builders' carpentry & joinery; manufacture of wood, cork, straw, plaiting materials; pulp, paper & paperboard; corrugated paper & paperboard, containers of paper & paperboard; other articles of paper & paperboard; 1/2 furniture

4. Printing; services related to printing; refined petroleum products; basic chemicals; pesticides & agrochemicals; paints, varnishes, printing inks and mastics; soap & detergents, cleaning & polishing preparations, perfumes & toilet preparations; other chemical products; pharmaceuticals, medical chemical & botanical products

5. Plastics & synethetic rubber; ***rubber tyres, tubes, re-treading & rebuilding of rubber tyres*** *; manufacture of other rubber products; plastic products*

6. ***Coke oven products*** *; clay building; clay building materials; porcelain & ceramic products; cement, lime & plaster; articles of concrete, cement & plaster; cutting, shaping & finishing of stone*

7. Basic iron & steel; basic precious & other non-ferrous metals; casting of iron & steel

8. Structural metal products, tanks, reservoirs & containers of metals; treatment & coating of metals, machining; cutlery, hand tools, hardware; fabricated metal products; furniture/2; repair of fabricated metal products

9. Manufacture of measuring, testing, navigating & control equipment; ***fluid power equipment*** *; pumps, compressors, taps & valves; bearings, gears, gearing & driving elements;* ***lifting & handling equipment*** *; general purpose machinery;* ***machinery for mining, quarrying & construction*** *; other special-purpose machinery; parts & accessories for motor vehicles; repair of machinery; installation of industrial machinery & equipment*

10. Electronic components & boards; consumer electronics; electronic motors, generators, transformers & electricity distribution & control apparatus; batteries & accumulators; electronic & electric wires & cables; other electrical equipment; repair of electronic & optical equipment; repair of electrical equipment

11. Jewellery; other manufacturing

Table 34 Breakdown of Lusaka Province's manufacturing sector into the Ministry of Commerce's categorisations of subsectors

Table: Lusaka province firms by size and sector, 2012

	Small	Medium	Large	Total	large as % of total sector	large % of total large
1 Food and food products	177	34	66	277	24%	34%
2 Textiles and garments	398	8	5	411	1%	3%
3 Wood and wood products	217.5	9	12.5	239	5%	6%
4 Chemicals	93	11	33	137	24%	17%
5 Plastics and rubber	5	3	16	24	67%	8%
6 Non-metallic mineral products	41	11	23	75	31%	12%
7 Basic metals	7	2	6	15	40%	3%
8 Fabricated metal products	187.5	9	13.5	210	6%	7%
9 Machinery and equipment	22	2	11	35	31%	6%
10 Electronics	8	0	3	11	27%	2%
11 Other manufacturing	7	3	7	17	41%	4%
Total	1163	92	196	1451		

Adopted from Annex 7 of Zambian Ministry of Commerce, Trade & Industry Central Statistics Office, 2011-12 Manufacturing Sector Study Report published August 2014

What is included in the taxonomy for Lusaka province (***bold*** *is what is not in Copperbelt):*

1. Processing & preserving of meat; ***processing & preserving of fish, crustaceans & molluscs*** *;* ***processing & preserving of fruit & veg*** *; manufacture of vegetable & animal oils & fats; dairy products; grain mill products, bakery products; cocoa, chocolate & sugar confectionery; other food products; prepared animal feeds; distilling, rectifying & blending of spirits; wines; malt liquors; soft drinks, mineral waters;* ***tobacco***

2. Preparation & spinning of textile fibres; weaving of textiles; finishing of textiles; manufacture of made-up textile articles, except apparel; manufacture of wearing apparel, except fur apparel; knitted & crocheted apparel; tanning, dressing of leather, dressing & dyeing of fur; ***luggage, handbags, saddlery, harness*** *; footwear*

3. Sawmilling & planing of wood; manufacture of builders' carpentry & joinery; manufacture of wood, cork, straw, plaiting materials; pulp, paper & paperboard; corrugated paper & paperboard, containers of paper & paperboard; other articles of paper & paperboard; 1/2 furniture

4. Printing; services related to printing; ***reproduction of recorded media*** *; refined petroleum products; basic chemicals; pesticides & agrochemicals; paints, varnishes, printing inks and mastics; soap & detergents, cleaning & polishing preparations, perfumes & toilet preparations; other chemical products; pharmaceuticals, medical chemical & botanical products*

5. Plastics & synethetic rubber; manufacture of other rubber products; plastic products

6. ***Glass & glass products; refractory products*** *; clay building; clay building materials; porcelain & ceramic products; cement, lime & plaster; articles of concrete, cement & plaster; cutting, shaping & finishing of stone*

7. Basic iron & steel; basic precious & other non-ferrous metals; casting of iron & steel

8. Structural metal products, tanks, reservoirs & containers of metals; treatment & coating of metals, machining; cutlery, hand tools, hardware; fabricated metal products; furniture/2; repair of fabricated metal products

9. ***Manufacture of communication equipment*** *; manufacture of measuring, testing, navigating & control equipment;* ***manufacture of fibre optic cables; manufacture of domestic appliances*** *; pumps, compressors, taps & valves; bearings, gears, gearing & driving elements; general purpose machinery;* ***agricultural & forestry machinery; manufacture of motor vehicles; manufacture of bodies (coachwork) for motor vehicles, manufacture of trailers;*** *other special-purpose machinery; parts & accessories for motor vehicles;* ***building of pleasure & sporting boats*** *;* ***manufacture of bicycles & invalid carriages*** *; repair of machinery; installation of industrial machinery & equipment*

10. Electronic components & boards; consumer electronics; electronic motors, generators, transformers & electricity distribution & control apparatus; batteries & accumulators; electronic & electric wires & cables; other electrical equipment; repair of electronic & optical equipment; repair of electrical equipment

11. Jewellery; other manufacturing; ***sports goods***

Annex 2c – Execution of the data collection

Building and incentivising a field team for the manufacturing survey

Thanks to the generosity of the International Growth Centre, it was possible to hire, train and monitor a field team. The first member of the team was 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.

Mr Sianjase also had an MBA and Bachelor's degree in electrical and electronic engineering from Copperbelt University. As a telecommunications sales professional who worked both in the Copperbelt and Lusaka, Mr Sianjase had a good array of contacts in the Copperbelt and Lusaka that helped us recruit our enumerators for Ndola and Kitwe, the two major cities of the Copperbelt, that helped initiate conversations with relevant people at ZESCO, Zambia Association of Manufacturers and PACRA, and that helped guide the approach to initiating conversations with people at firms where we knew no one.

Graham and key informants helped identify the six enumerators that were 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. Each of the enumerators received in-person training either with Graham Sianjase alone or with us both, and Beauty, Johanna, Mundia and Nandi received live training in the field with a real firm either with Graham or me.

All selected enumerators had their own cars. Enumerators were given in advance call, SMS and data credit to use for their work, and baseline compensation in advance to pay for their car fuel and lunch. They were also paid for each survey that they completed.

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

Below is a table of enumerators that we hired, the periods in which they worked and the number of surveys they uploaded that we then analysed.

Table 35 Table of hired enumerators' qualifications and output

Enumerator	How we found them	City	Qualifications	Experience	# surveys uploaded	Period
Beauty Nkosha	Known to the Field Manager	Kitwe	Bachelor's degree	Sales Associate	19	10 Apr – 17 Aug, 2018
Johanna Mwila	Known to the Field Manager	Ndola & Lusaka	Bachelor's degree candidate	Executive Assistant	41	9 Apr – 17 Aug, 2018
Mundia Kayamba	Known to the Field Manager	Lusaka	Diploma	Data Analyst	10	13 May – 6 Jul, 2018
Enumerator M	Referred to Investigator via a third party who used his services	Lusaka	Diploma	Worked as an enumerator & in data entry	0	2 Jun – 11 Jul, 2018
Nandi Ngwenye	Referred to Investigator via a third	Lusaka	Bachelor's degree	Worked as an enumerator &	14	2 Jun – 13 Jul, 2018

	party who used his services			Research Assistant		
Tapiwa Christine Janda	Referred to via Mundia	Lusaka	Bachelor's degree status awaiting	Research Assistant & enumerator	39	2 Jun - 31 Aug, 2018
Enumerator A	Referred to via Nandi Ngwenye	Lusaka	Bachelor's degree	Research Associate	22	17 Jul - 31 Aug, 2018

Enumerators highlighted in red yielded either no results or compromised results.

A good amount of the variance in the performance can be explained without referring to the abilities of the enumerators. Beauty had uploaded 13 surveys by the first week of May, and thereafter uploaded surveys at an increasingly slow rate. Her performance was affected by the apparent limit on number of firms available to survey in Kitwe. Johanna uploaded as many surveys as Tapiwa and Enumerator A in the weeks she was in Lusaka. She slowed down when she returned to Ndola. Tapiwa and Enumerator A accelerated as bonus payments were introduced in the last month to incentivise an increased number of survey uploads (see Annex 2d for two of the emails explaining the bonus structures). Enumerator B did not upload any surveys because he did not apply himself. He had to be let go of for his lack of effort and good faith. More than anyone, Mundia, whom I observed first hand, had trouble converting conversations that she began with personnel at firms into interviews.

Iterations of questions for the manufacturing survey asked, and the learning process of asking the right questions

The survey in Annex 2a, drafted in July 2018, is the last of many iterations that were used. Changes to surveys were based on patterns I observed 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.

Challenges faced in interviewing manufacturing firms

A challenge faced with getting information from most firms was that the field team had to initiate conversations without knowing anyone at them. In some cases, this resulted in up to 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.)

Several setbacks exogenous to the questionnaire itself were faced that delayed progress of the research, including:

1. Delay in receiving funds from the IGC;
2. A cholera outbreak in Zambia in late 2017 and early 2018 delayed the start of surveys;
3. Internal UCL bureaucracy led to delays in payments to the overseas field team.

Annex 2d – Emails to enumerators explaining bonus structures to incentivise a higher rate of uploads

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From: Ahmed, Imad
Sent: 21 August 2018 17:48
To: Johanna Mwila; Beauty Nkosha; Tapiwa christine Janda; angela_hamakando@yahoo.co.uk; stanistar nandy; mundia kayamba
Cc: Sianjase, Graham; Coffman, D'Maris; jim.meikle@btinternet.com
Subject: Last push & additional K 500 bonus available

Dear Team,

Well done on your push the last couple of weeks. 31 August will be the last day we want you to collect surveys for us.

To help you make the final push, we are making additional bonuses available:

- Pending diligence that your surveys meet the standard, if you upload **10 more surveys** for this and next week by 3rd September, you will earn an additional bonus of **K 500**. If you upload 9 surveys, you'll earn K 400 and if you upload 8, you'll earn K 300.
- A bonus of **K 100**/survey with a production facility in the **south Lusaka MFEZ**: http://www.lsmfez.co.zm/ (NRB Group, British American Tobacco, Roland Imperial, Zambian Fertilizers, Mylan, Afrizam, Global Logistics).

These are in addition to the existing bonus structure.

Tapiwa can earn K 300 for uploading 5 surveys this week because it would be her third consecutive week. Angela can earn K 250 for uploading 5 surveys this week because it would be her second consecutive week. If either of you upload 4 surveys, you will earn a "streak freeze" to be eligible for those bonus rates the following week. Everyone else will be eligible for a K 200 bonus this week for uploading 5 surveys this week.

