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Abstract

Although the relationship between unreliable electric power costs and firm productivity has received considerable attention from researchers, few studies have asked why some firms succeed in an unreliable electric power environment while others are unable to. To achieve the study's purpose, the paper compares the World Bank Enterprise survey’s unbalanced panel data over two periods: 2006-2014 and 2008-2023. Additionally, it uses the "k-means clustering" algorithm to rank clusters of sub-Saharan African firms that share similar electricity shortages experience, adaptation strategies and productivity profiles. The multinomial probit model is used to determine the success factors of firms operating in an unfavorable environment, at firm and industry level over time. We find that there are three categories of firms operating under the constraints of power shortages: “heavily impacted firms”, partially impacted firms”, and “resilient firms”. Strong institutions reduce the probability of belonging to the group of firms that are “heavily impacted” by electricity shortages. In contrast, the probability of belonging to the “resilient” group of firms increases with gross domestic product. When we look at the influence of entrepreneurs' perception of certain obstacles in the business environment (electricity shortage and the informal sector) on cluster membership, we find that, for both grouped and period data, the perception of electricity shortage and the informal sector as a major obstacle in the business environment also explain cluster membership.

Keywords: Electricity shortages, productivity, *K-means clustering*, multinomial probit, Sub-Saharan Africa

JEL codes : D24, O13, L9

1. Introduction

The productivity of firms in Sub-Saharan Africa (SSA) is frequently hampered by difficulties in the supply of electrical energy. For example, 78.7% of firms in SSA experience power outages with a frequency of 12.21 outages per month, compared to only 59.1% in the rest of the world, 66.2% in South Asia and 64.1 % in Latin America (World Bank Enterprise Surveys data from 2010 to 2017)[1]. In addition, 45.9% of entrepreneurs in SSA consider the lack of electrical energy as the main constraint in the exercise of their activity (Asiedu et al., 2021) against 36.9% in North Africa and the Middle East and 39.6% in South Asia (World Bank Enterprise Surveys data from 2008 to 2023)[2].

This problem of electrical energy deficit is obvious in SSA compared to other developing countries and could explain the weak productive performance of SSA companies. Indeed, the average technical efficiency score of SSA companies is only 0.11 (World Bank Enterprise Surveys data from 2008 to 2023)[3]. This lack of technical efficiency may explain the low contribution of SSA firms to economic growth compared to other developing countries. For example, The Word Development Indicator (WDI) data shows that the share of the Added Value of SSA firms to economic growth is only 9.5% compared to 18.5% in South Asia and 15.3% in Latin America and the Caribbean[4].

This weak performance of the productive efficiency of SSA firms is worrying for the continent. In fact, in some cases, technical inefficiency can lead to the bankruptcy of firms and consequently jeopardize the prospects for economic development. Increasing the productive efficiency of enterprises is a channel through which job creation and poverty reduction can be achieved (Moyo, 2018).

Empirically, the literature on the impact of the electricity deficit on firm productivity is complex and mixed. The complexity of the relationship is explained in the literature of the adaptation strategies of firms in the face of electricity shortages and the environment in which they operate (Allcott et al.,

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[1]World Bank Enterprise Survey (WBES) available at https://www.enterprisesurveys.org/en/enterprisesurveys

[2] World Bank Enterprise Survey (WBES) available at https://www.enterprisesurveys.org/en/enterprisesurveys

[3]Enterprise technical efficiency scores were calculated using World Bank enterprise survey data. These efficiency scores were calculated using the stochastic frontier method. These efficiency scores are included in an interval of 0 to 1. The score 1 shows that the company is fully efficient. Below 1 the firm is inefficient.

[4]World Development Indicators consulted on July 29, 2021. As a percentage of GDP

2016; Ramachandran et al., 2018; Baafra Abeberese, 2020; Hardy and McCasland, 2021). This literature shows that the strategies most commonly used by companies in the literature take into account the use of the generator; switching to products that consume less electricity; technology adoption; raw material storage during power outages; outsourcing production and modifying production time (Alam, 2013; Fisher-Vanden et al., 2015; Allcott et al., 2016; Abeberese et al., 2021). The literature also documents the ability of these strategies to mitigate the negative effects of power shortages on business productivity. For example, Abeberese et al. (2021) and Alam (2013) show that firms adopt capital-based strategies to counter electricity shortages. The first authors show that Ghanaian companies modify their product mix to favor products with low electricity intensities and reduce productivity losses due to electricity shortages, but companies using the generator fail to mitigate the negative effect of electricity shortages on their productivity. The second author shows that the Indian rice firms manage to cancel the losses of productivity by adopting technologies and the steel firms continue to undergo considerable losses of their productivity despite the use of the generator. Hardy and McCasland (2021) instead show that one-person business owners in Ghana reduce their weekly labor supply by 5% for each day of outage, using labor as the main input to contract production in response to changes of productivity. Anas et al. (1996) instead show that electricity shortages have disproportionately differentiated impacts on Nigerian, Indonesian and Thailand companies depending on the regulatory environment.

Furthermore, the disparity in the mixed results of the literature may also stem from the complexity of the relationship between energy shortages and productivity at the firm level. Additionally, the observed prevalence of these different relationships depends on the environment in which businesses operate, the quality of institutions, and other business environment in which firms operate. The quality of institutions is considered, on the one hand, as a key factor that affects electrical reliability (Jamasb et al., 2021; Soroush et al., 2021) and on the other hand, as an important factor that affects business productivity (Jibir et al., 2019; Chang, 2023).

In general, some studies find a significant negative effect (Cole et al., 2018; Abeberese et al., 2021; Xiao et al., 2022) , while others report a small negative and significant effect (Grainger and Zhang, 2019) and other studies do not find a significant effect (Scott et al., 2014). In addition, the last study group finds a non-linear effect between the deficit of electricity shortages and firm productivity (Ramachandran et al., 2018; Hardy and McCasland, 2021).

On this basis, this paper analyzes the heterogeneous relationship between electricity shortages and firm productivity and identify the factors behind this heterogeneity. More specifically, the study assesses the heterogeneous relationship between electricity shortages, and the productivity of firms in SSA; and determines the factors behind the heterogeneous relationship between electricity shortages and the productivity of firms in SSA.

This paper makes at least three contributions to literature. First, this paper systematically documents the heterogeneity of the relationship between electricity shortages and firm productivity at both firm and country level. Second, the paper uses temporal dynamics over two periods, to describe how this heterogeneity is linked to firm-level and environmental characteristics in which the company operates. Finally determine the success factors of firms operating in an unreliable electrical environment, both on all data at the firm level, but also through a comparative analysis at the country level between the oldest and most recent years of data available for each country.

For policy purposes, it is crucial to examine this heterogeneity considering the evolving energy situation in SSA. This analysis is important because the energy situation in SSA has evolved significantly since the 2000s. Therefore, the temporal dynamics of the data will make it possible to verify whether changes in the business environment of firms are factors that determine the success of firms who suffer from electricity shortages.

We start from the principle that heterogeneity is likely to exist between firms, on the one hand, and between countries on the other. In addition, from the principle that firm's coping strategies differ from one firm to another or from one firm sector to another and from the fact that the cost and burden of electricity shortages are more accentuated in certain firms than in others. We explore these differences using a methodology known as "*K- means clustering*", to see the effect of electricity shortages, technical efficiency and labor productivity on membership in a cluster, to answer the following question: What are the factors that determine the success of firms in an unreliable electrical energy environment?

The situation in SSA is fascinating, for several reasons. Firstly, SSA is one of the regions in the world, which is characterized by its abundance in energy resources, and the least endowed with the reliability of electrical energy. It also represents an ideal region to study the changing dynamics of the electricity sector, as it has experienced strong economic growth alongside a rapid expansion of electrification across the countries. As a result, it has seen its electrification rates increase from 30% (as a percentage of the population) in 1999 to 50% (as a percentage of the population) in 2021 (data from 2023

Word Development)[5]. However, these electrification rates show disparities between rural and urban populations. They went from 61.6% (percentage of the urban population) and 11.6% (percentage of the rural population) in 2000, to 80.7% (percentage of the urban population) against 30.4% (percentage of the rural population) in 2021.

In addition, SSA is characterized by an average of 3.1 on a scale of 1 to 6 for the quality of institutions (CPIA-Afrique, 2022). It is also characterized by a low contribution of firms to GDP in terms of value added. More importantly, the quality of institutions varies widely across countries. Some countries, such as (Burundi, Chad and Nigeria), have weak institutions with scores below the average. In contrast, others, like (Rwanda, Kenya and Benin), have relatively high institutional quality.

Determining the successful factors of firms experiencing energy shortages will contribute to the design of targeted and effective public policies that would unlock the commercial potential of SSA firms. This could ultimately lead to a better optimization of the environment for the private sector to operate in, thereby making sub-Saharan Africa more attractive to foreign direct investment and multinational firms. It will also contribute to attracting investors in the production of electrical energy. This is because the propensity of private players in the energy sector to seek business opportunities depends on their perception of the local investment environment, which is influenced, among other things, by the quality of the external environment in which firms operate and the quality of institutions (Falchetta et al., 2021). Improving the local investment environment is urgent, as SSA needs about $30 billion per year in addition to base investments, until 2030 to improve the reliability of electricity supply (Falchetta et al., 2021).

Research Objectives and Hypotheses

This paper aims to analyze the heterogeneous relationship between electricity shortages and firm productivity, and to identify the factors behind this heterogeneity. More specifically, the aim will be: (i) to assess the heterogeneous relationship between electricity shortages, technical efficiency, and labor productivity of firms in SSA; (ii) to determine the factors behind the heterogeneous relationship between electricity shortages, technical efficiency and labor productivity of firms in SSA. H1 Electricity shortages have a heterogeneous relationship with technical efficiency and labor productivity of firms in SSA; H2: The distribution of SSA firm types that represent different relationships between electricity shortages and

[5]Accessed June 10, 2023.

productivity is influenced by firm-specific factors and factors inherent in the external environment in which the firm operates.

Contextual Situation of Electricity in Sub-Saharan Africa

The Value Added of manufacturing and services firms as a percentage of GDP in 2021 are respectively on average 12% and 47.2% in SSA against 25% and 65.1% in East Asia and Pacific, 16% and 65.1% in Latin America and the Caribbean and 15% and 48.8% in South Asia. This low contribution of SSA firms to GDP compared to the rest of the world can be explained by inefficiencies in the allocation of production factors (African-Union, 2020). Improving business productivity and ensuring inclusive growth in SSA will require cultivating a dynamic and competitive private sector by alleviating the most binding constraints on business activities.

One of the major constraints hampering business activity in SSA is poor electricity availability (World Bank Enterprise Surveys data from 2008 to 2023). Indeed, three-quarters (3/4) of SSA companies suffer from an electricity deficit (Blimpo and Cosgrove-Davies, 2019). Electricity deficit durations are relatively longer in SSA than in other developing countries. SSA firms suffer on average 7.8 outages per month for a duration of 5 hours. In contrast, firms in Eastern Europe experience only 2 outages per month for a duration of 1.2 hours. Meanwhile, firms in Latin America and the Caribbean face 2.8 outages per month for an hour and a half, and firms in South Asia and the Pacific have 3.5 outages per month for a duration of 2 hours (World Bank Enterprise Surveys data from 2008 to 2023).

