SA-TIED

Southern Africa – Towards Inclusive Economic Development

WORKING PAPER 234

Dancing on the grid: electricity crises, manufacturing energy vulnerability, and jobs in South Africa

Gideon Ndubuisi,[1] Elvis Korku Avenyo,[2] and Rex Asiama[2]

June 2024

UNU WIDER

national treasury
Department:
National Treasury
REPUBLIC OF SOUTH AFRICA

SARS

Co-funded by
the European Union

British
High Commission
Pretoria

About the project

Southern Africa – Towards Inclusive Economic Development (SA-TIED)

SA-TIED is a unique collaboration between local and international research institutes and the government of South Africa. Its primary goal is to improve the interface between research and policy by producing cutting-edge research for inclusive growth and economic transformation in the southern African region. It is hoped that the SA-TIED programme will lead to greater institutional and individual capacities, improve database management and data analysis, and provide research outputs that assist in the formulation of evidence-based economic policy.

The collaboration is between the United Nations University World Institute for Development Economics Research (UNU-WIDER), the National Treasury of South Africa, the South African Revenue Services, and other universities and institutes. It is funded by the National Treasury of South Africa, the Delegation of the European Union to South Africa and UNU-WIDER through the Institute's contributions from Finland, Sweden, and the United Kingdom to its research programme.

[1] Delft University of Technology, Netherlands, corresponding author email g.o.ndubuisi@tudelft.nl; [2] University of Johannesburg, South Africa

WIDER Working Paper 2024/41

Dancing on the grid: electricity crises, manufacturing energy vulnerability, and jobs in South Africa

Gideon Ndubuisi,[1] Elvis Korku Avenyo,[2] and Rex Asiama[2]

June 2024

Abstract: South Africa's current electricity crises have worsened, placing the country on an uncertain and turbulent economic trajectory. To identify the manufacturing sub-sectors that are most vulnerable to this crises, we use the input–output matrices for the period between 1993 and 2021 to develop a sub-sector energy vulnerability index. Second, we employ the self-constructed energy vulnerability index in a flexible empirical framework to examine the effect of the electricity crises on manufacturing sector jobs in the country. We find that energy vulnerability has a high degree of heterogeneity across manufacturing sub-sectors, highlighting cross-sector differences in the level of exposure and susceptibility to the energy-related crises. Results from the empirical analysis, on the other hand, suggest that electricity crises are associated with significant job destruction, with this adverse effect severe for manufacturing sectors with higher energy vulnerability intensity. The severity of this adverse effect holds irrespective of the nature of jobs, whether formal or informal.

Key words: electricity crises, energy vulnerability, manufacturing, jobs, South Africa

JEL classification: L60, O14, Q40

Acknowledgements: We would like to thank Philippe Burger, Richard Kima, Lilenstein Kezia, and other project researchers for their useful and constructive comments and feedback. We are also grateful to Aino Hiltunen for support and UNU-WIDER for financial support.

---

[1] Delft University of Technology, Netherlands, corresponding author email g.o.ndubuisi@tudelft.nl; [2] University of Johannesburg, South Africa

This study has been prepared within the UNU-WIDER project Southern Africa—Towards Inclusive Economic Development (SA-TIED).

Information and requests: publications@wider.unu.edu

ISSN 1798-7237 ISBN 978-92-9267-503-5

https://doi.org/10.35188/UNU-WIDER/2024/503-5

Typescript prepared by Lesley Ellen.

United Nations University World Institute for Development Economics Research provides economic analysis and policy advice with the aim of promoting sustainable and equitable development. The Institute began operations in 1985 in Helsinki, Finland, as the first research and training centre of the United Nations University. Today it is a unique blend of think tank, research institute, and UN agency—providing a range of services from policy advice to governments as well as freely available original research.

The Institute is funded through income from an endowment fund with additional contributions to its work programme from Finland and Sweden, as well as earmarked contributions for specific projects from a variety of donors.

Katajanokanlaituri 6 B, 00160 Helsinki, Finland

1 Introduction

South Africa is currently facing a severe electricity crisis. Although the South African government has responded by declaring a state of emergency in the electricity sector, bringing new electricity supply online is time consuming and prohibitively costly. Accordingly, regular enforced power cuts (also known as 'loadshedding') have become a pathway to keep the lights on in the country. In 2022 alone there were about 3,773 hours of loadshedding, with an upper limit of 11,529 gigawatt hours (GWh) relative to actual energy shed of 8,301 GWh (see Pierce and Le Roux 2022). Importantly, anecdotal evidence also suggests that daily loadshedding can extend to almost ten hours per day, which is a cause for concern.

Several studies present evidence which suggests that electricity crises pose serious threats to a country's domestic development and global competitiveness (Allcott et al. 2016; Andersen and Dalgaard 2013; Montalbano and Nenci 2019; Ndubuisi, Denis et al. 2023; Xu et al. 2022). For instance, Allcott et al. (2016) found that electricity shortages in India reduced the average plant's revenues and productivity and distorted plant size distribution. Andersen and Dalgaard (2013) found that weak power infrastructure in sub-Saharan African countries dragged the economic growth of countries in the region. Xu et al. (2022) associated power outages with poor firm productivity and profitability in Pakistan, while more recently Ndubuisi, Denis et al. (2023) found that energy poverty undermines a country's productive efficiency. In South Africa, a forecast by the South African Reserve Bank suggests that the electricity crisis is curtailing economic growth by two percentage points per year, reducing the forecast real economic growth rate to 0.3 per cent in 2023, 0.7 per cent in 2024, and 1 per cent in 2025.

Whereas the foregoing evidence suggests that electricity crises can stymie a country's development, their effect may not be uniform across the economy as some firms or sectors may be more affected than others. For instance, energy-intensive manufacturing sectors such as the hard-to-abate steel sector may be affected more than light manufacturing sectors such as apparels and paper. Because solutions to electricity crises are innately long term, short- to medium-term solutions entail government policies and initiatives that enable economic agents or sectors to cope with the negative impact of a crisis effectively and efficiently. In this case the potency of the government's short- to medium-term initiatives largely depends on how targeted these policies are to those sectors that are most vulnerable to electricity crises.

To date there has been a lack of rigorous empirical analysis examining how electricity crises are affecting the real sector in South Africa. At the same time scholarly debate on measures the government can take in response to electricity crises have often proceeded without due consideration of the potential heterogenous responses of the real sector to the crises. This lack of evidence is surprising, as analyses of the heterogeneous relationships and trade-offs could guide critical decisions relating to the allocation and reallocation of energy and other productive resources across sectors, particularly in a fiscal-constrained setting. This is particularly important as remedial measures entail (re-)allocation of limited resources, with different degrees of intensity mattering for evidence-based policy.

The purpose of this paper, therefore, is to fill the above-identified knowledge gaps. We develop a sector energy vulnerability index for South Africa and then use it to assess the implications of the electricity crisis for manufacturing sector jobs in the country. Specifically, we examine the sectoral linkages between the electricity and manufacturing sub-sectors, and the extent to which electricity crises influence manufacturing jobs in South Africa. We focus on the manufacturing sector given the sector's key role as an engine of long-term growth and development (Szirmai 2012) and because of the evidence of de-industrialization in South Africa (Andreoni and Tregenna 2021; Imbs 2013). In addition the expansion of manufacturing jobs is a strong predictor of higher levels of economic development (Kruse et al. 2023). Accordingly, to address our research objective, we first employ input–output data on the universe of South Africa's domestic sectoral forward and backward linkages to the electricity sector to develop a sub-sector energy vulnerability index for the period from 1993 to 2021. Second, we employ the self-constructed energy vulnerability index in a flexible empirical framework to explain the causal pathway of how the electricity crisis is affecting manufacturing jobs in the country, building on the generalized difference-in-difference model developed by Rajan and Zingales (1998).

To preview our results, our self-constructed energy vulnerability index shows that there is heterogeneity across manufacturing sub-sectors. For instance, whereas the least vulnerable manufacturing sub-sector in our sample (i.e. household appliances [QSIC 358]) has a median energy vulnerability score of 0.01, the most vulnerable manufacturing sub-sector (i.e. coke, petroleum products, and nuclear fuel [QSIC 331-333]) has a median energy vulnerability score of 0.6.[1] This highlights cross-sector differences in the level of exposure and susceptibility to potential energy-related crises. By extension, as well as informing policy on the need for sector prioritization, it also identifies sectors that the South African government should prioritize while rolling out policies and initiatives that enable sectors to cope with the short- to medium-term negative impact of the ongoing electricity crises. Findings from our econometric analysis confirm the latter argument. In particular, while we find that electricity crises are associated with significant job destruction across manufacturing sectors, this adverse effect is higher for manufacturing sectors with higher levels of energy vulnerability intensity. This result holds irrespective of whether we consider formal or informal manufacturing sector jobs. It is also robust to several robustness checks.

This paper is closely linked to the incipient growing literature on the development, energy demand, and institutional performance implications of South Africa's electricity crises (Eberhard 2008; Inglesi 2010; Inglesi and Pouris 2010). Our analyses and findings contribute to this literature in two ways. First, we deviate from extant studies by developing a sectoral energy vulnerability index that could be used to direct policy in terms of which sectors to prioritize based on their energy needs. Second, we deviate from the conventional approach of documenting patterns and trends of electricity crises to document causal consequences of electricity crises and how these are distributed at the sector level. To the extent that our findings draw imperatives for broad-based policy intervention to address the country's energy needs, our study also relates to the broader debate on the need to diversify South Africa's energy mix away from coal to renewables (Jain and Jain 2017; Pegels 2010; Winkler 2005). Finally, our paper also adds to the broader literature on how firm performance is negatively affected by energy inefficiency, electricity shortages, and energy crises at the firm, regional, or country level (Allcott et al. 2016; Andersen and Dalgaard 2013; Montalbano and Nenci 2019; Ndubuisi, Denis et al. 2023; Xu et al. 2022). We contribute to this literature by providing country-specific evidence for South Africa.

The rest of this paper is structured as follows. Section 2 provides a synopsis on South Africa's electricity sector and crises. Section 3 then provides a theoretical link between electricity crises and manufacturing jobs. The research design, including the data and descriptive statistics are presented in Section 4. Section 5 presents and discusses the study's findings, while Section 6 concludes the paper.

---

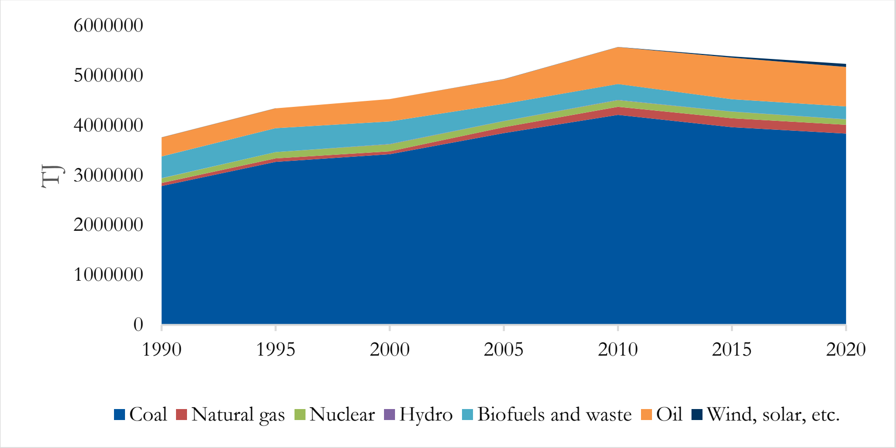
[1] The energy vulnerability index is normalized, ranging from 0 to 1, with higher values indicating higher levels of energy vulnerability.