You will earn K50 for every additional survey on top of the 5 surveys/week. You will be paid K 235.77/survey regardless of bonus or not.

If you need help with new companies to talk to, please contact Graham.

If three of you earn the maximum bonus these next two weeks, we will hit our target of 150 surveys, so good luck!

Imad

Imad Ahmed
Research Project Manager
Electricity outages in Zambia: Estimating the costs of unreliability at firm level
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From: Sianjase, Graham
Sent: 01 August 2018 11:27:08
To: Johanna Mwila; Beauty Nkosha; Tapiwa christine Janda; Angela Hamakando
Cc: Ahmed, Imad
Subject: Introduction of Bonus Payments for Research Surveys

Dear All

The following performance bonus structure has been introduced. The bonus will be paid over-and-above what is currently in place.

1. Extra K200 for 5 surveys/week uploaded.
2. Extra K50 for each additional survey uploaded above 5 surveys/week.
3. Extra K250 for uploading 5 surveys/week for 2 consecutive weeks.
4. Extra K300 for uploading 5 surveys/week for 3 consecutive weeks.
5. Streak Freeze* if 4 surveys/week but no bonus

As an example:

- If you upload 7 surveys in one week (e.g. Week 10), for the surveys in that week you get a total of K1,496.00 (5*239.2 + 2*50 + 200).
- If the following week (e.g. Week 11) you upload 8 surveys, for the surveys in that week you get a total of K1,596.00 (5*239.2 + 3*50 + 250).
- If the you upload 9 surveys in the week after that (e.g. Week 12), for the surveys in that week you get a total of K1,646.00 (5*239.2 + 4*50 + 300).

* Example: If you upload 7 surveys in Week 10, then you only manage to upload 4 surveys in Week 11, and you upload 5 surveys in Week 12 - the Streak Freeze allows you to get K250 bonus in week 3, as opposed to starting afresh with K 200.

Please let me know if you need further clarification.

All the best in getting the low-hanging bonuses!

Best regards

Graham

Annex 2e – Key informants with whom interviews were secured

Government stakeholder interviews

i. ZESCO economists on 10 November, 2017 and Puseletso Mwakalombe on 6 June, 2018 in Lusaka and again on 3 September, 2019; and a director on 4 September, 2019 (A3.1.1a – First interview with ZESCO economists, 10 November 2017, A3.1.1b – Second interview with a ZESCO economist, 6 June, 2018 and A3.1.4 – Notes from a Government of Zambia (Ministry of National Development Planning, Energy Regulation Board, Ministry of Finance, Ministry of Energy and Central Statistical Office) and ZESCO stakeholder engagement presentation at the Ministry of National Development Planning on 4 September, 2019)

ii. Department of Energy officers on 6 June, 2018 in Lusaka and again on 4 September, 2019 as well as correspondence on 30 April 2020 (A3.1.2 – Interview with Department of Energy officers on 6 June, 2018)

iii. 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; his colleague and co-author Cletus Sikwanda on 4 September, 2019 (A3.1.3 – Interview with Alfred Mwila, Director of Economic Regulation at the Energy Regulation Board, 6 June, 2018)

Private energy developer interviews

iv. CEO of a developer of an independent coal power plant on 4 June, 2018 in Lusaka (A3.2.1 Interview with the CEO of a developer of an independent coal power plant on 4 June, 2018)

v. CCO Cathy Oxby and CEO Ana Hajduka of Africa GreenCo, a prospective credit-worthy off-take alternative to ZESCO for renewable energy in Zambia on 23 April, 2019 and 1 August, 2019 September, 2019 in London (A3.2.2a – Interview with Cathy Oxby, Chief Commercial Officer of Africa GreenCo prospective alternative credit-worthy off-taker to ZESCO, on 23 April, 2019 and A3.2.2b – Interview with Ana Hajduka, Chief Executive Officer and Lovemore Chilimanzi, Technical Director at Africa GreenCo, a prospective alternative credit-worthy off-taker to ZESCO, on 1 August, 2019)

vi. CEO of a developer in Lusaka on 3 September, 2019 (A3.2.3 – Interview with the CEO of an energy developer, on 3 September, 2019)

vii. 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 (A3.2.4 – Mikko Marttala, CFO at KPA Unicon, a developer and engineering, procurement, construction contractor of energy solutions using industrial waste on 2 November, 2018)

Public and private advocates for the manufacturing and private sector

viii. Zambia Association of Manufacturers CEO Chipego Zulu on 28 May, 2018 in Lusaka (A3.3.1 Interview with Chipego Zulu, CEO of Zambia Association of Manufacturers on 28 May, 2018)

ix. Zambia Chamber of Commerce and Industry (ZACCI), Chairman 2004-07 Wamulume Kalabo (A3.3.2 Interview with Wamulume Kalabo, Chairman of Zambia Chamber of Commerce and Industry (ZACCI), 2004-07 on 4 June, 2018)

x. Zambia Development Agency M&E Officer Sampa Chilanga on 30 May, 2018 in Lusaka (A3.3.3 Interview with Sampa Chilanga, Monitoring and Evaluation Officer at Zambia Development Agency on 30 May, 2018)

Donors

xi. A consultant with 40 years in Zambian and African energy policy working for a donor agency on 27 February, 2019 by telephone (A.3.4.1 Phone interview with an energy expert within a donor agency on 27 Feb, 2019)

Colleague researcher interviews

xii. 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 (A.3.5.1 Interview with 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)

xiii. IGC Zambia Country Economist Miljan Sladoje on 28 May, 2018 in Lusaka (A3.5.2 Meeting with Miljan Sladoje, IGC Zambia Country Economist on 28 May, 2018)

Other useful unstructured conversations

xiv. Chibelushi Maxwell Musongole, Lecturer and retired Assistant Director at the Central Bank of Zambia on 28 May, 2018 in Lusaka (A3.6.1 Interview with Chibelushi Maxwell Musongole, Lecturer, retired Assistant Director at the Central Bank of Zambia and retired Director General at the Zambia Public Procurement Authority on 28 May, 2018)

xv. Natty Chilundiki, Research Coordinator, on 29 May, 2018 in Lusaka (A3.6.2 Meeting with Natty Chilundiki, Research Coordinator, on 29 May, 2018)

xvi. Jim Friedlander, a lawyer with decades of experience working in Africa, on 3 May, 2018 in London (A3.6.3 Interview with Jim Friedlander, Partner KIAP Law Firm on 3 May, 2018)

xvii. Michael Mainelli, who as a consulting partner with BDO Binder Hamlyn, looked at the energy supply to Zambia Consolidated Copper Mines in 1992-1993. Email on 18 February, 2019 (A3.6.4 Email from Michael Mainelli, Consulting Partner at BDO Binder Hamlyn on the privatisation of Zambia Consolidated Copper Mines, 1992-1993)

We also visited the following institutions for requests for data:

xviii. Patents and Companies Registration Agency (PACRA)

xix. Bank of Zambia on 30 May, 2018

xx. Ministry of Commerce, Trade and Industry on 30 May, 6 June, 2018

xxi. Central Statistical Office on 30 May, 6 June, 2018

xxii. Zambia Meteorological Department on 26 October, 2018

Annex 3 – Collected interviews with key informants

A3.1 Government stakeholder interviews

A3.1.1a – First interview with ZESCO economists, 10 November 2017

10 November, 2017, ZESCO HQ, Lusaka
ZESCO Limited

Institution's participants: three economists in the institution's business development division
Interview notes anonymised

Project participants in the meetings: Imad Ahmed, Graham Sianjase
How the meeting was arranged: Graham Sianjase arranged the meeting through a personal contact.

What was learned:
The economists informed us that they knew of only manufacturing firm located in an MFEZ. Clients were prioritised for power – those whose power needs exceeded 10MW would be awarded power purchase agreements. Exceptions are made where a company's smooth supply of power is seen as in the national interest, or where there is growth potential. Their one MFEZ manufacturing client had been awarded a power purchase agreement because though its current power capacity was below 10MW, they saw growth in the company and it was deemed to award the agreement in the national interest.

2015 and 2016 were particularly bad years for low hydropower dam reservoirs.

Zambia's almost absolute dependence on hydro power had recently changed, with 16% of Zambia's energy-mix now coming from thermal energy; Maamba Collieries Ltd, a 300MW coal-power plant had started delivering energy to the grid in late July 2017 (http://www.moneycontrol.com/news/business/stocks-business/nava-bharat-ventures-up-2-achieves-provisional-acceptance-of-300-mw-power-plant-2338365.html). The power plant was brought online and owned by Nava Bharat Ventures, a Bombay Stock Exchange-listed company, under the provisions of a 20 year US dollar denominated power purchase agreement.

ZESCO has 900 additional megawatts of thermal plants contracted with independent power producers being studied for feasibility, and for commencement to potentially start as soon as 2021. It also is looking into additional solar and hydro plants both on an in-house as well as on a public private partnership basis. 775MW is under in-house construction and due to be delivered in 2017, 2018 and 2020, 40MW of hydro is under construction by China Electronics Corporation. ZESCO has awarded a further 100MW of hydro to engineering, procurement and construction contracts. The total additional capacity of new projects under construction or being studied and projected to be commissioned by 2024 is 5,200MW. ZESCO's economists do not anticipate 100% of these projects to be executed. Expect to be able to export some energy.

Data shared: Besides what was shared by email before the meeting, ZESCO shared the names of generation projects that they were working on closing, and a chart of the energy portfolio mix.

A3.1.1b – Second interview with a ZESCO economist, 6 June, 2018

6 June, 2018
ZESCO
Institution’s participants: One of the economists met last time
Interview notes anonymised

Addressee: Imad Ahmed

Conversation:

- Off peak 2200-0600, baseload 0600-1800, peak hour 1800-2200. << this means that peak solar comes during baseload hours, which means that adding 524MW solar to the grid would be useless unless it is used to pump water back up to the reservoirs for hydro plants (see handout given by ZESCO in November for planned projects to be added to the grid)
- Claims that there has been no load shedding since 2016, only planned maintenance which usually happens on Sundays << this seems to contradict what firms tell us, i.e. that there barely are any notifications given for planned outages. We are also recording power outages by firms, although they are not frequent anymore.
- We don’t know whether the tariff will increase because we are waiting for the cost of services study to come through.
- Whether Treasury will continue issuing sovereign guarantees is beyond ZESCO to comment on.
- Not in fear of having a surplus of power as they envision selling energy to the region.

A3.1.2 – Interview with Department of Energy officers on 6 June, 2018

6 June, 2018, Department of Energy, Lusaka
Department of Energy (referred to by Ministry of Energy)

Institution’s participants:

- Two energy officers
- Interview notes anonymised

Project participants: Imad Ahmed
How the meeting was arranged: Leaving a letter for the PS Ministry of Energy with her PA’s Assistant in Government Complex.

Following the meeting, the meeting notes were shared. Revised notes were sent back on 30 April 2020 and are copied below as follows with permission:

- In 2015, the country’s electricity demand was 1,959MW while the installed capacity was 2,411MW.
- The country experienced poor rainfall during the 2014/2015 rainy season which resulted in low water levels in the main water reservoirs and impacting negatively on the capacity of the hydropower plants to generate electricity. This is because the country’s generation mix was highly dominated by hydropower.
- With the National Development Plans seeking universal access to electricity (90% for urban areas and 51% for rural areas) by 2030, the country is promoting investments in generation,

transmission and distribution facilities. The electricity generation infrastructure is developed in line with the projected demand so as to ensure security of energy supply at all times. In case of excess electricity, the country can export it to the countries in the region which have proved to have a need for importing electricity.