These frequent power outages hamper business productivity in SSA. It is accepted in the literature that the reliability of electrical energy contributes to the adoption of innovative technologies which in turn improve the performance of the production process, and in turn, reduce production costs and improve business productivity (Xiao et al., 2022).

The rest of the paper is as follows: Section 2 presents a theoretical framework of the analysis, Section 3 provides a review of the literature, Section 4 presents the empirical strategy, Section 5 presents the descriptive data and analysis, Section 6 presents the results and Section 7 concludes.

Theoretical Framework

Figure 1 illustrates the complexity of the relationship between electricity shortage and firm productivity. This conceptual framework is inspired by the literature on the business environment and firm productivity (Kinda, 2010; Dethier et al., 2011); the business environment and the supply of electrical infrastructure (Heffner et al., 2010), and the business environment and the behavior of firms (Restuccia and Rogerson, 2008). As shown in the Figure 1 the effect of electricity shortage on firm productivity results from interdependence between four factors: The business environment, electricity shortages, firm adaptation strategies and firm productivity.

The business environment or business climate affects all economic activity, particularly investment incentives. It is made up of certain key variables: physical infrastructure (electricity, water, and internet), financial institutions, governance, political stability, fiscal, monetary, and budgetary policies, and the regulatory framework, including competition policies, protection, and property rights. The quality of the business environment is a determining factor in the reliability of the availability of electrical energy. The improvement in the business climate increases the attractiveness of foreign direct investment and promotes investment in the production of electrical energy and in the maintenance of factories and transmission lines of electrical energy. On the other hand, a weak business climate can not only discourage investment in the production of electrical energy (reduction of investments in production, in the maintenance of factories and transport lines), but also reduce productivity of firms through the drop in investments caused by uncertainty in the electricity market (Abeberese et al., 2021; Guo et al., 2023).

According to the literature, there is a two-way relationship between electricity shortages and firm productivity fueled by the quality of institutions. The first relationship is the one mentioned above. The second relationship states that an improvement in the quality of institutions can indirectly affect the reliability of electric power availability through national productivity growth. Regarding electricity shortages, the increase in national productivity about the improvement of the business climate could lead to an increase in household income. The increase in household income will have a positive effect on human capital and will contribute to improving business productivity. Growth in business productivity will lead to an increase in demand for electrical energy. If government policies do not respond quickly with investment in the production of electrical energy, the availability of electrical energy will decline and cause electricity shortages which in turn will lead to a reduction in investment and reduce business productivity (Heffner et al., 2010).

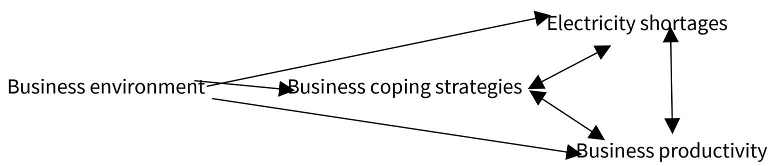
As shown in Figure (1), electricity shortages and business productivity are also determined by business adaptation strategies such as the use of generators, outsourcing of intermediate goods; changing the time of the day during which production takes place, and modifying the production process to make it less dependent.

In the existing literature, a long-term option to counter the effect of electricity shortages on business productivity is the use of generators. This strategy can lead to either a positive or a negative effect on business productivity. Following the argument, which stipulates the drop in the average cost of production of a product or service resulting from the increase in the quantities produced, the use of the generator can contribute to mitigating the impact of electricity shortages on the productivity of large businesses but may potentially maintain the negative effect on small business productivity. The negative effect may be due to the fact that, self-generated electricity is generally more expensive than electricity from the public grid (Steinbuks and Foster, 2010). Small businesses with fewer resources suffer increased investment and operating costs and cannot achieve economies of scale. The business environment in which the firm operates (location, quality of institutions) and the characteristics of the firms can play a determining role in the direction of the relationship.

Outsourcing the production of energy-intensive intermediate goods is often a short-term option for firms to counter the effects of electricity shortages on productivity. Thus, materials would be a substitute for electricity. In addition to the substitution of capital (material) with electricity, internationalization also results in less use of labor and other energy sources in the production of these intermediate goods. This reduced use of capital and labor input can counter the effect of electricity shortages on firm productivity, if and only if the change in input is less costly.

Some firms instead opt to change production hours during periods of electricity shortages. They produce only when electrical energy is available. This technique leads to underutilization of production capacities by firms and leads to a drop in production. The drop in production can lead to a reduction in sales and productivity of the firm.

Figure 1: Complexity of the relationship between electricity shortages and firm productivity



Source: Authors based on theoretical and empirical literature

2. Brief review of the literature

The complexity of the relationship between electricity shortages and firm productivity, highlighted in the previous theoretical literature, is also highlighted in the empirical literature. This empirical review therefore focuses on structuring this theoretical framework. In this respect, the empirical findings on the impact of the business environment on electricity shortages at the firm level will be presented, followed by the literature on the impact of the business environment on firm performance, and finally the literature on the relationship between electric power shortages and firm coping strategies.

Numerous studies have shown the decisive role played by the business environment in reducing and/or increasing electricity shortages at the firm level. For example Pless and Fell (2017), associate frequent power outages with the tendency of firms to give bribes to electricity officials in a set of developing countries. The results of the study reveal that the likelihood of paying a bribe for an electricity connection is associated with an increase of around 14 power cuts per month. Following the same line of argument, Asiedu et al. (2021) assert that bureaucratic red tape and corruption, such as the time it takes to obtain an electricity connection, and the bribe firms have to pay to obtain electricity service, are the consequences of weak institutions that cause electricity shortages at firm level.

Another topic that has received particular attention in the literature is firm-level inefficiency caused by institutions and policies related to the business environment, as well as distortions in the allocation of resources between firms (Bah and Fang, 2015). Development literature has shown that both channels play an important role in reducing firm productivity. Restuccia and Rogerson (2008) argue that policies and institutions can create taxes or subsidies on the establishment's production, leading to a decline in overall TFP and output. To validate the empirical mechanisms in Sub-Saharan Africa, Bah and Fang (2015) develop a general equilibrium model to assess the quantitative effects of the business environment, including regulation, crime, corruption, infrastructure, and access to finance, in Total Factor Productivity (TFP) in sub-Saharan African countries. The results show that TFP is highly correlated with the data, and the model accounts for 48% of the variation in productivity in the data.

Other studies instead show that a better investment climate leads to greater business productivity (Dollar et al., 2005). For example, (Chang, 2023) studies show how different aspects of institutional quality influence the productivity of firms in 41 developed and developing countries; the empirical results indicate that better institutional quality increases TFP and firm value and that the political institutional quality with the highest positive impact on business value and technological progress. In the context of sub-Saharan Africa, Kpognon et al. (2022) assessed the effect of investment climate on productivity in 31 SSA countries. The results show that investment climate indicators have a positive and significant influence on labor productivity. Political stability, government effectiveness, and the rule of law are indicators that contribute most to increased productivity in SSA. The authors Jibir et al. (2019) examine the role of investment climate in improving firm performance using a set of 23 SSA countries. The study concludes that corruption control, government efficiency, regulatory quality, and the rule of law are market-friendly institutions that effectively create a favorable business and investment climate.

Regarding the effect of firm' adaptation strategies on the relationship between electricity shortages and business productivity relation, the literature reveals that some firms reduce the workforce to counter the impact of energy shortages. Hardy and McCasland (2021) show that this technique reduces the productivity of very small businesses.

Along the same lines, Allcott et al. (2016) use a sample of large firms where 44% of these firms use generators to assess the impact of electricity shortages on the productivity of Indian firms. They find that firms that use the generator do not suffer any loss of productivity while those that do not use a generator are severely affected. Elliott et al. (2021) instead show that large Vietnamese firms with less reliable electricity have low productivity, which is not mitigated by the use of generators. In Ethiopia, the self-production of electricity by firms leads to higher productivity losses compared to firms without backup energy (Abdisa, 2018). Taking into account a set of countries Cole et al. (2018) on a sample of manufacturing companies in SSA, show that the impact of electricity shortages is more marked for firms that do not have a generator. The results of (Mensah, 2024) on a sample of manufacturing firms are contrary to those of Cole et al. (2018). (Mensah, 2024) results reveal that contrary to the idea that self-production can be useful to businesses during periods of electricity shortages; it is associated with productivity losses.

In the light of existing work, this study seeks to understand why some firms succeed in an environment where the supply of electricity is unreliable, while others are unable to do so. To contribute to the existing literature, this study aims to determine the success factors of firms in an environment poor in electrical energy. The results of these analyses could contribute to the design of targeted and effective public policies and offer strong policy implications regarding the improvement of energy supply in the pursuit of business performance in sub-Saharan Africa, where government budgets are relatively tight and overburdened. They could also help unleash the commercial potential of sub-Saharan African firms. Ultimately, this could lead to a better optimization of the environment in which private firms operate and thus facilitate the attraction of foreign direct investment and multinational firms to sub-Saharan Africa.

3. Empirical strategy

This study aims to analyze the heterogeneity of the relationship between energy shortages and firm productivity; and to identify the factors behind this heterogeneity. The methodology is broken down into three steps:

Calculation of the productive efficiency of firms

The stochastic frontier and non-parametric frontier methods are the two main approaches used to estimate the production possibility frontier needed to measure efficiency. These two approaches, which each have their advantages and disadvantages, differ in their underlying assumptions. The Data Envelopment Analysis (DEA) method, initiated by the work of Charnes et al. (1978) ggeneralizes the work of Farrell (1957) through a mathematical programming approach. The main advantage of non-parametric DEA is that it does not require specification of the functional form of the production function. The main disadvantage of this method lies in its sensitivity to extreme values and the omission of the statistical error term. These limitations make this method inapplicable to research on the technical efficiency of firms that use a large sample, and that carry out an analysis on firms of different sizes and that operate in different countries.

The stochastic frontier approaches developed by Aigner et al. (1977) to estimate technical efficiency indices, postulate an error term split into two independent parts, namely a technical inefficiency component and a random component. There are many arguments in favor of the use of the SFA method. SFA assumes heterogeneity in technologies and accounts for random noise and inefficiency in production. It is also suitable when there is a well-defined theoretical model underlying the production process and when detailed information on input-output relationships is available.

We use the method of Stochastic Frontier Analysis to generate technical efficiency scores.

The estimation of efficiency scores using the stochastic frontier model inspired by Battese and Coelli (1995) (for cross-sectional data) is specified as follows:

$$lnq_i = \theta + \delta lnz_i + \pi_i \quad (1)$$

Where q represents the added value of firms; z is the set of input variables: Capital (electricity cost, raw material coast) and labor (Number of employees); $\boldsymbol{\pi_i} = \boldsymbol{v_i} - \boldsymbol{u_i}$, $\boldsymbol{u_i}$ is the efficiency term for firm i. ($\boldsymbol{u_i}$>0) and $\boldsymbol{v_i}$ is the idiosyncratic error term. The estimation of the productivity term $\boldsymbol{u}_{\boldsymbol{i}}$follows a consistent estimation of the parameters of the equation (1). The distribution of $\boldsymbol{v_i}$ is generally assumed to be normal with independently and identically distributed observations. Different distributions can be assumed for $\boldsymbol{u_i}$ among which the semi-normal distribution (Aigner et al., 1977), the exponential distribution (Meeusen and van Den Broeck, 1977), and the truncated normal distribution (Stevenson, 1980). We will use the semi-normal distribution and the method of (Greene, 2008) to generate the efficiency scores.