2 South Africa's electricity sector: capacity, landscape, and crises

2.1 South Africa's electricity capacity and sector landscape

South Africa's total domestic electricity generation capacity is around 58,095 megawatts (MW). Figure 1 shows that the country's electricity largely comes from coal, which accounts for about 80 per cent of the energy mix. The rest of the electricity comes from a combined contribution of other sources such as natural gas, nuclear energy, hydropower, and renewables (e.g. wind and solar). South Africa's electricity dependence on coal reflects the natural abundance of coal in the country, making it a relatively cheap energy source. However, the country has been making efforts to diversify its energy mix away from coal to renewables. One of the notable policies that underscores this commitment is the Renewable Independent Power Producer Program, which aims to add more MW to the nation's electricity grid through private-sector investment in renewable energy sources. In general the country's pursuit of energy diversity aims to ensure energy security and self-sufficiency, and to decarbonize the energy sector.

Figure 1: South Africa energy mix



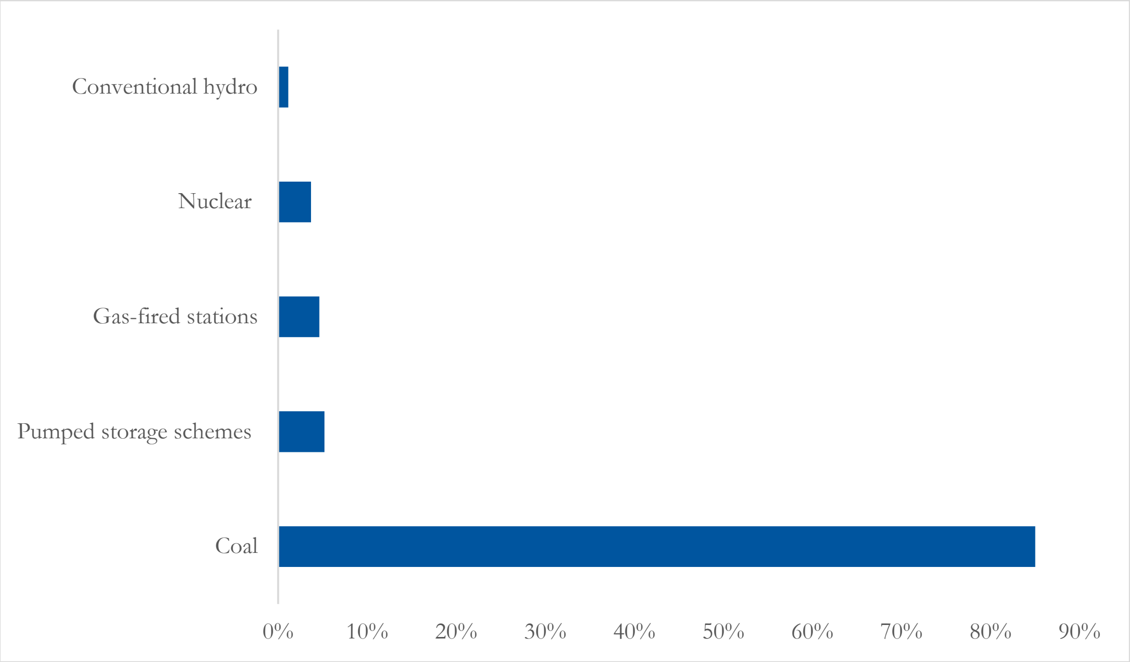
Source: authors based on data from IEA (2023).

The South African electricity sector is dominated by Eskom—a public utility and major electricity provider in the country. Eskom was established in 1923, and its corporatization as Holdings Ltd in 2002 was considered a first step toward liberalizing the country's electricity sector (Baker and Phillips 2019; Bowman 2020). In 2003 the cabinet approved private-sector participation in the electricity sector and decided that future power generation capacity would be divided between Eskom (70 per cent) and independent power producers (IPPs) (30 per cent). This notwithstanding, Eskom has remained a vertical monopoly since its establishment, dominating the country's electricity value chain vis-à-vis electricity generation, transmission, and distribution.

Eskom currently generates about 95 per cent of the electricity used in the country, while the rest is covered by IPPs, municipalities, and electricity imports. Eskom generates its own electricity and purchases electricity from IPPs and electricity-generating facilities beyond the country's borders. In some cases municipalities have electricity generation capacity but mostly on a limited scale. Hence, they mostly purchase electricity in bulk from Eskom at wholesale prices, which they then mark up and sell to the end user. As per transmission and distribution, Eskom is responsible for about 95 per cent of electricity transmission[2] and 60 per cent of the electricity distribution in the country (Baker and Phillips 2019; Ting and Byrne 2020), thus earning it the description of a vertically integrated monopoly. Municipalities alone are responsible for the other 40 per cent and the distribution function is therefore shared between Eskom and municipalities.

Eskom's plant mix includes a variety of technologies employed to generate electricity. Figure 2 shows Eskom's plant mix from which electricity was generated as of 26 June 2022. Coal-fired power stations make up the largest portion of Eskom's plant mix. The coal-fired plants use coal as their energy source and operate 24 hours a day to meet the demand for electricity (Eskom Generation Division 2022). Eskom generally has 15 high-volume coal-fired power plants with a total installed capacity of 44,602 MW, accounting for about 85 per cent of the utility's total installed capacity. The remaining 15 per cent comes from six technologies: one nuclear station with an installed capacity of 1,934 MW; two conventional hydro stations with an installed capacity of 600 MW; three pumped storage schemes with an installed capacity of 2,732 MW; four gas-fired stations with an installed capacity of 2,426 MW; one windfarm with an installed capacity of 100 MW; and four non-dispatchable mini-hydro stations with an installed capacity of 61.4 MW (Eskom Generation Division 2022). Since 2007 Eskom has also been developing two new coal-fired power plants, the Medupi and Kusile power stations, which are expected to supply about 4,800 MW when completed.

Figure 2: Generation plant mix



Note: figure excludes 'windfarm' and 'non-dispatchable mini-hydro', which when combined contribute less than 0.5%.

Source: authors based on data from Eskom Generation Division (2022).

---

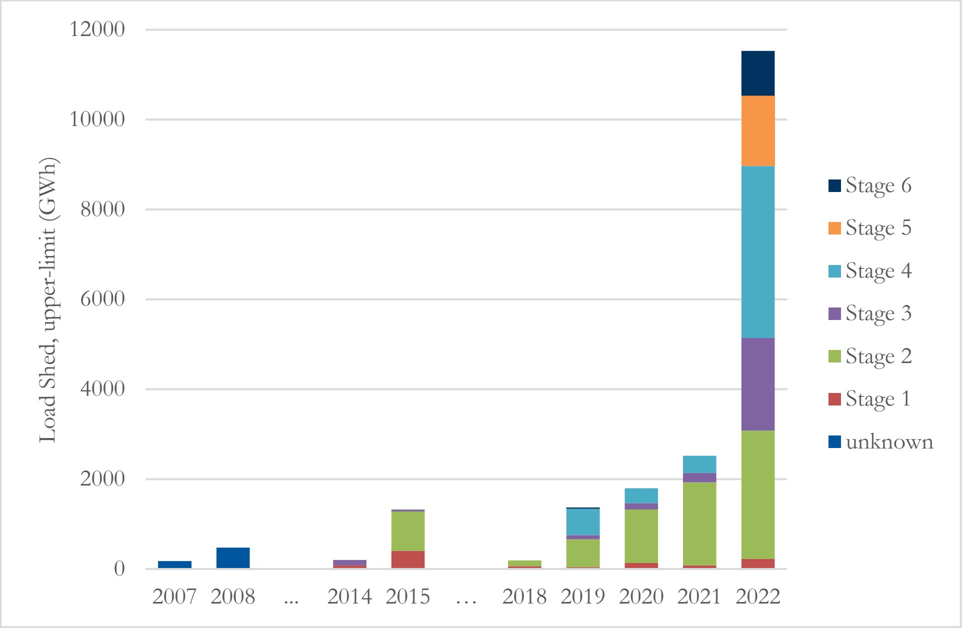
[2] This also means that electricity generated by IPPs and through imports is transmitted and distributed through Eskom. However, electricity generated by municipalities can be directly distributed by them to the end users.

2.2 Synopsis on South Africa's electricity crises

South Africa has experienced pronounced electricity shortages since late 2007, giving birth to the 'South African electricity crises'. The crises are characterized by Eskom's insufficient capacity to generate and reticulate electricity. Hence, one of the hallmarks of these crises is loadshedding—deliberate and planned power cuts intended to limit electricity demand to its constrained supply. Loadshedding is implemented according to a rotational schedule across different areas. Eskom has adopted this approach since late 2007 as a last resort to relieve pressure on the electricity grid and prevent nationwide blackouts. Inglesi-Lotz (2023: 1) argues that loadshedding is implemented any time that generating units are taken offline for maintenance, repairs, or refuelling with a reserve margin of 8 per cent or less.

There are currently eight loadshedding schedules or intensities mapped out by Eskom that allow varying levels of MW of the national load to be shed. These are: 1,000 MW for Stage 1; 2,000 MW for Stage 2; 3,000 MW for Stage 3; 4,000 MW for Stage 4; 5,000 MW for Stage 5; 6,000 MW for Stage 6; 7,000 MW for Stage 7; and 8,000 MW for Stage 8. Each stage of loadshedding entails power outages for hours and the schedules are implemented based on the extent to which electricity demand is exceeded—for example stage 4 can be initiated without stages 2 and 3. Figure 3 shows the upper limit (GWh) of the annual implementation of the different loadshedding schedules across the country. Two patterns emerge from the figure: loadshedding has worsened recently; and there are three distinct periods of loadshedding—2007–08, 2014–15, and the most recent from 2018 onwards.

Figure 3: Loadshedding, upper limit in GWh



Source: authors' elaboration based on data from Pierce and Le Roux (2022).

Inglesi and Pouris (2010) note that the main reason that Eskom gave for the electricity crisis was the imbalance between electricity supply and demand. However, this is more of a proximate than a root cause. There is near consensus in the literature that Eskom is characterized by a long history of state capture and corruption, resulting in decades of financial and investment mismanagement (Baker and Phillips 2019; Bhorat et al. 2017; Bowman 2020). A more notable root cause can be traced to the country's fleet of ageing coal power plants, most of which were constructed under apartheid. As of the early 2000s, therefore, they were already approaching the end of their lifespan, leading to several breakdowns and unplanned maintenance (Doran 2023; Folly 2021; Igamba 2023). More generally, most of the coal power plants in Eskom's fleet operate below capacity, thus highlighting Eskom's legacy of operational challenges. Ting and Byrne (2020) stressed this further using two indicators of plant performance: the energy availability factor (EAF) and unplanned capability loss factor (UCLF). Their study shows that, between 2001 and 2008, the EAF declined from 92 per cent to 85 per cent and further to 70 per cent in 2015. On the other hand energy lost due to unplanned interruptions increased from 2 per cent in 2001 to 5 per cent by 2008, and further to 15 per cent in 2015 (Ting and Byrne 2020).

