



Association between rural electrification and agricultural output: Evidence from Sub-Saharan Africa[☆]

Salome Amuakwa-Mensah^{a,*}, Yves Surry^b

^a Department of Social Sciences, Technology and Arts, Luleå University of Technology, Luleå, Sweden

^b Department of Economics, Swedish University of Agricultural Sciences, Uppsala, Sweden

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ABSTRACT

This paper explores the association between rural electrification and agricultural output at the macro level using panel data on 43 Sub-Saharan African countries from 1990 to 2016. We employed Fully Modified Ordinary Least Squares (FMOLS) with time trend and country fixed effect in our econometrics estimation to address the potential serial correlation. Our study investigates the following; i) the association between rural electrification and agricultural output, measured as agricultural output per GDP and agricultural output per worker, ii) whether the relationship between rural electrification and agricultural output is conditional on institutional quality of a country, and iii) whether electrification enhances the marginal effect of factor inputs. We find a positive significant association between rural electrification and agricultural output. Also, our result shows that the relationship between electrification and agricultural output is conditional on the quality of institution and factor inputs of a country. With the exception of capital, the association between the interaction term of rural electrification and factor inputs (labour and land), and agricultural output is negative. However, we find a higher positive direct relationship between labour and agricultural output per GDP, implying a higher productivity for those labour who remain in the sector. Our results are heterogenous across population size quartiles sub-samples.

1. Introduction

In Africa, the number of people living in rural communities are about 60% and majority of these rural dwellers are engaged in agriculture (Sumberg et al., 2014). According to the Sustainable Energy for All (SE4ALL) initiative, there are about 789 million people who do not have access to electricity and about 72% of these people are in the rural areas of Sub-Saharan Africa¹. The rate at which rural communities get access to electricity is slower than rural population growth (Foley, 1992), hence having the lowest electricity connection rates (Jeuland et al, 2021). With the growing demand for energy, the United Nations Sustainable Development Goal 7 has set a target to have universal access to energy by 2030. To this end, policymakers and investors have made it a priority to make electricity accessible in developing countries (Lee et al, 2020). Other initiatives include the USAID Power Africa initiative whose aim is to increase electricity by 60 million households across Africa².

In some studies, electrification in some rural communities is considered a driver of sustainable and economic development (Onyeji et al., 2012; Kyriakarakos et al, 2020). Access to electricity allows rural households sufficient time to work on their farms as household chores can be shifted to the evening (Lee et al, 2020; Peters & Sievert, 2016), and the day does not have to end at sundown. In Sub-Saharan Africa, most of the agricultural activities take place in the rural communities and it continues to be the major source of livelihood in such communities (Ayanlade & Radeny, 2020). According to Namara et al. (2010), there are about 1 billion people who live on less than \$1 a day and 850 million rural poor are primarily engaged in agriculture. Some studies have found that agricultural electrification results in long-lasting positive effects on rural communities (Kyriakarakos et al, 2020). A systematic review by Knox et al, (2013) found that electrification stimulates agricultural output and has the tendency of increasing employment. As the level of employment increases, this will, in turn reduce the poverty

[☆] This paper is dedicated to the memory of my co-author, Yves Surry, who passed on during the first revision (March, 2021) of the manuscript. He was instrumental in shaping the ideas of this paper.

* Corresponding author.

E-mail addresses: salome.amuakwa.mensah@ltu.se (S. Amuakwa-Mensah), Yves.Surry@slu.se (Y. Surry).

¹ <https://www.seforall.org/data-stories/seforall-analysis-of-sdg7-progress-2021>.

