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Jobs, investments, and exporting: The real effects of electricity crisis in South Africa

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ABSTRACT

South Africa's grid remains unstable and characterized by frequent power cuts. This paper examines the implications of South Africa's electricity crisis on jobs, capital investment, and exporting across manufacturing firms. Exploiting sectoral differences-in-exposure to the crisis, we find robust evidence that the electricity crisis has destroyed jobs, lowered capital investments, and upended export activities of manufacturing firms, with this adverse effect severe for firms in energy-intensive vulnerable sectors. Furthermore, we find that differing sources of firm heterogeneity vis-à-vis ownership structure, age, and financial status modulate the effect of electricity crisis on firm performance. Overall, these results indicate that policies aimed to help firms cope with the effect of the electricity crisis must consider the unique differences across and between manufacturing firms in South Africa.

1. Introduction

South Africa has faced a persistent and deepening electricity crisis for nearly two decades. Once hailed as having one of the most advanced and reliable electricity grids on the African continent, South Africa has experienced a dramatic deterioration in energy supply reliability since the early 2000s, albeit with notable relief between 2008 and 2014 and 2015–2018. This crisis—manifested most acutely through rolling blackouts known as load-shedding—have plagued the country since 2007 and are now regarded as a structural feature of the economy.

For instance, estimates from the World Bank Enterprise (WBE) survey indicates that the number of power outages in a typical month reported by firms in the country grew by 88.3% between 2007 and 2020. At the same time, the share of firms experiencing electrical outages in the country increased from 45% in 2007 to 92% in 2020.[1] Economic literature highlights the importance of electricity to economic activities and performance (Jorgenson, 1984; Stern and Kander, 2012), implying that South Africa's ongoing electricity crisis poses a significant threat to the competitiveness of firms in the country. Yet, we know little about how firms in the country are affected by the ongoing electricity crisis. This paper fills this gap by examining how jobs, capital investments, and export activities of manufacturing firms are affected by the ongoing electricity crisis in the country.

Electricity crisis can affect firm activities and performance via the intensive and extensive margins (Mensah, 2024). Regarding the intensive margin, it disrupts business operations and plans, and forces existing firms to either operate using suboptimal approaches or reallocate resources to provide alternative sources of electricity. This leads to inefficiency and a higher cost of production as well as reallocation of investments and profits to adapt to the electricity constraint with resources that would otherwise have been used to enhance productivity and create new jobs and employ new workers (Xu et al., 2022). On the other hand, electricity crisis generally distorts confidence in the economy and lead to a general increase in the cost of doing business. As a result, new firms looking to invest in the economy will be hesitant to invest and delay their investments while incumbents may exit due to the high cost of doing business (Xu et al., 2022). This lack of or limited entry of new businesses due to deferred or foregone investments coupled with the exit of incumbents affect investments and lead to job losses, low international competitiveness, and loss of new jobs that would have

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[1] These shares are computed from the World Bank's Enterprise (WBE) database. WBE is based on surveys of sampled firms rather than the entire population of firms in the economy. See: https://data.worldbank.org/indicator/IC.ELC.OUTG?locations=ZA; https://data.worldbank.org/indicator/IC.ELC.OUTG.ZS?locations=ZA

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otherwise been created (extensive margin) (Mensah, 2024; Ndubuisi et al., 2025a).

While the preceding discussion indicates a negative effect of electricity crisis on firm activities and performance, firms and sectors can be impacted differently based on their innate characteristic. Xu et al. (2022), Abeberese (2020), Moyo (2013), and Fisher-Vanden et al. (2015) found that energy-intensive industries respond differently to electricity outages and shortages and, as a result, have differential outcomes compared with non-energy intensive industries. Guo et al. (2023) found that the negative effect of power shortages on research and development (R&D) investments and productivity were much pronounced for small-sized, non-export-oriented, and private-owned firms in China. Mensah (2024) finds that electricity outages have a negative effect on employment, sales per worker, and value added per worker in African countries, with the effect most prevalent in non-agricultural sectors, skilled jobs, and in the private sector. Bhorate and Kohler (2025), in a recent study focused on South Africa, found a positive association between loadshedding and working hours in the utility industry, which they argue "may reflect increased labour demand given the industry's responsibility for electricity generation and distribution."

Motivated by these discussions, this paper examines the effects of South Africa's electricity crisis on the performance of its manufacturing firms, focusing on three critical dimensions: jobs, capital investments, and export activity. It also explores how these effects differ based on firm characteristics such as age, financial status, and foreign ownership structure. In doing so, the paper not only provides an overall assessment of the electricity crisis' impact on the manufacturing sector but also highlights its uneven effect across different types of firms. This dual perspective offers a more nuanced and policy-relevant understanding of how energy disruptions affect firms differently—insights that are crucial for designing targeted interventions and prioritizing support measures that can enhance the resilience of the sector. The focus on manufacturing is deliberate: while the sector has long been recognized as a cornerstone of long-term economic growth and structural transformation (Szirmai, 2012), it is highly vulnerable to electricity shocks due to the energy-intensive nature of many production processes, including heating, cooling, and machinery operation. Generating robust empirical evidence on how manufacturing firms are affected by the crisis is thus vital to inform evidence-based policy on how to safeguard the sustainability of this crucial sector and preserve South Africa's industrial capabilities and global competitiveness.

This paper leverages a rich panel dataset encompassing firm-level information from 41 distinct manufacturing subsectors to address its central research objective. The dataset, maintained by the South African Revenue Service and National Treasury (SARS-NT), draws from administrative tax records covering the universe of formal firms in the economy. As our empirical strategy, we recur to the methodology of Rajan and Zingales (1998), which has been extensively applied elsewhere in the literature (Dutta and Sharma, 2008; Ma et al., 2010; Chen, 2017; Turco et al., 2019; Alimov, 2019; Maskus et al., 2019; Ndubuisi and Owusu, 2022). The approach offers a flexible framework to identify the effect of a country level variable at the sector or firm-level by exploiting unique country-industry variation. For instance, in their seminal paper, Rajan and Zingales (1998) applied the method to determine how country-level financial development affect industry-level output growth, by exploiting unique country-industry variation in financial development and sector financial vulnerability via an interaction, conditional on other industry characteristics.

We apply the method in an empirical design that examines how firm-level outcomes— jobs, capital investments, and export activity—respond to the electricity crisis, conditional on the firm's vulnerability to electricity supply shocks. This strategy allows us to isolate and analyse one specific mechanism—energy vulnerability—by which the effect of the electricity crisis is passed down to firms. To operationalize this concept, we rely on the sector energy vulnerability index developed by Ndubuisi et al. (2025a). The index was constructed using South Africa's input-output table that covers the universe of sectors in the economy. The index captures the intensity of each sector's forward and backward linkages with the energy sector, thereby reflecting the degree of dependency on electricity. Sectors with higher vulnerability scores are considered more susceptible to electricity supply or demand shocks, providing a meaningful way to assess heterogeneous effects across firms. This is complemented by self-constructed, time-varying electricity crisis index that captures the severity of South Africa's electricity supply disruptions, enabling a robust empirical assessment of the economic ramifications of the electricity crisis.

Our results show that the ongoing electricity crisis has led to significant job losses, reduced capital investments, and disrupted export activities across manufacturing firms in the country, with the adverse effect being particularly severe for firms in energy intensive vulnerable sectors. For instance, the results indicate that a one–standard deviation increase in the electricity crisis leads to a 0.08% decline in employment within the Household Appliances sector (QSIC 358)—the least energy-vulnerable industry—but results in a much larger reduction of up to 3.2% in the Coke, Petroleum Products, and Nuclear Fuel sector (QSIC 331_333), which is the most energy-vulnerable. Regarding capital investment, the effects also vary substantially across industries: in the least vulnerable sector, investment declines by only 0.02%, whereas in the most vulnerable sector, the reduction reaches as high as 0.8%.

Our findings are robust to several alternative model specifications and measurement of the electricity crisis. Further analysis on the role of a firm's ownership structure, age, and financial status show that these factors interact with sector energy vulnerability to determine how the ongoing electricity crisis affects firm outcomes. We found that domestic firms, older firms and financially constrained firms in energy intensive vulnerable sectors were significantly more affected than their foreign, younger and financially unconstrained counterparts, for whom no adverse effects were evident. Overall, our findings corroborate the nascent evidence that suggest that the electricity crisis has significantly upended economic activities in South Africa (see, for instance, Ndubuisi et al., 2025a; Bhorat and Köhler, 2025). However, our findings highlight that firms are not uniformly affected by the crisis. In this case, policy interventions aimed at supporting manufacturing firms in coping with the crisis must explicitly account for this heterogeneity.

The paper relates to the broader literature on the economic effects of electricity crisis in South Africa. This literature can be broadly categorized into two: those that broadly consider the implications of electricity consumption (e.g., see Odhiambo, 2009; Lin and Wesseh Jr, 2014; Bah and Azam, 2017) and those that specifically consider the implications of the ongoing electricity crisis. The latter, which our study relates more to, has to date examined the effect of the crisis on economic growth (Mabugu and Inglesi-Lotz, 2022), consumer emotions and behavior (Wiese and van der Westhuizen, 2024), mortality rate (Budlender, 2024), carbon emissions (Pretorius et al., 2015), manufacturing jobs (Ndubuisi et al., 2025a), and labour market outcomes including employment rates, working hours, and earnings (Bhorat and Köhler, 2025). Our main contribution to this literature is to provide firm-level evidence on how manufacturing firms in the country were affected by the crisis. To our knowledge, our paper is the first to do this using comprehensive firm-level data.

Because of our empirical approach and focus on the manufacturing sector, this paper is closest to Ndubuisi et al. (2025a), which shows that the ongoing electricity crisis in the country is associated with significant manufacturing job destruction, and this adverse effect is severe for sectors with higher energy vulnerability intensity. The current paper deviates from Ndubuisi et al. (2025a) in two important ways. First, it provides firm-level evidence as opposed to sector-level evidence, as done by Ndubuisi et al. (2025a). Second, in addition to the manufacturing job effects of the electricity crises, it provides novel evidence on how the electricity crisis affects export activities and capital investments, areas not covered in the previous study. Third, it provides additional analyses and insights on how the effects of the electricity crisis varies by firm age, financial status, and foreign ownership structure. In this way, the current paper provides further insights on how policymakers can prioritize firms based on the combination of sector-firm characteristics.

This study also relates to the broader literature examining the firm-level effects of electricity shortages or energy crisis, especially in Africa (see, Moyo, 2013; Cole et al., 2018 Abeberese et al., 2021; Mensah, 2024). Our innovation to this literature is twofold. First, rather than merely examining the average effect of the electricity crisis on firms, this paper provides evidence on how the firm-level effect varies across firms based on a novel energy vulnerability index. Along this line, the paper shows how negative electricity supply shocks are passed down to manufacturing firms. Second, it provides evidence on how firms' heterogenous characteristics—vis-à-vis age, foreign ownership, and financial status—further determine the implications of any electricity shortages or energy crisis on firm-level activities and outcomes. To our knowledge, evidence on the heterogeneous impact of electricity crisis on firm outcomes in South Africa remains scant. We add to this literature.

The rest of this paper is organized as follows. The next section presents an overview of the electricity crisis in South Africa. The third section presents the research design, where we specified our econometric model and estimation approach. Section 4 discusses the data sources and the computation of all key variables. The results from the empirical analysis are presented as well as discussed in Section 5, while Section 6 concludes the paper.

2. Electricity crisis in South Africa

South Africa's energy sector is heavily reliant on coal. In 2023, coal contributed about 94% of the country's domestic energy production and 82% of its electricity generation mix (IEA, 2025), making it one of the most carbon-intensive economies in the world. The sector is also dominated by a state-owned power utility company, Eskom, which was established in 1923 when the Electricity Supply Commission (ESCOM, later renamed Eskom) was institutionalized to centralize electricity generation and distribution (Baker and Phillips, 2019; Bowman, 2020; Ndubuisi et al., 2025a). Eskom currently accounts for about 95% of the electricity used in the country and is responsible for about 95% of electricity transmission and 60% of the electricity distribution in the country (Baker and Phillips, 2019; Ting and Byrne, 2020; Ndubuisi et al., 2025a), thus earning it the description of a vertically integrated monopoly. However, concerted policy efforts are underway to unbundle the company's activities (Department of Public Enterprises, 2019; International Trade Administration, 2024).

The origins of South Africa's electricity challenges date back to the post-apartheid era, particularly in the late 1990s and early 2000s. At that time, Eskom operated with significant excess capacity, largely due to investments made during the apartheid era. Electricity was cheap, abundant, and heavily reliant on coal. However, rapid economic and industrial growth after 1994, coupled with ambitious efforts to expand electricity access to previously excluded communities, began to strain the system (Pretorius et al., 2015; Baker and Phillips, 2019; Ndubuisi et al., 2025a). For instance, between 1994 and 1999, the national government prioritized extending electricity to previously disadvantaged communities. Although the program achieved remarkable success in increasing access (Ting and Byrne, 2020), the pre-apartheid overcapacity masked the need for continued investment and modernization, leading to complacency in the post-apartheid period. Hence, the government did not match the expansion in electricity access with a corresponding investment in new generation capacity.

The lack of foresight, underinvestment in infrastructure, and policy inertia thus laid the ultimate foundation for the crisis that would erupt in 2007, marked by the first major episodes of load-shedding. Nevertheless, the government could have averted the crisis, as analysts and energy experts had already provided several warnings beforehand about impending electricity shortages. Notable among these was the 1998 White Paper on Energy Policy (Department of Mineral and Energy, 1998). While the then Minister of Energy endorsed the report, the national government took no action to implement key aspects of the report (Ndubuisi et al., 2025a). Specifically, concrete investments in new infrastructure only began in earnest after load shedding had already started.

