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

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## ABSTRACT

South Africa has been grappling with a persistent electricity crisis that has placed the country on an uncertain and turbulent economic trajectory. Based on a two-stage empirical approach, this paper unpacks the extent to which the country's manufacturing sector has been affected by this crisis. Notably, we first use South Africa's domestic input–output matrices to develop an index of manufacturing sub-sector energy vulnerability. The index reveals significant degree of heterogeneity across manufacturing sub-sectors, highlighting cross-sector differences in the level of exposure and susceptibility to the energy-related crises. Second, we employ the self-constructed energy vulnerability index in a flexible empirical framework to examine the effect of the electricity crisis on manufacturing sector jobs in the country. The empirical analysis results indicate that the electricity crisis is associated with significant job destruction, with this adverse effect severe for sectors with higher energy vulnerability intensity. The severity of this adverse effect holds irrespective of the nature of jobs, whether formal or informal. We discuss the implication of these findings in line with South Africa's economic recovery, resilience and development.

## 1. Introduction

South Africa is grappling with a severe electricity crisis driven by several interconnected factors, such as ageing infrastructure, mismanagement, and growing electricity demand. Notably, operational and financial inefficiencies within Eskom, a public utility and major electricity provider in the country, unleashed decades of underinvestment in infrastructure that cumulated into ageing power plants prone to frequent breakdowns. Corruption and mismanagement within Eskom exacerbated the situation as misallocated funds, inflated procurement costs, and maladministration drained resources needed for critical energy infrastructure upgrades and expansions (Baker and Phillips, 2019; Bhorat et al., 2017; Bowman, 2020). Hence, as electricity demand increased in the post-apartheid era due to economic expansion following the lifting of sanctions and the introduction of the early 2000s free basic energy policy aimed at providing “electricity for all”, electricity supply shortage set in.

The South African government has responded to the crisis by declaring a state of emergency in the electricity sector. However, 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, for instance, there were about 3773 h of loadshedding, with an upper limit of 11,529 GW h (GWh) relative to actual energy shed of 8301 GWh (see Pierce and Le Roux, 2022). Anecdotal evidence also suggests that daily loadshedding can extend to almost 10 h per day. Other things being equal, these daily long hours of loadshedding have far-reaching consequences for the economy, society, and the daily lives of citizens.

Several studies 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 et al., 2023a; 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 et al. (2023a) 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

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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 the 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, however, we lack 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 heterogeneous 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.

This paper aims to fill the above-identified knowledge gaps. To do this, 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. On the one hand, we focus on the manufacturing sector given the sector's key role as an engine of long-term growth and development (Szirmai, 2012). On the other hand, we pay a particular attention on manufacturing jobs because it is a strong predictor of higher levels of economic development (Kruse et al., 2023). There is, nonetheless, evidence of de-industrialization in South Africa (Andreoni and Tregenna, 2021; Imbs, 2013). Also, Fig. 1 clearly shows a declining manufacturing job share, which coincides with the electricity crisis. This raises the question to what extent the crisis has contributed to the declining manufacturing jobs in the country.

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.

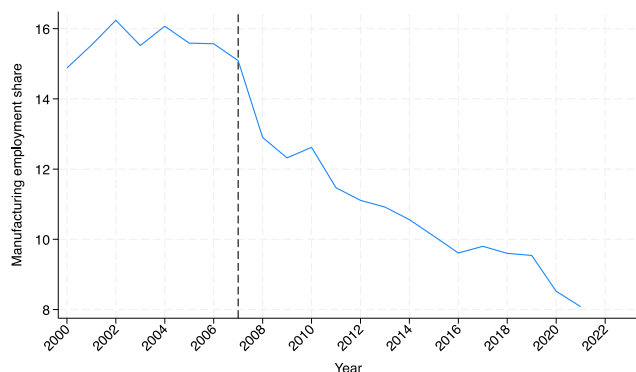


Fig. 1. Evolution of South Africa Manufacturing employment shares  
Source: authors' elaboration based on data from ourworldindata.org.