The country's ageing and underperforming coal power fleets coincided with a dramatic increase in electricity demand between 1994 and 2004. This trend was associated with two structural factors: i) expansion of the economy after the economic sanctions of the apartheid era were lifted, and ii) the free basic energy policy that was implemented in the early 2000s to provide 'electricity to all' through the provision of 50 KWh per month of free electricity to poor households (Baker and Phillips 2019; Pretorius et al. 2015). The exploratory power of these two factors is best understood through the lens of South Africa's structural transformation: under apartheid, few Black townships had access to electricity compared to White households, resulting in the entrenchment of access to affordable electricity as a basic human need and right during the transition to democracy and post-apartheid government's Reconstruction and Development Programme (Baker and Phillips 2019; Bowman 2020; Mayr et al. 2015). This gave impetus to the mass electrification in post-apartheid South Africa that connected many households to the grid. Unfortunately, this expansion was neither matched with commensurate expansion of power plants nor improvement in the electricity-generating capacity of the existing power plants. Hence, the expansion burdened the existing power plant, stretching it to its limit, such that by the early 2000s the capacity was severely constrained.

Despite this the crises could have still been averted. This is because a government energy white paper in 1998 warned about the country's poor energy planning and Eskom's weakened capacity to keep up with the nation's increasing energy demands amid poor infrastructure maintenance. The report recommended building new power plants and unbundling Eskom into separate electricity power generation, transmission, and distribution companies to improve power supply and reliability (DME 1998). While the then Minister of Energy endorsed the report, the national government took no action to implement key aspects of the report, primarily due to its consideration of Eskom's privatization. There was also a cabinet ruling that Eskom should no longer be allowed to build new electricity generation plants and that 30 per cent of electricity generation would come from IPPs (Baker and Phillips 2019; Eberhard 2007). Unfortunately, the lack of market structure and regulatory framework disincentivized IPPs from entering the market, resulting in Eskom remaining the dominant player in the electricity sector. This culminated in no additional generating capacity being built between 1998 and 2003, as the cabinet ruling prevented Eskom from embarking on capacity expansion activities when necessary (Baker and Phillips 2019; Phaahla 2015).

Amid load growth due to the structural factors highlighted earlier, this caused an erosion of the electricity reserve margin. With an imminent electricity crisis in sight, therefore, Eskom was once again granted permission to expand energy production in 2007, and two coal power plants in Medupi and Kusile with a combined capacity of 9.5 GW were commissioned to this effect. These power plants, however, are still to be completed as their construction has encountered challenges including technical problems and cost overruns. Ultimately, loadshedding continues to be the country's strategy for keeping the lights on. Moreover, to finance the new coal plants, the Department of Energy changed Eskom's pricing methodology in 2006 to move it towards cost reflectivity (Ting and Byrne 2020). Before then South Africa was known as the world's cheapest electricity generator. This, however, changed following a change in pricing methodology, with

Baker and Phillips (2019) noting that Eskom's average electricity prices increased by approximately 200 per cent between 2008 and 2016.

The incessant blackouts at a time of high electricity prices have spurred a 'culture of non-payment' and illegal electricity connections in townships and informal settlements (Baker and Phillips 2019). They have also led to the introduction of rooftop and ground-mounted solar photovoltaics (PV) by commercial, industrial, and residential households (Baker and Phillips 2019; Ting and Byrne 2020). Nonetheless, blackouts remain the norm rather than the exception in the country as several economic activities are frequently interrupted due to shortages in coal power energy from Eskom. In a mass effort to stall the incessant blackouts, several protests have also taken place but have met a dead end as the loadshedding has continued, and there is no evidence of any strong commitment that it will end any time soon.

3 From electricity crises to destruction of manufacturing jobs: a framework

The manufacturing sector's performance is a matter of significant concern because a thriving manufacturing sector is one of the hallmarks of any successful economic development. One of the logics behind this relationship is grounded in the external dynamic economies that are accelerated in the manufacturing sector relative to other sectors. In this case the manufacturing sector presents specific opportunities for capital accumulation, technological advancement, and the enhancement of intersectoral linkages and spillovers (Szirmai and Verspagen 2015). The manufacturing sector also exhibits unconditional labour productivity convergence (Rodrik 2013) and produces tradable goods that are subject to economies of scale and scope (Szirmai and Verspagen 2015), which are key to successful economic development. Ultimately, understanding the drivers of the manufacturing sector's performance is of utmost policy importance. This is especially true for developing and emerging economies, particularly in South Africa where there is evidence of de-industrialization (Andreoni and Tregenna 2021).

Although the size and performance of manufacturing can be measured in diverse ways, Kruse et al. (2023) argue in favour of employment-based indicators, noting that the expansion of manufacturing jobs is a strong predictor of higher levels of economic development. The preceding section revealed that one of the hallmarks of South Africa's current electricity crisis is loadshedding. As that section also reveals, however, there are cases of unplanned, infrequent power outages due to the breakdown of power plants. Hence, the country is besieged both by planned and unplanned power outages, although the former tend to be more frequent and the norm. In principle the effects of planned cut-offs may be lower than those of unplanned power outages as, for the former, firms may be better prepared to weather the adverse effects. This notwithstanding, planned power outages in the country have been persistent rather than temporary in the true sense.

Conceptually, persistent power outages can lead to manufacturing job destruction in several ways. Mensah (2024), albeit referring to the issue more broadly, argues that persistent power outages can destroy jobs and lead to aggregate unemployment by increasing the expected cost of doing business (the extensive margin) and lowering the productivity and profitability of incumbent firms (the intensive margin). As for manufacturing, it is well established in the literature that electricity is an important production factor, along with capital and labour (Jorgenson, 1984; Stern and Kander 2012). Hence, negative shocks such as power outages mean that firms cannot receive the necessary inputs, resulting in production disruption and employee lay-offs. Production disruption can also affect manufacturing jobs through the productivity channel.[3] Manufacturing equipment often relies on a continuous power supply. The most immediate impact of persistent power outages is idle capital and downtime, which drag labour and fixed capital productivity. This can indirectly cause production losses and, in some cases, damage manufacturing equipment and machinery. The culmination of these affects output and sales and, in turn, impacts the ability to maintain or expand the workforce.

Further, the quintessential role of electricity in production means that its cost constitutes a significant portion of manufacturing production costs. Thus, reliable, cost-efficient energy is intrinsic to production and profitability. Persistent power outages cause a deviation from this path because they prompt the use of back-up power sources such as generators, which imposes additional production and operational costs. Firms may also incur additional costs due to the need to reschedule production, expedite shipping to meet deadlines, or repair any damage caused by power outages. The culmination of these increases the cost of doing business and creates uncertainty about business operations.

Incumbent manufacturing firms can respond to this business environment by cost-cutting decisions, including lay-offs and hiring freezes. At the same time this environment can discourage new firms from entering the market and can encourage existing firms to exit the market (Fried and Lagakos 2023; Mensah 2024). Such firm dynamics are associated with an increase in job destruction and a reduction in job creation. The persistent power outages and the associated costly business environment they create can discourage manufacturers from producing or can encourage them to reconsider long-term investments (Abeberese 2020). Other things equal this also increases job destruction and reduces job creation.

Although the preceding highlights several ways in which power outages affect manufacturing jobs, the specific effects of power outages will depend, among other factors, on the specificity of affected industries. For instance, in a study focused on Ghanaian manufacturing firms, Abeberese (2020) found a decline in plant and machinery investment during the electricity rationing period, with a more pronounced decline for firms in electricity-intensive sectors. As noted in the introduction, the sector-specific attribute that our study explores is the energy vulnerability of manufacturing sub-sectors based on their respective backward and forward linkages to the electricity sector. Backward linkages here capture the interconnection of a manufacturing sector to the electricity sector based on the manufacturing sector's intermediate input (percentage of total intermediates) purchased from the electricity sector. Forward linkages, on the other hand, capture the interconnection of manufacturing to the energy sectors based on manufacturing sector output (percentage of total outputs) sold to the electricity sector.

Cross-sector variation in the levels of backward and forward linkages to the electricity sector signal differences in the extent to which each sector is vulnerable to potential electricity supply shocks. By extension it underpins potential sources of heterogeneous reactions to demand or supply shocks, such as those pertaining to the electricity crisis. For instance, a sector with a strong backward linkage to the electricity sector indicates that electricity is a strong input to that sector's output. In this case, whereas power outages are expected to destroy manufacturing jobs through the diverse pathways highlighted earlier, this effect will be worse for those sectors with stronger backward linkages to the electricity sector. In a similar fashion sectors with stronger forward linkages to the electricity sector will also experience the worst drop in final demand in the event of negative electric supply shocks, resulting in worse manufacturing job outcomes for those

---

[3] Several studies show that power outages are associated with decreased productivity and profitability (Cole et al. 2018; Elliott et al. 2021; Fried and Lagakos 2023).

sectors. In general, depending on the duration of this shock, this can cause firms to downsize or lead to intersectoral reallocation as they try to adjust to the shock. This conclusion is consistent with Alby et al. (2013), who found that electricity-intensive sectors in countries with a high frequency of power outages are characterized by a significantly lower share of small firms.[4] We examine these relationships in our empirical analysis.

4 Research design

4.1 Variables and data computation

4.1.1 Measuring manufacturing jobs

The major focus of our study is to assess the effect of electricity crises on manufacturing sector jobs. To this end we directly source data on manufacturing sector jobs from the Quantec statistical database. Descriptively, the manufacturing sector job variable used in our analysis is the sum of formal and informal manufacturing sector jobs. Quantec derives the data from two official sources of labour data in South Africa: the Quarterly Labor Force Survey (QLFS) and Quarterly Employment Statistics (QES). The former is a household-based survey and provides information on the number of formal and informal jobs. The QES data, on the other hand, provides information on non-agricultural enterprises and the number of formal jobs but excludes domestic workers. Quantec uses the QES formal figure, to which it adds formal agricultural and domestic workers from the QLFS. Using the total employment from the QLFS, informal employment is calculated as a residual. In general the sector dimension of our data covers 42 manufacturing sectors at the 3-digit Standard Industrial Classification (SIC) code, spanning the 1993–2021 period.

4.1.2 Constructing the energy vulnerability index

Disruptions in the electricity sector can have an effect on the sector's output (X_i) because of the dependency on its own intermediate input (X_{ii}) to produce its own output (X_i) (see Table 1). However, the interdependency of economic sub-sectors and the importance of electricity to the production of outputs in other sub-sectors imply that electricity crises may cause significant ripple effects on the economy—both on production across related sectors and on the demand for outputs from these sectors by the electricity sub-sector itself.