At the heart of South Africa's electricity crisis lies a complex interplay of technical, financial, and political factors. Eskom has been crippled by a legacy of poor governance, financial mismanagement, and deepening operational inefficiencies. One of the commonly held views in the literature is that these dynamics depleted the resources required for critical energy infrastructure upgrades and expansions (Bhorat et al., 2017; Baker and Phillips, 2019; Bowman, 2020). Hence, as electricity demand surged in the post-apartheid era due to economic expansion and national efforts to expand electricity access, an electricity supply shortage set in (Ndubuisi et al., 2025a). The structural overreliance on coal further complicated the crisis in two important ways. First, many of Eskom's coal-fired plants are old, with some dating back to the 1960s and 1970s. The aging fleet suffers from decades of under-maintenance, resulting from financial constraints or poor planning, which leads to frequent, prolonged, and unplanned breakdowns. Second, the lack of significant diversification in the energy mix has made the system rigid, inflexible, and vulnerable to supply shocks. Moreover, the environmental and health impacts of coal dependency have grown more acute, creating tension between energy security and climate commitments.

Since 2007, load-shedding has thus become an entrenched and escalating feature of life in South Africa—a strategy Eskom has employed to keep the lights on in the country and avoid a total collapse of the energy system. Eskom implements a staged load-shedding system, ranging from Stage 1 (mild interruptions) to Stage 8 (severe power rationing), often shifting unpredictably depending on supply and demand. Stage 1 corresponds to a load shed of 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. In 2022 and 2023, the country experienced the most severe load-shedding on record, with some areas losing power for up to 10 h per day. The economic and social costs are staggering, triggering protests and becoming a focal point of electoral discontent.

South Africa has made various attempts to resolve the electricity crisis, with mixed success. One of the most promising initiatives has been the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP), launched in 2011. It sought to diversify the energy mix by attracting private investment in wind, solar, and other renewable technologies. In its early phases, REIPPPP was widely acclaimed for its transparency, cost competitiveness, and success in rapidly increasing non-Eskom generation (Baker and Phillips, 2019). However, political resistance, bureaucratic delays, and inconsistent policy support caused the program to stall during critical periods, undermining its momentum (Ting and Byrne, 2020; Larsen and Hansen, 2022).

Another significant reform effort is the unbundling of Eskom into three separate entities—for generation, transmission, and distribution—as outlined in the 2019 Eskom Roadmap. This structural reorganization aims to enhance transparency, promote competition, and improve grid reliability. While progress has been slow and contested, notably by trade unions and political stakeholders, the separation of the Transmission Company of South Africa is underway and expected to be finalized in the near term. In 2021, President Cyril Ramaphosa announced regulatory reform that allowed embedded generation projects of up to 100 MW to operate without a license, significantly increasing the scope for private sector participation and reducing the burden on Eskom. In parallel, there has been a growing emphasis on decentralized energy systems, such as rooftop solar installations and microgrids, particularly in urban centers and among wealthier communities. This move has catalyzed new investments in self-generation. However, challenges remain, including grid constraints, local content requirements, and delays in municipal integration.

Taken together, South Africa's electricity crisis is a multi-dimensional challenge that encapsulates broader structural, institutional, and developmental dilemmas. While various reforms and interventions have been introduced, they have often lacked urgency, coordination, or political will, highlighting the need for a more coherent and decisive policy framework. Our study examines the implications of this structural failure for firms in terms of investment, employment, and exports.

3. Research design

3.1. Empirical framework and estimation

3.1.1. Model specification

As outlined in the introduction, this paper's empirical strategy builds on the influential framework developed by Rajan and Zingales (1998). The framework offers a flexible method for identifying how firm- or industry-level outcomes are shaped by broader national contexts, using interaction terms that combine sectoral or firm characteristics of interest. While Rajan and Zingales (1998) originally used the method to examine how financial development influences industry growth, it has since been applied extensively across diverse contexts to assess how broader national conditions shape firm and industry performance (see Dutta and Sharma, 2008; Ma et al., 2010; Chen, 2017; Turco et al., 2019; Alimov, 2019; Maskus et al., 2019; Ndubuisi and Owusu, 2022).

We adapt this framework to estimate how firm-level outcomes respond to the electricity crisis in South Africa. Our empirical design relates firm-level outcomes—employment, capital investment, and exports—to an interaction term comprising electricity crisis and sectoral energy vulnerability. Hence, rather than estimating the average effect of the electricity crisis, which in the absence of a credible external instrument, poses serious identification challenges, we focus on heterogeneous effects across sectors with varying degrees of energy vulnerability.

Eq. 1 formalizes the baseline model that guides our analysis:

$$\hat{\mathrm{A}}_{ijt} = \delta\left(EC_t{*}EV_j\right) + \theta X'ijt + D_i + D_j + D_t + \mu_{ijt} \tag{1}$$

From Eq. (1), $\hat{\mathrm{A}} \in \{\text{export}, \text{investment}, \text{job}\}$. The subscript i denotes firm, j denotes sector, t is the year index, and μ_{ijt} is the error term.

The variable EC_t captures the intensity of the electricity crisis, proxied by electricity supply volatility as detailed in Section 3.2.4. EV_j captures sector-level energy vulnerability intensity (detailed in section 3.2.3). It is an inherent technological attribute of each sector, reflecting input-output linkages with the energy sector. It has alimited scope for short-run substitution. Hence, we treat it as a time-invariant variable. The interaction term ($EC_t{*}EV_j$) is the central variable of interest. The coefficient (δ) captures the differential effect of the electricity crisis on firm performance across sectors with varying degrees of energy vulnerability. A negative and statistically significant estimate of (δ) indicates that firms operating in more energy-vulnerable sectors experience disproportionately worse outcomes during periods of heightened electricity supply volatility.

X'_{ijt} is a vector of time-varying firm-level controls, including firm age, size, labour productivity, financial status, working capital, foreign ownership, and international business linkages. These covariates are selected based on both data availability and insights from the existing literature on firm performance determinants (Yasar et al., 2006; Ding et al., 2013; Lipsey et al., 2013; Konte and Ndubuisi, 2021). Their inclusion strengthens the credibility of the empirical strategy by reducing omitted-variable bias and ensuring that identification of electricity crisis effects operates primarily through the interaction between sectoral energy vulnerability and electricity supply volatility, rather than through correlated dimensions of firm heterogeneity.

The specification also includes a comprehensive set of fixed effects designed to isolate the effect of electricity shocks from confounding factors. Firm fixed effects (D_i) absorb time-invariant firm characteristics such as management quality, location, or business model. This ensures that identification comes exclusively from within-firm variation over time rather than cross-sectional differences between firms. Sector fixed effects (D_j) control for persistent differences across industries, such as technology intensity, competitive structure, and regulatory environments. These fixed effects are particularly important given that energy vulnerability may be correlated with other sectoral characteristics that may independently affect firm outcomes. Year fixed effects (D_t) capture aggregate macroeconomic shocks, policy changes, and economy-wide trends that affect all firms simultaneously.

Note that because (EC_t) varies only over time and (EV_j) varies only across sectors, their main effects are fully absorbed by year and sector fixed effects, respectively. Thus, Eq. 1 excludes the main effects and focuses solely on their interaction. Identification therefore relies solely on the interaction term.

3.1.2. Identification assumption and endogeneity concerns

The structure of Eq. (1) allows us to identify the effect of the electricity crisis by effectively benchmarking firms across varying levels of energy-vulnerability within the same macroeconomic environment. In this context, our empirical strategy literally exploits systematic heterogeneity in sectoral exposure to electricity supply disruptions, rather than relying on aggregate variation in electricity conditions alone. The underlying intuition is straightforward: if electricity crisis indeed affects firm performance, its effect should be disproportionately larger in sectors that are inherently more vulnerable to electricity supply disruptions.

The validity of our empirical approach rests on the assumption that, conditional on firm, sector, and year fixed effects and observable firm-level controls, there are no unobserved time-varying shocks that simultaneously affect firm outcomes and are systematically correlated with the interaction between electricity crisis intensity and sectoral energy vulnerability. This assumption is standard in interaction-based designs of the Rajan–Zingales type and underpins the identification of the estimated coefficient on the interaction term (Dutta and Sharma, 2008; Ndubuisi et al., 2025a). Nonetheless, in the robustness section, we introduce additional interactions that combine electricity crisis with different indicators of sector characteristics to check whether our results are potentially driven by such confounding factors.

Several other potential sources of endogeneity also warrant careful consideration. The first is reverse causality, resulting from firm-level performance determining energy vulnerability intensity or electricity supply volatility. Given that energy vulnerability intensity is measured at the sector-level, we argue that it cannot be reversely determined by firm performance outcomes, in line with Guiso et al. (2009) and Avenyo et al. (2021). Moreover, as previously noted, energy vulnerability is an innate technological component of a sector, implying that it is structurally determined and not due to variation in the performance of any single firm. Individual firms—and even entire sectors—are unlikely to influence aggregate electricity supply volatility, which is driven by system-level factors such as generation capacity, infrastructure reliability, fuel availability, and governance of the power sector. This renders feedback effects from firm outcomes to electricity crisis intensity implausible and unlikely.

The second is that sectoral energy vulnerability may be correlated with unobserved sector-specific shocks that vary over time and co-move with electricity supply volatility. We believe that this concern, while valid, is sufficiently mitigated in our approach for two reasons. First, we treat and model sectoral energy vulnerability as a time-invariant technological characteristic, reflecting production processes and electricity dependence that evolve only slowly over long horizons. Second, sector fixed effects included in our model absorb all persistent differences across industries, thereby mitigating this concern. Any remaining bias would require the presence of sector-specific shocks that both vary over time and differentially affect electricity-intensive sectors precisely when national electricity volatility increases. While this scenario poses a threat to our identification, there is no empirical evidence or institutional rationale to suggest it occurs in practice in this case.

Finally, another potential concern is that firms may respond endogenously to electricity supply volatility by adopting coping strategies such as self-generation, energy-saving technologies, or production reorganization. While such adaptive responses are economically meaningful, they are unlikely to invalidate our identification strategy. To the extent that coping mechanisms mitigate the adverse effects of electricity disruptions, they would attenuate the estimated effect of the electricity crisis, biasing our estimates toward zero rather than generating spurious negative effects. Consequently, the estimated coefficients can be interpreted as conservative lower-bound effects of electricity supply instability on firm performance.

3.1.3. Estimation strategy and extensions

Following past studies that adopt similar empirical design (see Dutta and Sharma, 2008; Alimov, 2019; Maskus et al., 2019; Ndubuisi and Owusu, 2022), we estimate Eq. (1) using the ordinary least square (OLS) conditional on a range of firm characteristics as well as year and sector fixed effects. Under the identifying assumptions discussed above, the estimated coefficient (δ) captures the effect of the electricity crisis on firm-level outcomes through the channel of sectoral energy vulnerability.

The estimation of Eq. 1 only allows us to address our first research objective that focuses on firms' heterogenous response to the electricity crisis based on their energy vulnerability intensity. The second objective of our study is to unpack how firm characteristics such as ownership structure, age, and financial status further condition firms' heterogenous response to the electricity crisis. To this end, we follow Maskus et al. (2019) to perform a split sample analysis, re-estimating Eq. (1) across subsamples defined by ownership structure, firm age, and financial status.[2] This approach allows us to assess whether certain types of firms are better able to absorb or mitigate the adverse effects of electricity shocks, thereby shedding light on the microeconomic channels through which electricity crisis shape firm performance.

3.2. Data sources and variable computation

3.2.1. Firm-level data cleaning and processing

We source data on firm-level outcomes and characteristics from the South African Revenue Service and National Treasury (SARS-NT). We particularly use the CIT-IRP5 dataset from this source, spanning the period 2008–21 (Edwards et al., 2018; Pieterse et al., 2018; National Treasury and UNU-WIDER, 2023). The dataset is a panel containing detailed information about the activities and performance of formal firms in South Africa. Firms in the dataset are also grouped into sectors using the SIC classification. We are particularly able to identify and distinguish firms in the dataset based on either the one-, two-, or three-digit SIC classification. We restrict our sample to only firms in the manufacturing sector, exploiting mostly the three-digit SIC classification.

We observed missing or negative values for some variables such as sales, capital, age, and employment in the original dataset. We consider negative sales, employment and capital investment as coding errors since, the values of these variables can only range from zero to infinity. Hence, we exclude them from our sample as they are not economically meaningful. Missing values may reflect incomplete linkage between CIT and IRP5 in a given year, non-filing or late filing by otherwise active firms and/or occasional blank fields in returns that fail validation rules. A maximalist approach will be to impute the missing observations, while a minimalist approach will be to drop them. We opt for the later since we do not know the exact reason for the missing values.

Table A1 in the appendix examines whether firms with missing values differ systematically from those included in the final analytic sample. Except for employment, firms with missing data exhibit statistically significant differences across the considered variables. This suggests that selection into the final sample may not be random with respect to some of the firm characteristics. As a result, the findings should be interpreted with caution and are best understood as applying primarily to the firms observed in the analytic sample rather than to the full population.

3.2.2. Firm-level outcomes and characteristics

Our study seeks to explain three firm outcomes: jobs, capital investment, and exports. From the cleaned dataset, therefore, we define jobs as the log transformation of a firm's total number of employees. We deflate data on capital expenditure, total asset, and sales using the GDP deflator (2012 base year), as provided in the CIT-IRP5 dataset. Following Fu et al. (2022), we define a firm's investment as capital expenditure divided by total assets. To capture the export activity of a firm, we focus on the extensive margin defined herewith as a dummy variable that takes the value of one in a period if a firm reports positive export value and zero otherwise.[3]

As noted in Section 3.1.1, we condition our empirical specification on a set of firm-level controls that are known to shape export activity, investment behavior, and employment dynamics. Specifically, we control for firm age, firm size, labour productivity, working capital, foreign ownership, and foreign connections, based on data availability and the existing literature (Yasar et al., 2006; Ding et al., 2013; Lipsey et al., 2013; Konte and Ndubuisi, 2021). These variables capture fundamental dimensions of firm heterogeneity that influence both baseline performance and firms' capacity to absorb and respond to electricity supply–related shocks. Their inclusion thus ensures that the estimated effects are not driven by systematic differences in firm characteristics that are correlated with sectoral energy vulnerability or adjustment capacity.