- Since 2014, several investments have been made in generation infrastructure in order to meet the increasing electricity demand and also enhance the generation mix of the country. Some investments are as discussed below:
  - Kariba North Bank Extension Power Plant has a capacity of 360MW and it was commissioned in 2014. The extension plant is wholly owned and operated by the Kariba North Bank Extension Corporation which is a subsidiary of the public power utility ZESCO Limited. ZESCO is the off-taker of power from the extension plant under a Power Purchase Agreement (PPA). The plant is an extension of the old Kariba North Bank Power Station which has a capacity 720MW.
  - The 120MW Itezhi-Tezhi Power Plant was constructed on the Kafue River in Itezhi-Tezhi District, Central Province and was commissioned in 2016. The plant was developed through a joint venture between ZESCO and Tata Africa Holdings of India. The first phase of the project was commissioned in 2015.
  - The 300MW coal fired thermal power plant located in Maamba District in Southern Province was commissioned in 2016 and it is owned and operated by an Independent Power Producer (IPP);
  - The 105MW heavy fuel oil fired thermal power plant in Ndola District, Copperbelt Province was commissioned in two phases. Phase one was commissioned in 2013 while phase two was commissioned in 2017. The plant is owned and operated by an IPP.
  - The 34 megawatts Ngonye and 54MW Bangweulu solar PV power plants both located in Lusaka were commissioned in 2019. The two plants are owned and operated by an IPP.
  - The country's public power utility ZESCO Limited has also undertaken upgrading of some of the small hydropower stations located in the northern part of the country. The current capacities of the plants are as follows: Lusiwasi 12MW; Chishimba Falls 6MW; Shiwang'andu 1MW; Musonda Falls 5MW; and Lunzua 14.8MW.
  - Several mini-grid plants, mostly solar photovoltaic and located in rural areas, have been commissioned.
- The country has a Rural Electrification Authority (REA) which implements electrification projects in rural areas through grid extension and off-grid technologies. REA undertakes such projects using the Rural Electrification Fund and other funding mechanisms as stated by the Rural Electrification Act of 2003. Undertaking rural electrification projects by grid extension is not cost effective and this is the reason why REA undertakes such projects instead of ZESCO. After REA commissions grid extension projects, they are handed over to ZESCO for operation. REA owns and operates a 60kW solar photovoltaic mini-grid plant in Mpanta, Samfya District in Luapula Province. Several private companies have also invested in similar projects in rural areas. Off-grid solutions are a cost effective method of providing electricity in rural areas of the country which have low population densities below the national average of 22 persons per square kilometre.
- In 2017, the Beyond the Grid Fund for Zambia (BGFZ) programme was launched and will operate until 2021 with a funding of 20 million Euros. BGFZ is a new market-based initiative which aims to bring affordable and high-quality renewable energy services to one (1) million Zambians, while accelerating private- sector growth in off-grid renewable energy generation

and distribution in the country. During the launch, the funding was awarded to five 5 private companies. The programme is funded by SIDA.

- Government removed Import Duty and reduced Value Added Tax to 14% on all solar and energy efficient equipment through Statutory Instruments No. 32 and 33. This action was taken to promote access to electricity to mostly people in the rural and peri-urban areas and to also encourage self-generation among the urban community.
- Government had been working on the development of standards for solar equipment (particularly solar home systems) to ensure that the imported products conform to the minimum country standards and hence protect the consumers of the products. Lack of standards has exposed consumers to products of inferior quality.
- To promote electricity trade in the region and to make the country the hub of energy in the region, the Government was promoting investments in interconnector regional projects some of which are as listed:
    - Zambia-Tanzania-Kenya (ZTK) Interconnector;
    - Zimbabwe-Zambia-Botswana-Namibia (ZIZABONA) Interconnector; and
    - Zambia-Angola Interconnector.
- The Energy Regulation Board (ERB) is mandated to regulate the energy sector in the country. The Regulator assess the performance of energy companies based on the agreed Key Performance Indicators.
- The Government is very supportive in ensuring that the electricity tariffs migrate to cost reflective levels while ensuring access of electricity to the vulnerable citizens. In 2017, there was an increase in the electricity tariff for domestic consumers of 75%. The increment was done in two stages with the first one being done earlier in the year at 50% and the second one later in the year at 25%. This year, there was also an increase in the electricity tariff.
- A Cost of Service Study has been underway with the result expected later in 2020. The Study has delayed because the initial consultant pulled out. The study will inform the country on the actual cost reflective tariff.
- The PPAs between ZESCO and the IPPs are negotiated between the two parties and the utility parties are the custodians of the details of the PPA tariffs.
- Despite being a public power utility, ZESCO is an independent entity and government does not interfere in its operations. The company's service and technical performance is assessed by the ERB based on the agreed Key Performance Indicators. The government through the Ministry of Energy and in consultation with key stakeholders developed the Power System Development Master Plan and Rural Electrification Master Plan which are implemented by ZESCO and REA respectively.
- The Government has created Multi-Facility Economic Zones (MFEZ) and Farm Blocks. To actualise these projects, provision of vital infrastructure such as roads and electricity is critical and implementing Agencies are mandated to implement such infrastructure.
- Prior to the implementation of the Scaling Solar Project Round One by Zambia's Industrial Development Corporation, a Grid Integration Study was conducted and it established the amount of Variable Renewable Energy the grid could accommodate. The two solar photovoltaic projects that have been implemented under the programme have no storage and are not hybrid. There are however suggestions by developers of implementing solar photovoltaic projects with storage and hybrid with hydro. But nothing of that sought has materialised.
- The Seventh National Development Plan seeks to increase access to electricity by increasing generation, transmission and distribution facilities. To increase generation as well as enhance

the diversification of the energy mix, the government is promoting investments in renewable energy (e.g solar and wind) and alternative energy (e.g nuclear energy). Regarding possibilities of generating electricity using nuclear technology, I am not in a position to give you any information. The Office of the Permanent Secretary is better placed to do so.

A3.1.3 – Interview with Alfred Mwila, Director of Economic Regulation at the Energy Regulation Board, 6 June, 2018

6 June, 2018, ERB Office, Lusaka
Energy Regulation Board

Institution's participants: Alfred Mwila, Director of Economic Regulation
Permission granted to be published with the PhD thesis

Project participants: Imad Ahmed
How the meeting was arranged: Introduction by Miljan Sladoje

Conversation:

- JICA report on the power sector forecasting energy inflows and expenditures. Load forecasting from 2014.
- Latent demand: 2015-2016 was a one-off for a long time. We never reached 800MW. We've passed that stage now. Because it was just water crisis. We are near normal situation. What will come on board will potentially put us in surplus. Growth of demand is not expected to be exponential but gradual. Most of it is driven by mines who consume 60%. Their projections are currently being forecast.
    - Bulk of mines are from CEC but some of it is from ZESCO with two or three customers totalling about 1,000 MW
    - ZESCO sells to CEC. PPA. Back supply. CEC then has PPA with mines. That is \$0.05-\$0.06/kWh. CEC will top-up around \$0.02/kW
    - \$0.07/kWh
- Residential customers 75% tariff increase which brought average tariff to \$0.07/kWh. Account for 50% of the load.
    - Social tariffs for the social sector – schools, churches
    - Commercial tariff
    - Maximum demand – farmers, huge industries like Lafarge
    - ERB superintends on those tariffs
- Can you walk me through tariffs

- Section 8 of the Electricity Act ZESCO has to make an application to ERB if they want to change the tariff. Public Consultation Paper. Ask public to send in written hearings. We just listen in and allow the utility to defend itself. Then we analyse the data and make a determination. We use the revenue-requirement or rate of return methodology. Look at all the assets that the utility presents to us and assess whether they will be able to cover their operational and depreciation and tax. We then assess an average tariff. We then cascade it downwards depending on the load that they impose on the system. KPI framework. Once we make a determination, in our assessment, we may decide a lower assessment and then subject to a KPI framework.

- For the mines, we are at arms length. We have submitted changes to legislation that will make it clear that we are supposed to superintend over the mining tariffs. we don't regulate over

CEC. We made an attempt in 2014. Because the mining tariffs despite accounting for 50% of the load, they are low. There are indexation. Pegged towards US price index so movements are low and there is no way they would catch up with the actual increase in costs.

  - **We made a determination of $.068/kWh that all the mines should graduate to. That was not well received and we were taken to court. The mines said we have no jurisdiction over their PPAs and that we are at arms length. It is undergoing judicial review.**

- Are companies subsidising mines? This could be correct. The only alternative was to get the revenue from the residential (all non-mining) customers. They have suffered incidents on tariff increments compared to the mines. The opportunities we have with the cost of service tariff is it is speculative. What is clear is that ZESCO can unlock 70-80% of their revenue requirement if they charge the mines appropriately. They are still interactive. Study is still ongoing.
- KPI framework on transmission and distribution losses with ZESCO. They are about under 12%. It is quite good. When you benchmark it against others they go up to 25-30%. We doubt that 12% that it is too good for the kind of data we are able to extract from what they give us.
- **Mines argue that they are paying for ZESCO's inefficiencies. The last study in 2006 eroded with time. The current study cost of service study will establish the true cost of production. That's what the mines have been waiting for. They would be willing to pay if they can see there is no inefficiency. But it is speculative that they overemploy staff: customer ratios are too high. But when you drill down, the structure. The way they operate at the distribution level. they may just fire casual labour. They have their own justifications. We don't have an objective number.**

- Surplus? There is that fear that it is possible that the lessons of 2015 there might be an overinvestment and a lot of overstranded power. Why? Because there don't seem to be any integrated regional plan that can harmonise the balance of supply and demand. The only window available is the Southern Africa Power Pool. Where trading of power takes place. Almost 15 utilities that trade on this power pool. But its capacity is constrained by transmission constraints. So it cannot do so much. If we were to sell stranded power to a neighbouring country, there is still that constraint that the network is not yet developed. Surplus is a possibility (ZESCO, sovereign guarantees, credit rating.) A lot of positive movement towards renewable energy that will help to mitigate the problems.

- Solar: we realise there is the intermittent. Plant of 60MW can only use 30MW. That has to be done with a number of stable planned investment. so the REFIT strategy the aim is to go up to 600MW of solar which will translate to 300MW solar. In between these other smaller investments in solar, upto 20MW. GetFit investment encourage investment up to 20MW to feed into the grid. Sprung up.

- A lot of interest in the off-grid solutions. For rural customers. On the hydro front as well, we have seen a lot of interest in the Kafue Gorge 750MW. Also trying to reinvest in some of the smaller hydro plants to higher capacities. The outlook is such that we will be quite self-sufficient.

- Considering externalities such as pollution and nuclear fall-out? Part of the license commission, you need to be licensed by ourselves and abide by the technical specs that are prescribed – certificate from the environmental council which gives no objection to our other licenese conditions. From the environmental agency that this is not a threat environmentally. Then assess for other technical provisions.