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 [Q SIC 358]) has a median energy vulnerability score of 0.01, the most vulnerable manufacturing sub-sector (i.e. coke, petroleum products, and nuclear fuel [Q SIC 331–333]) has a median energy vulnerability score of 0.6.<sup>1</sup> 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 et al., 2023a; 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.

## 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 MW (MW) as at the time of writing. Fig. 2 shows that the country's electricity largely comes from coal, which accounts for about 80 per cent of the country's energy mix. The rest of the electricity comes

<sup>1</sup> The energy vulnerability index is normalized, ranging from 0 to 1, with higher values indicating higher levels of energy vulnerability.

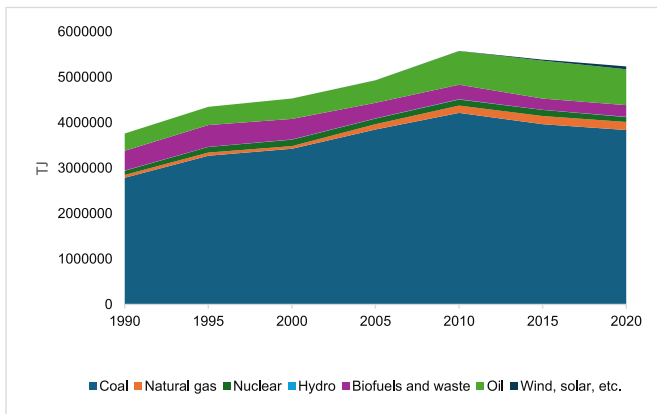


Fig. 2. South Africa energy mix  
Source: authors based on data from IEA (2023).

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.

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<sup>2</sup> 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. Fig. 3 shows Eskom's plant mix from which electricity was generated as of June 26, 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 h a day to meet the

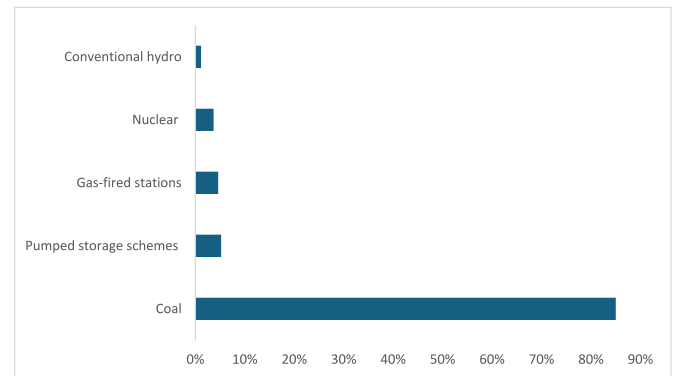


Fig. 3. Generation plant mix  
Note: figure excludes 'windfarm' and 'non-dispatchable mini hydro', which when combined contribute less than 0.5%. Source: authors based on data from Eskom Generation Division (2022).

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 1934 MW; two conventional hydro stations with an installed capacity of 600 MW; three pumped storage schemes with an installed capacity of 2732 MW; four gas-fired stations with an installed capacity of 2426 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 4800 MW when completed.

## 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: 1000 MW for Stage 1; 2000 MW for Stage 2; 3000 MW for Stage 3; 4000 MW for Stage 4; 5000 MW for Stage 5; 6000 MW for Stage 6; 7000 MW for Stage 7; and 8000 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. Fig. 4 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.

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

<sup>2</sup> 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.

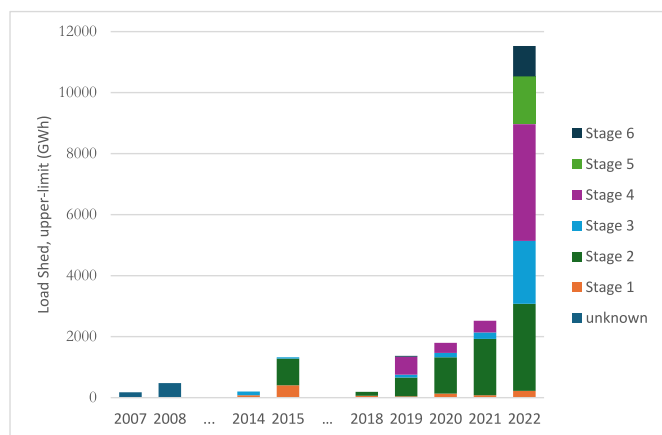


Fig. 4. Loadshedding, upper limit in GWh

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

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 explanatory 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.