Groupings of Enterprises into Clusters and Characterization of Groups

Second, instead of using the two-step SFA and DEA method to establish the functional causal relationship between energy shortages and firm productivity, we will examine natural clusters of firms in SSA. The use of this method enables us to examine how the endogenous variables (energy shortages, firm adaptation strategy, and business environment) in our study evolve together.

Indeed, the burden of energy shortages (number and duration) is endogenous, as they depend on the adaptation strategies adopted by the firm. For example, many firms are starting to produce their own energy using a generator, and it has been shown that these firms are much less affected by energy shortages.

On the other hand, another form of endogeneity can occur if governments deliberately target investment in energy infrastructure close to large, successful firms to support their activities. Similarly, government policies can simultaneously affect firm performance and interruption levels. For example, public investment in infrastructure more generally (roads and railroads) can improve the reliability of electricity supply (power lines can then be repaired more easily) but should also help firms to get their products to market more quickly.

Since the present study wants to divide the observations into a distinct number of non-overlapping groups, the method of cluster analysis by partition generally called "*k- means clustering*" is used. These groupings will take into account the duration of electricity shortages, losses linked to the lack of electrical energy, technical efficiency, and labor productivity.

Developed by MacQueen (1967), this clustering approach, better known as "*clustering* ", is an algorithm that allows each dataset to belong to a single cluster. At the same time, this algorithm constantly renews the clusters and continues until it has reached an optimal solution. The clusters obtained have maximum intra-cluster similarities and minimum inter-cluster similarities. This method is widely used in data mining with applications in industry and research. For example, Sariyer and Taşkın (2022) used it to rank firms based on environmental, social, and governance rating from BIST sustainability index.

Like Sariyer and Taşkın (2022) we use the K- means method which is a clustering method that divides a set of observations$\{\boldsymbol{x_1}, \boldsymbol{x_{2,\ldots\ldots}} \boldsymbol{x_n}\}$, where $\boldsymbol{x_i} = (x_{i^1}, x_{i2,\ldots,} x_i r)$ is a vector in a real-valued space X ⊆ R^r, and r is the number of attributes (dimension) in the data. The algorithm partitions the data of the K clusters. Based on the Euclidean distance between each observation and the centroid. *K-means clustering* iteratively partitions *n* observations in k (≤n) set $\boldsymbol{S} = \{s_1, s_2, \ldots s_k\}$**,** to minimize the sum of squares (*variance)* within-group of the distance between $\boldsymbol{x_i}$and the centroid.

Each iteration determines both the number of firms in the cluster and the centroid value. This process is equivalent to minimizing the squared deviations per pair of points within a cluster. As the total variance is constant, this is also equivalent to maximizing the squared deviations between the points of the different clusters (i.e., the sum of squares between the clusters). The “*K- means clustering*” technique stops at the point where it finds the lowest intra-group variance, and the highest inter-group variance.

Determination of the explanatory factors of the productivity of the companies in the period of energy shortages

In the third step, the aim is to examine the factors that moderate or cancel out the effect of the electricity shortages on firm productivity. To do this, we use membership in cluster k as the dependent variable. This membership in cluster k is used to explain whether a firm is more likely to be in, say, cluster 1 rather than another cluster. For this dependent variable, more than three groups of firms were formed using the "*k-means*" clustering method: The firm could belong to the most productive group or the least productive group. Given the polytomous nature of the dependent variable, and as there is no predefined order between clusters, the multinomial probit model is ideal for formalizing this study since the Independence of Irrelevant Alternative hypothesis carried out to check whether the random terms are independent and identically distributed is rejected.

If the results of the IIA test show that the random terms are independent or different, the multinomial logit model is the appropriate model. Furthermore, if the results of the IIA test show that the random terms are dependent and/or the test is indeterminate, the simple logit model can be used. But we can also interpret the independence of the alternatives by the fact that there are other factors that can explain the belonging to each group. In this way, the multinomial probit model can be used for the estimations. The study's dependent variable reflects the k groups formed using the "*k- means*" method (Heckman, 1979; Van de Ven and Van Praag, 1981).

We can write:

$$EREU_{it} = \beta_0 + \beta_1^* CAF_{it} + \beta_2^* COUN_{it} + \beta_3^* QINST_{it} + \mu_i + \delta_t + \varepsilon_{it} \qquad (2)$$

With:

$$ERUi \begin{cases} 0 \ if \ the \ company \ belongs \ to \ the \ first \ group \\ 1 \ if \ the \ company \ belongs \ to \ the \ second \ group \\ . \\ . \\ . \\ . \\ k \ if \ the \ company \ belongs \ to \ the \ kth \ group \end{cases}$$

And $\boldsymbol{\beta_j}$ are the parameters that are interpreted as deviations from the reference frame.

CAF stands for characteristics of firms since it is accepted in the literature that productivity varies depending on the characteristics of firms (Syverson, 2011). The variables retained are: The size of the firm, age of the firm, and the fact that the woman; is obstacle to is electricity shortage and informal sector obstacles.

COUN designates the gross domestic product. This variable is country-level variables, which can explain the difference in firm level of performance.

QINST stands for the quality of institutions. It is introduced to measure whether the probability of belonging to the most productive cluster increases with the quality of institutions. It measures the effect of the quality of the institution on the success of firms in the context of the electricity crisis. This includes government effectiveness (reflects the ability and credibility of government to deliver quality public services), regulatory quality (captures the level of bureaucracy that affects private sector development), rule of law (reflects the extent to which contracts are enforced) and corruption reflects corruption in government, such as paying bribes. The data comes from World Governance Indicators (Kaufmann et al., 2011). Each of the variables ranges between -2 and 2, however, to facilitate interpretation, they are transformed to take on positive values from 0 to 4, and the index of the quality of the institution is computed using principal component analysis (PCA).

δ_t is a fixed-year effect that varies with time t, representing the macroeconomic shock.

ε_{it} is a random error term.

4. Descriptive data and analysis

This study uses data from the World Bank Enterprise Survey (WBES); data from the World Development Indicators, and data from the World Governance Indicators, over two time periods. The first period or period (0) covers the oldest years of surveys conducted in each country from 2006 to 2014. The second period (1) covers the most recent years of surveys conducted in each country from 2008 to 2023.[6] The choice of periods is made according to the availability of data. The pairing of bases is done by appending the datasets from each country. The overall sample includes 28,924 firms in 34 countries in Sub-Saharan Africa. It should be noted that nearly 11,599 firms were not manufacturing firms. These firms have been excluded from the analyses because these firms do not have information on value-added value as well as the cost of raw materials, essential variables for calculating efficiency scores. In addition, in some countries' datasets, there was no information on some variables in the two periods such as the cost of raw materials. These countries are Burundi, Lesotho, Liberia, Mali and Sierra Leone. The final sample is made up of 12,668 firms from 29 countries, with 6,417 firms for the first period and 6,251 firms for the second period. All monetary variables are adjusted using the 2015 Gross Domestic Product (GDP) deflator and the Purchasing Power Parity (PPP) index in the current US. We calculate the total number of hours of power shortages in the month by multiplying the average number of outages by the number of hours per outage.

Firm performance is measured by two variables: efficiency scores estimated separately for each country considering the difference between the sectors (sector dummies variable has been added to the computation) and labor productivity. The average efficiency score of the pooled data (first and second periods) is 0.78, with a maximum value of 1 (Table 1); the value of average labor productivity is 18.42 with a maximum value of 32.16.

In terms of electrical energy supply, the average duration of electrical energy outages is 5.79 hours of outage per month with a maximum of 486 hours of outage. The Republic of Congo records the highest average outage duration, estimated at 27.38 hours of outages per month, while Rwanda records the

[6] See table 2A and 2B

lowest average of 1.56 hours of outages per month (see Table A1). Although the Republic of Congo records the highest average duration of outages, it is rather the Democratic Republic of Congo, which reports the highest average loss in the percentage of sales due to power outages 21.33%, while Namibia reports the lowest rate 1.31%. This suggests that there are other factors relating to the business environment and also relating to the characteristics and/or adaptation strategy of firms which can attenuate and/or exacerbate the effect of energy shortages on the productivity of business firms. The pooled country-specific mean values are reported in Table 1.

Table 1: Descriptive statistic for the pooled data

Variable	Observations	Mean	Std.Dev.	Min	Max
Countries	29				
Firms level data					
Electricity supply					
Duration cut; (hour per month)	12668	5.79	20.79	0	486
Loss cut (% of sales)	12668	8.55	12.82	0	100
Firm characteristics					
Small size (1-19 employees)	12668	0.17	0.38	0	1
Medium size (20-49 employees)	12668	0.45	0.49	0	1
Large size (50- 100 employees)	12668	0.27	0.44	0	1
Very Large size (101 or more employees)	12668	0.08	0.28		
Firm age; (log)	12668	2.54	0.76	0	5.22
Female owned (1=yes)	12668	0.24	0.43	0	1
Obstacle of electricity shortages	12668	0.47	0.50	1	75
Informal sector obstacle	12668	0.36	0.48		
Firm performance					
Labor productivity (log)	12668	18.42	4.45	3.51	32.16
SFA Efficiency Score	12668	0.78	0.29	0	1
Business environment					
obstacle of electricity (1=greatest obstacle, 0=no obstacle)	12668	0.47	0.05	0	1
Informal sector obstacle (1=greatest obstacle, 0=no obstacle)	12668	0.36	0.48	0	1
GDP (log deflator and ppp)	12668	27.51	2.41	22.6	31.78

Institution quality index	12668	2.25	0.90	0	4

Source: Authors based on study data. NB: We control for different sample sizes across countries by using the sampling weight from the data. As Asiedu et al. (2021), we log some of our macroeconomic variables (except for the concentration of banks) to mitigate the effect of outliers.