Beginning with firm age, we included it to account for life-cycle effects in firm behavior across all three outcome variables. A large body of empirical evidence shows that firm age is a key determinant of exports, investment, and employment growth (Farla, 2014; Barba Navaretti et al., 2014; Wagner, 2015; Banerjee and Jesenko, 2016; Liu, 2024). Younger firms often face a “liability of newness,” which constrains investment and employment expansion and reduces the likelihood of export participation. Older firms, by contrast, benefit from accumulated experience, established supplier–buyer relationships, and improved access to finance, which can stabilize employment and support sustained investment and exporting. However, age-related advantages may also be accompanied by organizational rigidities that limit adaptability, potentially amplifying vulnerability during systemic shocks such as electricity crisis. Controlling for firm age therefore helps to isolate electricity-related effects from maturity-driven performance differences. To compute the age variable, we rely on the firm's incorporation year, subtracting it from the year variable as provided in the SARS–NT dataset.

Firm size captures scale effects that are central to export participation, capital investment, and employment levels (Hirsch and Adar, 1974; Farla, 2014; Banerjee and Jesenko, 2016; Hernández, 2020; Konte and Ndubuisi, 2021; Liu, 2024), and may also shape firms' responses to supply disruptions arising from electricity crisis. The theoretical direction of this relationship is ambiguous. On the one hand, larger firms may

[2] Maskus et al. (2019) examine how patent protection interacts with sector patent intensities to determine sectoral R&D intensities and how this relationship differs across countries at different levels of financial development.

[3] Nonetheless, in the Appendix, we show results using the intensive margin, which entails estimating the differential effect of the electricity crisis on the actual reported positive export values.

be better equipped to absorb electricity shocks through diversification, internal reallocation of resources, or investment in backup power. On the other hand, large firms often operate complex, energy-intensive production systems with high fixed costs and limited short-run flexibility, making them particularly sensitive to electricity disruptions. In contrast, small and medium-sized enterprises typically rely on simpler production processes and smaller workforces, which may reduce their exposure to electricity instability. Empirical evidence supports this ambiguity. Cole et al. (2018), for example, show that power outages reduce firm sales across all firm sizes in sub-Saharan Africa, but the effects are more pronounced for large firms. Including firm size therefore ensures that sectoral energy vulnerability effects are not conflated with scale-related differences in exposure or resilience. In our analysis, firm size is captured by a dummy variable equal to one if a firm's gross sales exceed the sample median (large), and zero (small) if otherwise.

Labor productivity proxies for firm efficiency, which is strongly associated with export competitiveness, investment decisions, and labor demand (see Hirsch and Adar, 1974; Yasar et al., 2006; Autor and Salomons, 2017; Avenyo et al., 2019; Hernández, 2020; Konte and Ndubuisi, 2021). However, productivity differences may also influence firms' ability to reorganize production processes or adopt energy-saving technologies in response to electricity supply volatility. Controlling for labor productivity therefore helps disentangle efficiency-driven performance from electricity-related constraints. We operationalize labor productivity as the ratio of firm sales to total employment.

Financial status captures firms' overall financial health and access to external finance, which are critical for sustaining investment, retaining workers, and maintaining export relationships during periods of infrastructure instability (Fazzari and Petersen, 1993; Ding et al., 2013; Konte and Ndubuisi, 2021; Demirhan and Aldan, 2021). Firms with stronger financial positions are able to smooth temporary shocks, finance capital expenditures, and avoid layoffs when production is disrupted by electricity shortages. Conversely, financially constrained firms may reduce investment, scale back employment, or exit export markets altogether. Controlling for financial status therefore allows us to distinguish energy-driven effects from liquidity-driven adjustments. Following Hottenrott et al. (2016), we proxy firm financial status using working capital, defined herewith as total current assets minus total current liabilities.

Foreign ownership accounts for systematic differences in firm behavior associated with multinational affiliation. Foreign-owned firms are typically more export-oriented, more capital intensive, and more productive than domestically owned firms (see Sjöholm, 2003; Harris and Robinson, 2003; Yaşar and Paul, 2009; Konte and Ndubuisi, 2021; Ndubuisi et al., 2025b), and are often associated with higher employment growth (Karlsson et al., 2009; Lipsey et al., 2013). They also benefit from access to internal capital markets and superior technologies (Markusen, 1995; Bu et al., 2019), which can stabilize investment and employment during electricity shocks. Accounting for foreign ownership in our model thus ensures that the estimated effects are not confounded by ownership-related differences across firms. We capture foreign ownership with a dummy variable equal to one if the firm's ultimate holding company is resident outside South Africa, and zero otherwise.

Finally, foreign connections capture firms' degree of international integration beyond ownership status, such as participation in international supply chains or relationships with foreign buyers or suppliers. Such connections can improve access to capital, technology, and alternative production arrangements. Other things equal, this can affect directly affect firm performance as well as indirectly by potentially enhancing resilience to electricity shocks. Controlling for foreign connections, therefore, helps disentangle electricity-related effects from advantages or constraints associated with international linkages. In our model, foreign connection is captured by a dummy variable equal to one if a South African firm reports having a foreign connection, and zero otherwise.

3.2.3. Energy vulnerability

The sector energy vulnerability index is based on Ndubuisi et al. (2025a). The original data used by the authors to compute the index rely on the input-output (IO) table from the Quantec statistical database. The data cover IO linkages across 91 sectors at the three-digit SIC code in South Africa.[4] The authors proceeded in three steps to compute the index. First, they computed indicators of each of the 91 sectors' forward and backward linkages to the energy sector.[5] Second, they sum the backward and forward indicators to generate a sector-specific energy vulnerability index. Third, they normalize the resulting index to have a minimum value of zero and a maximum value of one. Ultimately, higher values of the resulting index imply higher energy vulnerability intensity—i.e. the higher, the more vulnerable the sector is to shocks in the energy sector. Our analysis relies on an extracted sample comprising only manufacturing sectors. Furthermore, our analysis relies on the gross energy vulnerability measure (which includes both the backward and forward component) of each of these sectors. For completeness, however, we show results using the subcomponents in the baseline estimate.

Intuitively, the core idea behind the energy vulnerability index is that a sector's susceptibility to energy supply and demand shocks stems from its degree of backward and forward dependence on the electricity sector. In this sense, the more electricity serves as an intermediate input to a sector's output, the more vulnerable that sector is to any shock in the electricity sector. Similarly, the more the electricity sector consumes a sector's output, the more vulnerable that sector is to any shock in the electricity sector. Ultimately, the index captures the strength of a sector's linkages to the electricity sector, with higher values indicating a stronger linkage and, consequently, greater susceptibility to electricity supply or demand shocks.

Using the three-digit sector description in the Quantec dataset, we manually map the sector energy vulnerability index to the three-digit sectors with comparable names in the CIT-IRP5 datasets. To maximize the mapping, we aggregated some of the sectors in the Quantec database to match the three-digit SIC classification in the CIT-IRP5 datasets (see Table A1 in the Appendix). We successfully mapped the energy vulnerability index to 80% of the three-digit manufacturing SIC sectors in the CIT-IRP5 datasets. About 51% of these successfully mapped sectors were unique matches, while the rest were achieved after reaggregating the sectors in the Quantec dataset. In all, we obtained 41 unique sectors for which our analysis relies on.

While Ndubuisi et al. (2025a) computed the index for the period 1993 to 2021, we restrict the observation to the period spanning 2008–21 for which we have corresponding firm-level information from the CIT-IRP5 dataset. As previously noted, our study explores the sector-specific energy vulnerability as an innate technological attribute. Therefore, to smooth the temporal fluctuations and reduce the effect of outliers, as is conventional in the related literature (see Rajan and Zingales, 1998; Chen, 2017; Turco et al., 2019), we aggregate each sector's energy vulnerability across the year using the median value.

Table 1 provides a summary statistic of the sector energy vulnerability considered in our analysis. The average energy vulnerability intensity is 0.19 with a standard deviation of 0.16. The median sector has an energy vulnerability intensity of 0.13. The three sectors with the least energy vulnerability intensity in our final sample include (in consecutive order) 'Household appliances (QSIC 358)' with an energy vulnerability intensity of 0.017, 'Other electrical equipment (QSIC 364_366)' with an energy vulnerability intensity of 0.018, and 'Motor vehicles (QSIC 381_382)' with an energy vulnerability intensity of 0.018. Conversely,

[4] Note that the 91 sectors include non-manufacturing sectors.

[5] The authors computed forward linkage as the relative share of the energy subsector in the total inputs used in other subsectors, while they computed backward linkage as the relative dependence of the electricity and gas subsector on the domestic output of other subsectors for its production.

Table 1
Energy vulnerability intensity.

SIC	SIC description	Energy vulnerability
358	Household appliance	0.017
364_366	Other electrical equipment	0.018
381_382	Motor vehicle	0.018
305	Beverages	0.023
383	Parts & accessories	0.033
371_373	Radio, television, & communication apparatus	0.047
374_376	Professional equipment	0.052
361_362	Electric motors, generators, transformers; electricity distribution & control apparatus	0.060
314	Wearing apparel	0.062
306	Tobacco	0.067
311	Textiles	0.082
363	Insulated wire & cables	0.092
317	Footwear	0.096
323	Paper & paper products	0.097
359	Office, accounting, computing machinery	0.101
342	Non-metallic mineral products	0.104
356	General purpose machinery	0.110
335_336	Other chemical products	0.112
301	Meat, fish, fruit, etc.	0.114
303	Grain mill products	0.123
321	Sawmilling & planning of wood	0.131
357	Special purpose machinery	0.132
302	Dairy products	0.137
304	Other food products	0.143
391	Furniture	0.154
315_316	Leather and leather and fur products	0.167
312	Other textile products	0.183
337	Rubber products	0.208
392_395	Other manufacturing groups	0.264
354	Structural metal products	0.264
338	Plastic products	0.279
384_387	Other transport equipment	0.288
322	Products of wood	0.310
334	Basic chemicals	0.316
355	Other fabricated metal products	0.349
324_326	Printing, recorded media	0.410
341	Glass & glass products	0.449
351	Basic iron and steel products	0.467
352	Non-ferrous metal products	0.514
313	Knitted, crocheted articles	0.601
331_333	Coke, petroleum products, & nuclear fuel	0.606

Original series were computed using the input-output table on the universe of sectors in the South African economy. The table therefore shows only a subsample energy vulnerability intensity of manufacturing sectors covered in our sample.
Source: authors' calculations using data from Ndubuisi et al. (2025a).

the three sectors with the highest energy vulnerability intensity in our sample include (in consecutive order) ‘Non-ferrous metal products (QSIC 352)’ with an energy vulnerability intensity of 0.514, ‘Knitted, crocheted articles (QSIC 313)’ with an energy vulnerability intensity of 0.6, and ‘Coke, petroleum products, and nuclear fuel (QSIC 331_333)’ with an energy vulnerability intensity of 0.605.

Comparing our sector energy vulnerability index to those in Ndubuisi et al. (2025a), we observe that the ranking of each sector's energy vulnerability is similar, albeit the intensity level differs. This difference stems from the sample coverage. As previously noted, our sample covers the period spanning 2008–21, while Ndubuisi et al. (2025a) cover the period spanning 1993–2021. Further, besides the sectors at the right and left tails of the index's distribution, we also observe slight differences in some of the rankings of the sectors in our sample when compared to those in Ndubuisi et al. (2025a). This difference is largely driven by the sector reaggregation we did to ensure comparability between the sectors in the Quantec and CIT-IRP5 datasets, respectively.

Table 2 reports mean difference tests comparing low-vulnerability and high-vulnerability energy-intensive sectors, focusing on the three key outcome variables of the study: employment, investment, and exports. High-vulnerability energy-intensive sectors are defined as those with energy vulnerability intensity above the sample median, while sectors below the median are classified as low-vulnerability. The results show that, across all three outcome variables, the mean differences between the two groups are statistically significant at the 1% level, indicating systematic differences in economic performance between low- and high-vulnerability energy-intensive sectors.

Table 2
Mean difference test between low and high energy vulnerability intensity.

	Low energy Vulnerability ($N = 40,417$)	High Energy Vulnerability ($N = 90,716$)	t value
Jobs (log)	3.85	3.65	22.6***
Investment	0.21	0.23	−15.5***
Export	0.34	0.27	26.5***

*** Significant at 1%.

3.2.4. *Electricity crisis*

One of the hallmarks of South Africa's electricity crisis is the underperformance of its power plants, as about 80% of them have reached or passed their mid-life cycle, leading to insufficient capacity to generate and reticulate electricity (Ndubuisi et al., 2025a). Ultimately, the country has resulted to regular enforced power cuts since 2007 to keep the lights on in the country. An ideal measure of the crisis in this context would be to exploit the introduction of loadshedding in 2007 as an exogenous electricity supply shock in the country and then examine how firms respond to it (see Ndubuisi et al., 2025a). Unfortunately, the CIT-IRP5 dataset only starts in 2008. As an alternative approach, therefore, we exploit variations in the country's electricity capacity factor to capture the trends in the country's electricity crisis.

Fig. 1 shows the evolution of South Africa's electricity capacity factor (ECF) from 1985 to 2021. We compute the variable as the ratio of the country's total electricity generated in a year to its total electricity-generating capacity in that year. The original data used to compute the variable are sourced from the EIA database. Higher values of ECF means better electricity-generating performance. Hence, Fig. 1 shows that the country's ECF has consistently declined since 2007, the year that the country witnessed its first loadshedding. The trends in the country's electricity crisis are therefore reflected and captured in the ECF. Since our study focuses on the electricity crisis, rather than merely employing the level variation in the country's ECF, we compute and use the volatility of the log-transformed ECF as an empirical measure of the electricity crisis. In this case, higher values of the resulting index would imply higher cyclicality and, therefore, a bad state.[6]

To measure the ECF volatility, we compute the rolling standard deviation of ECF over a three-year window. Since one of the weaknesses of this approach is that the window is arbitrarily chosen, we test the robustness of our results to ECF volatility computed based on five-year and seven-year windows, respectively. We rely on the long ECF series—that is, 1985–2021—to compute the volatility measure, after which we extract the time span that corresponds to observation in the CIT-IRP5 dataset—i.e. 2008–21.[7] In the robustness check, we also directly use the ECF in a regression, multiplying the variable by a negative constant such that higher values of the resulting index would mean poor electricity performance. Further, we use the electricity generation per capita, multiplying the variable also by a negative constant to obtain the inverse wherein the higher values would suggest poor electricity performance.