- It is in the pipeline to buy energy from manufacturing firms. We have developed open access guidelines. The open access regime has been launched. There is provision for selling into the grid. Provision for smart-meters and net meters. That will allow those with excess power to sell back to the grid and net out to the supplier.

    - Hand in hand with that, transmission pricing methodology. Mechanism for trade pricing. Has not yet involved. We are developing that methodology. Willing seller, willing buyer.
    - Also need an independent operator for the network who can govern the conduct of the trade in the transmission so there is equal access to that energy. We have developed a license ISO independent systems operator. If you need to sell power using that grid, you have non-discriminatory access to that grid. That will be licensed by ourselves. In preparation for the open access we have concluded on that.
    - In the interim, ZESCO will be the license holder. Ideally we would like another entity for non-discriminatory access because ZESCO is a player. It also owns some of the transmission system. It has competing generators. It will want to prefer its own generation.

ERB load shedding report. Simplistic study that gave anecdotal oversight. Cost of uncertain energy. UCL scope is higher.
Document that give overview of the sector.
Website has statistical bulletin.
Materials shared:
- ERB, 2017. Impact of load shedding on small scale enterprises.
- Energy Sector Report 2016 (hard copy)

A3.1.4 – Notes from a Government of Zambia (Ministry of National Development Planning, Energy Regulation Board, Ministry of Finance, Ministry of Energy and Central Statistical Office) and ZESCO stakeholder engagement presentation at the Ministry of National Development Planning on 4 September, 2019

4 September, 2019, Ministry of National Development Planning, Lusaka
Meeting notes anonymised

Information shared by a Director of ZESCO after I made my presentation and policy recommendations:
- The reason for delay on agreeing a Power Purchase Agreement with the 300MW coal-fire Maamba Colleries power plant was that ZESCO was at an impasse on the tariff. ZESCO entered the PPA on the behest of the Government. Initially, Maamba was supposed to sell directly to end-consumers. ZESCO found the tariff [of USD 0.1035/kWh] commercially disadvantageous [because ZESCO sells electricity at a lower tariff]. But if Maamba had not come online in 2016, the situation in 2016 would have been worse.
- Mining customers consume electricity at high voltages. ZESCO argues that the cost of distribution for lower voltage consumers should not be borne by the mining sector.
- ZESCO's PPA with the mining sector is indexed in USD and ZESCO is paid in USD and allows ZESCO to take US dollar loans.

- The 2006 cost of service study included the capital outlay required and had allowable and non-allowable costs that could be passed onto consumers. Costs of running ZESCO's football club were not allowable.
- Mining companies resist higher tariffs because they are already paying the nation's taxes.
- Cost-recovery is not being achieved for any sector of customer. All are being subsidised – firms and mining.
- During the current power crisis, ZESCO is importing 300MWh from South Africa from ZMK 13.5 billion/month [this would have worked out to c.USD 0.31/kWh – slightly more than the cost of diesel generation].
    - ZESCO does not want to subsidise this cost to customers; wants to charge this fully to customers including the costs of distribution and wheeling. This will not be regulated by the Energy Regulation Board. Will look to charge customers USD 0.12-0.15/kWh over the next 6 months and hope that that hydro situation will change. [I advised to give forewarning that tariffs would be charged at this rate so that people and business could adapt their consumption patterns.] The extra tariff will be shown on the bill. When imports are no longer needed, the levy will fall off.
    - The mining tariff was recently increased to USD 0.93/kWh.
- It is a valid recommendation to increase the tariff differential.
- The reason for why September is perhaps the month most complained about by manufacturing firms might be because of agricultural seasonality and the use of irrigation more. [This does not make sense since September sees more precipitation.]
- ZESCO will give thought to the recommendation that larger firms should pay a higher tariff.

Energy Regulation Board official:
- In line with my findings that firms complained most in September, the Energy Regulation Board also found in Mwila et al (2017) that High Fuel Oil was used in September and that Kitwe had more power outages.

A MNDP official:
- Asked the question whether it would be appropriate to offer a premium tariff before ZESCO could deliver on offering more reliable energy.

Ministry of Energy official:
- The Ministry is looking to encourage the use of more energy efficient compliances – fridges, LED lights. They have banned incandescent bulbs.
- Kafue Gorge Lower hydropower dam is 6 months away from being commissioned.

A3.2 Private energy developer interviews

A3.2.1 Interview with the CEO of a developer of an independent coal power plant on 4 June, 2018

4 June, 2018, Taj Pamodzi, Lusaka
This interview should not be cited in a publicly published report with the name of the company or person. Rather, it should be referred to as a conversation with an IPP.

Interview notes anonymised

Project participants: Imad Ahmed
How the meeting was arranged: Introduction by Wamulume Kalabo
Conversation:

- The developer has a portfolio of winder, solar and coal power plants and a coal mine across Asia.
- The sovereign guarantee signed by the President for an IPP resulted in calls for his impeachment [because it is not for the office of the president to issue sovereign guarantees, but for Treasury].
- Commercial Operations Date is expected to be in three years. They have a sovereign guarantee. They are now arranging debt financing with the Chinese government who can provide EPC and bridge financing. They have a 20 year Power Purchase Agreement, Implementation Agreement, licenses for water and land, mining concession for coal.
- Reasons for confidence:
  - The driver of the coal project came out of a JICA study recommending 1,000MW of thermal energy.
  - When there was no rain, there was a power deficit of 500MW 2016-17.
  - There is already one 300MW commissioned coal plant by Indian developers now running at full capacity since last year where they will be developing.
  - There won't be a surplus because
    - one copper mine can require 300MW and there would have been additional mines (Wamu says) but for the bottleneck in energy supply.
    - Wamu also says there is latent demand for agro-processing and timber in the Western Province.
    - Zambia has access to eight neighbouring countries and almost all of them have deficits. It can earn foreign exchange.
      - DRC has little power. Gen sets cost $0.3/kWh. it would make sense for Congolese mines to buy from ZESCO at $0.14/kWh.
  - One year ago, there was a huge difference between the ZESCO selling and buying price. ZESCO was losing money. Now they are breaking-even. They believe ZESCO is now committed to charging cost-reflective tariffs. They do not believe it will have to draw upon its sovereign guarantee.
- Way they got their power deal: They initially came to Zambia when they bought out a local Zambian's prospecting license. They prospected for 5 years. They found and tested coal, found that it would be feasible to provide power despite being low calorific and high ash coal and approached ZESCO for a Power Purchase Agreement. Their initial proposed tariff was higher than the previously commissioned plant because that was a brownfield, whereas their power plant would be greenfield. ZESCO insisted on having the same tariff because it did not come through a competitive tariff.
  - If they could find more coal, they would invest in supplying Congolese mining companies.
- Their coal plant has not received opposition from environmentalists. They are following World Bank emissions standards. They won't have NOx emissions because their temperatures will not reach 1000 degrees C (will reach 800 degrees C) and they will treat SOx with limestone. They have high chimneys to disperse SPM.

A3.2.2a – Interview with Cathy Oxby, Chief Commercial Officer of Africa GreenCo prospective alternative credit-worthy off-taker to ZESCO, on 23 April, 2019

23 April, 2019, National Liberal Club, London

Permission granted to publish these meeting notes following some revisions from the interviewee.

About how Africa GreenCo can create value for the Zambian power market and attract private capital to develop new generation capacity, including some of the short-term challenges it faces and some general conversation about Zambia's power market:

- The entrepreneurs are seeking to create a credit-worthy off-taker (GreenCo) to buy renewable energy from Independent Power Producers (IPPs) and take the commercial risk of on-selling such energy to ZESCO as well as other clients, including via the Southern African Power Pool.
- Selling directly to some commercial end consumers would be challenging given the intermittent nature of renewable energy. Some industries need stability but others may be willing to accept some volatility at a lower power price. Until battery technology develops, dependable baseload sources of generation are required alongside intermittent generation as part of a hybrid solution, with the intermittent renewable sources being used first where possible.
- The Zambian power sector is heavily dollarized and GreenCo's transactions will initially be in USD as GreenCo cannot absorb currency risk. It has explored foreign currency hedging with TCX but there are challenges around exposure thresholds and tenor. However, by reducing the credit risk associated with investing in renewable energy IPPs, GreenCo hopes to attract local institutional investors to the sector, facilitating local currency tranches of power purchase agreements.
- GreenCo aims to be sufficiently well-capitalised to be able to bridge 15 months of power purchase payments to its renewable energy IPPs even if GreenCo is not being paid by its onward customers. During any such periods of payment default, GreenCo would seek to mitigate its losses by selling the power to alternative purchasers, either bilaterally or via the competitive markets of the Southern African Power Pool.
- GreenCo aim to facilitate investment into renewable energy and effectively provide ZESCO with indirect access to cheaper sources of capital (resulting in lower input tariffs) and helping to bridge the gap to cost-reflective end-user tariffs. It is unsustainable for Zambia to continue issuing sovereign guarantees to backstop ZESCO's power purchase obligations and GreenCo represents a stepping stone to demonstrating the benefits of a multi-buyer/multi-seller model and the ability of the market to mitigate payment risk.
- GreenCo is aiming to raise equity financing from various investors, including the African Development Bank (both in its own right and as co-accredited entity with the Development Bank of Southern Africa for the Green Climate Fund), the Zambian Industrial Development Corporation and the Rockefeller Foundation.
- Some of the recent solar PV tenders, including the IFC Scaling Solar tender in Zambia, have benefitted from highly concessional debt financing (including a portion priced at LIBOR + 0%) allowing them to charge tariffs as low as USD 0.06-0.08/kWh . However, there is not enough concessional finance to fund all the power generation needed, i.e. USD 60-90 billion for SSA by 2025 to achieve universal access (IEA Africa Energy Outlook).
- The winning bidders under the Zambia GETFiT programme run by KfW achieved tariffs of USD 0.04/kWh. The programme was open to individual projects of up to 20MW, with a total target of 100MW, but in the end a total of 120MWs were awarded to 3 bidders with 2 projects each, so 3x40MW. Will be contracted directly with ZESCO. They are probably targeting debt finance under the AfDB GCF Zambia debt facility.

- The broadly accepted view is that we need to mobilise pension funds and the insurance industry to mobilise the trillions of uninvested private capital.
- ZESCO seems to be becoming better at using their large hydro power stations more efficiently. Volumes of power traded on the SAPP short term markets during off-peak periods have increased, indicating that ZESCO and other hydro-heavy utilities are buying cheap off-peak power on the market and holding back their water to use in higher priced periods and to cover the morning and evening peak demand.
- There is potential for commercial and industrial rooftop solar on large manufacturing roofs. With net-metering, customers would only pay for the grid energy they consume. This can cause financial difficulties for utilities that have a bundled tariff as overheads are only recovered through the energy tariff. Countries such as Namibia are therefore moving towards unbundling their tariffs to ensure that overheads can still be recovered even if a grid-connected customer is a net exporter of electricity.
- Developers may have an appetite for some market risk in exchange for higher spot market tariffs but their lenders generally want the certainty of long-term fixed price Power Purchase Agreements (PPAs). However, having an uncapped fixed price tariff can lead to undue windfall gains for developers if production exceeds their base case assumptions. Under the GreenCo model, GreenCo aims to cap the volume of energy generation that benefits from the fixed tariff at the lender's base case required volume and to sell excess power at a lower tariff which may be linked to the SAPP market price.