The preceding notwithstanding, 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. 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.

### 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.<sup>3</sup> 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

<sup>3</sup> 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).

electricity sector. Forward linkages, on the other hand, capture the interconnection of manufacturing to the electricity sector 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, the sector 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 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.<sup>4</sup> 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 influence the sector's output ( $X_i$ ) because of the dependency on its own intermediate input ( $X_{ij}$ ) 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.

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:

<sup>4</sup> 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	...	Electricity and gas <sub>j</sub>	...	
Input sub-sector (i)	1				
	Electricity and gas <sub>i</sub>		X <sub>Electricity and gas,ij</sub>		X <sub>Electricity and gas-i</sub>
	n				
Total input or use (intermediate input + GDP at market prices) at basic prices			X <sub>Electricity and gas-j</sub>		

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

$$x = Ax + f = (I - A)^{-1}f \quad (1)$$

where  $x$  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 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):

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

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<sub>i</sub>* is the intermediate input use of electricity and gas across sub-sector  $i$  while *Total input or use<sub>i</sub>* 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):

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

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<sub>j</sub>* is the intermediate input use of other sub-sector outputs  $j$  in the electricity and gas sub-sector, while *Total output or sales<sub>j</sub>* 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):

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

where  $V_i^*$  is a normalized energy vulnerability index of sector  $i$ ,  $V_i = \ddot{F}_i + \ddot{B}_i$  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 forward linkages to the energy sector, with higher values indicating a stronger linkage. 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. As noted, the focus on the manufacturing sector is based on its importance in driving growth and recovery as well as structural transformation, in line with the seminal literature. To construct the vulnerability index, we use input–output data 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 several 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 2007–13 period; two for the 2014–17 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'.

Further, we complement the intensity analysis with two actual variables. First, we use 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 newly constructed variable 'electricity crisis intensity 3'. Second, we use indicator of hourly duration of outages. Data for the latter is from Pierce and Le Roux (2022).

#### 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.

#### 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:

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

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.  $V_{it}^*$  is a measure of the sector-specific time-varying energy vulnerability index, while  $\alpha$  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  $\gamma$  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.  $\delta_i$  are sector dummies, while  $\delta_t$  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 across the pre- and post-electricity crises periods, 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  $\gamma$ . Hence, our key explanatory variable is the interaction term  $E_t * V_{it}^*$ , while  $\gamma$  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 index is within the expected bound, ranging from 0 to 1. The lowest value in the sample is 0, corresponding to the vulnerability score of 'household appliances [Q SIC 358]' in 1993. On the other hand, the highest value in the sample is 1 and corresponds to the vulnerability score for 'leather and leather and fur products [Q SIC 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 [Q SIC 358]' remains the least energy-vulnerable sector with an energy vulnerability median score of 0.01. This is followed by 'other electrical equipment [Q SIC 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 [Q SIC 331–333]' with a score of 0.59. This is followed by 'knitted, crocheted articles [Q SIC 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.

#### 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.

##### 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

**Table 2**  
Summary statistics of energy vulnerability.

Panel A				
No. observations	Mean vulnerability	Standard deviation	Min	Max
1218	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	

**Table 2 (continued)**

Panel B			
SIC code	Sector description	Median vulnerability	Class
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 \(2023\)](#).

average effect of the electricity crises across manufacturing sector employment. Specifically, we regress manufacturing jobs 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 coefficient of the crisis variable is negative albeit statistically insignificant in column 1, while in column 2 it is both 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.