[6] In an unreported result, we have directly used the ECF when estimating Equation 1. As expected in this case, the coefficient of the interaction term turns out positive and statistically significant, implying that the better ECF the better the performance of firms with energy-intensive vulnerable firms being disproportionately better off. However, we opt to rely on estimation based on the volatility measure as it is better attuned with the concept and idea of a crisis.

[7] We use the ‘rangestat’ Stata routine to compute the standard deviation for the respective window periods.

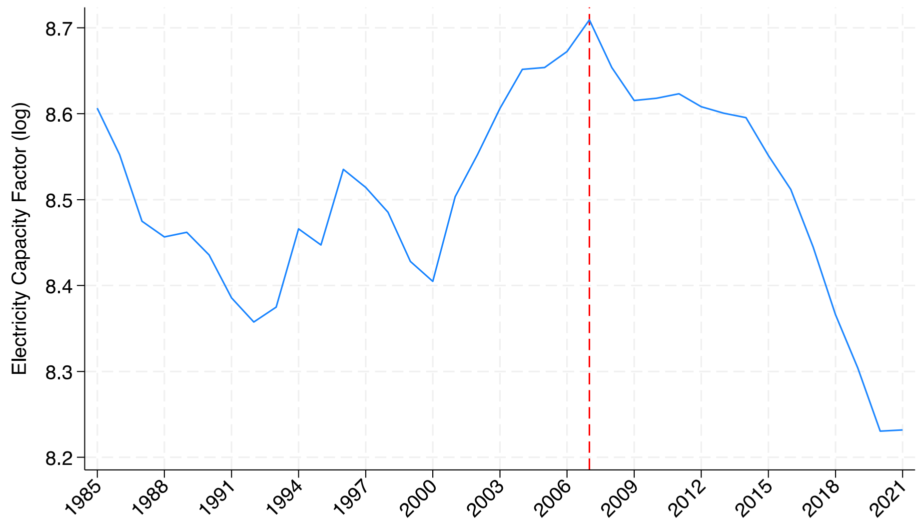

Fig. 1. Evolution of South Africa's electricity capacity factor (ECF).
ECF is computed as the ratio of South Africa's total electricity generated in a year to its total electricity generating capacity in that year. The red reference line shows the beginning of the electricity in 2007.
Source: authors' calculations using data from the EIA (2024) database.

Data used to compute these alternative indicators are all sourced from the Energy Information Administration (EIA) database.

After data cleaning, processing and merging, our final sample comprises an unbalanced panel of about 23,436 firms. Table 3 provides a basic summary of the variables included in our analysis. The variables on foreign connection and ownership structure are directly sourced from the database. The rest of the variables (age, size, labour productivity, working capital, ownership structure, and foreign connection) were computed using data series that were retrieved from the database.

4. Results and discussion

4.1. Baseline regression: main results

4.1.1. The effect of the electricity crisis on jobs

Table 4 presents the key results on manufacturing employment. Column (1) reports estimate from a specification that includes only the sector energy vulnerability index and its interaction with the electricity crisis indicator, conditioning on year and firm fixed effects. The energy vulnerability index enters positively and is significant at the 10% level. By contrast, the interaction term is negative and statistically significant at the 5% level. This indicates that electricity crisis reduces manufacturing employment, with the adverse effect being more severe for firms in energy-intensive vulnerable sectors. In Column (2), we introduce firm-level controls. The inclusion of these covariates does not alter the main finding: the coefficient of the interaction term remains negative and statistically significant, with only a marginal change in magnitude—rising slightly from 1.6 in Column (1) to 1.7 in Column (2).

Column (3) incorporates sector fixed effects, while excluding the controls. Column (4), on the other hand, includes the controls consistent with our baseline specification. The results in both Columns remain robust. The coefficient of the interaction term is nearly identical to earlier estimates, suggesting that the findings are not driven by unobserved heterogeneity at either the firm or sector level. In terms of economic significance, the preferred specification in Column (4) shows that for a firm in a sector with average energy vulnerability (0.19), a one--standard deviation increase in the crisis variable reduces employment by roughly 1%. The effect, however, varies sharply by sector as shown in Fig. 2: the same shock reduces jobs by only 0.08% in the Household Appliances sector (QSIC 358)—the least energy-vulnerable—but by as much as 3.2% in the Coke, Petroleum Products, and Nuclear Fuel sector (QSIC 331_333)—the most energy-vulnerable.

These findings resonate with Ndubuisi et al. (2025a), who document a negative association between the ongoing electricity crisis and sectoral manufacturing jobs, especially in energy-intensive industries. They also corroborate Mensah (2024), who shows that negative electricity supply shocks destroy jobs. Our study contributes to this literature by offering firm-level evidence from South Africa, highlighting that the extent of employment loss depends critically on the degree of exposure to electricity vulnerability.

Although our primary focus is on overall energy vulnerability, Columns (5)–(7) disaggregate the energy vulnerability into forward and backward linkages component. Column (5) excludes sector fixed effects and firm characteristics. Column (6) includes firm characteristics while still excluding sector fixed effects. Column (7) shows the result when we include the sector fixed effects. Across the three columns, only the coefficient of the interaction term involving forward linkage is statistically significant. This suggests that employment losses from electricity crises are especially acute for firms supplying inputs to the electricity sector.

Turning to control variables, most coefficients are positive and statistically significant, except for labor productivity. The negative coefficient on labor productivity supports the broader argument that technological improvements, while boosting output, may reduce labor demand as fewer workers are required per unit of output (Autor and Salomons, 2017). By contrast, the positive effect of foreign ownership aligns with Karlsson et al. (2009) and Lipsey et al. (2013), who show that foreign ownership is associated with employment growth. Similarly, the positive impact of working capital on jobs is consistent with findings that financial constraints reduce firms' ability to create employment (Demirhan and Aldan, 2021).

4.1.2. The effect of the electricity crisis on investments

Table 5 reports our main findings on the capital investment of manufacturing firms. Column (1) includes only the sector energy vulnerability index and its interaction with the electricity crisis variable, while controlling for year and firm fixed effects. The coefficient of the vulnerability index is positive, but the interaction term is negative and statistically significant at the 5% level. In Column (2), we add firm-level controls. Column (3) shows the result when we add the sector fixed effects, while excluding the firm characteristics. In Column (4), we reintroduce the firm characteristics, while controlling sector fixed effects. Across the four columns, the interaction term remains negative and

Table 3
Variable definition and descriptive statistics.

Variable	Descriptions	Obs	Mean	Std. dev.	Min	Max
Jobs	total number of employees (log)	131,133	3.715	1.449	0.000	10.728
Investment	Ratio of total capital expenditure to total asset	131,133	0.224	0.235	0.000	9.981
Export Dummy	=1 if a firm exports and = 0 if otherwise	131,133	0.290	0.454	0.000	1.000
Export Value	Export value (log)	37,992	14.344	2.674	0.000	24.566
Age	Log (age)	131,133	3.393	0.683	0.000	8.298
Foreign Ownership	=1 if a firm states that its ultimate holding company is resident outside South Africa; and = 0 otherwise	131,133	0.037	0.188	0.000	1.000
Firm Size	=1 if firm gross sales > sample median and = 0 if otherwise	131,133	0.500	0.500	0.000	1.000
Labor Productivity (log)	Ratio of sales to total employment (log)	130,407	9.181	1.314	0.000	17.613
Foreign Connection	=1 if South African firm but has a foreign connection; and = 0 otherwise	131,133	0.035	0.185	0.000	1.000
Working Capital	Total current asset less total current liability (log)	131,127	6.003	8.413	−18.715	20.014
Electricity Crisis	Rolling standard deviation of electricity capacity factor (ECF) over a three-year window	131,133	0.047	0.031	0.006	0.091

The logged variables are computed using the inverse hyperbolic function. Export value captures the actual export values reported by firms. To derive export dummy, these values take the value one, while non-reporting firms take the value zero.

Table 4
Baseline: electricity crisis, energy vulnerability and jobs.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Electricity crisis × energy vulnerability	−1.6042**	−1.7366***	−1.5787**	−1.7000***			
	(0.700)	(0.610)	(0.702)	(0.613)			
Energy Vulnerability	0.0999*	0.0622					
	(0.054)	(0.045)					
Electricity crisis × energy vulnerability (backward)					−0.5828	−0.7017	−0.6571
					(0.613)	(0.533)	(0.535)
Energy vulnerability (backward)					0.0903**	0.0503	
					(0.045)	(0.037)	
Electricity crisis × energy vulnerability (forward)					−1.9645***	−1.9989***	−1.9859***
					(0.656)	(0.568)	(0.569)
Energy vulnerability (forward)					0.0396	0.0316	
					(0.051)	(0.043)	
Age (log)		0.3452***		0.3447***		0.3450***	0.3446***
		(0.020)		(0.020)		(0.020)	(0.020)
Foreign Ownership		0.0928***		0.0926***		0.0925***	0.0923***
		(0.031)		(0.031)		(0.031)	(0.031)
Firm Size		0.6101***		0.6097***		0.6099***	0.6096***
		(0.012)		(0.012)		(0.012)	(0.012)
Labor Productivity (log)		−0.2616***		−0.2614***		−0.2615***	−0.2614***
		(0.012)		(0.012)		(0.012)	(0.012)
Foreign Connection		0.1802***		0.1801***		0.1807***	0.1807***
		(0.029)		(0.029)		(0.029)	(0.029)
Working Capital (log)		0.0025***		0.0025***		0.0025***	0.0025***
		(0.000)		(0.000)		(0.000)	(0.000)
Constant	3.7291***	4.6519***	3.7512***	4.6657***	3.7304***	4.6531***	4.6660***
	(0.010)	(0.130)	(0.008)	(0.130)	(0.010)	(0.130)	(0.130)
Observations	127,595	126,867	127,595	126,867	127,595	126,867	126,867
R-squared	0.917	0.937	0.917	0.937	0.917	0.937	0.937
Year FE	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	YES	YES	NO	NO	YES

Standard errors in parentheses are clustered at the sector-firm level. The dependent variable is the log of total number of employees. The logged variables are computed using the inverse hyperbolic function. The electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

statistically significant at the 5% level. The consistency in both sign and magnitude across specifications suggests that the results are not driven by omitted firm- or sector-level heterogeneity.

In terms of economic significance, the coefficient of the interaction term in Column (4) implies that a one–standard deviation increase in the electricity crisis reduces capital investment by 0.23% for a firm in a sector with the average energy vulnerability intensity (0.19). The effects vary substantially across industries as shown in Fig. 3. For instance, in the least vulnerable sector, the reduction is only 0.02%, while in the most vulnerable sector, the decline reaches 0.8%. These results show that the electricity crisis not only erodes manufacturing jobs (as demonstrated in Table 4), but also significantly dampens capital investment, with the effect being more severe for firms in sectors with higher energy vulnerability.

This finding aligns with evidence from other contexts. Sadath and Acharya (2015) find that energy price increases in India reduced firm-level investment, while Abeberese (2020) shows that electricity rationing in Ghana led to lower investments in plant and machinery, especially in electricity-intensive sectors. Our study contributes to this literature by offering a novel measure of sectoral electricity vulnerability—capturing both backward and forward linkages to the electricity sector—rather than relying solely on electricity expenditure shares.

Columns (5) and (7) further explore these linkages by disaggregating vulnerability into forward and backward components. The interaction terms remain negative and statistically significant at conventional levels in columns (5) and (6). However, only that of forward linkage remained

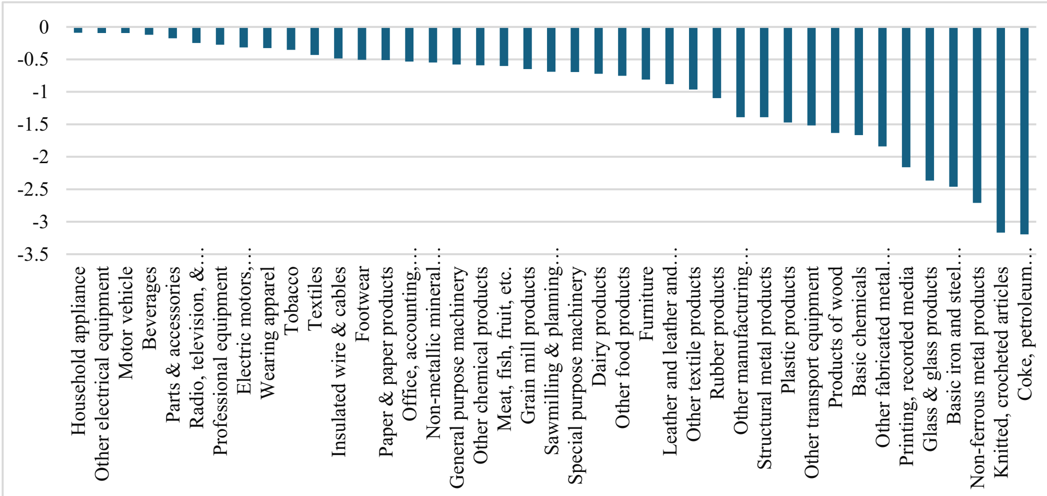

Fig. 2. Jobs effects of electricity crisis by sector energy vulnerability..
The marginal effects are computed based on a standard deviation expansion in energy crisis.