A3.2.2b – Interview with Ana Hajduka, Chief Executive Officer and Lovemore Chilimanzi, Technical Director at Africa GreenCo, a prospective alternative credit-worthy off-taker to ZESCO, on 1 August, 2019

1 August, 2019, National Liberal Club, London
Permission granted to publish notes as they are with the PhD thesis

- Updates on their fundraising from PIDG and Green Climate Fund and progress within ZESCO and engagement with Government of Zambia stakeholders Energy Regulation Board, Ministry of Energy, Ministry of Finance.
- Zimbabwe's higher electricity tariffs look more appropriate than Zambia's. Their increase was necessitated by importing energy.

A3.2.3 – Interview with the CEO of an energy developer, on 3 September, 2019

3 September, 2019, Taj Pamodzi Hotel, Lusaka
Meeting notes anonymised

- Energy losses of up to 18% shown by World Bank data are not necessarily due to technical transmission losses. They could also be due to 'non-technical' losses, i.e. pilfering.
- In 2015, ZESCO was importing electricity from South Africa's ESKOM power utility at USD 0.18-21 kWh and Mozambique's EDM power utility for USD 0.21/kWh (published on Parliament's website).
- According to sources, ZESCO was not paying the Maamba coal independent power plant the full agreed tariff because it was unable to with the tariff it was charging to end-consumers.
- In the 2019 round of outages, ZESCO has gone worked hard to give accurate schedules, but is still off-the mark on its residential outage load-shedding schedules.

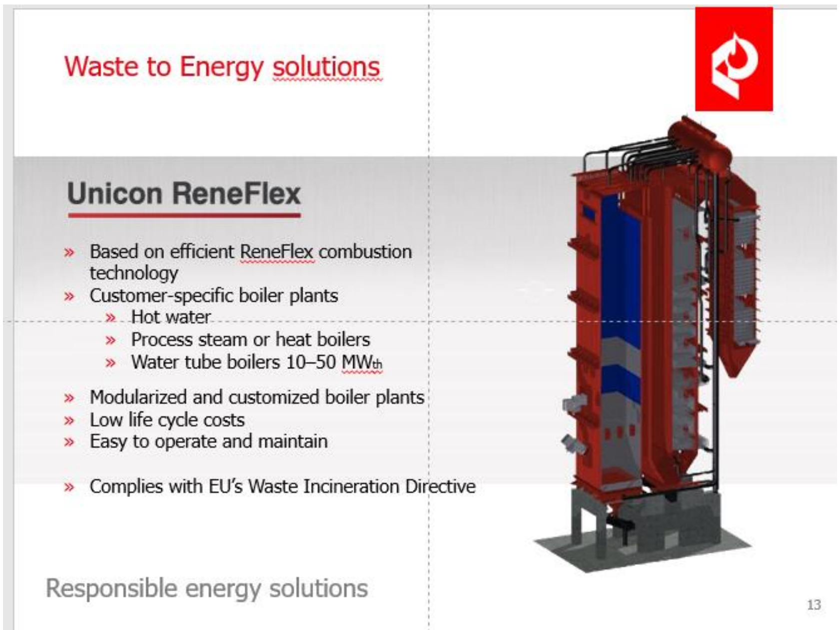
A3.2.4 – Mikko Marttala, CFO at KPA Unicon, a developer and engineering, procurement, construction contractor of energy solutions using industrial waste on 2 November, 2018

2 November, 2018, London House, London
Mikko Marttala
Permission granted to publish notes and slides with the PhD thesis.

Project participants in the meetings: Imad Ahmed
How the meeting was arranged: Mikko, a part-time MSc student of D'Maris and Imad's at UCL, looked into this research project and asked to meet.
General conversation:

- KPA Unicon is an EPC contractor and developer of energy solutions. They construct 5-40 MW independent power projects that are fuelled by industrial waste such as paper mill pulp (biomass) or such as steel mill blast furnace gas, or excess wood into biomass, or waste into fuel. They are interested in opportunities in Zambia. They are one of about 10 players operating in a niche space.

Excerpts from presentations shared subsequently:


Waste to Energy solutions
Unicon ReneFlex
» Based on efficient ReneFlex combustion technology
» Customer-specific boiler plants
» Hot water
» Process steam or heat boilers
» Water tube boilers 10–50 MWth
» Modularized and customized boiler plants
» Low life cycle costs
» Easy to operate and maintain
» Complies with EU's Waste Incineration Directive
Responsible energy solutions
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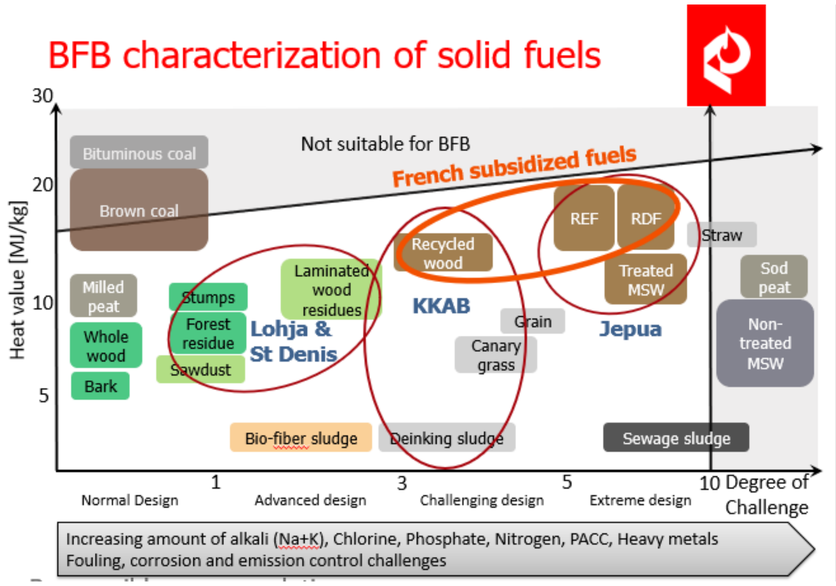

BFB characterization of solid fuels
Heat value [MJ/kg]
30
20
10
5
Not suitable for BFB
French subsidized fuels
Bituminous coal
Brown coal
Milled peat
Whole wood
Bark
Stumps
Forest residue
Sawdust
Laminated wood residues
Lohja & St Denis
Recycled wood
KKAB
Grain
Canary grass
REF
RDF
Treated MSW
Jepua
Straw
Sod peat
Non-treated MSW
Bio-fiber sludge
Deinking sludge
Sewage sludge
1
3
5
10 Degree of Challenge
Normal Design
Advanced design
Challenging design
Extreme design
Increasing amount of alkali (Na+K), Chlorine, Phosphate, Nitrogen, PACC, Heavy metals
Fouling, corrosion and emission control challenges

Waste derived fuels

SRF	Solid recovered fuel (EN15359)	New general term of all waste derived fuels including waste wood fractions
RDF	Refuse Derived Fuel	Old known term for treated waste
REF	Recycled Fuel	Old Finnish (VTT) classification system
MSW	Municipal Solid Waste	
CSR	Combustibles Solides de Récupération	French SRF term

Untreated Waste

Municipality

Industrial

Treated Industrial Waste fractions

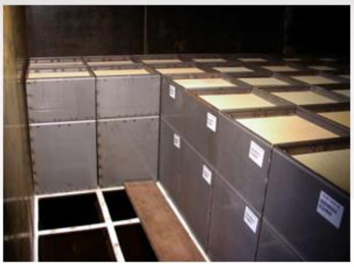
BFB

Cement kiln

Responsible energy solutions

ReneFlex emission control

- NO_x
  - SNCR when N < 1,5%-wt in ds
  - SCR when N < 3,0%-wt in ds
- SOx and HCl
  - Conditioned treatment – $Ca(OH)_2$
  - Dry treatment – $NaHCO_3$
- Heavy metals and PAHC
  - Activated carbon feeding



Responsible energy solutions

Emissions According EU's Industrial Emission Directive (IED)

IED limits		[mg/nm3] (11%-O2) dry	
Continuous measurement	**daily average**	½ hour average (100% A)	½ hour average (97% B)
Dust	**10**	30	10
TOC	**10**	20	10
HCl	**10**	60	10
HF	**1**	4	2
SO_2	**50**	200	50
NO_x	**200**	400	200
		10 min average	30 min average
CO	**50**	150	100

IED Emission limits for heavy metals and PAHC compounds		
Cadmium (Cd) + Thallium (TI)	**0,05**	[mg/nm3] (11%-O2) dry, sampling period 0,5-8h
Mercury (Hg)	**0,05**	
Heavy metals (Sb +As +Pb +Cr+Co+Cu+Mn+Ni+V)	**0,5**	
Dioxins and furans	**0,1**	[ng/nm3] (11%-O2) dry, sampling period 6-8h

Ekokem Oyj ReneFlex S 8-29

- 8,8 MW saturated steam for KWH Mirka factory (13.5 t/h, 29 bar, 234 °C)
- BFB boiler plant including SNCR and fabric filter
- Biomass, sandpaper leftovers or RDF (3 t/h)
- Boiler efficiency > 90 %
- Emissions limits according IED waste firing
- Location: Jepua, Finland
- Delivery: 12/2011–11/2013

Responsible energy solutions

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Ekokem Oyj ReneFlex S 8-29
History in brief

- 2013
  - First biofuel fire 8/2013
  - First waste fuel fire 9/2013
  - Handover 10/2013
  - Refractory lining of the furnace 12/2013
- 2014
  - Recirculated flue gas injection to secondary air
  - Installation of a new higher capacity recirculated flue gas fan
  - Several refractory changes in the furnace peak temperature area
- 2015
  - Explosion sootblowers to control furnace slagging
  - Automation system improvements, main topic on furnace slagging control
  - Fuel supply management changes
- 2016
  - Fuel feeding bin and chute modifications and level measurement
  - Primary air nozzle type change to machined nozzle
  - Fuel watering system to control very dry fuel run