---

[4] More generally, Allcott et al. (2016) show that power shortages distort plant size distribution, as there are significant economies of scale in generator costs, and that shortages more severely affect plants without generators.

Table 1: Structure of our input–output table at 91 industry aggregation

		Output sector (j)					Total output or sales (intermediate output + final output) at basic prices
		1	…	$\text{Electricity and gas}_{\text{j}}$	…	n	
Input sub-sector (i)	1						
	….						
	$\text{Electricity and gas}_{\text{i}}$			$\text{X}_{\text{Electricity and gas\_ij}}$			$\text{X}_{\text{Electricity and gas-i}}$
	…						
	n						
Total input or use (intermediate input + GDP at market prices) at basic prices				$\text{X}_{\text{Electricity and gas-j}}$			

Source: authors' elaboration based on Liu and He (2016: 58).

Following Dietzenbacher et al. (2005) and Go et al. (2019), we model sub-sector interdependencies on the electricity sub-sector in South Africa based on the input-output model (Leontief 1936) as:

$$x = \mathrm{A}x + \mathrm{f} = (\mathrm{I} - \mathrm{A})^{-1}\mathrm{f} \tag{1}$$

where $\boldsymbol{x}$ denotes a vector of total output produced by each sub-sector and A is the standard technical coefficients matrix, with a_{ij} as the number of inputs that sub-sector i contributes to sector j. f refers to the vector of final demand corresponding to each sub-sector's output. Finally, $(I - A)^{-1}$ measures the increase in the total output of sub-sector i that results directly and indirectly from an increase in the final demand of sector j—the so-called Leontief inverse matrix.

As noted in Sections 1 and 2, our paper explores each sector's energy vulnerability based on its backward and forward linkages with the energy sector. Due to lack of disaggregation we define this industry-specific attribute using the 'electricity and gas (SIC: 41)' sector classification in our dataset. To construct our energy vulnerability index, we proceed in two steps. First, we construct indicators of each sector's forward and backward linkages to the energy sector. We compute forward linkage as the relative share of the energy sub-sector in the total inputs used in other sub-sectors. This computation is guided by equation (2):

$$\ddot{F}_i = \frac{\text{Electricity and gas}_i}{\text{Total input or use}_i} \tag{2}$$

where $\ddot{F}_i$ is the share of the electricity and gas input in the total intermediate input demand of sub-sector i. $Electricity\ and\ gas_i$ is the intermediate input use of electricity and gas across sub-sector *i* while $Total\ input\ or\ use_i$ is the total intermediate input used across sub-sector i.

We compute backward linkage as the relative dependence of the electricity and gas sub-sector on the domestic output of other sub-sectors for its production. This computation is guided by equation (3):

$$\ddot{B}_j = \frac{\text{Electricity and gas}_j}{\text{Total output or sales}_j} \tag{3}$$

where $\ddot{B}_j$ is the share of total outputs that sub-sector j use as inputs in the electricity and gas sub-sector. $Electricity\ and\ gas_j$ is the intermediate input use of other sub-sector outputs j in the electricity and gas sub-sector, while $Total\ output\ or\ sales_j$ is the total output across each sub-sector j. In the second step we sum $\ddot{F}_i$ and $\ddot{B}_i$ to generate a composite energy vulnerability index

(V_i). Finally, we normalize the resulting index from the second step for easier interpretation and to reduce skewness in the data. To do this we follow the min–max approach as shown in equation (4):

$$V_i^* = \frac{V_i - \min(V_i)}{max(V_i) - min(V_i)} \tag{4}$$

where V_i^* is a normalized energy vulnerability index of sector i, $V_i = \ddot{F}_i + \ddot{B}_j$ and $0 \leq V_i^* \leq 1$. In line with the discussion in Section 3, V_i^* captures the strength of the sub-sectors' backward and/or forward linkages to the energy sector, with higher values indicating a stronger linkage and, by extension, a stronger susceptibility to shocks in the energy sector. Ultimately, higher values of V_i^* mean higher energy vulnerability intensity—i.e. the higher the V_i^*, the more vulnerable the sector is to shocks in the energy sector. Our analysis relies on the resulting index from equation (4). Further, we construct the vulnerability index using 91 sectors that comprise all the economy's sectors at the 3-digit SIC code. For our analysis, however, we extract and focus on 42 manufacturing sectors at the 3-digit SIC code. The input–output data used to construct the vulnerability index also comes from the Quantec statistical database.

4.1.3 Measuring electricity crises

Our analysis leverages Eskom's introduction of loadshedding in 2007 as an exogenous negative electricity supply shock to the country and examines how it has impacted manufacturing jobs. Accordingly, we construct an indicator variable that takes the value of zero before 2007 and one from 2007 onwards. We call this 'electricity crisis 1'. While we rely on this variable as the main indicator of electricity supply disruption, we construct three alternative indicators to account for the staggered nature of loadshedding in the country. As noted in Section 2.2, there are three distinct periods of loadshedding: 2007–08, 2014–15, and the most recent from 2018 onwards. To account for this staggered nature of loadshedding activation, including the uncertainty or expectation of firms, we create an indicator variable that only takes the value of one during those periods of major loadshedding change. We call this 'electricity crisis 2'. We also create a third variable to capture the intensity dimension of the electricity supply shock. This variable takes the following values: zero for the 1993–2006 period; one for the 2007–12 period; two for the 2013–18 period; and three for the 2018–21 period. We call this 'electricity crisis intensity 1'. Consistent with the first indicator variable, we also allow the intensity variable to only vary during those periods of major loadshedding change. Accordingly, the fourth indicator variable assumes the following values: one for the 2007–08 period, two for the 2014–15 period, and three for the 2018–21 period. For the other periods it takes the value of zero. We call the variable resulting from the construction 'electricity crisis intensity 2'.

Finally, we complement the intensity analysis with actual measures of manual load reduction, computed as the sum of loading and curtailment. Data for this variable is from Eskom and is available at the daily frequency. We sum this across years to get annual series. The data is also available only from 2007. Hence, we replace missing datapoints before this period with zero and log transform the variable using the inverse hyperbolic function to preserve the zeroes in the series. We call the variable resulting from the construction 'electricity crisis intensity 3'.

4.1.4 Other control variables

Due to the disaggregated nature of our data, we are constrained on the sector controls to be included in our analysis. Nevertheless, to minimize potential bias that may occur due to time-varying sector confounding factors, we include output price, import domestic demand ratio, and trade variables. Trade openness is computed as the ratio of the sum of exports and imports to real output. Data on sector-level controls employed in the regression analysis is also sourced from the Quantec database. In a robustness check we also control for possible confounding factors at the country level. We employ the following three variables for this purpose: share of private credit as a measure of financial development, rule of law as a measure of institutional quality, and tax revenue as a share of gross domestic product (GDP) and GDP per capita. We take these country-level variables from World Bank's World Development Indicators (WDI).

4.2 Model specification and estimation

As noted previously, rather than simply examining the average effect of electricity crises on manufacturing sector jobs, which in the absence of a good external instrument(s) suffers from severe identification problems, our empirical analysis examines the effect of the electricity crisis by comparing employment changes across sectors that are expected to be affected differently by electricity. Our identification assumption is therefore that, if electricity matters for jobs, this should apply more forcefully to sectors that are innately more dependent on electricity. In this case we expect the impact of the electricity crisis to be increasing in those sectors that depend more on electricity, i.e. energy-vulnerable sectors. Our empirical framework and identification strategy builds on the generalized difference-in-difference method developed by Rajan and Zingales (1998) and which has been extensively explored elsewhere in the literature (see Berkowitz et al. 2006; Manova 2013; Ndubuisi 2020; Nunn 2007). To this end, the empirical model that guides our analysis is formulated as:

$$y_{it} = \alpha V_{it}^{*} + \beta E_t + \gamma(E_t * V_{it}^{*}) + Z'_{it} + \delta_i + \delta_t + e_{it} \tag{5}$$

In equation (5) the subscripts i and t denote sectors and time, respectively. y_{it} is the outcome variable. Our main outcome variable is manufacturing total employment. However, in the extended analysis we also separately consider formal and informal employment as well as other sector performance variables vis-à-vis productivity, investment, export, and output. V_{it}^{*} is a measure of the sector-specific time-varying energy vulnerability index, while α is the associated coefficient that is to be estimated. As noted earlier, energy vulnerability is a sector's innate technological component that captures its dependence on electricity. E_t is a measure of country energy crises—a dummy variable that takes the value zero in a pre-crisis period and a value of one in a crisis period. $E_t * V_{it}^{*}$ is an interaction term that comprises the electricity crises dummy and sector energy vulnerability, while γ is the corresponding coefficient that is to be estimated. Z'_{it} is a vector of time-varying sector characteristics, which we include to reduce any bias that may arise from confounding factors at the sector level. Descriptions of these variables are provided in Section 4.1.4. δ_i are sector dummies, while δ_t are time dummies. The former absorb any permanent sector-level characteristics that might be correlated with y_{it} and thus ensure that estimates for the effect of $E_t * V_{it}^{*}$ on y_{it} are identified from within-sector variation in susceptibility electricity crises over time, and not from simple cross-sector correlations. The year dummies account for transitory global economy-wide factors, such as financial crises or technological improvements that are common across the sectors. Finally, e_{it} is the error terms.

In equation (5) the total effect of electricity crises on manufacturing employment is captured by $\Delta y_{it}/\Delta E_t = \beta + \gamma V_{it}^{*}$. However, we are more interested in the differential response of employment to electricity crises, which is given by the parameter γ. Hence, our key explanatory variable is the interaction term $E_t * V_{it}^{*}$, while γ is the coefficient of interest. The latter measures how changes in the outcome variable vary by jointly exploiting time variation in electricity crises and cross-sector variation in energy vulnerability. If an energy crisis makes manufacturing employment worse off, then we expect the coefficient gamma of $E_t * V_{it}^{*}$ to be negative. Under the identifying assumption that other factors affecting y_{it} were uncorrelated with $E_t * V_{it}^*$, this would indicate a causal influence of energy crisis on manufacturing employment.

5 Results and discussion

This section proceeds in two steps. First, we present results from the self-constructed energy vulnerability index. The second section presents the econometrics results based on the generalized difference-in-difference model in the spirit of Rajan and Zingales (1998) as discussed in the previous section.

5.1 Energy vulnerability of the South African manufacturing sub-sector

As noted in Section 4.1.2, our analysis relies on our normalized energy vulnerability index, which ranges from 0 to 1. Higher values indicate higher levels of energy vulnerability, while lower values indicate lower levels of energy vulnerability. Table 2 presents the summary statistics of the index.