Table 5
Baseline—electricity crisis, energy vulnerability and investment.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Electricity crisis × Energy vulnerability	−0.3909**	−0.4149**	−0.3781**	−0.4015**			
	(0.173)	(0.169)	(0.173)	(0.170)			
Energy Vulnerability	0.0322**	0.0331***					
	(0.013)	(0.013)					
Electricity crisis × Energy vulnerability (backward)					−0.2343	−0.2434*	−0.2317
					(0.150)	(0.147)	(0.147)
Energy vulnerability (backward)					0.0253**	0.0255**	
					(0.011)	(0.011)	
Electricity crisis × Energy vulnerability (forward)					−0.3885**	−0.4101**	−0.4016**
					(0.170)	(0.167)	(0.167)
Energy vulnerability (forward)					0.0223*	0.0232*	
					(0.012)	(0.012)	
Age (log)		−0.0394***		−0.0393***		−0.0394***	−0.0393***
		(0.005)		(0.005)		(0.005)	(0.005)
Foreign Ownership		0.0035		0.0035		0.0034	0.0035
		(0.005)		(0.005)		(0.005)	(0.005)
Firm Size		−0.0001		−0.0000		−0.0001	−0.0000
		(0.003)		(0.003)		(0.003)	(0.003)
Labor Productivity (log)		−0.0027**		−0.0027**		−0.0027**	−0.0027**
		(0.001)		(0.001)		(0.001)	(0.001)
Foreign Connection		0.0021		0.0020		0.0021	0.0021
		(0.004)		(0.004)		(0.004)	(0.004)
Working Capital (log)		−0.0035***		−0.0035***		−0.0035***	−0.0035***
		(0.000)		(0.000)		(0.000)	(0.000)
Constant	0.2211***	0.4014***	0.2282***	0.4082***	0.2211***	0.4015***	0.4085***
	(0.002)	(0.020)	(0.002)	(0.020)	(0.002)	(0.020)	(0.020)
Observations	127,595	126,867	127,595	126,867	127,595	126,867	126,867
R-squared	0.763	0.769	0.763	0.770	0.763	0.769	0.770
Year FE	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	YES	YES	NO	NO	YES

Standard errors in parentheses are clustered at the sector-firm level. The dependent variable is the capital investment measured as the ratio of total capital expenditures to total assets. The logged variables are computed using the inverse hyperbolic function. The electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

significant in column (7)—our preferred specification, underscoring the forward linkage as the robust channel through which the crisis effect is passed down to the firm. Economically, the magnitude of the interaction term indicates that for a firm in a sector with an average forward vulnerability of 0.082, a one–standard deviation increase in the electricity crisis reduces investment by about 0.10%.

Finally, among the firm-level controls, only age, size, and working capital emerge as significant. Older firms are less likely to invest, consistent with declining expansion needs, while larger firms invest more, reflecting greater capacity and resources. The negative coefficient on working capital underscores the financing trade-off between liquidity and long-term investment, in line with classic findings by Fazzari and Petersen (1993) and Ding et al. (2013).

4.1.3. The effect of the electricity crisis on exports

Electricity supply shocks have profound implications for firms' export behavior and capacity. Electricity shortages raise operational costs, undermine product quality, and erode international

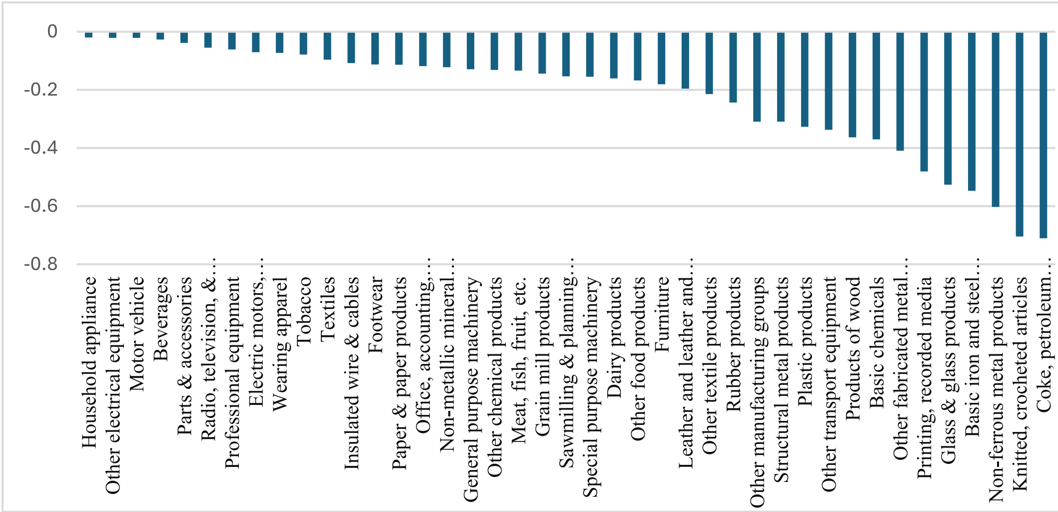

Fig. 3. Investment effects of electricity crisis by sector energy vulnerability.
The marginal effects are computed based on a standard deviation expansion in energy crisis.

competitiveness. They also generate production delays that cascade into supply chain disruptions. Yet, despite the growing literature on the firm-level consequences of electricity shocks, little is known about their effect on firms' export activities. We address this gap by providing novel evidence on how electricity shortages shape the extensive export margin of South African manufacturing firms.

Table 6 reports the core results. The dependent variable is a binary indicator that takes the value one if a firm exports and zero if otherwise. The table is structured analogously to Tables 4 and 5. Column (1) includes only the energy vulnerability index and its interaction with the electricity crisis indicator, conditioning on year and firm fixed effects. The interaction coefficient is negative and statistically significant at conventional levels, implying that the electricity crisis reduces the probability of exporting, with the effect being higher for firms in sectors with higher energy vulnerability intensity.

Column (2) introduces firm-level controls. Column (3) adds sector fixed effects, while excluding the firm-level controls. Column (4) reintroduces the controls, while retaining the sector fixed effects. Across the

Table 6
Baseline—electricity crisis, energy vulnerability, and export.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Electricity crisis × Energy vulnerability	−0.4983*	−0.4966*	−0.5059*	−0.5039*			
	(0.269)	(0.268)	(0.269)	(0.268)			
Energy Vulnerability	0.0829***	0.0840***					
	(0.021)	(0.021)					
Electricity crisis × Energy vulnerability (backward)					−0.2149	−0.2213	−0.2218
					(0.239)	(0.238)	(0.239)
Energy vulnerability (backward)					0.0698***	0.0699***	
					(0.017)	(0.017)	
Electricity crisis × Energy vulnerability (forward)					−0.5349**	−0.5236**	−0.5314**
					(0.250)	(0.249)	(0.249)
Energy vulnerability (forward)					0.0422**	0.0440**	
					(0.020)	(0.019)	
Age (log)		0.0875***		0.0874***		0.0874***	0.0873***
		(0.008)		(0.008)		(0.008)	(0.008)
Foreign Ownership		0.0080		0.0080		0.0079	0.0079
		(0.010)		(0.010)		(0.010)	(0.010)
Firm Size		0.0531***		0.0531***		0.0531***	0.0530***
		(0.005)		(0.005)		(0.005)	(0.005)
Labor Productivity (log)		0.0099***		0.0099***		0.0099***	0.0099***
		(0.002)		(0.002)		(0.002)	(0.002)
Foreign Connection		0.0081		0.0084		0.0081	0.0085
		(0.009)		(0.009)		(0.009)	(0.009)
Working Capital (log)		0.0003**		0.0003**		0.0003**	0.0003**
		(0.000)		(0.000)		(0.000)	(0.000)
Constant	0.2799***	−0.1375***	0.2986***	−0.1184***	0.2804***	−0.1369***	−0.1185***
	(0.004)	(0.031)	(0.003)	(0.031)	(0.004)	(0.031)	(0.031)
Observations	127,595	126,867	127,595	126,867	127,595	126,867	126,867
R-squared	0.773	0.775	0.774	0.775	0.773	0.775	0.775
Controls	NO	YES	NO	YES	NO	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	YES	YES	NO	NO	YES

Standard errors in parentheses are clustered at the sector-firm level. The dependent variable is a dummy variable that takes the value of one if a firm exports and zero otherwise. The electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

specifications, the coefficient of the interaction term remains negative and statistically significant at the 10% level, with magnitudes that are remarkably stable across columns. This consistency underscores that the results are not driven by omitted firm- or sector-level heterogeneity. In terms of economic significance, Fig. 4 reports the marginal response across the sectors. Columns (5) to (7) disaggregate the results into backward and forward linkages. In all cases, the interaction coefficient enters negatively, but only the forward linkage is statistically significant. This suggests that the adverse export effects are most pronounced for firms, with forward linkage to the electricity sector.

Appendix Table A3 reports results for the intensive export margin. Here, the evidence is even stronger, specifically in columns (2) and (3): the interaction term is negative and statistically significant at the 5% level across those specifications. This finding show that electricity crises suppress not only the decision to export but also the intensity of export activity, with the impact most severe in sectors characterized by high energy vulnerability.

Turning to firm-level characteristics, Table 6 indicates that firm age, size, and labor productivity are consistently positive and statistically significant determinants of export participation. These findings are corroborated in the intensive margin regressions (Appendix Table A3), where foreign connections and working capital also emerge as significant and positive. The positive role of firm age suggests that older firms are more likely to export, aligning with Wagner (2015). Similarly, the positive coefficients on firm size and productivity are consistent with prior evidence that larger and more efficient firms have a comparative advantage in exporting (Hirsch and Adar, 1974; Yasar et al., 2006; Hernández, 2020; Konte and Ndubuisi, 2021).

Overall, the results paint a clear picture: electricity crises constrain South African manufacturing firms' export performance both at the extensive and intensive margins. These constraints disproportionately affect energy-vulnerable sectors, amplifying structural weaknesses and eroding firms' ability to compete in global markets.

4.2. Baseline regressions: robustness checks

The results in the previous section demonstrate that South Africa's ongoing electricity crisis has significantly undermined jobs, capital investment, and exports, with the adverse effects most pronounced in energy-vulnerable sectors. In this section, we conduct a series of sensitivity checks to test the robustness of these findings.

First, our empirical framework may be subject to serial correlation, which could bias the estimation of standard errors. Previous studies have addressed this concern by modeling standard errors in alternative ways to guard against underestimation. Following this approach, we re-estimate our models using alternative specifications of the standard error. Appendix Table A4 reports results under the robust option, while Appendix Table A5 presents results with standard errors clustered at the firm level. In both cases, the results remain consistent with the baseline, reinforcing the reliability of our estimates.

Second, one of the key identification assumptions in Section 3.1 is that unobserved factors affecting $\widehat{A}_{ijt}$ are uncorrelated with the interaction term $\left(EC_t \times EV_j\right)$. To examine the sensitivity of our results to this assumption, we interact the crisis variable with additional sector-level characteristics, including labor productivity, the capital–labor ratio, trade openness, and real output. Data for these sectoral indicators are drawn from the Quantec statistical database.[8] Appendix Table A6 reports the results. Columns (1), (3), and (5) present specifications without sector fixed effects, while Columns (2), (4), and (6) include sector fixed effects. Across all specifications, the coefficient of $\left(EC_t \times EV_j\right)$ remains negative and statistically significant at conventional levels, suggesting that our baseline results are not confounded by these alternative sectoral characteristics.

Third, we test whether our findings are sensitive to the measurement of the electricity crisis variable. In the baseline analysis, crisis intensity is measured as the rolling three-year standard deviation of the electricity capacity factor (ECF). To ensure robustness, we recompute crisis volatility using five-year and seven-year rolling windows. Appendix Tables A7 and A8 report these results. In both cases, the interaction coefficient remains negative and statistically significant, confirming that the electricity crisis reduces employment, depresses capital investment, and constrains exports, with particularly severe effects for firms in energy-intensive vulnerable sectors.

Finally, we test alternative constructions of the crisis variable. Appendix Table A9 reports results when the crisis measure is defined as the inverse of the ECF, while Appendix Table A10 uses the inverse of the ratio of annual electricity generation to total population. Across both alternative measures, the results remain consistent with the baseline findings.

Taken together, these robustness checks demonstrate that our main results are not sensitive to serial correlation adjustments, alternative sectoral interactions, or different constructions of the electricity crisis variable. The evidence therefore strongly supports the conclusion that South Africa's electricity crisis has had a persistent and disproportionately negative impact on employment, investment, and exports, especially in electricity-vulnerable sectors.

4.3. Electricity crises, electricity vulnerability, and heterogenous firm response

Thus far, our analysis relied on the implicit assumption that firms within the same sector react uniformly to the electricity crisis. We relax this assumption in this section, exploring the role of firm characteristics in influencing how firms are affected by the ongoing electricity crisis in the country. We particularly examine how firm ownership structure, age, and financial status interact with a firm's electricity vulnerability to determine the effect of the ongoing electricity crisis on firm outcomes.

4.3.1. Firms' response to electricity crisis: the role of foreign ownership status

Foreign-owned firms may be more resilient to negative electricity supply shocks because they can draw on international networks and resources that provide strategic buffers against local disruptions (Dollar et al., 2005). In addition, foreign-owned firms often operate with superior technologies and infrastructure—ranging from advanced IT systems and automation to energy management solutions—that allow them to mitigate or moderate the impact of electricity crises. This perspective is consistent with Bu et al. (2019), who show that foreign direct investment (FDI) firms are typically more energy efficient than their domestic counterparts. All else equal, we therefore expect that foreign-owned firms would be less adversely affected by South Africa's ongoing electricity crisis than domestically owned firms.

Table 7 tests this hypothesis by splitting the sample according to ownership structure. Panel A presents results for domestic firms, while Panel B reports results for foreign-owned firms. The findings are interesting. For domestic firms, the coefficient of the interaction term remains negative and statistically significant across all specifications, indicating that electricity crisis significantly undermines their economic performance, especially in energy-intensive vulnerable sectors. By contrast, for foreign-owned firms, the interaction coefficient is statistically insignificant in every column. This suggests that their export activity, employment, and investment are largely insulated from the adverse effects of electricity disruptions.

4.3.2. Firms' response to electricity crisis: the role of financial status

Next, we examine the role of firm financial status, distinguishing between financially constrained and financially unconstrained firms.

[8] For each sector, we use the median value like in the case of the energy vulnerability intensity.