Responsible energy solutions

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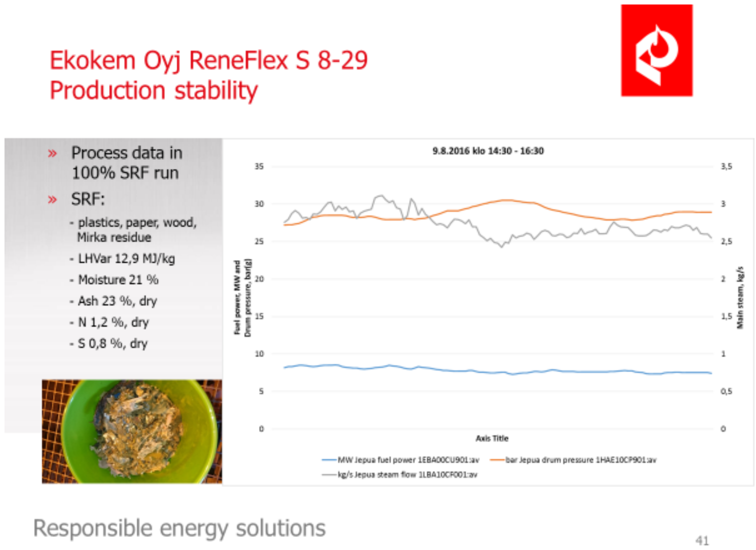
Ekokem Oyj ReneFlex S 8-29
Production stability
» Process data in 100% SRF run
» SRF:
- plastics, paper, wood, Mirka residue
- LHVar 12,9 MJ/kg
- Moisture 21 %
- Ash 23 %, dry
- N 1,2 %, dry
- S 0,8 %, dry
9.8.2016 klo 14:30 - 16:30
Fuel power, MW and Drum pressure, bar(g)
Main steam, kg/s
Axis Title
MW Jepua fuel power 1EBA00CU901:av
bar Jepua drum pressure 1HAE10CP901:av
kg/s Jepua steam flow 1LBA10CF001:av
Responsible energy solutions
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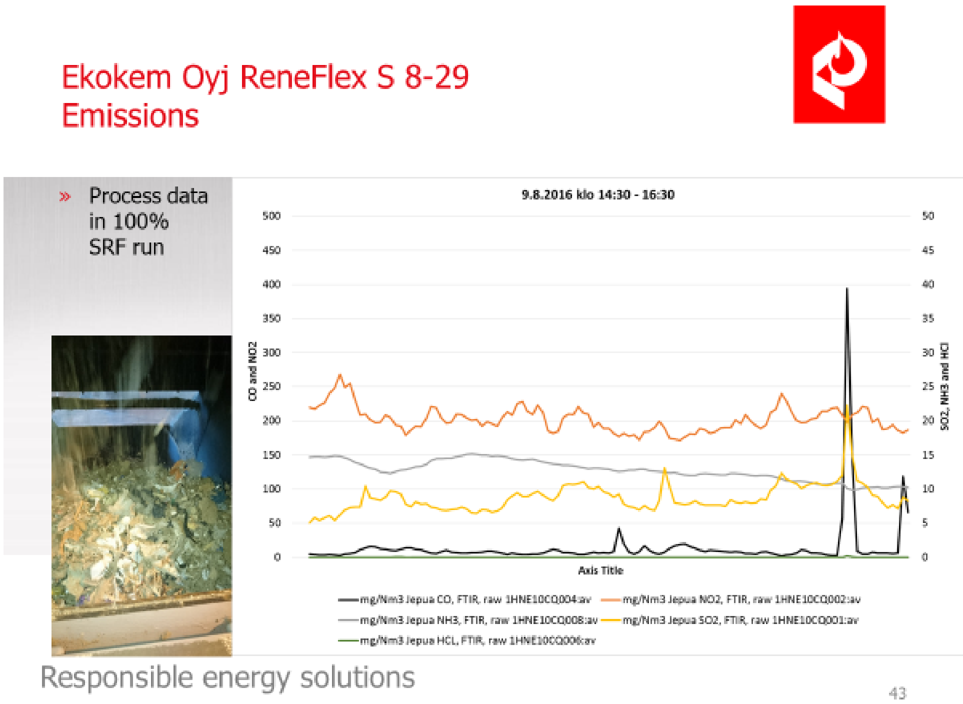
Ekokem Oyj ReneFlex S 8-29
Emissions
» Process data in 100% SRF run
9.8.2016 klo 14:30 - 16:30
CO and NO2
SO2, NH3 and HCl
Axis Title
mg/Nm3 Jepua CO, FTIR, raw 1HNE10CQ004:av
mg/Nm3 Jepua NO2, FTIR, raw 1HNE10CQ002:av
mg/Nm3 Jepua NH3, FTIR, raw 1HNE10CQ008:av
mg/Nm3 Jepua SO2, FTIR, raw 1HNE10CQ001:av
mg/Nm3 Jepua HCL, FTIR, raw 1HNE10CQ006:av
Responsible energy solutions
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Ekokem Oyj ReneFlex S 8-29
Operation and maintenance figures

Example month, November 2016 figures
- 790 tons of SRF
- 640 tons of recycled wood
- 11 tons of sand (bed material)
- 53 tons of bottom ash
- 130 tons of fly ash

General consumption figures
- Electricity ~20kWh/MWh_fuel
- Lime Ca(OH)2 ~20 kg/h
- Active carbon ~1,6 kg/h
- Ammonia ~5.5 l/fuel_ton

Maintenance
- Yearly maintenance cost is about 250k€
  - including fuel receiving and flue gas treatment
- Daily maintenance activities outsourced
  - Visits every weekdays

Operation
- 2 operators
  - Morning and afternoon shifts on weekdays
  - Nights and weekends remote operation from Vantaa (operator on call duty)

Responsible energy solutions

CHP Ceske Budejovice 14MW

Boiler Plant Key Figures		
Boiler capacity	14	MWth
Annual peak load	7500	h/a
Boiler efficiency	88	%
Fuel heat value	15	MJ/kg
Fuel moisture	30	%-w
Fuel ash content	16	%-dry fuel
Fly ash share	76	%

Consumables and ashes		
Sand	239	t/a
Bottom ash	1008	t/a
Fly ash	2747	t/a
Ammonia (24,5%)	158	m3/a
Lime $Ca(OH)_2$	286	t/a
Active carbon	23	t/a
Electricity	573	MWh/a

Responsible energy solutions

Veolia Prerov 20MW

Boiler Plant Key Figures		
Boiler capacity	20	MWth
Annual peak load	7500	h/a
Boiler efficiency	88	%
Fuel heat value	15	MJ/kg
Fuel moisture	30	%-w
Fuel ash content	16	%-dry fuel
Fly ash share	76	%

Consumables and ashes		
Sand	341	t/a
Bottom ash	1441	t/a
Fly ash	3924	t/a
Ammonia (24,5%)	225	m3/a
Lime $Ca(OH)_2$	409	t/a
Active carbon	33	t/a
Electricity	818	MWh/a

Responsible energy solutions

Katrinefors Kraftvärme
SUPERHEATED STEAM BOILER PLANT

Fuels:
- Waste wood
- Paper mill deinking sludge
- Forest residues

Superheated steam parameters:
- 478°C
- 62 Bar(g)
- 10 kg/s

Emissions (6%-O2):
- $CO < 100$ mg/Nm3
- $NO_x < 180$ mg/Nm3
- $NH_3 < 15$ mg/Nm3

Responsible energy solutions

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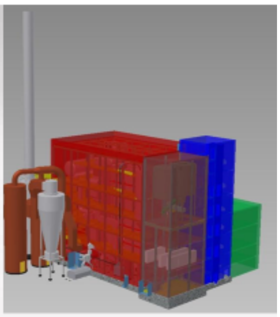
Katrinefors Kraftvärme
SUPERHEATED STEAM BOILER PLANT

A 28 MW combined heat and power plant to produce process steam for Metsä-Tissue paper mills, district heat to network, and power to grid

Scope of supply:
- 28 MWth BFB boiler
- Flue gas cleaning including cyclone and bag filters
- Flue gas condenser
- Air humidifier
- Fuel feeding system
- Stack
- Boiler house
- E&I
- Steam reduction stations



Responsible energy solutions

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Case
Arcelor Mittal Temirtau Kazakhstan
Unicon SF-150 (5 x 30 t/h 14 bar, 230°C)

- A large steel plant, where it was decided to utilize blast furnace (BFG) and coke oven gas (COG) for energy production
- Before gases were wasted when they were flared and exhausted into the atmosphere
- Project was implemented on a "turnkey" basis in 2011-2012
- Challenges – variations in fuel quality and pressure
- Environmental investment under special control of the President

Responsible energy solutions

Case
Arcelor Mittal Temirtau Kazakhstan
Unicon SF-150 (5 x 30 t/h 14 bar, 230°C)

Challenges with BFG:
- Low calorific value of 2,5-3,5 MJ/m3n, the calorific value varies
- Pressure 100 mbar
- Includes dust

- ➢ Wobbe-Index measuring
- ➢ Anticipation of calorific value changes through the automation system

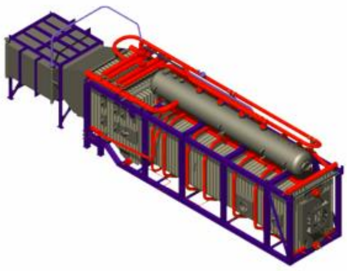
Challenges with COG:
- Low pressure 20-30 mbar
- Includes moisture, naphthalene

- ➢ Booster fan to increase gas pressure
- ➢ Heating of gas
- ➢ Filtering of gas

Responsible energy solutions

Case
Arcelor Mittal South Africa
Unicon MST-50 (2 x 25 t/h, 66 bar(g), 495 C)

- » Plant delivered to a steel mill which needs more electricity generation capacity due to electricity shortages in Kazakhstan.
- » Will give Arcelormittal electricity generation capability of 15 Mwe.
- » Fuels: BFG, COG, natural gas – simultaneous combustion
- » Module type prefabricated Unicon MST boiler
- » The project was implemented on "turnkey" basis in 2015-2016



Responsible energy solutions

A3.3 Public and private advocates for the manufacturing and private sector

A3.3.1 Interview with Chipego Zulu, CEO of Zambia Association of Manufacturers on 28 May, 2018

28 May, 2018, ZAM HQ, Lusaka
Zambia Association of Manufacturers
Institution's participants: Chipego Zulu, Chief Executive Officer
Permission granted to publish notes as they are with the PhD thesis

Project participants in the meetings: Imad Ahmed, Graham Sianjase
How the meeting was arranged: Graham arranged the meeting
Statements of the CEO:

- **About ZAM:** ZAM is not a government agency. It engages on behalf of its private sector members with the Ministry of Commerce, Trade and Industry.
    - Has not changed fees in the past 4-5 years. All we did was create a structure that was more responsive to SMEs, charging them K 1,000/y for policy advocacy. Medium and large are charged K 2,500; 5,000; 7,500; 10,000; 20,000. Conglomerates are treated as one large company, so they get excellent value.
    - We are sometimes confused with the Chamber of Commerce, who have changed their fees.
    - We have lost some members in the Copperbelt because of our lack of engagement there. We shut our office in Ndola but are reopening it this year.
- **Access to energy is a huge topic.** Energy supply has to be consistent, otherwise it results in damage to machinery, wastage, redoing work and increased cost of production.
- **Reduced output:** When we saw low rainfall, among other things [reduce the supply of power], and people couldn't afford generators and diesel, we saw a reduction in output. In particular there was a decrease in agro-processing output.
- **Nuclear:** So what's the solution? The Russian embassy is advocating a nuclear plant. We have uranium, but are hesitant. Are we able to manage all the things that could go wrong; do we have the expertise? Long-term it would mean Zambia would have adequate power, it would be more affordable and we could export energy to our neighbours. I have been castigated for not advocating nuclear power, but I don't want to di.e. The proposed location is in Changwe, where the residents have rejected it.
- **Coal:** ZAM is preparing a submission on a coal plant. The charges are unclear because there is a large discrepancy with what it costs to set up a coal power plant in India by the same company. [Coal upfront costs are high, whereas operating costs are low. Zambia is a landlocked country making set-up costs higher.]
- **Cost-reflective tariffs**: ZAM members are the first to recognise the importance of paying a cost-reflective tariff, but an increase of 75% in the tariff in two goes (one was 50%, the other 25%) meant that they were unable to gradually adjust to a revised tariff. The upward change came as a shock. Mining companies are paying less than industry due to a legacy issue with the Copperbelt Energy Company with the deals it signed. ZESCO's cost of service study should have been published at the beginning of the year, but we are still waiting. With cost-reflective tariffs, more will be invested into the energy sector.
- **Sovereign debt and the IMF:** Not having a cost-reflective tariff also causes problems with the IMF, with whom the government has not yet secured a deal on its debt situation, with Eurobonds needing to be paid back. The debt problem is exacerbated by falling copper prices

and an energy deficit and inconsistencies in policy. The IMF is dissatisfied with the Zambian government's management of expenditures, and negotiations are ongoing. The Attorney General's report says that there are wastages that are unaccounted for. If there is so money to waste, the IMF thinks why does it need to bail Zambia out.