Panel A shows the summary statistics of the index across sectors and time. The panel shows that the index is within the expected bound, ranging from 0 to 1. The lowest value of the index in the sample is 0, corresponding to the vulnerability score of 'household appliances [QSIC 358]' in 1993. On the other hand the highest value of the index in the sample is 1 and corresponds to the vulnerability score for 'leather and leather and fur products [QSIC 315-316]' in 1997. The mean score of the index across our sample period is 0.20 with a standard deviation of 0.17. Moving on to Panel B, it shows the sector median value of the normalized index. Again, 'household appliances [QSIC 358]' remains the least energy-vulnerable sector with an energy vulnerability median score of 0.01. This is followed by 'other electrical equipment [QSIC 364-366]' with an energy vulnerability median score of 0.03. On the other hand the sector with the highest energy vulnerability median score is 'coke, petroleum products and nuclear fuel [QSIC 331-333]' with a score of 0.59. This is followed by 'knitted, crocheted articles [QSIC 313]' with an energy vulnerability median score of 0.54. Hence, the panel suggests that there is a great deal of heterogeneity across the sectors in terms of energy vulnerability. Our analysis aims to explore this time and sector heterogeneity to identify how the electricity crisis is affecting manufacturing jobs in the country.

Next, we sort the sectors into intensive and less-intensive energy-vulnerable sectors by comparing each sector median to the sample average (0.20). Sectors whose median energy vulnerability is higher than that of the sample average are grouped as intensive energy-vulnerable sectors, while the reverse is the case for sectors whose median energy vulnerability is lower than that of the sample average. The result of this exercise is reported in the last column of Panel B. The classification identifies 16 sectors (out of the 42 sectors in our sample) as being intensive energy vulnerable sectors. Ultimately, given their high vulnerability, these sectors should be prioritized since some of these sectors in this category are in the downstream segment of mining, a sector for which South Africa is a global player. As beneficiation of natural resources is high on the country's political agenda, the need to prioritize these sectors cannot be overemphasized.

Table 2: Summary statistics of energy vulnerability

Panel A

No. observations	**Mean vulnerability**	**Standard deviation**	**Min**	**Max**
1,218	0.20	0.17	0	1

Panel B

SIC code	**Sector description**	**Median vulnerability**	Class
358	Household appliances	0.01	Non-intensive
364_366	Other electrical equipment	0.03	Non-intensive
381_382	Motor vehicles	0.03	Non-intensive
305	Beverages	0.04	Non-intensive
383	Parts and accessories	0.04	Non-intensive
371_373	Radio, television, and communication apparatus	0.05	Non-intensive
374_376	Professional equipment	0.07	Non-intensive
314	Wearing apparel	0.07	Non-intensive
361	Electric motors, generators, transformers	0.07	Non-intensive
317	Footwear	0.09	Non-intensive
311	Textiles	0.09	Non-intensive
323	Paper and paper products	0.09	Non-intensive
342	Non-metallic mineral products	0.10	Non-intensive
335_336	Other chemical products	0.11	Non-intensive
321	Sawmilling and planing of wood	0.11	Non-intensive
363	Insulated wire and cables	0.11	Non-intensive
306	Tobacco	0.11	Non-intensive
362	Electricity distribution and control apparatus	0.11	Non-intensive
359	Office, accounting, computing machinery	0.12	Non-intensive
303	Grain mill products	0.14	Non-intensive
356	General purpose machinery	0.14	Non-intensive
301	Meat, fish, fruit etc.	0.16	Non-intensive
391	Furniture	0.16	Non-intensive
357	Special purpose machinery	0.17	Non-intensive
302	Dairy products	0.17	Non-intensive
304	Other food products	0.17	Non-intensive
312	Other textile products	0.22	Intensive
337	Rubber products	0.22	Intensive
392_395	Other manufacturing groups	0.24	Intensive
315_316	Leather and leather and fur products	0.27	Intensive
338	Plastic products	0.28	Intensive
322	Products of wood	0.29	Intensive
334	Basic chemicals	0.30	Intensive
354	Structural metal products	0.31	Intensive
384_387	Other transport equipment	0.31	Intensive
351	Basic iron and steel products	0.36	Intensive
341	Glass and glass products	0.41	Intensive
324_326	Printing, recorded media	0.42	Intensive
355	Other fabricated metal products	0.44	Intensive
352	Non-ferrous metal products	0.48	Intensive
313	Knitted, crocheted articles	0.54	Intensive
331_333	Coke, petroleum products and nuclear fuel	0.60	Intensive

Source: authors’ calculations using Quantec statistical database (2023).

5.2 Econometric results

This section presents and discusses the econometric results. We first present the baseline results on the manufacturing job implications of the electricity crisis and how this depends on sector energy vulnerability. We then proceed to examine the relationship across formal and informal jobs as well as other economic outcomes including productivity, export competitiveness, investment, and output level.

5.2.1 Baseline results

Table 3 displays the baseline results analysing the effect of electricity crises in South Africa on manufacturing jobs. The dependent variable for each reported regression in the table is sector employment level in logs. The analysis relies on the respective first measures of electricity crises and energy vulnerability: electricity crises defined as a dummy variable that takes the value of zero before 2007 (pre-crisis period), and a value of one from 2007 onwards (crisis period); and energy vulnerability defined as a time-varying sector-specific index consisting of the sum of each sector's backward and forward linkages to the energy sector defined herewith as SIC 41, i.e. 'electricity and gas' sector.

Before exploring the differential effect of the electricity crises on manufacturing jobs, we conduct a preliminary analysis by estimating the average effect of the electricity crises across manufacturing sector employment. Specifically, we regress manufacturing employment levels on the electricity crisis dummy, excluding the interaction term, i.e. 'electricity crisis*energy vulnerability'. The results are presented in columns 1–4 of Table 3. Column 1 shows the result without sector dummies. In this case we assume that manufacturing sectors are homogenous. Column 2, on the other hand, shows the results with sector dummies. The results are negative albeit statistically insignificant in column 1, while those in column 2 are negative and statistically significant at the 1 per cent significance level. Column 3 shows the results when we further control for year dummies, while column 4 shows the results when we control for time-varying sector characteristics. The estimated coefficient of the electricity crisis remains negative and statistically significant at all conventional significance levels in columns 3 and 4. This, therefore, confirms that our results are robust and rules out the possibility that the findings across the columns are driven by confounding factors at the sector level.

Put together, the results presented in columns 1–4 show that the electricity crisis has been associated with negative within-industry manufacturing employment. This finding is consistent with extant studies which show that electricity shortages significantly reduce employment (see Mensah 2024). The results also corroborate recent concerns expressed in online media outlets regarding the negative effect of the electricity crisis on manufacturing productivity and unemployment in South Africa (Gumbi 2023; Phillips 2023) and the implications of the electricity crisis for alternative energy sources (renewables) (Jain and Jain 2017; Ting and Byrne 2020).

Next, we turn to our primary empirical investigation by focusing on the interaction term: 'electricity crisis*energy vulnerability'. Column 5 shows the baseline result for this analysis, excluding time-varying sector controls. In column 6, on the other hand, we include time-varying sector controls. In both cases the estimated coefficient of 'electricity crisis*energy vulnerability' turns out to be negative and statistically significant at all conventional significance levels. Importantly, the size of the estimated coefficient of the interaction term increases from 0.20 in column 5 to 0.23 in column 6, suggesting that previous estimates were picking up the effect of other sector characteristics, which resulted in an underestimation of the size of the coefficient. As per the economic significance, the estimated coefficient of the interaction term in column 6 implies that the average reduction in annual sector employment levels following the crisis in 2007 was roughly

3.9 percentage points higher in a sector with a one standard deviation higher energy vulnerability intensity.

Column 7 shows the result when we further control for time-varying country characteristics, with the results remaining largely similar both in quantitative and qualitative terms. In particular, the sign and size of the estimated coefficient of 'electricity crisis*energy vulnerability' is the same in both columns, further confirming that our results are not driven by confounding factors at the country level. To test the robustness of results to the COVID-19 effect, Columns 8–10 present our estimation results when we re-estimate equations (5)–(7) without the COVID-19 period, i.e. 2020–21. The results show that electricity crises destroy jobs, further corroborating our earlier findings. Overall, the results presented in Table 3 support our conjecture that electricity crises adversely affect manufacturing jobs and that this adverse effect tends to be more severe for energy-vulnerable sectors. This means that there is a strong sectoral heterogeneous effect of electricity crises on manufacturing jobs, driven by sectors' relative dependence on energy. To clearly show this heterogeneity, we compute the marginal response of each sub-sector based on its median energy vulnerability to a standard deviation expansion in energy crises. Figure 4 shows the results for this exercise with the blue shaded bars denoting non-intensive energy-vulnerable sectors, while the yellow shaded bars are intensive energy-vulnerable sectors, as described in Table 2. The figure shows that a one standard deviation expansion in the electricity crisis will reduce jobs by 0.11 percentage points in the least energy-vulnerable manufacturing sub-sector (i.e. household appliances sector) compared to a 6.8 percentage point job reduction in the highest energy-vulnerable manufacturing sub-sector (i.e. the coke, petroleum products, and nuclear fuel sector).

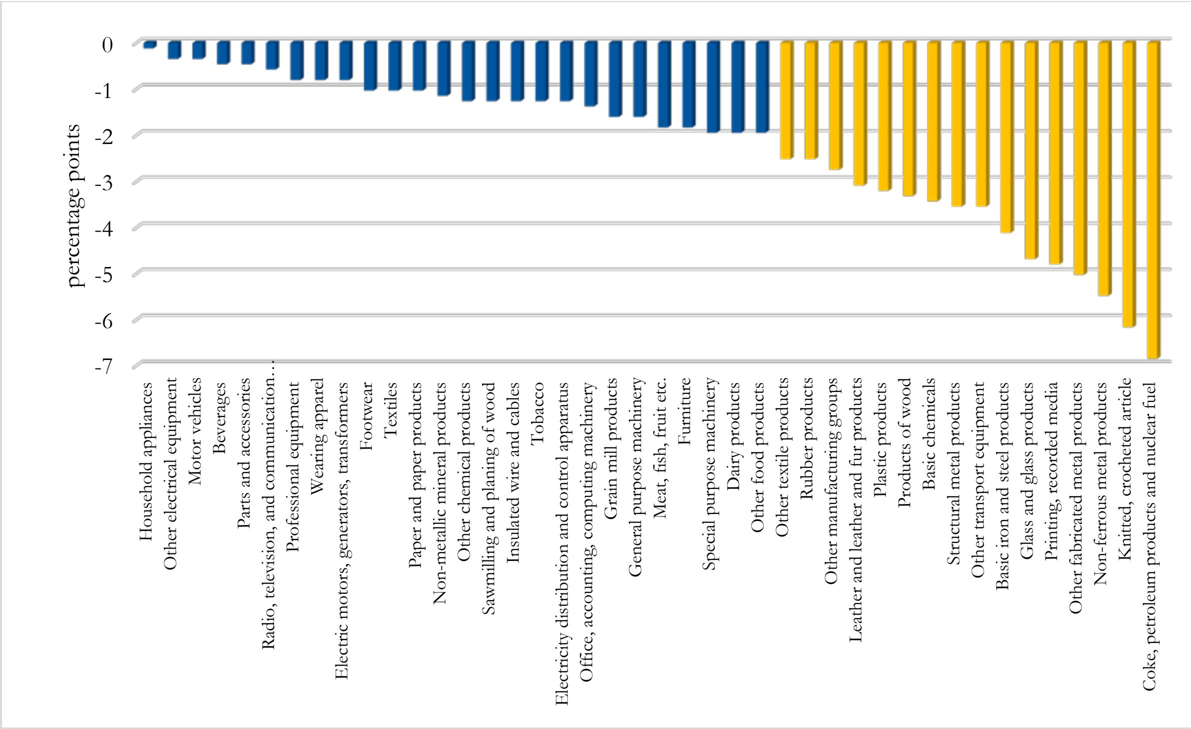
Table 3: Electricity crisis, energy vulnerability, and manufacturing jobs