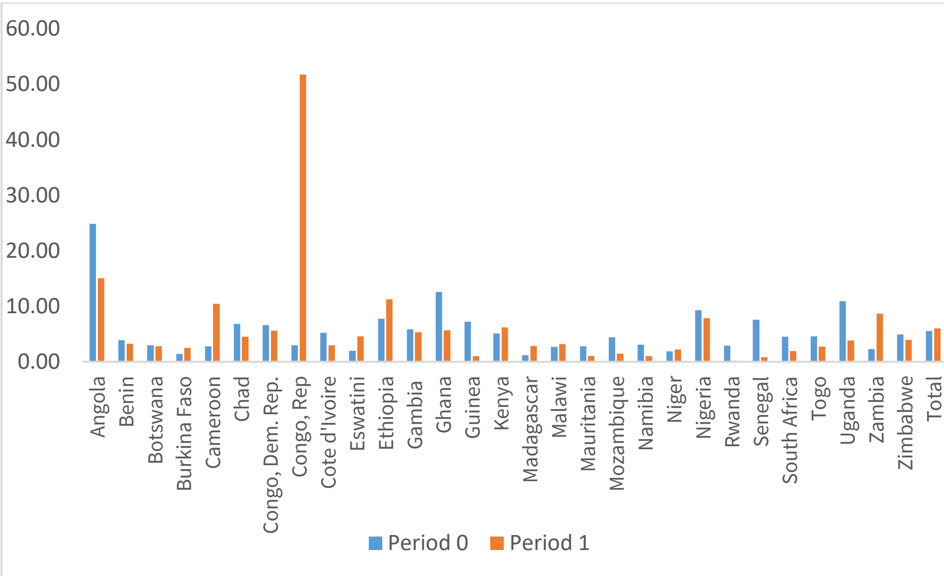
Regarding the size of firms: The proportion of large firms in the sample is the lowest at 11%, compared to 28% for medium-sized firms and 61% for small-sized firms. The average duration of electricity shortages per month for large, medium, and small firms are respectively 4.15 hours of outage, with a maximum value of 240 hours; 4.69 hours of outages with an average of 384 hours and 6.59 hours of outages with a maximum value of 486 hours. Unsurprisingly, the hourly volume of electricity shortages decreases when the size of firms increases. Descriptive analyses also suggest that firms led by women report lower losses due to energy shortages 8.41% than those led by men 8.6%.

Descriptive analysis disaggregated by period reveals that, in terms of electrical power supply, firms in period 0, on average, have access to a more reliable electrical power supply, and the variation between firms is also lower (Table A1 in the appendix). Firms in the period 1 survey face power shortages that last an average of 6.03 hours/month (average outage volume), while period 0 firms are characterized by average outage volumes lower (5.55 hours/month). Similarly, the losses relating to shortages in electrical energy are higher in period (1) on average 9.08% of turnover (CA), than in period (0) 8.03% of CA. These descriptive analyses suggest a reduction in the overall reliability of the power system. These results concur with those of Meles (2020) who asserts that, despite the obvious economic importance, the reliability of electric power in developing countries generally receives much less attention than problems of accessibility to electric power. These analyze are contrary to those of (Elliott et al., 2021), who show an improvement in the reliability of electrical energy between 2005 and 2015 in Vietnam. These contrary results can be explained by the fact that some countries have improved the reliability of their electrical system but compared to the majority of SSA countries, these countries are a minority, hence the reduction in the reliability of electrical energy at the global level.

Pooled averages of electricity shortages can mask wide variations in the electric power deficit in each country. Figure 2 shows the temporal dynamics of shortage duration for each country as a function of periods zero and one. Angola has practically cut the average volume of shortage duration in half. They went on average from (25.34 volume hours/month) to (15.45 volume hours/month). The average volume of shortage duration per month in Guinea and Mauritania has almost been eliminated; they went respectively from (7.16 volume hours/month) to (1.22 volume hours/month) and from (2.98 volume hours/month) to (1.03 volume hours). Ghana, Uganda, Chad, and South Africa have also significantly improved the reliability of electrical power supply.

In addition, the Republic of Congo occupies the head of the peloton as regards the reduction of the reliability of the electrical energy. Indeed, the average shortage duration increased from (2.99 to 36.69 volume hours/month) followed by Cameroon (2.16 to 7.54 volumes hours/month); Burkina (1.40 to 3.26 volumes hours/month): Zambia (2.32 to 6.53 volume hours/month). Eswatini, Liberia, Madagascar; Niger, Ethiopia, Kenya, Mali, and Benin experienced a deterioration in the reliability of electric power.

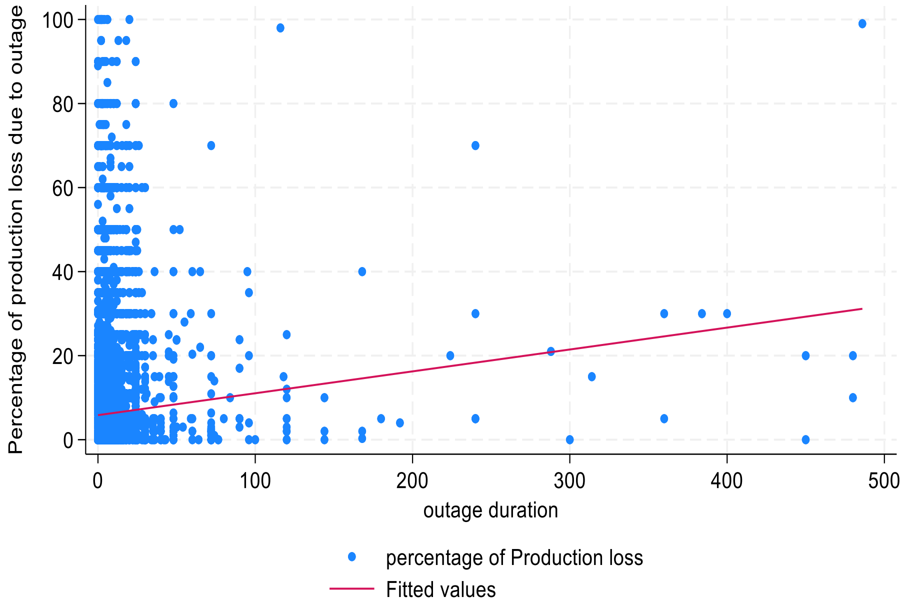
Figure 2: Average change in power outage duration by country



Source: Author's from WBES 2006-2013

To further elaborate the relationship between energy shortages and the productive efficiency of firms, Figure 3 shows the association between the percentage of lost sales of firms resulting from shortages of electrical energy and the total duration of electricity shortages. Overall, there appears to be a positive relationship, but disproportionately between outage duration and loss percentage. This positive relationship shows that power shortages reduce firm sales.

Figure 3: Duration of outages depending on the percentage of sales a positive association



Source: Authors based on data from WBES 2006-2023

The descriptive analyses of the pooled data presented above (Figure 3) indicate a positive but disproportionate association between electricity shortage and percentage losses in turnover. The disproportionality observed between the two variables encourages us to explore, using the K-means method, the factors behind the resilience of firms, which despite long outage duration record few or almost no losses.

To examine the relationship between electricity shortages and the firm's productivity, we define the vector $\boldsymbol{x_i}$ as being composed of four (4) main variables on which the clustering algorithm is applied: 1. Efficiency scores. Variable between 0.00015 and 1 for pooled analysis; 0.00015 and 1 for the period (0) and 0.01 and 1 for the period (1). 2. Labor productivity. Measured by revenues over the number of employees. Variable between 3.5 and 32.16 for pool analysis of both periods; 5.04 and 30.15 for period (0) and from 3.5 to 3.2.16 for period (1). This variable is introduced into the analysis of logarithmic value by Asiedu et al. (2021). 3. The average volume of outage duration varies the month between 0 and 360 for periods zero and 0 and 486 for period one. 4.

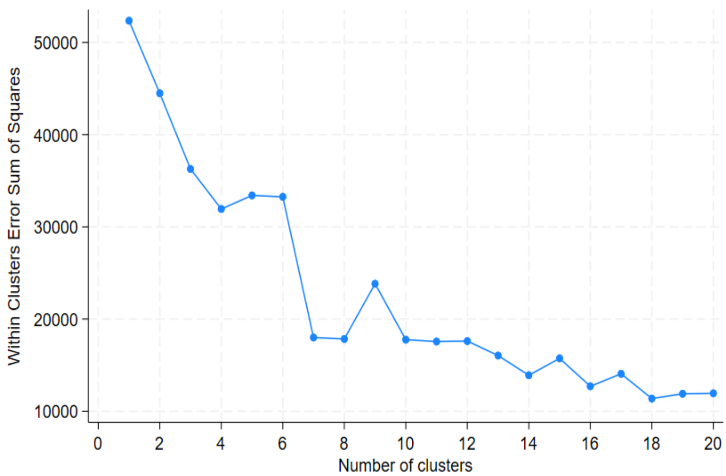
Percentage of sales lost due to electricity deficit. Variable between 0 and 100% for the pooled analysis and both periods.

All these variables are standardized to ensure balanced weighting by using the z-score. The z-score of each variable is computed in two steps. First, the mean and standard deviation of the variable are computed. Then, for each observed value of the variable, the mean of the variable is subtracted, and the result is divided by the standard deviation of the variable.

The success of this method lies in the optimization of the groups of firms to be formed. The four (4) variables above will allow us to determine the number of clusters or groups of firms in our sample. We use the “elbow method” to determine the optimal number of “clusters”. This method determines the optimal number of clusters by examining the within-cluster variance, explained in terms of the number of clusters: The optimal number of clusters is such that adding an additional cluster result in a negligible decrease in variation.

Figure 4 of the intra-class variances of 12 668 firms of the pooled data of the study shows the decline of the intra-class variance with the number of clusters. At some point, the marginal gain will decrease significantly until it reaches the “elbow” in the graph. The number of clusters is chosen near this point or at this point. About Figure 1, and through the 4 dimensions specified in the paragraph below, we find that the additional decreases in intra-group variance are not significant in magnitude at 4 with the efficiency scores generated. Therefore, 4 is the group number (k).

Figure 4: Cluster determination using the Elbow method for the pooled data



Source: Authors based on data from WBES 2006-2023

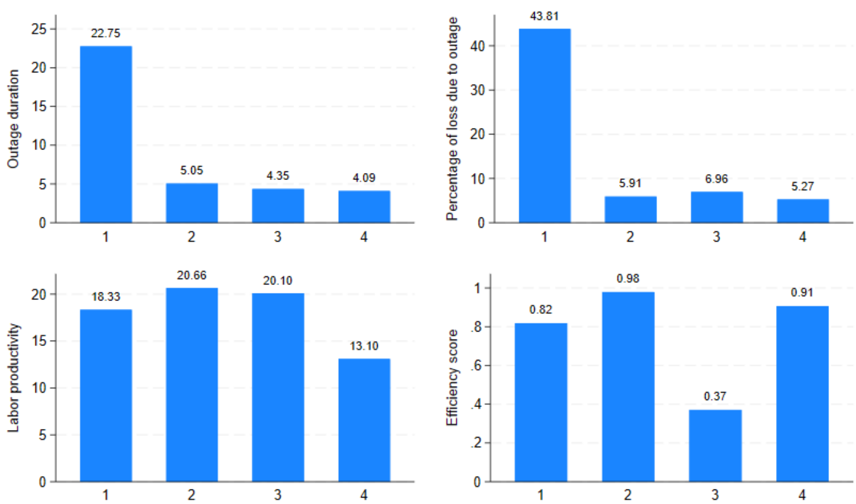
Four groups were formed using the k-means clustering method both in the pooled study sample and in the study, sample divided into periods. The description of the four clusters of the pooled sample is presented in the following paragraphs.

Description of the Clusters and Labelling

Four variables (efficiency score, labor productivity, percentage of sales lost due to electricity deficit, and outage duration), have been used to group the firms into four clusters. Figure 5 shows the distribution of electricity constraint variables (outage duration, percentage loss of sales due to the outage) and the distribution of performance variables (labor productivity, efficiency score) across clusters. In terms of outage duration, the burden is higher for Cluster 1 with a value of 22.75 hours/month, and lower for Cluster 4 with a value of 4.09 hours/month. Concerning the percentage loss of sales due to the outage, Cluster 1 has a higher value (43.81%) and Cluster 4 has a lower value 5.276%.