- **MFEZs:** There is an MFEZ in southern Lusaka with 6 Zambian manufacturing firms which include Zambian Breweries, Roland, Zambia Fertilisers and Trade Kings. The previous MFEZs have been difficult for Zambian firms to move into; the first in Copperbelt is popularly known as the 'Chinese MFEZ'. Its start-up capital requirement was $500,000. But the one in southern Lusaka is not perfect. It comes with a 40 year lease, as opposed to the 99 year standard nationally, so firms are reluctant to invest in it when they could lose their factories after 40 years and have no title to the land, which also makes access to financing difficult.
    - The infrastructure meant to be set up is not. A power substation was set up for the MFEZ but it is now supplying a residential area and not the MFEZ.
    - The MFEZs are far away from the financial services sector, namely banks. Banks want to rent, not to invest in buildings. With traffic, journeys to the banks in town can take long.
    - The MFEZs are far from town and so involve long commutes for their employees.
    - Zambia was the first mover on MFEZs in southern Africa, but is now lagging because of poor design issues.
- **Taxes:** ZAM has given the government a laundry list of fiscal tax-related incentives it would like to see – from 0 rating on VAT, to removal of mineral royalties on iron ore to removal of property transfer tax, electricity consumption tax, reduction in corporate income tax. But the most important tax reforms that need to be made are with regards to import duties. Components of Zambian-made products are imported and are slapped with import duties, which makes it difficult to manufacture in an already expensive environment because of high transportation costs involved to and from a landlocked country. The Ministry of Finance often looks at the short-term gains in tax revenues rather than the long-term view of creation of jobs, exports, gains in foreign reserves across 20 sectors if import duties can be lifted for raw materials.
- **Classifications of industries:** When ZAM started in 2007, it followed the Central Statistical Office's classification of industry into 20 subsectors. It then reduced that in accordance with the Ministry of Commerce, Trade and Industry reclassification.

Would speak in a public dissemination meeting on the record.

A3.3.2 Interview with Wamulume Kalabo, Chairman of Zambia Chamber of Commerce and Industry (ZACCI), 2004-07 on 4 June, 2018

4 June, 2018, Taj Pamodzi, Lusaka
Former ZACCI Chairman 2004-07, and before that Kitwe Chamber of Commerce Chairman, currently Executive Chairman of Basali Ba Liseli Resources Limited (Angola-Zambia Refined Petroleum Multi-Product Pipeline)
Permission granted to publish notes as they are with the PhD thesis

Project participants in the meetings: Imad Uddin Ahmed
How the meeting was arranged: Introduction by Jim Friedlander
General conversation:

- History of power outages: When Wamu was Chairman of ZACCI 2004-07, there very little trouble of power outages. The trouble began in 2008 when residences were experiencing 3 hour outages twice a week. The early 2000s were about coming out of the downturn of the economy in the 80s and 90s so all available energy was being used. Companies were a lot smaller then than they are now. Trade Kings for example has grown substantially. Any outages (which could last four days) prior to 2008 would be the result of trippings/transformers blowing up because of power maintenance, not load shedding. Once the economy had outgrown the existing infrastructure, and with the low rainfuall, that's when the outages started happening.
    - The driver behind economic growth
        - was that from 1991 onwards, Zambia became a multiparty country. Privatisations of parastatals initially resulted in lower revenues because the companies were being gutted for assets and their new owners were not entrepreneurial.
        - 2001 saw a new president who was private sector oriented and focused on Zambia's ease of doing business. His tenure ended in 2011.
            - 2005-11 he created momentum in the mining sector. He showed he was friendly towards investors. His policy framework was predictable. He constantly engaged the private sector. He would meet Wamu twice a year at the Zambia International Conference for business, which he would preside over and Wamu would deputy preside over. International investors saw good will on the president's part and that he would not change policy without consulting the private sector.
            - From 2006 on: Zambia entered lower middle-income status. Construction for domestic housing started rising in spite of credit constraints (people were using their own resources), which increased demand for energy.
            - The MFEZs are primarily pre 2011. They are a means for diversifying from copper dependency so once copper supplies have been exhausted, the copper towns won't be left as ghost towns.
        - In 2011, with the consultative president out, the government started doing this without consulting the private sector. The police environment was not predictable. The economy slowed down. But there was hope that the government or future governments would be investor friendly.
- Wamu is working on an oil and gas pipeline between Angola and Zambia. His hope is that the law will allow for direct off-takes between IPPs that use his oil and gas and industry and that they will compete against ZESCO. These IPPs will look to sell companies their baseload with PPAs. The upfront cost is high, but variable cost is low.

Energy is the heart of the economy. The Western Province has just 10MW power allocated to it. They could feed the whole world if they had the energy. They should be able to move into agro-processing, such as rice shelling, should be able to refrigerate mangoes so that they don't rot, should be able to extract juice. The only thing worse than the dearth of energy is the lack of stable environment.

A3.3.3 Interview with Sampa Chilanga, Monitoring and Evaluation Officer at Zambia Development Agency on 30 May, 2018

30 May, 2018, Zambia Development Agency Office, Lusaka

Institution's participants:
- Sombo Kaweza, Specialist – Research and Policy
- Sampa Chilanga, Monitoring and Evaluation Officer
- Permission granted to publish notes as they are with the PhD thesis

Project participants: Imad Ahmed
How the meeting was arranged: Chisala of Bank of Zambia introduced Imad to Sombo Kaweza
- Sampa sympathises with manufacturing firms that complain that they do not know the difference between planned and unplanned power outages. The ZDA and residential homes experience the same. One has to provide their own water and electricity. But fuel is expensive, making it difficult to be profitable.
- The greatest obstacles to doing business:
  - Access to finance. Collateral is an issue because people don't have land titles in Zambia. Lending rates Q4 2017 were 25.4% and fell to 24.3% in Q1 2018.
  - Import of inputs. When the Kwacha depreciates, it makes exports cheaper, but inputs more expensive.
  - Load shedding. Energy outages are a serious challenge for production.
  - Export non-tariff barriers.
  - Cost of land.
  - Absence of tax incentives. Customs duty exemptions only apply if manufacturing is rural, in an industrial area or in an MFEZ.

Material shared by ZDA:
- 400 manufacturing firms by pledged employment in Lusaka, 30 in Ndola, 50 in Kitwe
- ZDA, 2017. Foreign Private Investment and Investor Perceptions in Zambia (hard copy)

A3.4 Donors

A.3.4.1 Phone interview with an energy expert within a donor agency on 27 Feb, 2019

Anonymised.

- Now, close to 85% of power supply is from hydropower. Notwithstanding problems of drought and low rainfall, looking at 2,400MW project at the Batoke project. World Bank and AfDB feasibility studies. AfDB awarded the mandate to progress.
- Because of the low rainfall at Kariba, reduced power by 50%. From 2000MW to 1000MW at the same time that they're looking to invest in extra hydropower assets.
- On an experimental basis, the IFC in conjunction with the IDC which is the holding company of parastatal assets have done a programme which they call scaling solar.
- Awarded 2 solar plants to Italian company NL 27MW and a JV between French company Nonen and First Solar. That project is 47.5MW.
- Well on their way to constructing those power plants. Both believe they will reach COD by early 2020.

- Because of the uncertainty surrounding ZESCO itself and the fact that it is on weak footing - not credit worthy borrower or credible offtaker - financial institutions are concerned about its viability to pay its debts.
- While there were supposed to be 2 Scaling Solar and they had shortlisted half a dozen firms they have put it on hold because of LT viability of ZESCO.
- There has been talk over the years for a major restructuring.
- All of this at a time when the ZESCO tariffs even though their tariffs have gone up twice are not cost reflective.
- The original contractor for the cost of energy EA Consulting from the UK had their contract terminated. Speculation as to why that happened because they were reputable. Brand new tender which took additional time. Now awarded that contract. Was meant to be completed by end of last year. Now end of this year. Probably won't see light of day till after next election because people think they know what it will say i.e. increase tariff and restructure ZESCO and that is not politically appetising.
- The mines' tariffs have gone up to 8.5-9 cents which is still not cost reflective but much better.
- Commercial groups are still paying 3.5-4.5 cents/kWh - shopping malls. They recognise it's not cost reflective but they're not going to volunteer to pay more.
- There has been talk of ZESCO going to ERB for yet another increase.
- Solar can absolutely be useful during baseload hours.
- Because of the unreliability of ZESCO, most companies had to invest in diesel generated electricity. What firms are now relying on is dirty and high cost.
- What actually makes more sense LT is to switch to solar with diesel back up or batteries.
- Solar with a renewable back up.
- <15% solar on the grid is okay.
- Makes sense to encourage private entities to build generation assets using renewable technologies and sell to the grid.
- Copperbelt Energy Corporation << CDC planned to buy an interest in CEC.
- ZESCO sells about 55% of gen capacity to CEC which they sells to mining companies in Copperbelt.
- Under CDC plan, they were going to continue that but transition CEC into regional to DRC and southern Africa.
- Getting involved in generation assets - solar and hydro. Listed company listed on the Lusaka stock exchange. Didn't happen because CEC has a bulk supply agreement with ZESCO which expires next year.
- CDC wanted to engage in negotiations with ZESCO to extend the agreement. ZESCO didn't because not cost reflective and inflation pegged in USD not Kwacha (reason given) but deal fell through.
- A lot of changes that need to take place for it to become a credible organisation.
- He wouldn't be investing in incremental capital until they do major restructuring.
- Strongly encouraging private groups to invest in energy generation assets and provide them incentives to do so. Regulatory environment favourable for them to do so. Business to business energy transactions.
- Not an advocate of dirty energy at all. From a LT view of what's good for the environment.

A3.5 Colleague researcher interviews

A.3.5.1 Interview with 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

26 May, 2018, Taj Pamodzi, Lusaka
Yimbilanji Sichone
Permission granted to publish notes as they are with the PhD thesis

Author, Electricity load shedding: An econometric analysis of the productivity of firms in the manufacturing sector in Lusaka
Research Analyst, Joint Permanent Commission (Secretariat) – between the Ministry of Defence, Ministry of Foreign Affairs and Ministry of Home Affairs
Project participants: Imad Ahmed and Graham Sianjase
How the meeting was arranged: Imad was introduced by his friend Doreen Karake of Kigali.
What we learned:

In his full MSc thesis, Yimbi investigated the effect of firm age and whether a firm was foreign owned or not on its ability to mitigate against power outages through the use of generators. He found that older and foreign nationals were better able to mitigate the impact of power outages. Locally managed firms that were new did not have the resources or management business skills capacity to realise that they needed generators. Post 2010, firms started thinking of generators because it was a noticeable factor – people started coming alive to the fact that ZESCO can switch off power for preservation. The older firms invested in generators even if they didn't at the start.