² <https://www.usaid.gov/powerafrica>

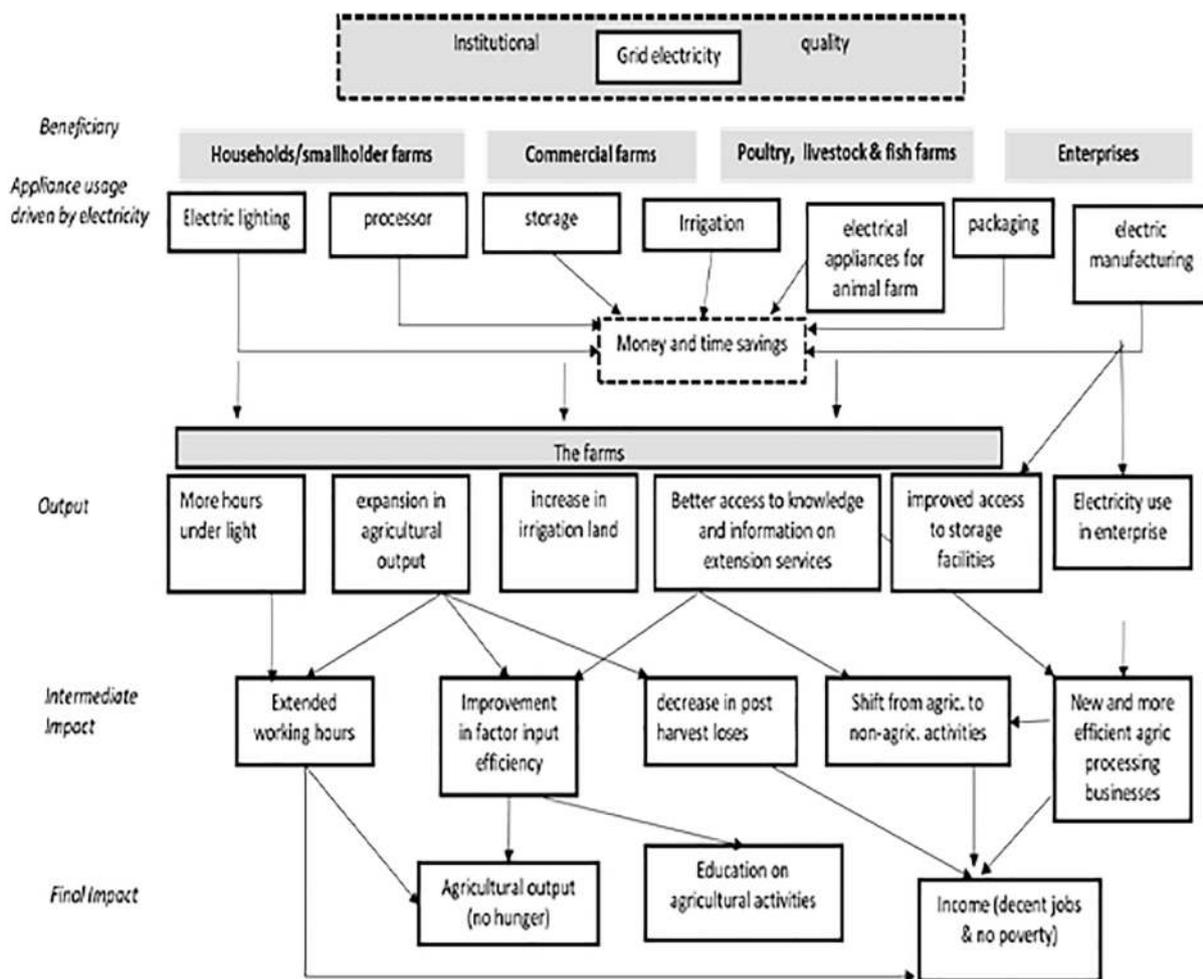


Fig. 1. Theory of change of electricity and agricultural output modified version from Peters and Sievert, (2016).

levels. In most developing countries, agriculture, “an engine for economic growth” (Sumberg et al., 2014), employs a large proportion of labour and in some cases contributes a higher share to the country’s employment and Gross Domestic Product (GDP).

The link between agricultural productivity and good governance is a positive one as reported by Lio & Liu (2008) who show that better governance indirectly fosters agricultural productivity. In their paper, Fulginiti et al. (2004) address the institutional and socio-political factors that may have affected agricultural productivity performance in SSA. Their study concludes that the relationship between growth in productivity and institutional factors strongly affects GDP growth rates. Productivity in countries with high political unrest have been found to be significantly lower than in countries where there is political stability and civil right (Fulginiti et al. (2004). Political institutions have been measured with different variables such as, stability, regime type and violence, on economic growth in Africa (Nkurunziza and Bates, 2004). Adom et al, (2018) stipulates that good political institutions matter in national development. This could infer that it is also relevant in determining how electricity among other necessary resources are allocated across the country especially when it promotes development. Supportive policies and institutional infrastructure have brought forth more than double agricultural productivity since the 1960s in many regions of the world (Namara et al., 2010).

This paper seeks to explore the association between agricultural

output and rural electrification, and how this relationship is influenced by a country’s institutional quality and factor inputs at the macro level. The emphasis of this paper is on Sub-Saharan Africa where access to electricity is low (Onyeji et al., 2012) but gradually increasing and agriculture sector is the highest employer of labour. Existing studies on electrification at the macro level has considered its relationship with economic growth (see Payne (2010) for literature review on this relationship), but there is little knowledge on how factors such as institutional quality and factor inputs influence this relationship. Thus, we contribute to the literature in that light. First, we investigate whether the relationship between electrification and agricultural output is conditional on institutional quality. In addition, we contribute to the literature by examining whether electrification enhances the marginal effect of factor inputs. According to Sims and Kienzle (2006), mechanization of the agricultural sector is expected to increase the marginal returns of the traditional factor inputs.