In terms of performance, there are very few differences between clusters. Cluster 4 is the one with the lower value in terms of labor productivity with a value of 13.1. Cluster two (2) is the cluster with the higher performance with a value of 20.66 for labor productivity and 0.98 for efficiency score.

Figure 5: Distribution of electricity constraint variables performance variable across clusters.



Source: Author's based on data from WBES 2006-2023.

Using this measure of variable does not allow for the definition of a pattern of the cluster. To be able to define a pattern and give the name of the clusters, for each indicator (dimension), a dichotomy variable which takes value 1 if the firm performs above the median of the indicator in the country and 0 otherwise is created. Using this approach, the dimension used to characterize the cluster (described in Figure 6) can be defined as follows:

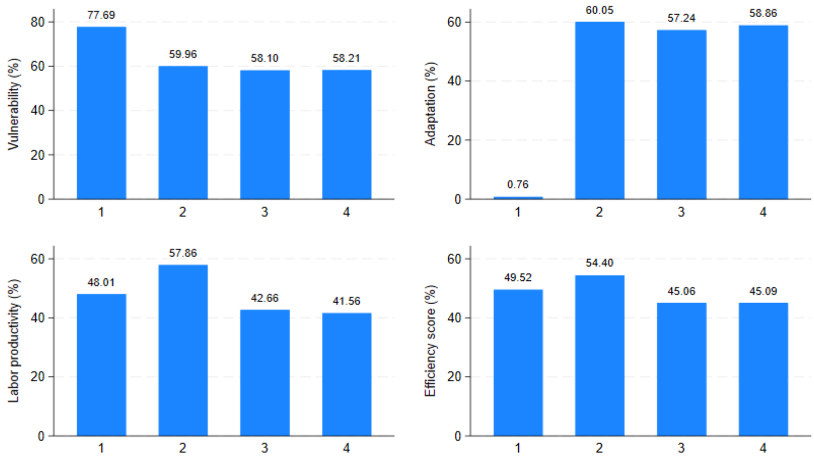
The vulnerability to electricity shortage. This dimension is measured by the duration of a power outage in the cluster. The highly vulnerable firms are those for which the duration of the outage is greater than the median duration of the outage in their country. Cluster 1 is the cluster with a high percentage of highly vulnerable companies (77.69%), followed by Cluster2 (59.96%), Cluster 4 (58.21%), and Cluster 3 with the least percentage of highly vulnerable companies (58.10%).

The adaptation. The adaptation is measured by the percentage loss of sales due to energy shortage. The highly adapted companies are those for which the percentage loss of sales due to energy shortage is less than the median percentage loss of sales due to energy shortage in their country. Cluster 1 does not have highly adapted companies. Cluster 2 has the highest percentage of highly adapted companies (60.05%). There are a few differences between Clusters 3 and 4 in terms of the percentage of adapted companies.

Labor productivity efficiency. The labor productivity is measured by the ratio between the production of value and the number of workers in the companies. The highly efficient companies in terms of labor productivity are those for which the labor productivity is higher than the median labor productivity of the companies in their country. Cluster 4 has the lowest percentage of highly efficient companies (41.56%) and Cluster 2 has the highest percentage of highly efficient companies (57.86%).

Efficiency score. The efficiency score provided by the stochastic frontier analysis (sfa) method measures efficiency. The highly efficiency companies in terms of efficiency score are those for which the efficiency score is higher than the median efficiency score of the companies in their country. Cluster 2 is the one with the higher percentage of highly efficiency companies (54.4%) among all four clusters.

Figure 6: Distribution of the companies in the four indicators (dimensions) by cluster



Source: Authors based on data from WBES 2006-2023.

Test of the independence relationship between dimension and cluster

To use the different dimensions to classify the clusters, it is important to first test the link between each dimension and clusters. Table 2a shows the results of the chi-square test for each dimension and the clusters. There is a link of dependency between all the dimensions (vulnerability to outages, adaptation efficiency score, and labor productivity) and the cluster.

Table2a: chi-square test of dependency between indicator dimensions and clusters

Dimensions	Clusters					
	1	2	3	4	Total	Pearson Chi2 (3)
Vulnerability to outage						
Low	5.94	43.49	18.49	32.08	5,272	83.8***
High	9.51	37.21	19.65	33.64	7,396	
Adaptability						
Low	17.24	35.05	17.47	30.24	5,834	1.3e03***
High	0.15	43.9	20.62	35.34	6,834	
Efficiency score						
Low	8.22	33.76	19.77	38.24	6,312	224.54***
High	7.82	45.85	18.57	27.77	4,179	
Labour productivity						

Low	8.93	30.95	17.88	42.23	6,313	598.48***
High	7.11	48.64	20.44	23.81	6,355	

Source: Authors based on data from WBES 2006-2023. *** for statistically significant at 1%

Test of independence between Clusters 3 and 4 and the analysis-selected dimension

From Figure 6, Cluster 3 and 4 seem to be too similar. The chi-square test allows us to know if it this relevant to combine these clusters or not. Table 2b shows the results of the chi-square test between Clusters 3 and 4 on the study dimensions. For these dimensions, there is no difference between Cluster 3 and Cluster 4. Therefore, Clusters 3 and 4 will be combined for the analysis.

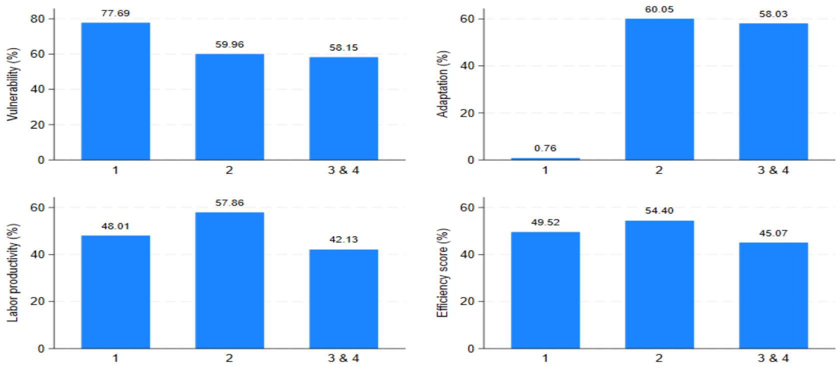
Table2b: Chi-square test of independence between indicator dimensions and Cluster 3 and 4

Dimensions	Clusters			
	3	4	Total	Pearson chi2(1)
Vulnerability to outage duration				
Low	36.57	63.43	2,666	006
High	36.87	63.13	3,941	
Adaptation				
Low	36.62	63.38	2,783	0.037
High	36.85	63.15	3,824	
Efficiency score				
Low	34.08	65.92	3,662	25.18***
High	40.07	59.93	2,945	
Labor productivity Efficiency				
Low	29.75	70.25	3,795	187.92***
High	46.19	53.81	2,812	

Source: Authors based on data from WBES 2006-2023. *** for statistically significant at 1%

Based on these results, Clusters 3 and 4 are combined and the study uses the vulnerability to outage dimensions, Adaptation dimension efficiency score and labor productivity dimension to classify the clusters. Figure 7 allows us to have the new distribution of the firms in each dimension.

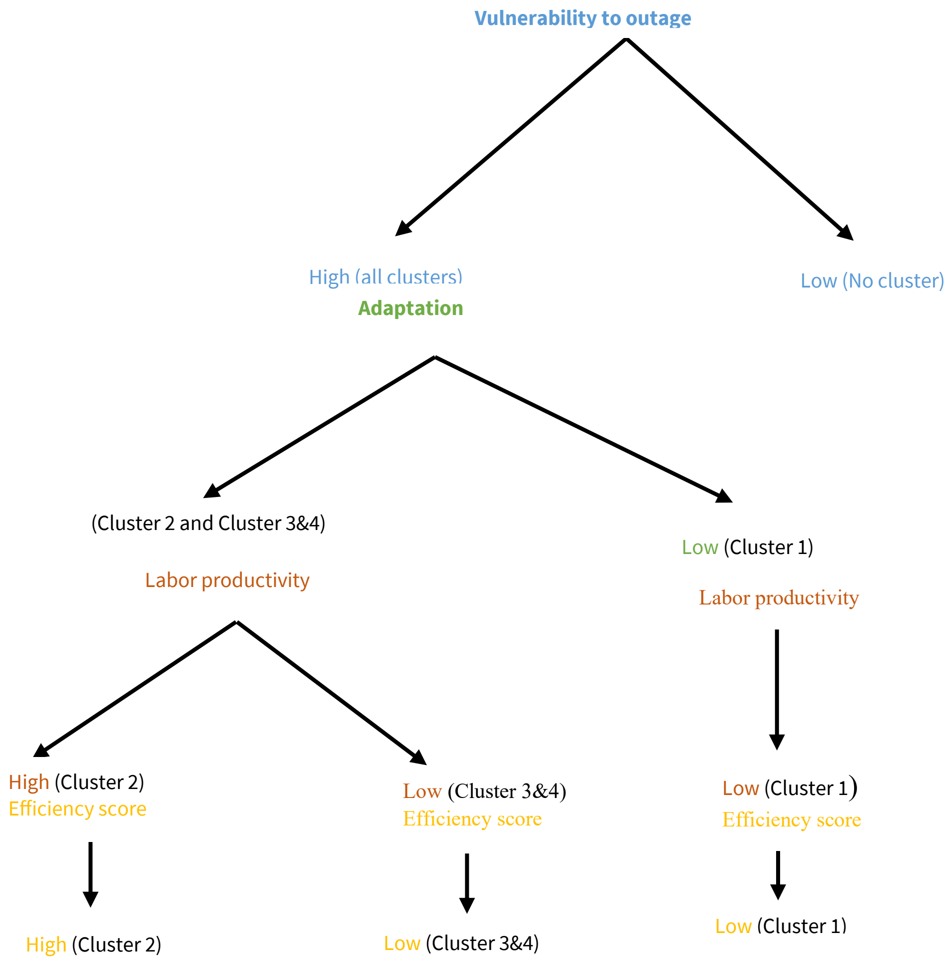
Figure 7: Distribution of the companies in the three indicators (dimensions) by cluster



Source: Authors based on data from WBES 2006-2023.

To be able to name the clusters, the distribution of the companies with the values of the indicators around the median is used. The cluster with most of the companies below the median (less 50%) should be named a "low" cluster for the given indicator (dimension). Concerning vulnerability to electricity outage dimension, all the clusters have more than 50% of the companies with the value of the duration of outage greater than the median value of the outage duration in their country. Concerning the adaptation dimension, Cluster 1 has less than 50% of the companies with a percentage of loss due to electricity shortages less than the median value of the percentage of loss due to electricity shortages in their country. Clusters 2, Clusters 3, and 4 have more than 50% of the companies with the percentage of loss due to electricity shortages less than the median value of the percentage of loss due to electricity shortages in their country. The labor productivity and efficiency score dimensions follow the same pattern. Cluster 1 is the one with high performance with more than 50% of the companies with the value of labor productivity or efficiency score greater than the median value of the labor productivity or efficiency score in their country. The tree below in Figure 8 allows us to have a graphical representation of the structure of the clusters.

Figure 8: Clusters classification tree using the four analysis dimensions



Source: Authors.