For the food sector and for metal fabrication, when production starts, there are some processes that should not be interrupted. To be on the safe side, they'll run the generator even when the power is running, because if they did not, they would risk spoilage of the product. In one instance he heard of damage to equipment; he had heard of clinker solidifying in the pipes of one glass manufacturer in Central Province, with the pipes needing replacement, but that seemed to be an isolated incident. Most damage Yimbi observed was done to computers and not machinery.

Sometimes ZESCO would give a schedule of load shedding but sometimes they would not stick to it.

The way Yimbi met companies was by attending a ZAM forum, where he met people. Some were willing to meet him in person again and share data, others he corresponded with only by email. He said he would share the contacts of those who would be happy to meet with our enumerators.

Yimbi struggled to get figures for self-generation because firms didn't think that self-generation was a permanent solution and didn't therefore record their expenses for it.

He seemed to think that the government prioritises energy to light and heavy industrial areas. He advises talking with the firms there because ZESCO might not be practicing what it says it is doing.

Follow-up research he wanted to do in his journal article was to remove electricity as an explanatory variable and see the impact it had on R-squared. He wanted to then use the two stage least squares approach [to put electricity in through another variable?]

Data shared: Yimbi clarified a question we had about a table in his published journal article, and shared with us World Bank Enterprise Survey data for Zambia.

A3.5.2 Meeting with Miljan Sladoje, IGC Zambia Country Economist on 28 May, 2018

28 May, 2018, International Growth Centre, Zambia Office, Lusaka
Institution's participants: Miljan Sladoje, Country Economist
Permission granted to publish notes as they are with the PhD thesis

Project participants in the meetings: Imad Ahmed, Graham Sianjase
How the meeting was arranged: Herryman Moono referred Imad to Miljan
What we learned:

- IGC separately commissioned during the electricity crisis a study to figure out the willingness to pay for reliable pay. I have shared the file with the team. Its citation is below.
- IGC commissioned a census of 45,000 firms in Lusaka. The firms were categorised by location, name, sector and whether they were electrified. The research has not yet been finished, but we could reach out to the PI Nava Ashraf to see whether they can share their data.
- The Centre for Trade Policy (CTPD) recently published a report on MFEZs. 6 have been announced. 3 are in operation.
- Local Councils and ZESCO would be the best authorities to consult on what constitutes a light or heavy industrial zone.
- The research needs to be pitched as still relevant even though it was commissioned during the depth of crisis and in the short-run it seems there is no crisis any longer. Mismanagement seemed to be a problem with transmission losses. The precipitation shortages could have been anticipated, but because it was not, power was shut for 3 days in 2015. If the long-run problems are not fixed, there could yet be future crises.
- After the report has been completed, there will be a public dissemination event. It would be good to have ready panellists to discuss the report. There will also be in-house presentations that are more targeted, e.g. for ZESCO. As such, it would be good to make contact with the Ministry of Energy.
- Miljan is available to join us for meetings.
- If we need to move forward the deadline from 31 August for the final report, we can do so without problem so long as we ask by email to do so. We can request up to 3 months more without requiring a contractual amendment.
- (Sylvester Hiba Jaya was the head of the Energy Regulatory Board and the Copperbelt Energy Corporation.)

Data and contacts shared:

- Batidzirai, B., Moyo, and A. Kapembwa, M. (2018). Willingness to pay for improved electricity supply reliability in Zambia – A survey of urban enterprises in Lusaka and Kitwe. Energy Research Centre, University of Cape Town, Cape Town.
- A person in the manufacturing sector: RosetaM.Chabala@generalcable.co.zm of ZAMEFA
- Energy Regulatory Board, Alfred Mwila, alfredmmwila@gmail.com, amwila@erb.org.zm

Will refer us to Innovations for Poverty Action for enumerators.

A3.6 Other useful unstructured conversations

A3.6.1 Interview with Chibelushi Maxwell Musongole, Lecturer, retired Assistant Director at the Central Bank of Zambia and retired Director General at the Zambia Public Procurement Authority on 28 May, 2018

28 May, 2018, Taj Pamodzi, Lusaka
Chibelushi Maxwell Musongole
Part-time lecturer, Zambia Centre for Accountancy Studies and University of Lusaka. Retired Assistant Director at the Central Bank of Zambia, retired lecturer at the University of Zambia
Permission granted to publish notes as they are with the PhD thesis

Project participants: Imad Ahmed
How the meeting was arranged: Jim Meikle met him at a conference in Abidjan, Cote d'Ivoire
General conversation:

- Politics have degenerated. People are losing their freedom to comment against the government because the government's supporters don't allow dissent. This is allowing the government to be corrupt with impunity. The public are shielded from this, and the government appoints posts to the Daily Mail, Zambia Broadcasting Corporation and Times of Zambia [which is why they do not publish real news]. The Lusaka Time is free from government influence.
- FDI is there, but only from China. The Chinese are very active in the economy, especially in construction. He suspects that they may often come through corruption. While their projects are legitimate, they come at inflated costs, and this commits the government to high debt levels. Chinese investment is regarded positively in that they are in Zambia to do things, but negatively in that they inflate prices. The USA and EU are not active here because they won't bribe to get business.
- Indian expats are big into manufacturing, trading and farming. Lebanese expats are big in trading, and he suspects, also in government contracts.
- Zambia has historically been welcoming to refugees, since the freedom fighters of South Africa and Angola came, to those from DRC and Rwanda during the genocide.
- The Central Bank's statistics are updated, accurate and independent and meet IMF standards, but they cannot collect statistics on every matter. Statistics outside of those that the Bank of Zambia collects generally could be better. There is generally low capacity, and lack of understanding among the people heading institutions the importance of statistics for decision-making. People are not reprimanded for collecting poor statistics. There is little accountability. Lack of funding for the Central Statistical Office.

Introduction made: Jacob Lungu, Senior Economist, Information and Statistics Division, Economics Department, Bank of Zambia

A3.6.2 Meeting with Natty Chilundiki, Research Coordinator, on 29 May, 2018

29 May, 2018, Taj Pamodzi, Lusaka
Natty Chilundiki
Former Rhodes Scholar, currently Grants Manager and Research Coordinator at University of Zambia School of Public Health and Managing Partner of Preaz Research Consultancy.

Permission granted to publish notes as they are with the PhD thesis

Project participants in the meetings: Imad Ahmed
How the meeting was arranged: Imad's friend Taiwei Lin of Goodenough College introduced the two
General conversation:

- There is a debt crisis coming up.
- Factors holding up the economy: Access to capital for indigenous businesses, which are being crowded out by foreign (particularly Chinese) direct investment and by the government; and lack of policies to nurture home grown businesses.
- Zambia has made good progress in the past years with regards to literacy and health indicators, such as in HIV prevalence, maternal and child mortality, life expectancy (largely as a result of reduced HIV prevalence). Cholera though breaks out every year and could be prevented.

Introductions made: To six enumerator candidates. Two were hired and trained.

A3.6.3 Interview with Jim Friedlander, Partner KIAP Law Firm on 3 May, 2018

3 May, 2018, London House, London
Jim Friedlander, Partner, KIAP law firm
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Project participants: Imad Ahmed
How the meeting was arranged: Met Jim at a friend's dinner party in London. He worked for the World Bank, then Citibank in Nairobi and then as an independent lawyer based in Africa for many years. He still advises on investments into Africa and consults for African governments.
General conversation points:

- Things happen in Zambia in spite of the government, not because of it, even if the Zambia Development Agency thinks it is doing wonderfully for the country.
- Resource rich, allowing people to have disposable income, resulting in high alcoholism and drink driving being a problem
- Trading is restricted

Introductions made:

- CEO of a milling company who shared his milling company's ZESCO bills
- Wamulume Kalabo, ex-Chairman of Zambia Chambers of Commerce and Industry

A3.6.4 Email from Michael Mainelli, Consulting Partner at BDO Binder Hamlyn on the privatisation of Zambia Consolidated Copper Mines, 1992-1993

Permission granted to publish notes as they are with the PhD thesis

From: Michael Mainelli <michael_mainelli@zyen.com>
Sent: 17 February 2019 12:51
To: Ahmed, Imad
Subject: Zambia Consolidated Copper Mines and Electricity

Imad,

It was great to chat two weeks ago in Budapest. I promised you a paragraph or two on electricity and copper and development:

From 1987 to 1994 I was a consulting partner with BDO Binder Hamlyn, the international accounting and consulting firm. I led a number of international projects, many on privatisation. From 1992 to 1993 one project was to work with "Rio Tinto Zinc" (RTZ), today just "Rio Tinto", on the potential for privatising Zambia Consolidated Copper Mines (ZCCM). Our project's objective was to provide an overall assessment of the privatisation and commercial potential of ZCCM. Our client was RTZ, but they in turn were working for the World Bank. At the time ZCCM comprised about eight to ten major mines, three smelters, two refineries, a tailings plant, and lots of social infrastructure (schools, houses, hospitals, road, telecoms). I can't remember the employment numbers but I believe it was more than 100,000.

The importance of electricity in copper mining is well-known [https://pubs.usgs.gov/of/2011/1253/report/OF11-1253.pdf see tables 13 & 14] [https://www.sciencedirect.com/science/article/pii/S0301420716300824], and the electro-refining process is key to high-grade outputs - http://www.ct.ufrgs.br/ntcm/graduacao/ENG06631/5-b_copper.pdf

During the course of the project, we realised that the Zambian resources were well-regarded, but management, government, and processing were not. One of the points we failed to get the government to take seriously enough was that variability in the electricity supply was leading to production problems and thus variability in the output. In turn, these production problems were impeding the sales potential for Zambian copper as buyers were concerned about irregularity of supply. Clearly Zambia had significant hydropower production potential, but it was often out of action, or diverted elsewhere for political purposes. We wanted to consider directing large quantities of energy towards stable electro-refining, but this was not political feasible. A small feedback problem related to this was that because Zambia's intermittent supply caused sub-optimal contracts, it in turn caused significant forex (FX) problems in turn, a second-order effect.

Page 163-188 of this 1990 thesis has an interesting overview contemporaneous with our work - http://etheses.whiterose.ac.uk/490/1/uk_bl_ethos_291037.pdf

e.g. "Zambia has hydro power stations at Victoria Falls, Kariba and Kafue Gorge with a capacity greater than national demand. Exports have been made to Zimbabwe, but in 1989 power was imported from Zimbabwe and Zaire due to a fire at the Kafue station. The cost of electricity is one of the lowest in the world."
Also - http://documents.worldbank.org/curated/en/722101468204567891/pdf/multi-page.pdf , and http://pubs.iied.org/pdfs/G02454.pdf

In the end, we recommended that there were significant direct improvements the government could make to realise a much higher price for its copper, and thus for ZCCM. We suggested that many of these improvements should occur before privatisation. Our suggestions covered mining, management, and transport, but a significant decision (in our view) was how to guarantee stable supplies of electricity. We had two proposals. One was to let ZCCM control primary electricity production, e.g. a dam of its own. The other was to give a 'top slice' of baseload to ZCCM so a guaranteed amount of electro-refining could occur each month. We justified some of this on the basis of 'real option' theory. In the round, the government ignored the advice and proceeded with a controversial privatisation as swiftly as it could while doing little to stabilise electricity supply.

One could speculate on how taking consumers off the main grid through micro-grid supply might have made a difference.

With all best wishes,

Michael