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Electricity crisis	-0.0712	-0.0712***	-0.2722***	-0.8300***	-0.2443***	-0.7812***	-1.8108**	-0.1302*	-0.7100***	-0.7649
	(0.051)	(0.014)	(0.075)	(0.130)	(0.077)	(0.128)	(0.750)	(0.070)	(0.095)	(6.375)
Energy vulnerability				-0.3101***	-0.1080	-0.2134**	-0.2134**	-0.1062	-0.2395***	-0.2395***
				(0.099)	(0.100)	(0.092)	(0.092)	(0.099)	(0.089)	(0.089)
Electricity crisis*Energy vulnerability					-0.1966**	-0.2281***	-0.2281***	-0.1576*	-0.1934**	-0.1934**
					(0.095)	(0.087)	(0.087)	(0.096)	(0.085)	(0.085)
Sector control	NO	NO	NO	YES	NO	YES	YES	NO	YES	YES
Country controls	NO	NO	NO	NO	NO	NO	YES	NO	NO	YES
Sector dummy	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year dummy	NO	NO	YES	YES	YES	YES	YES	YES	YES	YES
Observations	1,218	1,218	1,218	1,218	1,218	1,218	1,218	1,134	1,134	1,134
R-squared	0.002	0.924	0.929	0.935	0.930	0.935	0.935	0.934	0.940	0.940

Note: robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Outcome variable across the columns is manufacturing jobs (log). In addition to energy vulnerability, time-varying sector controls include trade openness, import– domestic demand ratio and output price. Country controls include rule of law, tax revenues as share of GDP, domestic credit to private sector, and GDP per capita. Except for electricity crisis, energy vulnerability, trade openness, and rule of law, all other variables are logged.

Source: authors’ calculations using Quantec statistical database (2023) and World Development Indicators (2023)

Figure 4: The effect of electricity crises on manufacturing jobs by sector energy vulnerability



Note: the marginal effects are computed based on a standard deviation expansion in energy crises. The blue shaded bars denote non-intensive energy-vulnerable sectors, while the yellow shaded bars are intensive energy-vulnerable sectors as described in Table 2.

Source: authors' calculations using Quantec statistical database (2023).

5.3 Further robustness checks

In this section we further subject our baseline results to a battery of robustness checks. We begin by defining the outcome variable differently. First, rather than using employment levels, we use employment growth, defined as the log difference of employment level. Columns 1–3 of Table 4 show the results of this exercise. Column 1 shows the regression result when we exclude time-varying sector and country controls, except for sector energy vulnerability and its interaction with electricity crisis. Column 2, on the other hand, shows the result when we include time-varying sector controls, while column 3 shows the result when we further include time-varying country controls. Across the three columns, the interaction variable, i.e. 'electricity crisis*energy vulnerability', remains negative and statistically significant at conventional significance levels. Ultimately, the electricity crises have not only destroyed manufacturing jobs but have also significantly reduced manufacturing job growth, with the effect been disproportionately higher for those sectors that depend more on energy.

Furthermore, we compute sector employment shares and employ them as alternative outcomes variables. Columns 4–6 of Table 4 show the results when we use manufacturing employment share as the outcome variable in a regression. The structure of the columns is like those of columns 1–3. Across these columns, the estimated coefficient of the variable of interest, i.e. 'electricity crisis*energy vulnerability', turns out to be similar and is consistent with the baseline results. Hence, the additional results presented in Table 4 show that the baseline results are not driven by how we define the outcome variable.

Table 4: Baseline robustness checks—alternative outcome measures

	Job growth			Job shares (log)		
	(1)	(2)	(3)	(4)	(5)	(6)
Electricity crisis	0.0039	-0.1298	-0.2444	0.0169	-0.5200***	-0.8162
	(0.098)	(0.168)	(0.991)	(0.077)	(0.128)	(0.750)
Energy vulnerability	-0.2228**	-0.2549**	-0.2549**	-0.1080	-0.2134**	-0.2134**
	(0.106)	(0.111)	(0.111)	(0.100)	(0.092)	(0.092)
Consider energy vulnerability	-0.2024*	-0.2416**	-0.2416**	-0.1966**	-0.2281***	-0.2281***
	(0.106)	(0.102)	(0.102)	(0.095)	(0.087)	(0.087)
Sector control	NO	YES	YES	NO	YES	YES
Country controls	NO	NO	YES	NO	NO	YES
SectordDummy	YES	YES	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES	YES	YES
Observations	1,189	1,189	1,189	1,218	1,218	1,218
R-squared	0.925	0.926	0.926	0.929	0.935	0.935

Note: robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In addition to energy vulnerability, time-varying sector controls include trade openness, import–domestic demand ratio and output price. Except for electricity crisis, energy vulnerability, rule of law and trade openness, all other variables are in log.

Source: authors' calculations using Quantec statistical database (2023) and World Development Indicators (2023).

Our main analysis focused on how electricity supply shocks interact with sector energy vulnerability to determine employment level. The baseline results may be biased if the electricity crisis (energy vulnerability) variable is correlated with other sector (country) characteristics. To isolate the effect of the interaction variable 'electricity crisis*energy vulnerability', we introduced different interaction variables. We begin with the sector characteristics.

To ensure our result are not driven by sector employment-specific characteristics, we compute an index of average sector employment growth and interact it with the electricity crisis dummy. Column 1 of Table 5 shows the results of this exercise. The estimated coefficient of 'electricity crisis*energy vulnerability' remains negative and statistically significant at all conventional significant levels. Columns 2–4 of Table 5 show the results when we interact the electricity crisis dummy with other sector characteristics to ensure that the estimated coefficient of 'electricity crisis*energy vulnerability' is not picking the effect of any other variable. Again, the results remain qualitatively unchanged. In column 5 we further interact the electricity crisis dummy with sector dummies and the main results remain unchanged in qualitative terms. To further isolate the effect of 'electricity crisis*energy vulnerability' from the influence of any other country characteristics, we introduce an interaction between the energy vulnerability and country characteristics. This includes a measure of institutional quality in column 6 and financial development in column 7. In both cases our main results indicating the destruction of manufacturing jobs due to the electricity crisis remain unchanged. Put together, the results presented in Table 5 indicate that the observed negative effect of electricity crises on manufacturing jobs is robust across different specifications and independent of other sector characteristics.

Table 5: Baseline robustness checks—addressing potential sector and country characteristics

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Electricity crisis	-0.7629***	-0.7440***	-0.4976***	0.0924	-0.0736	-0.0615	-1.8116**
	(0.134)	(0.131)	(0.156)	(0.926)	(0.145)	(10.085)	(0.751)
Energy vulnerability	-0.1477	-0.2083**	-0.1706*	-0.2141**	0.0812	-0.2468**	-2.0707
	(0.104)	(0.093)	(0.092)	(0.092)	(0.128)	(0.112)	(2.133)
Electricity crisis*energy vulnerability	-0.2932***	-0.2392***	-0.2629***	-0.2226**	-0.5238**	-0.2023**	-0.2778***
	(0.085)	(0.089)	(0.085)	(0.087)	(0.211)	(0.092)	(0.107)
Electricity crisis*average employment growth	YES	NO	NO	NO	NO	NO	NO
Electricity crisis*trade	NO	YES	NO	NO	NO	NO	NO
Electricity crisis*import–DD ratio	NO	NO	YES	NO	NO	NO	NO
Electricity crisis*output price	NO	NO	NO	YES	NO	NO	NO
Electricity crisis*sector dummy	NO	NO	NO	NO	YES	NO	NO
Rule of law*energy vulnerability	NO	NO	NO	NO	NO	YES	NO
Private credit*energy vulnerability	NO	NO	NO	NO	NO	NO	YES
Country controls	NO	NO	NO	NO	NO	YES	YES
Sector controls	YES	YES	YES	YES	YES	YES	YES
Sector dummy	YES	YES	YES	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES	YES	YES	YES
Observations	1,189	1,218	1,218	1,218	1,218	1,218	1,218
R-squared	0.934	0.935	0.936	0.935	0.975	0.935	0.935

Note: robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In addition to energy vulnerability, time-varying sector controls include trade openness, import–domestic demand ratio and output price. Except for electricity crisis, energy vulnerability, rule of law, and trade openness, all other variables are in log.

Source: authors' calculations using Quantec statistical database (2023) and World Development Indicators (2023).

Moving on, the baseline results rely on the electricity crisis index which uses 2007 as the cut-off, wherein the pre-crisis period takes the value of zero and the crisis period, i.e. 2007 onwards, takes the value of one. To ensure that our results are not driven by how we constructed the index, we test the robustness of the baseline result to four alternative electricity crisis variables.

First, we use a crisis variable that only takes the value of one in those periods for which we know there was loadshedding. As discussed in Section 4.1.3, the index takes the value of one for the following periods: 2007–08, 2014–15, and 2018–21. The results using this index as an empirical measure of electricity crisis are reported in column 1 of Table 6. Second, we employ two alternative indicators aimed at capturing the intensity dimension of the electricity supply shock. Descriptions of both variables are provided in Section 4.1.3, while columns 2–3 of Table 6 show the results when we employ these respective intensity variables as a measure of the electricity crisis. Across these columns the results turn out to be similar and are consistent with the baseline results. Estimation results when we employ actual data of manual load reduction as an intensity measure are further provided in column 4. Again, the results on the interaction variable remain the same in suggesting that the electricity crisis has destroyed manufacturing jobs in the country, with the effect being disproportionately higher for energy-vulnerable sectors. Hence, the conclusion of our analysis is not vulnerable to how we define the crisis.

Finally, column 5 shows the results when we interact energy vulnerability with three electricity crisis dummies representing the subsequent loadshedding changes, Yr 2007–08, Yr 2014–15, and Yr 2018–21, as shown in Figure 3. In this specification each successive period dummy picks up a cumulative effect over the previous one. While the coefficient on the interaction of energy vulnerability with Yr 2007–08 or Yr 2018–21 is not statistically significant, the one on Yr 2014–15*energy vulnerability is negative and statistically significant at conventional significance levels. This implies that the cross-industry divergence in employment level which began around 2007 widened further after 2014, the year in which additional loadshedding was introduced.