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. [Fig. 5](#) 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-

**Table 3**  
Electricity crisis, energy vulnerability, and manufacturing jobs.

	(1)	(2)	(3)	(4)	(5)	(6)
Electricity crisis	-0.0712 (0.051)	-0.0712*** (0.014)	-0.2722*** (0.075)	-0.8300*** (0.130)	-0.2443*** (0.077)	-0.7812*** (0.128)
Energy vulnerability				-0.3101*** (0.099)	-0.1080 (0.100)	-0.2134** (0.092)
Electricity crisis*Energy vulnerability					-0.1966** (0.095)	-0.2281*** (0.087)
Sector control	NO	NO	NO	YES	NO	YES
Sector dummy	NO	YES	YES	YES	YES	YES
Year dummy	NO	NO	YES	YES	YES	YES
Observations	1218	1218	1218	1218	1218	1218
R-squared	0.002	0.924	0.929	0.935	0.930	0.935

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. Except for electricity crisis, energy vulnerability, and trade openness, all other variables are logged.

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).

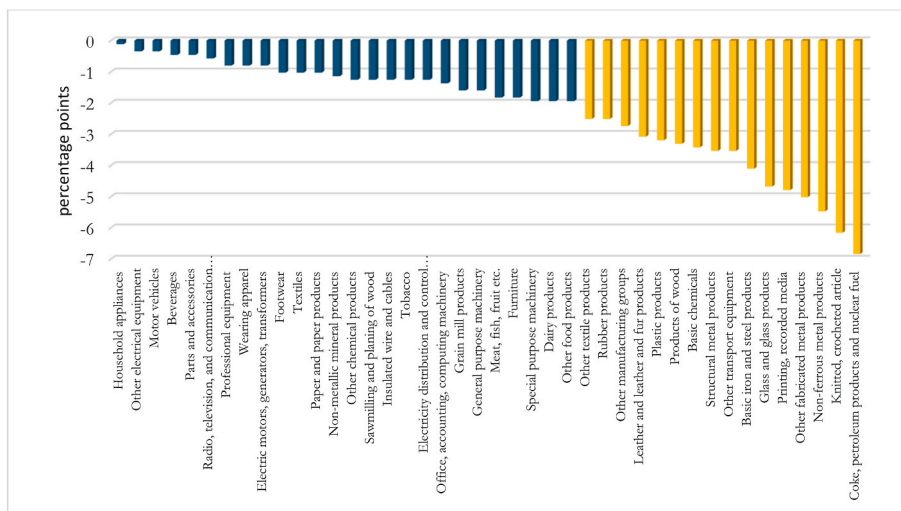
5.2.2. Further robustness checks

In this section we 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 and 2 of Table 4 show the results of this exercise. Column 1 shows the regression result when we exclude time-varying sector 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. Across the 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 3 and 4 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 and 2. Across the 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.

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 that our results are not picking up any other effect of the crises through sector-specific characteristics, we introduced an interaction term comprising the crisis variable and other sector characteristics. To this end, we compute indexes of average sector employment and output growth and interact them with the electricity crisis dummy. Columns 1 and 2 of Table 5 show the results of these exercise. Column 3 further shows the result when we interact the electricity crisis dummy with sector-specific trade variable. In the three columns, the estimated coefficient of “electricity crisis\*energy vulnerability” remains negative and statistically significant at conventional



**Fig. 5.** Manufacturing jobs effects of electricity crises 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. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

**Table 4**  
Baseline robustness checks—alternative outcome measures.

	Job Growth		Job shares (log)	
	(1)	(2)	(3)	(4)
Electricity crisis	0.0039 (0.098)	-0.1298 (0.168)	0.0169 (0.077)	-0.5200*** (0.128)
Energy vulnerability	-0.2228** (0.106)	-0.2549** (0.111)	-0.1080 (0.100)	-0.2134** (0.092)
Electricity crisis*Energy vulnerability	-0.2024* (0.106)	-0.2416** (0.102)	-0.1966** (0.095)	-0.2281*** (0.087)
Sector control	NO	YES	NO	YES
Sector Dummy	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES
Observations	1189	1189	1218	1218
R-squared	0.925	0.926	0.929	0.935

Note: robust standard errors in parentheses. \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$ . Outcome variables in columns 1 and 2 are manufacturing job growth, while the outcome variables in columns 3 and 4 are manufacturing job shares in log. 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.

significant level. In column 4, 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 5 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.