Based on the tree, the following names can be given to the clusters.

Cluster1, the Companies heavily impacted: This cluster is characterized by the high proportion of vulnerable companies in terms of outage duration, the low proportion of adapted companies in terms of percentage loss of sales due to shortages, the low proportion of performance companies in terms of labor productivity as well as in terms of efficiency score. This cluster has 1016 companies distributed across all the study countries. Table 3 shows that the mostly represented countries in this cluster are the Democratic Republic of Congo with 19.61% of its companies, followed by Congo Republic (18.15) Gambia (17.67%), and Nigeria (16.50%).

Cluster 2, the resilient companies: This cluster is characterized by the high proportion of vulnerable companies in terms of outage duration, the high proportion of adapted companies in terms of percentage loss of sales due to the outage, and high performance in terms of labor productivity as well as in terms of efficiency score. This cluster has 5045 companies distributed across all the study countries of except Chad, Gambia, and Togo. Table 3 shows that the mostly represented countries in terms of concentration of his companies in this cluster is Rwanda with 98.81%, followed by Burkina Faso (98.25%), Niger (97.8%), and Chad (96.79%).

Cluster 3 and 4, the partially impacted companies: This cluster is characterized by the high proportion of vulnerable companies in terms of outage duration, the high proportion of adapted companies in terms of percentage loss of sales due to the outage, and low performance in terms of labor productivity as well as in terms of efficiency score. This cluster has 6607 companies distributed across all the study countries. The mostly represented countries in terms of concentration of his companies in this cluster is Côte d'Ivoire with 99.08% followed by Namibia (98.62%), Togo (96.6%), and Guinea (95.38%)[7].

Classifying companies based on the four dimensions mentioned provides a more detailed understanding of the different realities; they face electricity shortages and have practical implications for policymakers and managers.

Table 3: Cluster distribution across countries

	cluster with names		
Countries	**heavily impacted companies**	**Partially impacted companies**	**Resilient companies**
Angola	11.92	8.71	79.37
Benin	7.53		92.47
Botswana	2.66	95.36	1.98
Burkina Faso	1.75		98.25
Cameroon	1.66	87.00	11.34
Chad	3.21		96.79
Congo, Dem. Rep.	19.61	80.39	
Congo, Rep	18.15		81.85

[7] See table 3 for a breakdown of company groups by country.

Cote d'Ivoire	0.77	99.08	0.16
Eswatini	4.42	95.15	0.43
Ethiopia	5.54	80.70	13.76
Gambia	17.67	78.44	3.89
Ghana	8.13	91.87	
Guinea	3.75	95.38	0.88
Kenya	7.66	9.45	82.89
Madagascar	12.62	87.06	0.32
Malawi	3.44	93.76	2.79
Mauritania	2.34	10.28	87.38
Mozambique	0.56	84.28	15.16
Namibia		98.62	1.38
Niger	2.20		97.80
Nigeria	16.50	14.16	69.34
Rwanda		0.19	99.81
Senegal	2.78		97.22
South Africa	3.67	91.11	5.22
Togo	3.40	96.60	
Uganda	11.08		88.92
Zambia	15.34	38.77	45.89
Zimbabwe	4.74	95.26	
Total	6.66	52.81	40.53

Source: Authors based on data from WBES 2006-2023.

5. Results

Preliminary test results

Test of independence between firm and environmental characteristics and clusters

Before running regression, it's good practice to check the association between the variables to include in the model and the dependent variable. Therefore, the ANOVA test and Chi-square test are used to check the relation between environment and firm-level characteristics and the belonging to a cluster. Table 4 shows that there is a link between all the selected variables and the cluster. These tests are significant at the level of 1%.

Table 4: Test of independence between firm and environmental characteristics and clusters.

	Heavily impacted companies	Partially impacted companies	Resilient companies	Total	Statistics
ANOVA test					
Firm age+	17.94 (13.94)	18.47 (16.89)	13.69 (13.78)	17.60 (15.52)	26.1***
Manger's experience+	16.16(10.60)	15.89 (10.42)	14.7 (9.96)	15.44 (10.27)	22.1***
Bank concentration (log %)+	4.03 (0.33)	4.22 (0.29)	4.08 (0.32)	4.15 (0.31)	383***
GDP (log current USD)+	28.5 (2.73)	26.82 (2.63)	29.11 (1.8)	27.87 (2.29)	1339***
Institution quality index+	2.58 (0.71)	2.23 (0.98)	2.46 (0.67)	2.35 (0.86)	138.5***
Firm size (Chi2-test)++					
Small size (1-19 employees)	193[9.09]	1,104 [51.98]	827 [38.94]	2,124 [100]	
Medium size (20-49 employees)	421 [8.12]	2,477 [47.77]	2,287 [44.11]	5,185 [100]	124.2***
Large size (50- 100 employees)	298 [7.92]	2,023 [53.75]	1,443 [38.34]	3,764 [100]	
Very Large size (101 and more)	104 [6.52]	1,003 [62.88]	488 [30.60]	1,595 [100]	
Female owned (Chi2-test)++					
No	700 [7.90]	4824 [54.43]	3338 [37.67]	8862 [100]	64.4***
Yes	316 [8.30]	1783 [46.85]	1707 [44.85]	3806 [100]	

Source: Authors based on data from WBES 2006-2023. ( ) Standard deviation into brackets, [ ] contains the proportions. *** significant at the level of 1%; + statistics column gives the F-statistics, ++ statistics column gives the chi2 statistics.

Result of the test of independence of relevant alternatives (IIA test)

The use of the multinomial model can make it possible to highlight the different factors that explain membership in a cluster for the entire study and for each period (heavily impacted companies, partially impacted companies, and resilient companies). However, the test of independence of relevant alternatives (IIA test) which seeks to verify whether the different modalities of the variables of interest are independent or different (Ho) does not allow us to take a position. Because certain modalities are independent while others are not. In addition, the Wald test whose hypothesis (Ho) maintains that the modalities of the variable of interest can be combined is not validated (table 5). The result of this means that the multinomial logit cannot be used but the multinomial probit still useable as stated in the methodology section. Then the multinomial probit will be used.

Table 5: Wald tests for combining outcome categories.

Categories tested	chi2	Df	P>chi 2
heavily impacted companies' vs Partially impacted companies	21478.364	9	0,00
heavily impacted companies' vs Resilient companies	47335.827	9	0,00
Partially impacted companies' vs Resilient companies	60844.256	9	0,00

Source: Authors based on the WBES 2006-2023

Results and discussions

As indicated previously, the dependent variable represents the clusters formed by the K-means clustering method. It is 3 clusters for the entire study and for each period. As is standard in the literature, the estimates are based on the multinomial probit model. The analysis has been done at the firm level. Table 6 presents the marginal effects from the multinomial probit model clustering at the sector level. These marginal effects are calculated at the mean of the qualitative exogenous variables and indicate the variation in the probability of belonging to the "Heavily impacted companies", ''partially impacted companies", or "Resilient companies" cluster attributable to the change of the exogenous variables, all other things being equal. This table reports the estimated effect on the probability of being in one of the three clusters defined earlier ("Heavily impacted companies'', ''partially impacted companies", and "Resilient companies"). Columns (1, 2, and 3) present the results of the pooled sample. Columns (4, 5, and 6) present the result of period (0) and columns (7, 8, and 9) present the result of period (1). In each sample group, the first, second, and third columns show respective results for the "heavily impacted" "partially impacted" and "resilient" clusters.

The results of Table 6 show overall that certain inherent company characteristics (size and age) influence cluster membership. As far as company size is concerned, the trend shows a positive correlation between membership of the good cluster (given the fact that resilient clusters in better than partially impacted clusters which is better than heavily impacted clusters) and firm size. Indeed, being a large company reduces the chances of belonging to the cluster of partially impacted companies and increases the chances of belonging to the cluster of the most resilient companies. This trend observed at the global level is the same as observed at period 1 level. Being a large firm significantly increases at the 5% threshold by 8.56 percentage points, the chances of belonging to the most resilient cluster in period 1. Similarly, being a medium-sized firm significantly increases at the 1% threshold by 7.91 percentage points the chances of belonging to the most resilient cluster. The results of the previous analyses corroborate the findings of previous empirical studies (Xiao et al., 2022) . The results also show that firm age influences cluster membership in the form of a hyperbolic function. Overall, young firms are more likely to belong to the most impacted cluster, but beyond a certain age, the chances of belonging to the least impacted or resilient cluster increase. A plausible reason why younger firms may be less resilient to electricity shortages could be attributed to the fact that, over time, firms tend to find solutions to eradicate or mitigate the negative impact of power cuts on their productivity. The increase in firm age with its resilience to power shortage is in line with previous studies that confirm the positive link between firm age and firm energy poverty , firm productivity (Elliott et al., 2021) , and firm sales (Cole et al., 2018).

In addition to firm characteristics, we find country-level characteristics (GDP, institutional quality index), which also have a positive influence on belonging to the good cluster. All else equal, a 1% increase in gross domestic product for both pooled and period data increases the probability of being in the ‘‘resilient’’ cluster respectively by 7.18, 7.31, and 8.3 percentage points. In the same way, a 1% increase in the gross domestic product has a negative effect on belonging to the ‘heavily impacted’ cluster and the ‘partially impacted’ cluster. Globally this result suggests that an improvement in the gross domestic product of the country will increase the number of firms in the “resilient” cluster.

Table 6: Marginal effects from the Multinomial probit model for pooled, period 0 and period 1 sample

	Pooled			**Period 0**			**Period 1**		
VARIABLES	Heavily impacted (1)	Partially impacted (2)	Resilient (3)	Heavily impacted (4)	Partially impacted (5)	Resilient (6)	Heavily impacted (7)	Partially impacted (8)	Resilient (9)
Medium **(ref : Other size)**	-0.00580	-0.0521**	0.0579***	0.00754	-0.0535*	0.0459**	-0.0211	-0.0580***	0.0791***
	(0.00985)	(0.0229)	(0.0162)	(0.00962)	(0.0288)	(0.0205)	(0.0162)	(0.0153)	(0.0291)
Large **(ref : Other size)**	-0.00332	-0.0432***	0.0465***	0.00429	-0.0295	0.0252	-0.0138	-0.0718**	0.0856**