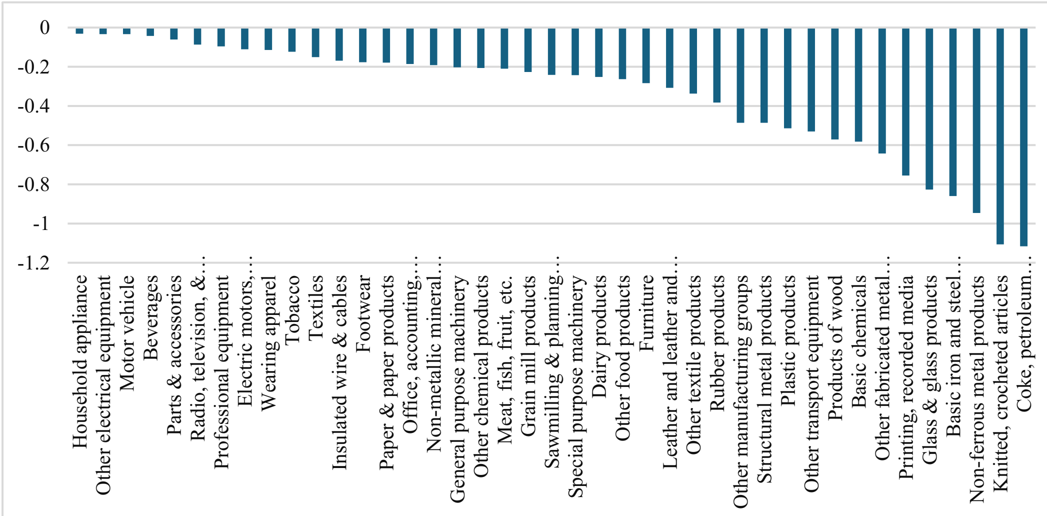

Fig. 4. Export effects of electricity crisis by sector energy vulnerability.
The marginal effects are computed based on a standard deviation expansion in energy crisis.

Table 7
Ownership structure and the real effect of the electricity crisis.

	Jobs			Investment			Export		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A: Domestic									
Electricity crisis × Energy vulnerability	−2.0657***	−1.8248**	−2.0403***	−0.4453**	−0.4315**	−0.4315**	−0.4752*	−0.4982*	−0.4834*
	(0.604)	(0.723)	(0.605)	(0.177)	(0.178)	(0.178)	(0.280)	(0.281)	(0.281)
Energy Vulnerability	0.0692			0.0344***			0.0877***		
	(0.043)			(0.013)			(0.022)		
Controls	YES	NO	YES	YES	NO	YES	YES	NO	YES
Constant	5.0696***	3.6848***	5.0847***	0.4086***	0.2311***	0.4158***	−0.1270***	0.2779***	−0.1071***
	(0.133)	(0.008)	(0.133)	(0.021)	(0.002)	(0.021)	(0.031)	(0.003)	(0.030)
Observations	121,941	122,665	121,941	121,941	121,941	121,941	121,941	122,665	121,941
R-squared	0.936	0.912	0.936	0.769	0.769	0.769	0.764	0.762	0.764
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	YES	NO	YES	YES	NO	YES	YES
Panel B: Foreign Firm									
Electricity crisis × energy vulnerability	−3.3955	−2.4545	−3.3330	0.5304	0.7752	0.5856	−0.3038	−0.0310	−0.1683
	(2.937)	(3.265)	(2.999)	(0.624)	(0.651)	(0.635)	(1.080)	(1.119)	(1.101)
Energy Vulnerability	0.7742*			−0.0072			−0.0234		
	(0.397)			(0.044)			(0.081)		
Controls	YES	NO	YES	YES	NO	YES	YES	NO	YES
Constant	3.5529***	5.5077***	3.7264***	0.3574***	0.1599***	0.3606***	0.2866	0.8115***	0.2811
	(0.396)	(0.031)	(0.390)	(0.071)	(0.006)	(0.072)	(0.207)	(0.010)	(0.206)
Observations	4668	4671	4668	4668	4671	4668	4668	4671	4668
R-squared	0.947	0.938	0.948	0.842	0.839	0.843	0.795	0.792	0.797
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	YES	NO	YES	YES	NO	YES	YES

Standard errors clustered at the sector-firm level in parentheses. Except for the foreign ownership variables that was excluded, all columns contain unreported firm characteristics as contained in Tables 4–6, ex. The dependent variable in columns 1 and 2 is the log of total number of employees. The dependent variable in columns 3 and 4 is capital investment measured as the ratio of total capital expenditure to total asset. The dependent variable in columns 5 and 6 is a dummy variable that takes the value of one if a firm exports and zero otherwise. The electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Conceptually, electricity crisis often compels firms to adopt costly coping strategies—such as investing in backup power systems, maintaining daily operations under duress, or deploying advanced technologies and automation to minimize disruption. These strategies require substantial financial resources. Financially constrained firms with tighter cash flows and limited liquidity struggle to finance such investments. They face difficulties covering the costs of prolonged downtime or repairing damages, such as replacing lost inventory, fixing equipment, or compensating customers for delayed deliveries.

Moreover, unlike financially unconstrained firms that typically maintain robust risk management frameworks and contingency plans, financially constrained firms possess less operational flexibility. They cannot easily shift production schedules, relocate activities, or make rapid adjustments in response to shocks. This limited adaptability leaves them more exposed to the adverse consequences of electricity crisis. In this case, constrained firms are structurally less capable of mitigating the crisis's impact on their economic activities and overall performance.

Table 8 provides empirical evidence on this mechanism. To identify

Table 8
Financial status and the real effect of the electricity crisis.

	Jobs			Investment			Export		
	(2)	(3)	(4)	(8)	(9)	(10)	(14)	(15)	(16)
Panel A: Financial Constrained									
Electricity crisis × Energy vulnerability	−1.9980***	−1.9452**	−1.9849***	−0.4462**	−0.4084**	−0.4319**	−0.5265*	−0.5578*	−0.5350*
	(0.640)	(0.784)	(0.642)	(0.205)	(0.206)	(0.206)	(0.294)	(0.295)	(0.295)
Energy Vulnerability	0.0667			0.0359**			0.0808***		
	(0.046)			(0.015)			(0.022)		
Controls	YES	NO	YES	YES	NO	YES	YES	NO	YES
Constant	4.8898***	3.5021***	4.9036***	0.4109***	0.2412***	0.4190***	−0.1612***	0.2318***	−0.1422***
	(0.139)	(0.009)	(0.139)	(0.023)	(0.002)	(0.023)	(0.032)	(0.003)	(0.031)
Observations	109,447	110,159	109,447	109,447	110,159	109,447	109,447	110,159	109,447
R-squared	0.924	0.895	0.924	0.759	0.759	0.759	0.735	0.733	0.735
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Panel B: Financial Unconstrained									
Electricity crisis × Energy vulnerability	−0.7144	−0.2770	−0.7712	−0.3271	−0.3490	−0.3308	−0.1023	−0.1380	−0.1519
	(1.410)	(1.494)	(1.432)	(0.265)	(0.267)	(0.267)	(0.700)	(0.710)	(0.707)
Energy Vulnerability	0.1244			0.0243			0.1239**		
	(0.152)			(0.022)			(0.060)		
Controls	YES	NO	YES	YES	NO	YES	YES	NO	YES
Constant	4.6546***	5.3629***	4.6875***	0.1873***	0.1471***	0.1873***	0.1395	0.7288***	0.1744
	(0.380)	(0.015)	(0.373)	(0.042)	(0.003)	(0.042)	(0.116)	(0.007)	(0.116)
Observations	16,494	16,500	16,494	16,494	16,500	16,494	16,494	16,500	16,494
R-squared	0.949	0.939	0.949	0.846	0.847	0.847	0.805	0.805	0.806
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES	YES	YES	YES

Standard errors clustered at the sector-firm level in parentheses. Except for the working capital variable that was excluded, all columns contain unreported firm characteristics as contained in Tables 4–7. The dependent variable in columns 1 and 2 is the log of total number of employees. The dependent variable in columns 3 and 4 is capital investment measured as the ratio of total capital expenditures to total assets. The dependent variable in columns 5 and 6 is a dummy variable that takes the value of one if a firm exports and zero otherwise. The electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

firms' financial status, we follow Hottenrott et al. (2016) and use working capital as the benchmark. Firms with working capital above the sample median are classified as financially unconstrained, while those below the median are considered financially constrained. Panel A reports the results for financially constrained firms, and Panel B for unconstrained firms. The results strongly support our argument. In Panel A, the estimated coefficient of the interaction term is negative and statistically significant across all columns, confirming that electricity crisis disproportionately harm financially constrained firms, with the effects amplified in energy-intensive sectors. By contrast, in Panel B the interaction coefficient is consistently statistically insignificant, suggesting that financially unconstrained firms are largely shielded from the negative effects of electricity disruptions.

Taken together, these findings underscore the critical role of financial capacity in shaping firms' vulnerability to electricity crisis. While all firms face challenges from supply shocks, financially constrained firms bear the brunt of the impact, lacking the resources to adapt or cushion themselves against sustained energy disruptions.

4.3.3. *Firms' response to electricity crisis: the role of firm age*

Older firms often face significant structural rigidities that amplify their vulnerability during systemic shocks such as electricity crises. A central challenge is path dependency: over time, older firms accumulate investments in specific technologies, routines, and organizational structures. These sunk costs create technological lock-in, making it prohibitively costly to pivot toward newer, more resilient energy solutions. As a result, even in the face of recurring electricity disruptions, they may continue relying on outdated systems that are ill-suited for resilience or competitiveness.

Organizational inertia further compounds this problem. Established firms often struggle to overcome internal resistance to change, whether due to entrenched management practices, bureaucratic processes, or concerns about the financial and operational risks of upgrading existing infrastructure. Large-scale overhauls of legacy production systems are not only complex but also costly, deterring rapid adaptation. Consequently, older firms tend to rely on legacy machinery and outdated infrastructure that are especially vulnerable to power interruptions, leaving them exposed to greater productivity losses and competitive pressures during electricity crisis.

By contrast, younger firms are generally more agile and adaptive. They are less encumbered by legacy infrastructure and are more likely to integrate modern, energy-efficient technologies from the outset. Their relatively smaller size also allows them to implement alternative strategies quickly—such as shifting production schedules, adopting distributed energy solutions, or reorganizing operations to cope with disruptions. This agility provides them with a degree of resilience that older firms often lack. Conceptually, therefore, one would expect the electricity crisis to impose disproportionately severe effects on older firms relative to younger ones.

Table 9 examines this hypothesis by splitting the sample into younger and older firms, using the median firm age as the threshold. Panel A reports results for younger firms, while Panel B presents results for older firms. The findings reveal a nuanced pattern. For younger firms, the coefficient of the interaction term is statistically insignificant across outcomes, suggesting that their employment, investment, and export activities are not significantly disrupted by the electricity crisis. For older firms, however, the interaction term is negative and statistically significant for jobs and capital investment. For export, the coefficient of the interaction term remains negative, but turns statisticallyinsignificant.

These results partially validate our theoretical expectations: older firms are indeed more vulnerable to electricity shocks in terms of employment and investment outcomes, while younger firms show greater resilience. The absence of a significant effect on exports for older

Table 9
Firm age and the real effect of the electricity crisis.

	Jobs			Investment			Export		
	(2)	(3)	(4)	(8)	(9)	(10)	(14)	(15)	(16)
Panel A: Younger Firms									
Electricity crisis × energy vulnerability	−1.5564	−1.3734	−1.4969	−0.4219	−0.3542	−0.4281	−0.3894	−0.4816	−0.3850
	(1.074)	(1.232)	(1.079)	(0.285)	(0.292)	(0.286)	(0.418)	(0.420)	(0.419)
Energy Vulnerability	0.0529			0.0204			0.0654**		
	(0.073)			(0.019)			(0.029)		
Controls	YES	NO	YES	YES	NO	YES	YES	NO	YES
Constant	5.6665***	3.5724***	5.6769***	0.3057***	0.2467***	0.3103***	0.0986***	0.2365***	0.1141***
	(0.147)	(0.012)	(0.147)	(0.014)	(0.003)	(0.014)	(0.021)	(0.004)	(0.021)
Observations	66,217	66,697	66,217	66,217	66,697	66,217	66,217	66,697	66,217
R-squared	0.928	0.907	0.928	0.768	0.761	0.769	0.772	0.771	0.772
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Panel B: Older Firms									
Electricity crisis × energy vulnerability	−2.2273***	−2.6685***	−2.2859***	−0.5165**	−0.4952**	−0.5171**	−0.5416	−0.5819	−0.5746
	(0.803)	(0.901)	(0.806)	(0.225)	(0.228)	(0.226)	(0.402)	(0.402)	(0.403)
Energy Vulnerability	0.0890			0.0394**			0.1020***		
	YES	NO	YES	YES	NO	YES	YES	NO	YES
Constant	5.9575***	3.9687***	5.9767***	0.2263***	0.2084***	0.2357***	0.2295***	0.3707***	0.2517***
	(0.181)	(0.011)	(0.182)	(0.013)	(0.003)	(0.013)	(0.025)	(0.005)	(0.024)
Observations	58,886	59,127	58,886	58,886	59,127	58,886	58,886	59,127	58,886
R-squared	0.953	0.941	0.954	0.812	0.809	0.812	0.791	0.791	0.791
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	YES	YES	YES	YES	YES	YES	YES	YES	YES

Standard errors clustered at the sector-firm level in parentheses. Except for the age variable that was excluded, all columns contain unreported firm characteristics as contained in Tables 1–3. The dependent variable in columns 1 and 2 is the log of total number of employees. The dependent variable in columns 3 and 4 is capital investment measured as the ratio of total capital expenditures to total assets. The dependent variable in columns 5 and 6 is a dummy variable that takes the value of one if a firm exports and zero otherwise. The electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

firms suggests that some dimensions of firm performance may be shielded by established external networks and long-term trade relationships, which can act as buffers. Nonetheless, the evidence underscores that the electricity crisis is not uniformly distributed across the age profile of firms. Firm exposure to electricity crisis interacts with its age profile to produce differentiated vulnerabilities.

5. Conclusion

Electricity is fundamental to modern society, underpinning virtually every aspect of business operations. Its influence spans operational efficiency, cost management, technological advancement, and market competitiveness. Stable and affordable electricity is therefore critical for firms to perform effectively and remain competitive both domestically and internationally. Motivated by these considerations, this paper investigates how South Africa's electricity affected employment, capital investment, and export activities among manufacturing firms.