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 several alternative

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

	(1)	(2)	(3)	(4)	(5)	(6)
Electricity crisis	-0.7629*** (0.134)	-0.7492*** (0.132)	-0.7440*** (0.131)	-0.0736 (0.145)	-0.7872*** (0.130)	-0.9759*** (0.269)
Energy vulnerability	-0.1477 (0.104)	-0.3068*** (0.095)	-0.2083** (0.093)	0.0812 (0.128)	-0.2468** (0.112)	-2.0707 (2.133)
Electricity crisis*Energy vulnerability	-0.2932*** (0.085)	-0.1475* (0.083)	-0.2392*** (0.089)	-0.5238** (0.211)	-0.2023** (0.092)	-0.2778*** (0.107)
Electricity crisis*average employment growth	YES	NO	NO	NO	NO	NO
Electricity crisis*average real output growth	NO	YES	NO	NO	NO	NO
Electricity crisis* trade	NO	NO	YES	NO	NO	NO
Electricity crisis*sector dummy	NO	NO	NO	YES	NO	NO
Rule of law*energy vulnerability	NO	NO	NO	NO	YES	NO
Private credit*energy vulnerability	NO	NO	NO	NO	NO	YES
Sector controls	YES	YES	YES	YES	YES	YES
Sector dummy	YES	YES	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES	YES	YES
Observations	1189	1189	1218	1218	1218	1218
R-squared	0.934	0.934	0.935	0.975	0.935	0.935

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. Except for electricity crisis, energy vulnerability, rule of law, and trade openness, all other variables are in log.

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.

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 Fig. 4. 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.

Finally, column 6 shows the result when we interact energy vulnerability with the duration of power outage. The coefficient of the interaction term comprising the energy vulnerability index and power outage duration is negative and statistically significant at conventional significance levels. Overall, the results presented in Table 6 shows that our baseline result is robust to different measures of the electricity crisis. Put in context, the results also indicate that the adverse job effects of the ongoing electricity crisis in the country is jointly driven by both the extensive (as captured by the dummy variables) and the intensive (as captured by the MLR or power outage duration) margins of the crisis. In this case, manufacturing jobs are negatively affected by both power disruption and the intensity of the energy shed, or the outage duration

**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)	Electricity crisis (Duration)
	(1)	(2)	(3)	(4)	(5)	(6)
Electricity crisis	−0.7875*** (0.129)	−0.2452*** (0.043)	−0.2541*** (0.043)	−0.0541*** (0.009)		−0.1075*** (0.018)
Energy vulnerability	−0.2713*** (0.097)	−0.2164** (0.094)	−0.2707*** (0.097)	−0.2623*** (0.096)	−0.2270** (0.095)	−0.2764*** (0.098)
Electricity crisis*energy vulnerability	−0.1945* (0.107)	−0.1516*** (0.054)	−0.1111** (0.056)	−0.0173** (0.008)		−0.0507** (0.025)
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	YES
Sector dummy	YES	YES	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES	YES	YES
Observations	1218	1218	1218	1218	1218	1218
R-squared	0.935	0.936	0.935	0.935	0.936	0.935

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. Except for electricity crisis, energy vulnerability, and trade openness, all other variables are in log.

associated with such power disruption.

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 mean 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.

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 intensive energy-vulnerable sectors, while those whose average energy vulnerability is below or equals that of the sample average are 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 intensive energy-vulnerable sectors, while those whose median energy vulnerability is below or equals that of the sample median are 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.