	(0.00702)	(0.0166)	(0.0136)	(0.00983)	(0.0360)	(0.0331)	(0.0101)	(0.0329)	(0.0374)
Age of firm	0.00163**	0.000398	0.00202**	0.00201***	-0.00309*	0.00108	0.000310	0.000726	-0.00104
	(0.000636)	(0.000738)	(0.000870)	(0.000427)	(0.00172)	(0.00164)	(0.00121)	(0.00161)	(0.00154)
Age of firm square	-2.51e-05***	1.76e-05*	7.55e-06	-3.01e-05***	6.96e-05**	-3.95e-05*	-7.83e-06	4.73e-06	3.10e-06
	(9.37e-06)	(1.05e-05)	(1.26e-05)	(1.02e-05)	(2.73e-05)	(2.12e-05)	(1.51e-05)	(1.52e-05)	(1.94e-05)
Female owned (ref: No)	0.00380	-0.0313	0.0275	-0.00963	-0.0804	0.0900*	0.0250	0.0240	0.0490***
	(0.0120)	(0.0328)	(0.0263)	(0.00952)	(0.0491)	(0.0475)	(0.0218)	(0.0180)	(0.0103)
GDP	-0.00117	-0.0709***	0.0721***	-0.00319	-0.0777***	0.0809***	-0.00149	-0.0728***	0.0743***
	(0.00163)	(0.00548)	(0.00477)	(0.00217)	(0.00886)	(0.00991)	(0.00279)	(0.00984)	(0.0102)
Quality institution	-0.0110***	-0.0143**	0.0253***	-0.0132***	-0.0186	0.0318**	-0.00935***	-0.0133	0.0226***
	(0.00231)	(0.00647)	(0.00514)	(0.00224)	(0.0129)	(0.0129)	(0.00256)	(0.00912)	(0.00756)
Informal sector obstacle (ref: No)	0.00242	-0.0842***	0.0817***	0.00178	-0.0958***	0.0940***	-0.00214	-0.0765**	0.0786**
	(0.00449)	(0.0164)	(0.0165)	(0.00783)	(0.0209)	(0.0245)	(0.0103)	(0.0347)	(0.0391)
Electricity shortage obstacle (ref: No)	0.0707***	-0.105***	0.0341***	0.0408***	-0.129***	0.0885***	0.0962***	-0.0905***	-0.00574
	(0.00798)	(0.0107)	(0.0126)	(0.00518)	(0.0150)	(0.0158)	(0.0132)	(0.0289)	(0.0337)
Sector (ref: rubber and plastic)									
Food and tobacco	-0.0241***	-0.205***	0.229***	0.0233***	-0.269***	0.246***	-0.0562***	-0.151***	0.208***
	(0.00341)	(0.00733)	(0.00509)	(0.00268)	(0.00906)	(0.00767)	(0.00470)	(0.0141)	(0.0140)
Textile	-0.0496	0.0315***	0.0180***	0.00283	-0.104*	0.101***	-0.0717	0.198***	-0.127*

	***				**		***		**
	(0.00326)	(0.00658)	(0.00514)	(0.00267)	(0.00986)	(0.00959)	(0.00548)	(0.0175)	(0.0171)
Wood furniture	0.0380***	-0.141***	0.103***	0.0720***	-0.346***	0.274***	0.0183*	0.00996	-0.0283
	(0.00564)	(0.0129)	(0.00877)	(0.00191)	(0.0102)	(0.0104)	(0.0103)	(0.0297)	(0.0289)
Printing paper	-0.00391*	-0.161***	0.165***	0.0237***	-0.276***	0.252***	-0.0216***	-0.0801***	0.102***
	(0.00232)	(0.00720)	(0.00600)	(0.00222)	(0.0140)	(0.0124)	(0.00120)	(0.00468)	(0.00473)
Chemical proteleum	-0.0170***	-0.0444***	0.0614***	0.00580***	-0.00235	-0.00345	-0.0294***	-0.0702***	0.0996***
	(0.00281)	(0.00628)	(0.00425)	(0.00152)	(0.00487)	(0.00445)	(0.00466)	(0.0142)	(0.0132)
No metallic mineral	-0.0124***	-0.166***	0.178***	0.0414***	-0.203***	0.161***	-0.0491***	-0.135***	0.184***
	(0.00133)	(0.00541)	(0.00613)	(0.00269)	(0.00908)	(0.00956)	(0.00675)	(0.0227)	(0.0254)
Basic metals product	-0.0101***	-0.169***	0.179***	0.0414***	-0.182***	0.141***	-0.0462***	-0.163***	0.210***
	(0.00303)	(0.00441)	(0.00317)	(0.00207)	(0.00585)	(0.00560)	(0.00807)	(0.0258)	(0.0286)
Machinery industry	-0.0241***	-0.138***	0.162***	-0.0262***	-0.124***	0.150***	0.00638	-0.178***	0.171***
	(0.00305)	(0.00184)	(0.00377)	(0.00289)	(0.0159)	(0.0169)	(0.00922)	(0.0222)	(0.0224)
Transport equipment	0.00267	-0.307***	0.304***	0.0416***	-0.374***	0.332***	0.0270	-0.109***	0.0816**
	(0.00312)	(0.00419)	(0.00385)	(0.00121)	(0.00610)	(0.00590)	(0.0123)	(0.0271)	(0.0250)
Observations	12,668	12,668	12,668	6,417	6,417	6,417	6,251	6,251	6,251

Source: Authors based on the WBES 2006-2023, The Standard errors in brackets ***, **, * respectively indicate the significance at 1%, 5%, 10%. The analysis has been weighted to make the result representative at the country level and clustering at the sector level.

When we look at the influence of entrepreneurs' perception of certain obstacles in the business environment (electricity shortage and the informal sector) on cluster membership, we find that, for both grouped and period data, the perception of electricity shortage and the informal sector as major obstacles in the business environment also explain cluster membership. Specifically, perceiving electricity shortage as a major obstacle increases the chances of belonging to the 'resilient' cluster by 3.41 and 8.85 percentage points respectively for grouped data and for period (0). This result can be explained by the fact that entrepreneurs who perceive electricity shortage as a major obstacle to doing business are taking steps to counter the negative effect of the electricity shortage on their productivity. In this context, entrepreneurs who see the constraint of electricity shortage as a major obstacle are those who invest more in alternative sources of electricity, in restructuring their production methods, modifying their organization, or using technology. As a result, the latter are more resilient. This result is in line with Fisher-Vanden et al. (2015), which show that adopting coping strategies to counter the effect of electricity shortages enables companies to be more resilient. This result underscores the importance of promoting policies that encourage substitution towards other sources of electricity that are conducive to business productivity, value creation, and job creation.

The influence of the perception of the informal sector as an obstacle to doing business is significant for both pooled and period data. Indeed, the estimates show that perceiving the informal sector as an obstacle in the exercise of business activities by entrepreneurs increases the probability of belonging to the resilient cluster. Moreover, the influence of the perceived obstacle of the informal sector in terms of belonging to the resilient cluster diminished between period (0) and period (1), from 9.4% to 7.86%. This result can be explained by the fact that, since the informal sector is responsible for precarious jobs Estevão et al. (2022), formal firms that consider the informal sector as an obstacle to benefit from the precarious jobs created by the informal sector to restructure their production during periods of power shortage.

Given that there is dispersion in the intra-industry performance of firms (Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009), an analysis by sector activity is important to determine the sector activities that adapt best or which are most impacted by electrical shortages to formulate targeted economic policy recommendations. To analyze the influence of business sectors on cluster membership, the International Standard Industrial Classification of All Economic Activities (ISIC) was used to rank companies by sector. The results show that the rubber and plastic sectors are the most disadvantaged. Indeed, compared to rubber and plastic sectors, belonging to any sector increases the chances of belonging to the resilient cluster and reduces the chances of belonging to the cluster of the impacted or partially impacted companies. The exception is the textiles and wood and supplies sectors. As a result, the rubber and plastics, textiles, wood and furniture sectors are the ones to which particular attention should be paid in terms of economic policy. This result can be explained by the non-adaptation of these sectors to the electricity shortage and is in line with those of Guo et al. (2023) obtained in China, which shows that some firms are more resilient than others. This result therefore supports the idea of the importance of electricity in the growth of the industrial sector in sub-Saharan African countries.

6. Conclusion

As firms are a vital source of employment and income for poor and vulnerable households, and the engine of growth and development in sub-Saharan Africa, it is important to identify the factors that hinder their productivity. This study extends the existing literature on the factors influencing the impact of electricity shortages on business productivity; and enriches the literature on the impact of the business environment on the relationship between electricity shortages and business productivity, followed by a comparative approach over time. Given the uncertainties surrounding future energy trends (given COVID-19 and the war in Ukraine), the study's two-period comparative approach will enable us to develop economic policies tailored to current energy needs.

Using survey data from 29 sub-Saharan African countries over the period 2006-2023, the analysis reveals three groups (clusters) of companies: “heavily impacted companies", "partially impacted companies" and "resilient companies". The first group “heavily impacted companies" are characterized by high vulnerability to electricity shortages, low adaptation to electricity shortages, and low labor productivity and technical efficiency. The second group “Partially impacted companies” are characterized by high vulnerability to electricity shortages, high adaptation to electricity shortages, low labor productivity, and low technical efficiency. The last group “resilient companies” are characterized by the low vulnerability of the companies in terms of outage duration, the high adaptation capacity of the companies in terms of percentage loss of sales due to the outage, and high performance in terms of labor productivity and efficiency score.

As far as firm size is concerned, the trend shows a positive correlation between membership of the most resilient cluster and firm size. This trend observed at the global level is the same as observed at period 1 level. The results also show that young firms are more likely to belong to the most impacted cluster, but beyond a certain age, the chances of belonging to the least impacted or resilient cluster increase. In addition, the result suggests that an improvement in the gross domestic product of the country will increase the number of firms in the “resilient” cluster. We also find that firms that operate in countries that have a low institutional quality index are more likely to be in the heavily impacted companies and partially impacted companies. This result is consistent with that of Asiedu et al. (2021) and Geginat and Ramalho (2018) who find evidence that the country’s institutional quality is correlated with the reliability of electrical energy at firms level and the ease of getting electricity. When we look at the influence of entrepreneurs' perception of certain obstacles in the business environment (electricity shortage and the informal sector) on cluster membership, we find that, for both grouped and period data, the perception of electricity shortage and the informal sector as major obstacles in the business environment also explain cluster membership.

We ended by making three recommendations that governments could implement to improve the productivity of low-electricity businesses. First, all governments need to make efforts to improve the reliability of electric infrastructure to maintain firm performance since the reliability of electrical energy decreases over time. This increase in electricity shortages over time suggests that more effort should be made to mitigate electricity shortages. Reliability being different from accessibility, the focus here should be on the maintenance of electricity transmission equipment, the maintenance of power plants, and the use of renewable energies according to the dominance of primary sources of electricity production in the various localities to reduce the duration and frequency of power cuts. This recommendation is in line with sustainable development goal 7 with emphasis in the necessity to provide affordable, reliable, and sustainable modern energy to all.

Second, reading the cluster classification tree “heavily impacted companies”, “Partially impacted companies”, and “resilient companies” allows us to identify the specific needs of different categories of companies, to facilitate the elaboration and design of targeted policies for firm policies and managers, to promote private sector development. The government should put in place policies oriented to small firms which are the most likely to belong to the “heavily impacted cluster”

Third, governments can facilitate the purchase of backup generators and/or the installation of mini power plants based on the region's dominant primary power generation sources in the industrial parks of firms most affected by power shortages.

Finally, given the adverse effect of institutional quality on amplifying the negative impact of power shortages on business productivity, countries should adopt policies that will enhance their institutions. Improving institutional quality to reduce electricity shortages will have a double dividend: it will also help improve economic growth (North, 1990; Rodrik et al., 2004).