The analyses use a flexible empirical framework and draw on a merged panel dataset that combines a national indicator of electricity disruptions, sector-level measure of electricity vulnerability, and firm-level performance indicators for the period 2008–2021. The results are stark: the electricity crisis has led to substantial job losses, reduced capital investments, and disrupted export activities. Importantly, these adverse effects are concentrated among firms with higher energy vulnerability intensity—defined as those operating in sectors with strong backward and forward linkages to the electricity sector. Further analyses reveal how firm-specific characteristics mediate these effects. Domestic, older, and financially constrained firms in energy-intensive vulnerable sectors are disproportionately affected. These findings underscore the importance of sectoral and firm heterogeneity in shaping vulnerability to electricity shocks, highlighting that the crisis does not impact all manufacturing firms uniformly in South Africa.

From a policy perspective, the results carry significant implications. The observed heterogeneity indicates that one-size-fits-all interventions are unlikely to be effective in cushioning the adverse effects of electricity crisis. For example, the finding that adverse effects intensify with sectoral electricity vulnerability calls for tailored policies targeting the most exposed sectors. Simultaneously, the disproportionate vulnerability of domestic and financially constrained firms—even within similarly exposed sectors—suggests that policy measures must also be granular, accounting for firm-level differences in resilience. Given South Africa's constrained fiscal space, such targeted and nuanced policy interventions are essential to protect employment, investment, and export capacity in manufacturing firms.

Despite these contributions, the study has some limitations. First, our analysis is constrained to 2008–2021, as the CIT-IRP5 firm-level dataset only becomes available from 2008. Future research could extend the temporal scope as alternative or updated firm-level panel data become available. Second, manufacturing sectors are interconnected through supply chains, implying potential spillover effects: a sector with lower electricity vulnerability may still be adversely affected if it relies on inputs from highly vulnerable sectors. Exploring these inter-sectoral effects could further enrich the literature. Finally, investigating how firms adapt to electricity shocks—through investments in generators, solar power, or other resilience measures—would provide valuable insights once relevant data are accessible in the CIT-IRP5 or similar sources.

Overall, this study provides novel evidence on the real economic effects of electricity crisis in South Africa's manufacturing sector, highlighting the critical interplay between sectoral exposure and firm characteristics. By identifying which manufacturing firms and sectors are most vulnerable, the findings offer actionable guidance for policymakers seeking to safeguard industrial performance, employment, and export competitiveness in the face of persistent energy challenges in South Africa.

CRediT authorship contribution statement

Gideon Ndubuisi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Elvis K. Avenyo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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Appendix A. Appendix

Table A1
Sample comparison.

	Non-Missing Sample (mean)	Missing Sample (mean)	Mean Difference	t-value
Gross Sales	7.76e+07	1.53e+07	6.23e+07	5.3932***
Jobs	69.09664	67.15868	1.937967	0.2694
Capital	1.31e+07	3,573,490	9,496,076	3.9982***
Age	13.95979	8.52565	5.434143	12.0132***
Total Asset	5.64e+07	1.07e+07	4.57e+07	3.6768***
Total current asset	2.87e+07	1.50e+07	1.37e+07	2.7445***
Total current liability	2.17e+07	1.08e+07	1.09e+07	3.2755***

*** Significant at 1%.

Table A2: Concordance table between CIT-IRP5 and Quantec.

SIC Sectors in the CIT-IRP5 dataset	SIC sectors in the Quantec dataset	QSIC	merge_
Processing and preserving of fruit and vegetables			
Processing and preserving of fish, crustaceans and molluscs			
Processing and preserving of meat	Intermediate Input: Meat, fish, fruit etc. [QSIC 301]	301	m:1
Manufacture of dairy products	Intermediate Input: Dairy products [QSIC 302]	302	1:1
Manufacture of grain mill products, starches and starch products	Intermediate Input: Grain mill products [QSIC 303]	303	1:1
Manufacture of vegetable and animal oils and fats			
Manufacture of prepared animal feeds	Intermediate Input: Other food products [QSIC 304]	304	m:1
Manufacturing of beverages	Intermediate Input: Beverages [QSIC 305]	305	1:1
Manufacture of tobacco products	Intermediate Input: Tobacco [QSIC 306]	306	1:1
Spinning, weaving and finishing of textiles	Intermediate Input: Textiles [QSIC 311]	311	1:1
Manufacture of other textiles	Intermediate Input: Other textile products [QSIC 312]	312	1:1
Manufacture of knitted and crocheted apparel	Intermediate Input: Knitted, crocheted articles [QSIC 313]	313	1:1
Manufacturing of wearing apparel, except fur apparel	Intermediate Input: Wearing apparel [QSIC 314]	314	1:1
Tanning and dressing of leather; manufacture of luggage, handbags, saddlery and harness; dressing and dyeing of fur			
Manufacture of articles of fur	Intermediate Input: Leather and leather and fur products [QSIC 315–316]	315_316	m:1
Manufacture of footwear	Intermediate Input: Footwear [QSIC 317]	317	1:1
Sawmilling and planing of wood	Intermediate Input: Sawmilling and planing of wood [QSIC 321]	321	1:1
Manufacture of products of wood, cork, straw and plaiting materials	Intermediate Input: Products of wood [QSIC 322]	322	1:1
Manufacture of paper and paper products	Intermediate Input: Paper and paper products [QSIC 323]	323	1:1
Reproduction of recorded media			
Printing and service activities related to printing	Intermediate Input: Printing, recorded media [QSIC 324–326]	324_326	m:1
Manufacture of coke oven products			
Manufacture of refined petroleum products	Intermediate Input: Coke, petroleum products and nuclear fuel [QSIC 331–333]	331_333	m:1
Manufacture of basic chemicals, fertilizers and nitrogen compounds, plastics and synthetic rubber in primary forms			
Manufacture of pharmaceuticals, medicinal chemical and botanical products	Intermediate Input: Basic chemicals [QSIC 334]	334	m:1
Manufacture of other chemicals products	Intermediate Input: Other chemical products [QSIC 335–336]	335_336	1:1
Manufacture of rubber products	Intermediate Input: Rubber products [QSIC 337]	337	1:1
Manufacture of plastic products	Intermediate Input: Plastic products [QSIC 338]	338	1:1
Manufacture of glass and glass products	Intermediate Input: Glass and glass products [QSIC 341]	341	1:1
Manufacture of non-metallic mineral products n.e.c	Intermediate Input: Non-metallic mineral products [QSIC 342]	342	1:1
Manufacture of basic iron and steel	Intermediate Input: Basic iron and steel products [QSIC 351]	351	1:1

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(*continued*)

SIC Sectors in the CIT-IRP5 dataset	SIC sectors in the Quantec dataset	QSIC	merge_
Manufacture of basic precious and other non-ferrous metals	Intermediate Input: Non-ferrous metal products [QSIC 352]	352	1:1
Manufacture of structural metal products, tanks, reservoirs and steam generators	Intermediate Input: Structural metal products [QSIC 354]	354	1:1
Manufacture of other fabricated metal products; metalworking service activities	Intermediate Input: Other fabricated metal products [QSIC 355]	355	1:1
Manufacture of general-purpose machinery	Intermediate Input: General purpose machinery [QSIC 356]	356	1:1
Manufacture of special-purpose machinery	Intermediate Input: Special purpose machinery [QSIC 357]	357	1:1
Manufacture of domestic appliances (electric, gas or other fuel) (for manufacture of commercial and industrial appliances, see division 28)	Intermediate Input: Household appliances [QSIC 358]	358	1:1
Manufacture of computers and peripheral equipment	Intermediate Input: Office, accounting, computing machinery [QSIC 359]	359	1:1
Manufacture of electronic components and boards Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus	Intermediate Input: Electric motors, generators, transformers [QSIC 361] + Intermediate Input: Electricity distribution and control apparatus [QSIC 362]	361_362	m:m
Manufacture of wiring and wiring devices	Intermediate Input: Insulated wire and cables [QSIC 363]	363	1:1
Manufacture of electric lighting equipment Manufacture of other electrical equipment	Intermediate Input: Other electrical equipment [QSIC 364–366]	364_366	m:1
Manufacture of consumer electronics Manufacture of communication equipment	Intermediate Input: Radio, television and communication apparatus [QSIC 371–373]	371_373	m:1
Manufacture of medical and dental instruments and supplies Manufacture of irradiation, electromedical and electrotherapeutic equipment Manufacture of optical instruments and photographic equipment Manufacture of measuring, testing, navigating and control equipment; watches and clocks (for manufacture of optical measuring and checking devices and instruments (e.g. fire control equipment, photographic light meters, range finders), see 2670) Manufacture of magnetic and optical media (for reproduction of recorded media (computer media, sound, video, etc.), see 1820)	Intermediate Input: Professional equipment [QSIC 374–376]	374_376	m:1
Manufacture of motor vehicles (for manufacture of bodies for motor vehicles, see 2920) Manufacture of military fighting vehicles	Intermediate Input: Motor vehicles [QSIC 381–382]	381_382	m:1
Manufacture of parts and accessories for motor vehicles Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semi-trailers	Intermediate Input: Parts and accessories [QSIC 383]	383	m:1
Manufacture of other transport equipment n.e.c	Intermediate Input: Other transport equipment [QSIC 384–387]	384_387	1:1
Manufacture of furniture (for manufacture of furniture of ceramics, concrete and stone, see 2393, 2395, 2396)	Intermediate Input: Furniture [QSIC 391]	391	1:1
Other manufacturing n.e.c.	Intermediate Input: Other manufacturing groups [QSIC 392–395]	392_395	1:1

1:1 is the unique merge i.e. one to one merge. m:1 means many to one merge, while m:m means many to many merge. In the case of m:1 and m:m, we use the median energy vulnerability intensity.

Source: authors' calculation using data from National Treasury and UNU-WIDER (2023), Ndubuisi et al. (2025a), and Quantec Statistical Database (2023).

Table A3. Electricity crisis, energy vulnerability, and export intensity.

	(1)	(2)	(3)	(11)	(12)	(13)	(14)
Electricity crisis × Energy vulnerability	−4.8010*	−5.2583**	−4.9279*	−5.4346**			
	(2.578)	(2.540)	(2.588)	(2.552)			
Energy Vulnerability	0.4004**	0.4371**					
	(0.191)	(0.186)					
Electricity crisis × Energy vulnerability (backward)					−4.2701*	−4.6576**	−4.8327**
					(2.309)	(2.269)	(2.277)
Energy vulnerability (backward)					0.2615	0.2720*	
					(0.166)	(0.163)	
Electricity crisis × Energy vulnerability (forward)					−2.6572	−2.9523	−3.0280
					(2.483)	(2.447)	(2.458)
Energy vulnerability (forward)					0.3329*	0.3762**	
					(0.178)	(0.173)	
Age (log)		0.6689***		0.6695***		0.6684***	0.6689***
		(0.080)		(0.080)		(0.080)	(0.080)
Foreign Ownership		0.0741		0.0784		0.0741	0.0782
		(0.066)		(0.066)		(0.066)	(0.066)
Firm Size		0.4416***		0.4398***		0.4424***	0.4402***
		(0.052)		(0.052)		(0.052)	(0.052)
Labor Productivity (log)		0.1611***		0.1609***		0.1612***	0.1609***
		(0.020)		(0.020)		(0.020)	(0.020)
Foreign Connection		0.2476***		0.2454***		0.2467***	0.2443***
		(0.061)		(0.061)		(0.061)	(0.061)
Working Capital (log)		0.0072***		0.0073***		0.0072***	0.0073***
		(0.002)		(0.002)		(0.002)	(0.002)
Constant	14.4157***	9.9967***	14.4998***	10.0900***	14.4172***	10.0001***	10.0944***

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	(1)	(2)	(3)	(11)	(12)	(13)	(14)
	(0.033)	(0.349)	(0.026)	(0.348)	(0.034)	(0.349)	(0.348)
Observations	36,128	36,047	36,128	36,047	36,128	36,047	36,047
R-squared	0.850	0.854	0.850	0.854	0.850	0.854	0.854
Controls	NO	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	YES	YES	NO	NO	YES

Standard errors in parentheses are clustered at the sector-firm level. The dependent variable is the log of positive export values. Age, labor productivity and working capital is log transformed using the inverse hyperbolic function. Electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A4. The real effect of electricity crisis: Robust standard error.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
Electricity crisis × Energy vulnerability	−1.7366***	−1.7000***		−0.4149***	−0.4015***		−0.4966**	−0.5039**	
	(0.366)	(0.367)		(0.104)	(0.104)		(0.201)	(0.201)	
Energy vulnerability	0.0622*			0.0331***			0.0840***		
	(0.034)			(0.010)			(0.020)		
Electricity crisis × Energy vulnerability (Backward)			−0.7017**			−0.2434***			−0.2213
			(0.319)			(0.091)			(0.179)
Energy vulnerability (Backward)			0.0503*			0.0255***			0.0699***
			(0.028)			(0.009)			(0.017)
Electricity crisis × Energy vulnerability (Forward)			−1.9989***			−0.4101***			−0.5236***
			(0.338)			(0.100)			(0.187)
Energy vulnerability (Forward)			0.0316			0.0232**			0.0440**
			(0.033)			(0.009)			(0.019)
Constant	4.6519***	4.6657***	4.6531***	0.4014***	0.4082***	0.4015***	−0.1375***	−0.1184***	−0.1369***
	(0.092)	(0.092)	(0.092)	(0.014)	(0.013)	(0.014)	(0.024)	(0.024)	(0.024)
Observations	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867
R-squared	0.937	0.937	0.937	0.769	0.770	0.769	0.775	0.775	0.775
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	NO	NO	YES	NO	NO	YES	NO

Robust standard errors in parathesis. All columns contain unreported firm characteristics as contained in Tables 3–5. The dependent variable in columns 1–3 is the log of total number of employees. The dependent variable in columns 4–6 is capital investment measured as the ratio of total capital expenditure to total asset. The dependent variable in columns 7–9 is a dummy variable that takes the value of one if a firm exports, and zero if otherwise. Electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A5. The real effect of electricity crisis: Standard error clustered at the firm level.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
Electricity crisis × Energy vulnerability	−1.7366***	−1.7000***		−0.4149***	−0.4015**		−0.4966**	−0.5039**	
	(0.578)	(0.580)		(0.160)	(0.160)		(0.253)	(0.253)	
Energy vulnerability	0.0622			0.0331**			0.0840***		
	(0.049)			(0.014)			(0.023)		
Electricity crisis × Energy vulnerability (Backward)			−0.7017			−0.2434*			−0.2213
			(0.505)			(0.139)			(0.224)
Energy vulnerability (Backward)			0.0503			0.0255**			0.0699***
			(0.040)			(0.012)			(0.019)
Electricity crisis × Energy vulnerability (Forward)			−1.9989***			−0.4101***			−0.5236**
			(0.532)			(0.156)			(0.235)
Energy vulnerability (Forward)			0.0316			0.0232*			0.0440**
			(0.047)			(0.013)			(0.021)
Constant	4.6519***	4.6657***	4.6531***	0.4014***	0.4082***	0.4015***	−0.1375***	−0.1184***	−0.1369***
	(0.124)	(0.125)	(0.124)	(0.019)	(0.019)	(0.019)	(0.030)	(0.030)	(0.030)
Observations	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867

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	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
R-squared	0.937	0.937	0.937	0.769	0.770	0.769	0.775	0.775	0.775
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	NO	NO	YES	NO	NO	YES	NO

Clustered standard errors in parathesis. All columns contain unreported firm characteristics as contained in Tables 3–5. The dependent variable in columns 1–3 is the log of total number of employees. The dependent variable in columns 4–6 is capital investment measured as the ratio of total capital expenditure to total asset. The dependent variable in columns 7–9 is a dummy variable that takes the value of one if a firm exports, and zero if otherwise. Electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A6. The real effect of electricity crisis: the role of confounding factors.