### 5.2.3. 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

**Table 7**  
Baseline robustness checks—alternative energy vulnerability measure.

	Mean		Median	
	Constant	Dummy	Constant	Dummy
	(1)	(2)	(3)	(4)
Electricity crisis	−0.7179*** (0.118)	−0.7321*** (0.120)	−0.7339*** (0.118)	−0.7432*** (0.120)
Energy vulnerability	2.6677** (1.300)	0.1470*** (0.042)	1.1371** (0.532)	−0.0035 (0.045)
Electricity crisis*energy vulnerability	−0.2128** (0.095)	−0.1103*** (0.025)	−0.1751* (0.105)	−0.1042*** (0.027)
Sector Controls	YES	YES	YES	YES
Sector Dummy	YES	YES	YES	YES
Year Dummy	YES	YES	YES	YES
Observations	1218	1218	1218	1218
R-squared	0.935	0.935	0.934	0.935

Note: robust standard errors in parentheses. \*\*\* $p < 0.01$ , \*\* $p < 0.05$ , \* $p < 0.1$ . 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. Except for electricity crisis, energy vulnerability and trade openness, all other variables are in log.

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.

## 6. Conclusion

This paper uses a two-prong approach to examine the heterogenous

effect of South Africa's electricity crises on manufacturing jobs. First, we use South Africa's domestic input–output matrices to develop an index of manufacturing sub-sector energy vulnerability. 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. The 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.

Our findings hold significant policy implications. First, the documented overall adverse effect of the electricity crises on manufacturing jobs indicates that the crises have significantly distorted economic activities. While this calls for proactive measures to address the challenge, such measures must be multifaceted. Notably, it must include clear policy directions to reform Eskom's operational and financial inefficiencies and upgrade and maintain existing infrastructure. It must also provide incentive packages to encourage the adoption of energy-efficient technologies. Strategic investments in alternative energy sources, especially renewables, which would diversify the country's energy mix, are also highly needed. Regarding the latter, there is need for policies incentivizing private-sector investment or public-private partnerships to achieve the required investment level.

Second, the cross-sectoral variations in the intensity of electricity crisis impacts indicate that a one-size-fits-all policy response to the adverse effect of the electricity crises may be ineffective. In this case, policymakers 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. This tailored approach is especially crucial considering governments' fiscal constraints. Notably, by prioritizing sectors, policymakers will optimize the use of limited resources, ensuring that their interventions have the greatest possible impact. The success of such policies will help sectors cushion the immediate impacts of energy crises while strengthening the resilience of key industries.

Despite the several 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 et al., 2023b). 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.

#### CRedit authorship contribution statement

**Gideon Ndubuisi:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Elvis Korke Avenyo:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Rex Asiam:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

**Table 8**

Electricity crisis: formal and Informal jobs.

	Formal jobs (log)		Informal jobs (log)	
	(1)	(2)	(3)	(4)
Electricity crisis	−0.2339*** (0.077)	−0.7563*** (0.127)	−0.3146*** (0.077)	−0.8370*** (0.127)
Energy vulnerability	−0.1221 (0.100)	−0.2247** (0.093)	−0.1221 (0.100)	−0.2247** (0.093)
Electricity crisis*energy vulnerability	−0.1949** (0.096)	−0.2231** (0.088)	−0.1949** (0.096)	−0.2231** (0.088)
Sector control	NO	YES	NO	YES
Sector dummy	YES	YES	YES	YES
Year dummy	YES	YES	YES	YES
Observations	1218	1218	1218	1218
R-squared	0.927	0.933	0.942	0.946

**Note:** Robust standard errors in parentheses. \*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1. Outcome variables in columns 1 and 2 is manufacturing formal jobs (log), while outcome variable in columns 3 and 4 is manufacturing informal jobs (log). In addition to energy vulnerability, time-varying sector controls include trade openness, import– domestic demand ratio and output price. Except for electricity crisis and energy vulnerability, capital labour ratio, and trade openness, all other variables are in log.

#### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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#### Data availability

The data that has been used is confidential.

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