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8. Appendices

Table A1: Distribution of the outage duration by country and period

	Period		
Countries	**Period 0**	**Period 1**	**Total**
Angola	24.85	15.06	19.95
Benin	3.89	3.28	3.58
Botswana	2.95	2.80	2.88
Burkina Faso	1.41	2.51	1.96
Cameroon	2.81	10.46	6.63
Chad	6.82	4.50	5.66
Congo, Dem. Rep.	6.61	5.62	6.11
Congo, Rep	2.98	51.77	27.38
Cote d'Ivoire	5.23	3.00	4.11
Eswatini	2.00	4.60	3.30
Ethiopia	7.76	11.23	9.50
Gambia	5.82	5.32	5.57
Ghana	12.57	5.67	9.12
Guinea	7.21	1.01	4.11
Kenya	5.13	6.18	5.65
Madagascar	1.16	2.87	2.02
Malawi	2.68	3.17	2.93
Mauritania	2.82	1.09	1.96
Mozambique	4.39	1.45	2.92
Namibia	3.10	1.01	2.05
Niger	1.87	2.24	2.05
Nigeria	9.28	7.86	8.57

Rwanda	2.92	0.20	1.56
Senegal	7.60	0.86	4.23
Sierra Leone		8.62	8.62
South Africa	4.50	1.95	3.23
Togo	4.57	2.72	3.65
Uganda	10.93	3.82	7.37
Zambia	2.29	8.65	5.47
Zimbabwe	4.93	3.97	4.45
Total	5.55	6.12	5.84

Source: Authors based on the WBES 2006-2023

Table A2: Descriptive statistics for period 0 and period 1

	Period 1 (N=6251)				Period 0 (N=6417)			
Variable	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD.**	**Min**	**Max**
Countries	29				29			
Firms level data								
Electricity supply								
Duration cut;(hour per month)	6.03	27.53	0.00	486	5.55	10.32	0.00	360
Loss cut (% of sales)	9.08	14.32	0.00	100	8.03	11.08	0.00	100
Firm characteristics								
Small size (1-19 employees)	0.17	0.38	0	1	0.19	0.39	0	1
Medium size (20-49 employees)	0.47	0.50	0	1	0.44	0.50	0	1
Large size (50-100 employees)	0.28	0.45	0	1	0.27	0.45	0	1
Large size (101 or more)	0.08	0.28	0	1	0.10	0.29	0	1
Firm age; (log)	16.74	13.37	0	184	14.7	13.4	0	117
Female owned (1=yes)	0.23	0.42	0.00	1.00	0.25	0.43	0.00	1.00
Firm performance								
Labour productivity (log)	18.43	4.77	3.50	32.16	18.4	4.10	5.05	30.2
SFA Efficiency Score	0.78	0.30	0.00	1.00	0.79	0.29	0.01	1.00
Business environment								
GDP (log current USD)	23.72	1.21	21.24	27.08	23.4	1.20	20.78	26.5
Informal sector obstacle	0.37	0.48	0	1	0.35	0.48	0	1
Electricity obstacle	0.51	0.50	0	1	0.44	0.50	0	1
Institution quality index	2.23	0.85	0.00	3.74	2.26	0.95	0.03	4.00

Source: Authors based on the WBES 2006-2023

Table A2: Cluster distribution by country according to period0

	Year	cluster names Heavily impacted	Partially impacted	Resilient
Countries				
Angola	2006	5.10	1.01	93.89
Benin	2009	1.53		98.47
Botswana	2006		100.00	
Burkina Faso	2006			100.00
Cameroon	2009	0.71	81.71	17.58
Chad	2009	2.70		97.30
Congo, Dem. Rep.	2010	31.73	68.27	
Congo, Rep	2006	3.96		96.04
Cote d'Ivoire	2008		100.00	
Eswatini	2006		100.00	
Ethiopia	2011	4.10	86.92	8.98
Gambia	2006	18.45	78.34	3.21
Ghana	2007	1.10	98.90	
Guinea	2006	5.82	94.18	
Kenya	2013	5.89	9.23	84.88
Madagascar	2014	4.36	95.64	
Malawi	2009	3.43	93.40	3.17
Mauritania	2006	1.10	19.10	79.80
Mozambique	2007	0.55	89.53	9.92
Namibia	2006		99.24	0.76
Niger	2009	0.99		99.01
Nigeria	2007	9.12	7.07	83.81
Rwanda	2011			100.00
Senegal	2007	1.41		98.59
South Africa	2007	0.24	97.45	2.30
Togo	2009	4.73	95.27	
Uganda	2006	11.97		88.03
Zambia	2013	12.52	0.86	86.63
Zimbabwe	2011	3.05	96.95	
Total		4.64	52.18	43.19

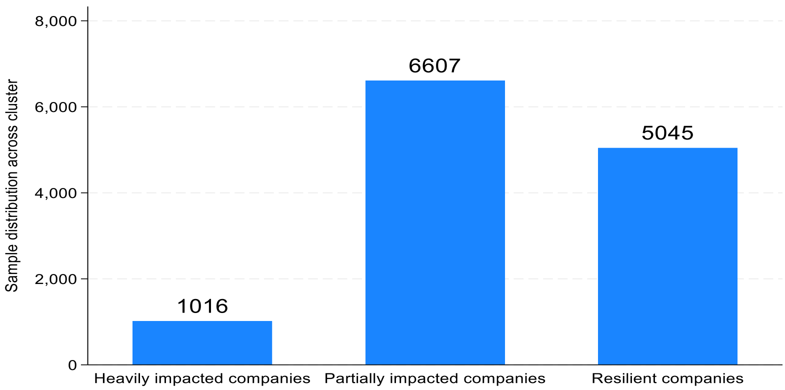
Source: Authors based on the WBES 2006-2023

Table A3: Cluster distribution by country periode1

		cluster names		
	Year	Heavily impacted	Partially impacted	Resilient
Countries				
Angola	2010	18.74	16.41	64.85
Benin	2016	13.54		86.46
Botswana	2010	5.32	90.71	3.97
Burkina Faso	2009	3.51		96.49
Cameroon	2016	2.61	92.29	5.11
Chad	2018	3.73		96.27
Congo, Dem. Rep.	2013	7.49	92.51	
Congo, Rep	2008	32.34		67.66
Cote d'Ivoire	2016	1.53	98.15	0.32
Eswatini	2016	8.84	90.30	0.86
Ethiopia	2015	6.98	74.48	18.53
Gambia	2018	16.88	78.54	4.57
Ghana	2014	15.17	84.83	
Guinea	2016	1.67	96.58	1.75
Kenya	2018	9.44	9.67	80.90
Madagascar	2022	20.87	78.48	0.65
Malawi	2014	3.46	94.13	2.41
Mauritania	2014	3.57	1.47	94.97
Mozambique	2018	0.57	79.03	20.40
Namibia	2014		97.99	2.01
Niger	2017	3.42		96.58
Nigeria	2014	23.88	21.25	54.87
Rwanda	2019		0.37	99.63
Senegal	2014	4.14		95.86
South Africa	2020	7.09	84.78	8.13
Togo	2016	2.07	97.93	
Uganda	2013	10.20		89.80
Zambia	2020	18.16	76.69	5.15
Zimbabwe	2016	6.43	93.57	
Total		8.68	53.45	37.87

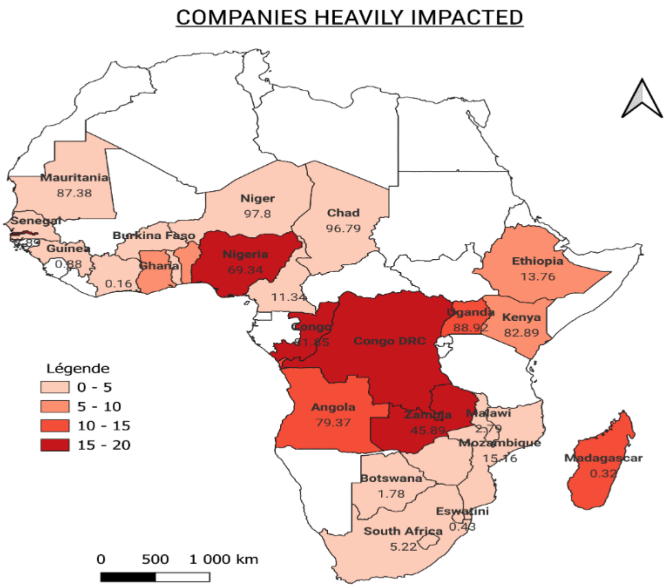
Source: Authors based on the WBES 2006-2023

Figure A1: Sample distribution across clusters



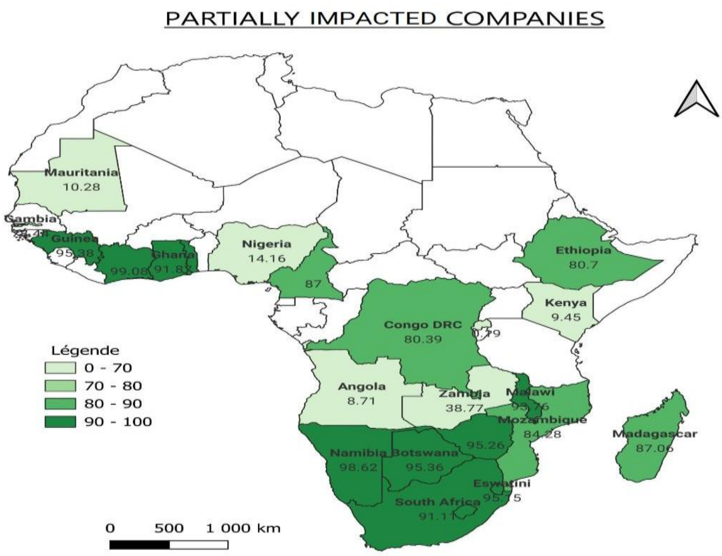
Source: Authors based on the WBES 2006-2023

Figure A2: geographical representation of heavily impacted companies



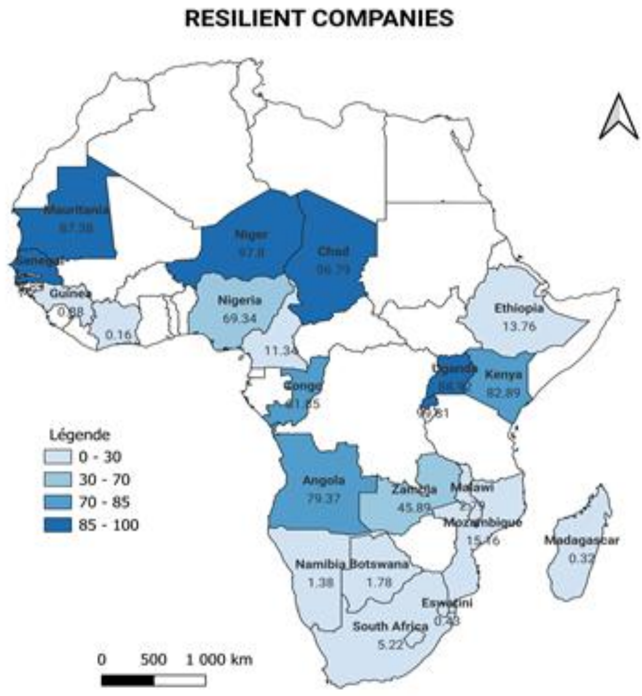
Source: Authors based on the WBES 2006-2023

Figure A3: Geographical representation of partially resilient companies



Source: Authors based on the WBES 2006-2023

Figure A4: Geographical representation of resilient companies



Source: Authors based on the WBES 2006-2023

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

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