Table 6: Baseline robustness checks—alternative electricity crisis measure

	electricity crisis 2	*electricity crisis intensity 1*	*electricity crisis intensity 2*	*electricity crisis intensity 3*	*Electricity crisis (Cumulative)*
	(1)	(2)	(3)	(4)	(5)
Electricity crisis	-0.7875***	-0.2452***	-0.2541***	-0.0541***	
	(0.129)	(0.043)	(0.043)	(0.009)	
Energy vulnerability	-0.2713***	-0.2164**	-0.2707***	-0.2623***	-0.2270**
	(0.097)	(0.094)	(0.097)	(0.096)	(0.095)
Electricity crisis*energy vulnerability	-0.1945*	-0.1516***	-0.1111**	-0.0173**	
	(0.107)	(0.054)	(0.056)	(0.008)	
Yr2007–08					-0.5019***
					(0.092)
Yr2014–15					-0.0289
					(0.059)
Yr2018–21					-0.2105***
					(0.076)
Yr2007–08*energy vulnerability					-0.0964
					(0.092)
Yr2014–15*energy vulnerability					-0.2772*
					(0.142)
Yr2018–21*energy vulnerability					-0.0451
					(0.231)
Sector controls	YES	YES	YES	YES	YES
Sector dummy	YES	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES	YES
Observations	1,218	1,218	1,218	1,218	1,218
R-squared	0.935	0.936	0.935	0.935	0.936

Note: robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In addition to energy vulnerability, time-varying sector controls include trade openness, import–domestic demand ratio and output price. Except for electricity crisis, energy vulnerability, and trade openness, all other variables are in log.

Source: authors' calculations using Quantec statistical database (2023).

The baseline results presented in Table 3 are based on a time-varying sector energy vulnerability index. One potential criticism of this approach is that the findings may be driven by the cyclical nature of the index or be endogenous to the macroeconomic dynamics of the country, rather than resulting from the innate technological nature of the sector which the index is expected to capture. To address this concern we construct an alternative energy vulnerability index based on each sector's average and median value. In this way the index becomes a constant across time but varies across sectors. The results for this exercise are presented in columns 1 and 3 of Table 7. The estimated coefficient of the variable of interest remains negative and statistically significant at all conventional significance levels in both columns.

Table 7: Baseline robustness checks—alternative energy vulnerability measure

	Mean		Median	
	Constant	Dummy	Constant	Dummy
	(1)	(2)	(3)	(4)
Electricity crisis	-0.7179***	-0.7321***	-0.7339***	-0.7432***
	(0.118)	(0.120)	(0.118)	(0.120)
Energy vulnerability	2.6677**	0.1470***	1.1371**	-0.0035
	(1.300)	(0.042)	(0.532)	(0.045)
Electricity crisis*energy vulnerability	-0.2128**	-0.1103***	-0.1751*	-0.1042***
	(0.095)	(0.025)	(0.105)	(0.027)
Sector controls	YES	YES	YES	YES
Sector dummy	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES
Observations	1,218	1,218	1,218	1,218
R-squared	0.935	0.935	0.934	0.935

Note: robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. In addition to energy vulnerability, time-varying sector controls include trade openness, import–domestic demand ratio and output price. Except for electricity crisis, energy vulnerability and trade openness, all other variables are in log.

Source: authors' calculations using Quantec statistical database (2023).

Next we use the sample energy vulnerability average to divide the sectors into two: intensive and less-intensive energy-vulnerable sectors, respectively. Sectors whose average energy vulnerability is higher than that of the sample average are considered to be intensive energy-vulnerable sectors, while those whose average energy vulnerability is below or equals that of the sample average are considered to be intensive energy-vulnerable sectors. Column 2 shows the results of this exercise. Column 4 repeats this exercise but in this case using the sample energy vulnerability median to sort the sectors. In this case sectors whose median energy vulnerability is higher than that of the sample are considered to be intensive energy-vulnerable sectors, while those whose median energy vulnerability is below or equals that of the sample median are considered to be intensive energy-vulnerable sectors. The results presented in columns 2 and 4 are consistent with those obtained in our baseline analysis, further confirming that our findings are robust and not driven by how we define the energy vulnerability index.

5.3.1 Formal and informal manufacturing sector jobs

Our baseline analysis focuses on total employment, which comprises formal and informal manufacturing sector jobs. Compared to informal firms, formal firms may have access to resources that enable them to cope more with the negative effects of the electricity crisis. Such resources can include access to external finance, which enables them to buy generators or meet the additional operational costs caused by the electricity crisis. Such subtle heterogeneity could lead to differences in how manufacturing jobs are affected by the electricity crises, even after accounting for sectors' energy vulnerability. We therefore independently consider the effect of the electricity crises on formal and informal manufacturing sector jobs. Table 8 shows the results of this exercise. Interestingly, the estimated coefficient of the interaction term is symmetric across the columns, indicating similar effects of electricity across employment types.

Table 8: Electricity crisis: formal and Informal jobs

	Formal employment (log)			Informal employment (log)		
	(1)	(2)	(3)	(4)	(5)	(6)
Electricity crisis	-0.2339***	-0.7563***	-1.2274	-0.3146***	-0.8370***	-0.9286
	(0.077)	(0.127)	(1.771)	(0.077)	(0.127)	(1.771)
Energy vulnerability	-0.1221	-0.2247**	-0.2247**	-0.1221	-0.2247**	-0.2247**
	(0.100)	(0.093)	(0.093)	(0.100)	(0.093)	(0.093)
Electricity crisis*energy vulnerability	-0.1949**	-0.2231**	-0.2231**	-0.1949**	-0.2231**	-0.2231**
	(0.096)	(0.088)	(0.088)	(0.096)	(0.088)	(0.088)
Sector control	NO	YES	YES	NO	YES	YES
Country controls	NO	NO	YES	NO	NO	YES
Sector dummy	YES	YES	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES	YES	YES
Observations	1,218	1,218	1,218	1,218	1,218	1,218
R-squared	0.927	0.933	0.933	0.942	0.946	0.946

Note: robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Outcome variable across the columns is manufacturing jobs (log). In addition to energy vulnerability, time-varying sector controls include trade openness, import– domestic demand ratio and output price. Country controls include rule of law, tax revenues as share of GDP, domestic credit to private sector, and GDP per capita. Except for electricity crisis and energy vulnerability, capital labour ratio, trade openness, and rule of law, all other variables are in log.

Source: authors' calculations using Quantec statistical database (2023) and World Development Indicators (2023).

6 Conclusion

The electricity crisis in South Africa has disrupted and upended economic activities in the country. Although the economic effects of the crisis are likely to vary across sub-sectors, the scholarly debate on response measures that the government could take has often proceeded without consideration of this heterogeneity. This is surprising given that analysis of the possible heterogeneous relationship could guide policy makers in allocating and reallocating productive resources to tackle the crisis.

This paper filled this knowledge gap by developing a sector energy vulnerability index, using input–output matrices for the period between 1993 to 2021 to identify economic sub-sectors that are most vulnerable to electricity crises in South Africa. Using the sector energy vulnerability index, the paper assessed the impact of the electricity crises on manufacturing sector jobs in South Africa. Findings from the newly developed energy vulnerability index highlight significant variations across sectoral energy vulnerability to the crises, while the econometrics analysis shows that electricity crises are associated with significant job destruction across the manufacturing sub-sectors, with this adverse effect being severe for manufacturing sectors with higher energy vulnerability intensity. Further analysis shows that the severity of the adverse effect of electricity crises on manufacturing jobs holds irrespective of whether they are formal or informal manufacturing sector jobs.

From a policy perspective, these findings indicate that cross-sectoral variations in energy vulnerability to the electricity crises require a heterogenous policy response. In this case policy makers could prioritize sectors based on their energy vulnerability intensity when rolling out government policies and initiatives that enable sectors to cope with the negative impact of electricity crises. Practical examples of these policies and initiatives could encompass a range of interventions, including subsidies for energy-efficient technologies, incentives for renewable energy adoption, or investments in infrastructure to enhance energy resilience. Tailoring them based on sector-specific energy vulnerability would enable policy makers to maximize their effectiveness in mitigating crises impacts. For instance, by integrating insights on manufacturing energy vulnerability into the deployment of renewable energy strategies in the country, policy makers could ensure that these policies are targeted and impactful. We argue that this is crucial given the limited fiscal space that many governments face.

Despite the useful policy implications of our findings, our paper can be extended in different ways. While our energy vulnerability index was constructed for all sectors in the economy, our subsequent econometric analysis focused on manufacturing sub-sectors. New studies could therefore focus on services which nascent evidence suggests have experienced a significant rise in emerging economies (see Ndubuisi, Owusu et al. 2023). Future studies could also examine how electricity crises have affected firms in South Africa and their different coping mechanisms based on their differential energy vulnerability intensity. Considering how the electricity crisis is affecting business formation, firm entry and exit is another promising area of research. In principle, business formation rates as well as firm entry and exit are important determinants of the extensive margin of job creation, while productivity, profits, and output are important determinants of the intensive margin of job creation. Also, the input–output framework has the following limitations: fixed proportion of consumption of inputs by each sector; constant returns to scale; and no substitution between different inputs (see Munroe and Biles 2005). While our analysis should be interpreted with these limitations in mind, future studies could also use other data sets that avoid some of these limitations.

References

Abeberese, A.B. (2020). 'The Effect of Electricity Shortages on Firm Investment: Evidence from Ghana'. *Journal of African Economies*, 29(1): 46–62.

Alby, P., J.J. Dethier, and S. Straub (2013). 'Firms Operating Under Electricity Constraints in Developing Countries'. *The World Bank Economic Review*, 27(1): 109–32. https://doi.org/10.1093/wber/lhs018

Allcott, H., A. Collard-Wexler, and S.D. O'Connell (2016). 'How Do Electricity Shortages Affect Productivity? Evidence from India'. *American Economic Review*, 106(3): 587–624. https://doi.org/10.1257/aer.20140389

Andersen, T.B., and C.-J. Dalgaard (2013). 'Power Outages and Economic Growth in Africa'. *Energy Economics,* 38: 19–23. https://doi.org/10.1016/j.eneco.2013.02.016

Andreoni, A., and F. Tregenna (2021). 'The Middle-income Trap and Premature Deindustrialization in South Africa'. In A. Andreoni, P. Mondliwa, S. Roberts, and F. Tregenna (eds), *Structural Transformation in South Africa: the Challenges of Inclusive Industrial Development in a Middle-income Country*. Oxford: Oxford University Press. https://doi.org/10.1093/oso/9780192894311.001.0001

Avenyo, E.K., M. Konte, and P. Mohnen, P. (2021). 'Product Innovation and Informal Market Competition in sub-Saharan Africa: Firm-level Evidence'. *Journal of Evolutionary Economics*, 31(2): 605–37. https://doi.org/10.1007/s00191-020-00688-2

Baker, L., and J. Phillips (2019). 'Tensions in the Transition: The Politics of Electricity Distribution in South Africa'. *Environment and Planning C: Politics and Space*, 37(1): 177–96. https://doi.org/10.1177/2399654418778590

Berkowitz, D., J. Moenius, K. and Pistor (2006). 'Trade, Law, and Product Complexity'. *Review of Economics and Statistics*, 88(2): 363–73.

Bhorat H., M. Buthelezi, I. Chipkin, S. Duma, L. Mondi, C. Peter, M. Qobo, M. Swilling, and H. Friedenstein (2017). *Betrayal of the Promise: How South Africa Is Being Stolen.* Johannesburg: Public

Affairs Research Institute. Available at: https://pari.org.za/wp-content/uploads/2017/05/Betrayal-of-the-Promise-25052017.pdf (accessed 27 May 2024).