	Jobs		Investment		Export	
	(1)	(2)	(3)	(4)	(5)	(6)
Electricity crisis × Energy vulnerability	−2.7796***	−2.7499***	−0.5149**	−0.5111**	−0.6617**	−0.6777**
	(0.721)	(0.722)	(0.200)	(0.200)	(0.308)	(0.308)
Energy vulnerability	0.1308**		0.0330**		0.1046***	
	(0.054)		(0.015)		(0.025)	
Electricity crisis × Labourproductivity	0.0052	0.0055	0.0028	0.0029	0.0048	0.0047
	(0.010)	(0.010)	(0.003)	(0.003)	(0.005)	(0.005)
Labor productivity	−0.0000		0.0001		0.0002	
	(0.001)		(0.000)		(0.000)	
Electricity crisis × Capitallabourratio	3.5425***	3.5322***	0.1180	0.1503	0.9995*	1.0357*
	(1.152)	(1.156)	(0.305)	(0.306)	(0.533)	(0.533)
Capital labor ratio	−0.1521*		0.0123		−0.0273	
	(0.084)		(0.024)		(0.043)	
Electricity crisis × Tradeopen	−0.1309	−0.1408	−0.0411	−0.0423	0.0046	0.0032
	(0.122)	(0.123)	(0.031)	(0.031)	(0.061)	(0.060)
Trade openness	0.0084		0.0045*		0.0063	
	(0.009)		(0.003)		(0.005)	
Electricity crisis × Realoutput	0.0000	0.0000	−0.0000	−0.0000	−0.0000	−0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Real output	−0.0000**		0.0000		−0.0000	
	(0.000)		(0.000)		(0.000)	
Constant	4.6353***	4.6460***	0.3746***	0.3973***	−0.1818***	−0.1401***
	(0.140)	(0.137)	(0.026)	(0.025)	(0.040)	(0.040)
Observations	126,867	126,867	126,867	126,867	126,867	126,867
R-squared	0.937	0.937	0.769	0.770	0.775	0.775
Control	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	NO	YES	NO	YES

Standard errors clustered at the sector-firm level in parentheses. All columns contain unreported firm characteristics as contained in Tables 3–5. The dependent variable in columns 1 and 2 is the log of total number of employees. The dependent variable in columns 3 and 4 is capital investment measured as the ratio of total capital expenditure to total asset. The dependent variable in columns 5 and 6 is a dummy variable that takes the value of one if a firm exports, and zero if otherwise. Electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a three-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. Note that labor productivity, capital labor ratio, trade openness, and real output displayed in the sector are at the sector level and the original series used to construct them are from the Quantec statistical database. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A7. The real effect of electricity crisis: Alternative electricity crisis indicator (1).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
Electricity crisis × Energy vulnerability	−1.4162***	−1.3828***		−0.2598**	−0.2508*		−0.4383**	−0.4392**	
	(0.470)	(0.472)		(0.132)	(0.132)		(0.210)	(0.210)	
Energy vulnerability	0.0661			0.0294**			0.0871***		
	(0.045)			(0.013)			(0.021)		
Electricity crisis × Energy vulnerability (Backward)			−0.5623			−0.1654			−0.1858
			(0.410)			(0.114)			(0.185)
Energy vulnerability (Backward)			0.0516			0.0241**			0.0707***
			(0.037)			(0.011)			(0.017)
Electricity crisis × Energy vulnerability (Forward)			−1.6453***			−0.2529*			−0.4804**
			(0.438)			(0.130)			(0.197)
Energy vulnerability (Forward)			0.0360			0.0193			0.0480**
			(0.042)			(0.012)			(0.019)

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	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
Constant	4.6512***	4.6658***	4.6524***	0.4013***	0.4073***	0.4013***	−0.1377***	−0.1180***	−0.1371***
	(0.130)	(0.130)	(0.130)	(0.020)	(0.020)	(0.020)	(0.031)	(0.031)	(0.031)
Observations	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867
R-squared	0.937	0.937	0.937	0.769	0.770	0.769	0.775	0.775	0.775
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	NO	NO	YES	NO	No	Yes	NO

Standard errors in parentheses are clustered at the sector-firm level. All columns contain unreported firm characteristics as contained in Tables 3–5. The dependent variable in columns 1–3 is the log of total number of employees. The dependent variable in columns 4–6 is capital investment measured as the ratio of total capital expenditure to total asset. The dependent variable in columns 7–9 is a dummy variable that takes the value of one if a firm exports, and zero if otherwise. Electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a five-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A8. The real effect of electricity crisis: Alternative electricity crisis indicator (2).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
Electricity crisis × Energy vulnerability	−1.2780***	−1.2483***		−0.2352*	−0.2279*		−0.4269**	−0.4251**	
	(0.457)	(0.458)		(0.129)	(0.129)		(0.207)	(0.207)	
Energy vulnerability	0.0708			0.0303**			0.0907***		
	(0.047)			(0.013)			(0.022)		
Electricity crisis × Energy vulnerability (Backward)			−0.4731			−0.1529			−0.1561
			(0.399)			(0.111)			(0.182)
Energy vulnerability (Backward)			0.0511			0.0249**			0.0705***
			(0.039)			(0.011)			(0.018)
Electricity crisis × Energy vulnerability (Forward)			−1.5347***			−0.2305*			−0.5088***
			(0.424)			(0.127)			(0.194)
Energy vulnerability (Forward)			0.0444			0.0202			0.0545***
			(0.044)			(0.012)			(0.020)
Constant	4.6510***	4.6666***	4.6522***	0.4012***	0.4075***	0.4012***	0.1378***	−0.1173***	−0.1372***
	(0.130)	(0.130)	(0.130)	(0.020)	(0.020)	(0.020)	(0.022)	(0.031)	(0.031)
Observations	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867
R-squared	0.937	0.937	0.937	0.769	0.770	0.769	0.775	0.775	0.775
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	No	NO	YES	NO	NO	YES	NO

Standard errors in parentheses are clustered at the sector-firm level. All columns contain unreported firm characteristics as contained in Tables 3–5. The dependent variable in columns 1–3 is the log of total number of employees. The dependent variable in columns 4–6 is capital investment measured as the ratio of total capital expenditure to total asset. The dependent variable in columns 7–9 is a dummy variable that takes the value of one if a firm exports, and zero if otherwise. Electricity crisis is computed as the rolling standard deviation of electricity capacity factor (ECF) over a seven-year window. Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A9. The real effect of electricity crisis: Alternative electricity crisis indicator (3).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
Electricity crisis × Energy vulnerability	−0.4154***	−0.4064***		−0.0850**	−0.0823**		−0.1415**	−0.1418**	
	(0.144)	(0.144)		(0.040)	(0.040)		(0.064)	(0.064)	
Energy vulnerability	−3.8197***			−0.7639**			−1.2343**		
	(1.315)			(0.365)			(0.582)		
Electricity crisis × Energy vulnerability (Backward)			−0.1581			−0.0553			−0.0576
			(0.126)			(0.034)			(0.056)
Energy vulnerability (Backward)			−1.4292			−0.4920			−0.4672
			(1.151)			(0.315)			(0.512)
Electricity crisis × Energy vulnerability (Forward)			−0.4920***			−0.0809**			−0.1591***
			(0.133)			(0.040)			(0.060)
Energy vulnerability (Forward)			−4.5643***			−0.7357**			−1.4363***
			(1.223)			(0.363)			(0.546)

(*continued on next page*)

(*continued*)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
Constant	4.6513***	3.8145***	4.6526***	0.4013***	0.2352***	0.4013***	−0.1377***	−0.4145***	−0.1371***
	(0.130)	(0.318)	(0.130)	(0.020)	(0.085)	(0.020)	(0.031)	(0.136)	(0.031)
Observations	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867
R-squared	0.937	0.937	0.937	0.769	0.770	0.769	0.775	0.775	0.775
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	NO	NO	YES	NO	NO	YES	NO

Standard errors in parentheses are clustered at the sector-firm level. All columns contain unreported firm characteristics as contained in Tables 3–5. The dependent variable in columns 1–3 is the log of total number of employees. The dependent variable in columns 4–6 is capital investment measured as the ratio of total capital expenditure to total asset. The dependent variable in columns 7–9 is a dummy variable that takes the value of one if a firm exports, and zero if otherwise. Electricity crisis is computed as electricity capacity factor (ECF) multiplied by a negative constant (−1). Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A10. The real effect of electricity crisis: Alternative electricity crisis indicator (4).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Job			Investment			Export		
Electricity crisis × Energy vulnerability	−0.9361**	−0.9176**		−0.2288**	−0.2219**		−0.4123**	−0.4130**	
	(0.374)	(0.375)		(0.103)	(0.103)		(0.167)	(0.167)	
Energy vulnerability	−2.0638**			−0.4861**			−0.8402**		
	(0.819)			(0.225)			(0.365)		
Electricity crisis × Energy vulnerability (Backward)			−0.3227			−0.1626*			−0.1528
			(0.331)			(0.088)			(0.147)
Energy vulnerability (Backward)			−0.6874			−0.3410*			−0.2743
			(0.723)			(0.193)			(0.323)
Electricity crisis × Energy vulnerability (Forward)			−1.1524***			−0.1993*			−0.4845***
			(0.345)			(0.103)			(0.157)
Energy vulnerability (Forward)			−2.5804***			−0.4313*			−1.0399***
			(0.755)			(0.227)			(0.345)
Constant	4.6518***	4.1989***	4.6532***	0.4014***	0.2954***	0.4014***	−0.1376***	−0.3259***	−0.1368***
	(0.130)	(0.219)	(0.130)	(0.020)	(0.054)	(0.020)	(0.031)	(0.089)	(0.031)
Observations	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867	126,867
R-squared	0.937	0.937	0.937	0.769	0.770	0.769	0.775	0.775	0.775
Controls	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Firm FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Sector FE	NO	YES	NO	NO	YES	NO	NO	YES	NO

Standard errors in parentheses are clustered at the sector-firm level. All columns contain unreported firm characteristics as contained in Tables 3–5. The dependent variable in columns 1–3 is the log of total number of employees. The dependent variable in columns 4–6 is capital investment measured as the ratio of total capital expenditure to total asset. The dependent variable in columns 7–9 is a dummy variable that takes the value of one if a firm exports, and zero if otherwise. Electricity crisis is computed as the ratio between annual electricity generation to total population multiplied by a negative constant (−1). Energy vulnerability is computed as each sector's forward and backward dependence on the energy sector. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Appendix B. Data appendix

This data appendix is created in accordance with the requirements for users of the National Treasury Secure Data Facility (NT-SDF).

B.1. Data access

The data used for this research were accessed from the NT-SDF. Access was provided under a non-disclosure agreement, and our output was checked so that the anonymity of no firm or individual would be compromised. Our results do not represent any official statistics (NT or SARS). Similarly, the views expressed in our research are not the views of the NT or SARS.

B.2. Data structuring and cleaning

Our analysis relies on three primary sources: self-computed indicator of electricity crisis using information from the EIA database, energy vulnerability index from Ndubuisi et al. (2025) using the Quantec I—O Table for South Africa, and the custom transaction level dataset (citirp5_v5_0) (National Treasury and UNU-WIDER 2023). All our firm-level variables are drawn from the custom transaction dataset. To use the dataset, we first merge it with the incorporation year of each firm extracted from the IRP5, which is assessable from the NT-SDF. From the merged sample, we drop observations in the custom transaction data with negative or missing values for the following variables: sales, capital, employment, total asset, total current liabilities, and assets.

Table 2 provides a description of the firm-level characteristics drawn from the cleaned sample that we included in our analysis. Particularly, the variables on foreign connection and ownership structure are directly sourced from the database. The rest of the variables (jobs, export, size, labour productivity, financial status, working capital, ownership structure, and foreign connection) were computed using data series that were retrieved from the database, as described in Section 3.1 and Table 1. To identify the age of the firm, we use the incorporation year as a proxy.

To merge the citirp5_v5_0 data to the sector energy vulnerability index, we manually map the sector energy vulnerability index to the three-digit sectors with comparable names in the CIT-IRP5 datasets using the three-digit sector description in the Quantec I—O Table for South Africa. To maximize the mapping, we aggregated some of the sectors in the Quantec database to match to the three-digit SIC classification in the CIT-IRP5 datasets (see Table A1 in the Appendix). We successfully mapped the energy vulnerability index to 80% of the three-digit manufacturing SIC sectors in the CIT-IRP5 datasets. About 51% of these successfully mapped sectors were unique matches, while the rest were achieved after reaggregating the sectors in the Quantec dataset.

Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2026.109234.

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