Bowman, A. (2020). 'Parastatals and Economic Transformation in South Africa: The Political Economy of the Eskom Crisis'. *African Affairs*, 119(476): 395–431. https://doi.org/10.1093/afraf/adaa013

Cole, M.A., R.J. Elliott, G. Occhiali, and E. Strobl (2018). 'Power Outages and Firm Performance in Sub-Saharan Africa'. *Journal of Development Economics*, 134: 150–59. https://doi.org/10.1016/j.jdeveco.2018.05.003

Dietzenbacher, E., R.L. Isidoro, and S.B. Niels (2005). 'Using Average Propagation Lengths to Identify Production Chains in the Andalusian Economy'. *Estudios de Economia Aplicada*, 23: 405–22.

DME (1998). *White Paper on The Energy Policy.* Pretoria: Department of Minerals and Energy.

Doran, S. (2023). 'South Africa's Power Failures Are a Symptom of a Deeper Disease'. The Strategist: Australian Strategic Policy Institute. Available at: https://www.aspistrategist.org.au/south-africas-power-failures-are-a-symptom-of-a-deeper-disease/ (accessed 27 May 2024).

Eberhard, A. (2007). 'The Political Economy of Power Sector Reform in South Africa'. In D.G. Victor and T.C. Heller (eds), *The Political Economy of Power Sector Reform.* Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511493287.007

Eberhard, A. (2008, July). 'Africa's Power Crisis: and Power Shortages in South Africa'. Presentation to Africa Energy Forum, Nice.

Elliott, R.J., V. Nguyen-Tien, and E.A. Strobl (2021). 'Power Outages and Firm Performance: A Hydro-IV Approach for a Single Electricity Grid'. *Energy Economics*, 103: 105571. https://doi.org/10.1016/j.eneco.2021.105571

Eskom Generation Division (June 2022). Fact Sheet: Generation Plant Mix. Available at: https://www.eskom.co.za/wp-content/uploads/2022/06/GX-0001-Generation-Plant-Mix-Rev-26.pdf (accessed 27 May 2024).

Folly, K.A. (2021). 'Competition and Restructuring of the South African Electricity Market'. In T. Pinto, Z. Vale, and S. Widergren (eds), *Local Electricity Markets.* London: Academic Press.

Fried, S., and D. Lagakos (2023). 'Electricity and Firm Productivity: a General-Equilibrium Approach'. *American Economic Journal: Macroeconomics*, 15(4): 67–103. https://doi.org/10.1257/mac.20210248

Go, D.J., M.A. Promentilla, K. Aviso, and K.D. Yu (2019). 'The Evolution of the Key Sectors in the Philippine Economy Using an AHP-Based Sector Prioritization Index'. *Economies,* 7(3): 78. https://doi.org/10.3390/economies7030078

Guiso, L., P. Sapienza, and L. Zingales (2004). 'Does Local Financial Development Matter?'. *The Quarterly Journal of Economics*, 119(3): 929–69. https://doi.org/10.1162/0033553041502162

Gumbi, K. (2023). 'South Africa's Unemployment Rate Rises Amid Power Crisis'. *Reuters*, 16 May. Available at: https://rb.gy/yaw8zf (accessed 27 May 2024).

IEA (2023). 'South Africa'. Available at: https://www.iea.org/countries/south-africa (accessed 27 May 2024).

Igamba, J. (2023). 'How Eskom and the Government Can Put an End to Loadshedding in South Africa'. Greenpeace, 22 February. Available at: https://shorturl.at/htOV8 (accessed 27 May 2024).

Imbs, J. (2013). 'The Premature Deindustrialization of South Africa'. In J.E. Stiglitz, J. Lin Yiful, and E. Patel (eds), *The Industrial Policy Revolution II: Africa in the 21st Century.* London: Palgrave Macmillan. https://doi.org/10.1057/9781137335234_20

Inglesi, R. (2010). 'Aggregate Electricity Demand in South Africa: Conditional Forecasts to 2030'. *Applied Energy*, 87(1): 197–204. https://doi.org/10.1016/j.apenergy.2009.08.017

Inglesi, R., and A. Pouris (2010). 'Forecasting Electricity Demand in South Africa: a Critique of Eskom's Projections'. *South African Journal of Science*, 106(1/2): 50–53. https://doi.org/10.4102/sajs.v106i1/2.16

Inglesi-Lotz, R. (2023). 'Load Shedding in South Africa: Another Nail in Income Inequality?'. *South African Journal of Science*, 119(9/10): 1–4. https://doi.org/10.17159/sajs.2023/16597

Jain, S., and P.K. Jain (2017). 'The Rise of Renewable Energy Implementation in South Africa'. *Energy Procedia*, 143: 721–26. https://doi.org/10.1016/j.egypro.2017.12.752

Jorgenson, D.W. (1984). 'The Role of Energy in Productivity Growth'. *The Energy Journal*, 5(3): 11–26. https://doi.org/10.5547/ISSN0195-6574-EJ-Vol5-No3-2

Kruse, H., E. Mensah, K. Sen, and G. de Vries (2023). 'A Manufacturing (Re)naissance? Industrialization in the Developing World'. *IMF Economic Review*, 71(2): 439–73. https://doi.org/10.1057/s41308-022-00183-7

Leontief, W.W. (1936). 'Quantitative Input and Output Relations in the Economic Systems of the United States'. *The Review of Economic Statistics*, 18: 105–25. https://doi.org/10.2307/1927837

Liu, C., and S. He (2016). 'Input–Output Structures of the Australian Construction Industry'. *Construction Economics and Building*, 16(2): 56–70. https://doi.org/10.5130/AJCEB.v16i2.4819

Manova, K. (2013). 'Credit Constraints, Heterogeneous Firms, and International Trade'. *Review of Economic Studies*, 80(2): 711–44.

Mayr, D., E. Schmid, H. Trollip, M. Zeyringer, and J. Schmidt (2015). 'The Impact of Residential Photovoltaic Power on Electricity Sales Revenues in Cape Town, South Africa'. *Utilities Policy*, 36: 10–23. https://doi.org/10.1016/j.jup.2015.08.001

Mensah, J.T. (2024). 'Jobs! Electricity Shortages and Unemployment in Africa'. *Journal of Development Economics*, 167: 103231. https://doi.org/10.1016/j.jdeveco.2023.103231

Montalbano, P., and S. Nenci (2019). 'Energy Efficiency, Productivity and Exporting: Firm-level Evidence in Latin America'. *Energy Economics*, 79: 97–110. https://doi.org/10.1016/j.eneco.2018.03.033

Munroe, D.K., and J.J. Biles (2005). 'Regional Science'. In K. Kempf-Leonard (ed.), *Encyclopedia of Social Measurement*. London: Elsevier. https://doi.org/10.1016/B0-12-369398-5/00365-0

Ndubuisi, G. (2020). 'Trust and R&D Investments: Evidence from OECD Countries'. *Journal of Institutional Economics*, 16(6): 809–30. https://doi.org/10.1017/S1744137420000156

Ndubuisi, G., Y. Denis, C. Urom, and I. Abid (2023). 'Too Big to Be Ignored: How Energy Poverty Undermines Productive Efficiency'. *Energy Policy*, 181: 113733. https://doi.org/10.1016/j.enpol.2023.113733

Ndubuisi, G., S. Owusu, R. Asiama, and E.K. Avenyo (2023). 'Drivers of Services Sector Growth Acceleration in Developing Countries'. WIDER Working Paper 2023/87. Helsinki: UNU-WIDER. https://doi.org/10.35188/UNU-WIDER/2023/395-6

Nunn, N. (2007). 'Relationship-Specificity, Incomplete Contracts, and the Pattern of Trade'. *Quarterly Journal of Economics*, 122(2): 569–600. https://doi.org/10.1162/qjec.122.2.569

Pegels, A. (2010). 'Renewable Energy in South Africa: Potentials, Barriers and Options for Support'. *Energy Policy*, 38(9): 4945–54. https://doi.org/10.1016/j.enpol.2010.03.077

Phaahla, E. (2015). 'The State of Electricity in South Africa – Part I: the Problems in Eskom'. Helen Suzman Foundation. Available at: https://shorturl.at/hoqIY (accessed 27 May 2024).

Phillips, D. (2023). 'Energy Crisis Driving Down Manufacturing Productivity'. BizCommunity, 7 March. Available at: https://www.bizcommunity.com/Article/196/365/236586.html# (accessed 27 May 2024).

Pierce, W., and M. Le Roux (2022). 'Statistics of Utility-scale Power Generation in South Africa'. CSIR Energy Centre. Available at:

https://www.csir.co.za/sites/default/files/Documents/Statistics%20of%20power%20in%20SA%202022-CSIR-%5BFINAL%5D.pdf (accessed 27 May 2024).

Pretorius, I., S.J. Piketh and R.P. Burger (2015). 'The Impact of the South African Energy Crisis on Emissions'. *WIT Transactions on Ecology and the Environment*, 198: 255–64.

Quantec Statistical Database (2023). 'Input-Output Table'. Available at: https://www.easydata.co.za/ (accessed 2 September 2023).

Rajan, R., and L. Zingales (1998). 'Financial Dependence and Growth'. *American Economic Review*, 88(3): 559–86.

Rodrik, D. (2013). 'Unconditional Convergence in Manufacturing'. *Quarterly Journal of Economics*, 128(1): 165–204. https://doi.org/10.1093/qje/qjs047

Stern, D. I., and A. Kander (2012). 'The Role of Energy in the Industrial Revolution and Modern Economic Growth'. *The Energy Journal*, 33(3). https://doi.org/10.5547/01956574.33.3.5

Szirmai, A. (2012). 'Industrialisation As an Engine of Growth in Developing Countries, 1950–2005'. *Structural Change and Economic Dynamics*, 23(4): 406–20. https://doi.org/10.1016/j.strueco.2011.01.005

Szirmai, A., and B. Verspagen (2015). 'Manufacturing and Economic Growth in Developing Countries, 1950–2005'. *Structural Change and Economic Dynamics*, 34: 46–59. https://doi.org/10.1016/j.strueco.2015.06.002

Ting, M.B., and R. Byrne (2020). 'Eskom and the Rise of Renewables: Regime-resistance, Crisis and the Strategy of Incumbency in South Africa's Electricity System'. *Energy Research & Social Science*, 60: 101333. https://doi.org/10.1016/j.erss.2019.101333

Winkler, H. (2005). 'Renewable Energy Policy in South Africa: Policy Options for Renewable Electricity'. *Energy Policy*, 33(1): 27–38. https://doi.org/10.1016/S0301-4215(03)00195-2

World Development Indicators (2023). 'World Development Indicators'. Available at: https://databank.worldbank.org/source/world-development-indicators (accessed 23 September 2023).

Xu, J., M. Akhtar, M. Haris, S. Muhammad, O.J. Abban, and F. Taghizadeh-Hesary (2022). 'Energy Crisis, Firm Profitability, and Productivity: an Emerging Economy Perspective'. *Energy Strategy Reviews*, 41: 100849. https://doi.org/10.1016/j.esr.2022.100849