We test these hypotheses at the macro level using panel data on 43 Sub-Saharan African countries from 1990 to 2016 and employing a Fully Modified Ordinary Least Squares (FMOLS) to correct potential endogeneity and autocorrelation as a result of the long time period. In spite of the advantages of the FMOLS method, it is likely that the potential endogeneity associated with electrification rate could still persist. As a result, we are careful in claiming causal effect of electrification rate on agricultural output in the interpretation of our result. Our result shows a

positive significant association between rural electrification and agricultural output. Also, we find that the relationship between electrification and agricultural output is conditional on the quality of institution of a country. With the exception of capital, the association between the interaction term of rural electrification and factor inputs (labour and land), and agricultural output is negative. However, we find a higher positive direct relationship between labour and agricultural output per GDP, implying a higher productivity for those labour who remain in the sector. Our results are heterogeneous across population size quartiles subsamples.

For the remaining sections of this paper, the structure is as follows. In the next section, we review some existing literature on the topic. In section 3, we present description of the data and explain the methodological approach we use in our estimation. In Section 4, we present and discuss the results. Finally, we conclude in Section 5 with a summary of our research and policy recommendations.

2. Literature review

2.1. Conceptual framework

One of the threats to long term economic development in Africa is the power sector coupled with other factors (Pueyo & Maestre, 2019). In low-income and developing countries, access to energy has become a major focus of governments and investors as the rate of rural electrification is 14% (Peters & Sievert, 2016). Access to electricity is believed to reduce poverty and increase productivity among other benefits in developing countries (Pueyo & Maestre, 2019). The quality of institutions which shapes economic performance is considered one of the drivers and determinants of access to electricity (North, 1994; Nanka-Bruce, 2008; Onyeji et al., 2012).

Fig. 1 shows the relationship between institutional quality & electricity, and the various sectors of rural areas, namely, households & small farms; commercial farms; poultry, livestock & fish farms; and enterprises adopted from Peters & Sievert (2016). The diagram is not exhaustive as we do not study all the changes and outcomes that may occur due to electrification, but we focus on some of the SDGs namely, no poverty; zero hunger; quality education; and industry, innovation & infrastructure. We also do not focus on the use of alternative sources of energy.

As a means to improve economic and social development, governments deem it important to increase access to electricity in rural communities to make certain services which are considered basic in developed countries accessible to the rural dwellers (Bernard, 2012). The first stage of this theory of change is that the rural communities, through the allocation of resources as a result of the quality of institutions, have access to electricity and the beneficiaries start using electric appliances in their respective fields (Peters & Sievert, 2016). These electric appliances include electric lighting, processors, storage, irrigation, packaging, and other electric appliances used in animal farms and manufacturing. Among the different beneficiaries, the type of electric appliance they use is based on each beneficiaries' need for energy (Jeuland et al., 2021). The use of electricity in these ways saves time and money in the long run. The money saving aspect may not be experienced at the start of using electric appliances because of the cost of electric connections and appliances but the expected benefits from their use includes higher incomes which will in the long run, reduce the high-cost impacts of the electric appliances on the beneficiaries (Peters and Sievert, 2016; Bos et al., 2018; Jeuland et al., 2021).

It is expected that the birth of new industries and sectors other than the agricultural sector as a result of electrification, will compete for agricultural labour (Pueyo & Maestre, 2019). These industries could use

raw materials from the agricultural sectors, hence increasing the demand for agricultural output. In effect, this could expand agricultural production in subsequent years. Electric lighting allows for extended working hours and hence, the day does not have to end at sundown (Lee et al., 2020). Households and smallholder farms can spend more time on their farms instead of rushing home to finish house chores before it gets dark. Commercial farms and poultry, livestock & fish farmers can expand their output and improve on their storage facilities to decrease post-harvest losses (Lee et al., 2020). Using extension services, they can also access relevant knowledge and information.

The formation of new industries is expected to employ not only agricultural labour but also to create decent jobs for those who were otherwise unemployed or involved in menial jobs that do not promote development in the rural communities (Pueyo & Maestre, 2019). These decent jobs reduce the poverty level in the rural communities (Bernard, 2012). Regarding the farms, it is expected that with the information they have access to, they can educate themselves more and use the resources available efficiently in producing agricultural output. Access to electricity is also believed to have effects on education in general (Bernard, 2012).

2.2. Empirical review

Underdeveloped economies in Africa have been associated with households' lack of electricity (Bos et al., 2018). In rural areas, where access to electricity is low (Lenz et al., 2017), rural communities engage in less electricity powered activities for their everyday life. For example, the use of firewood and charcoal for heating and cooking, battery powered LED lamps and kerosine fuelled lanterns as lighting devices (Bos et al., 2018; Peters & Sievert, 2016). The Global Environment Facility (GEF) and the UN Food and Agricultural Organization (FAO) define productive uses of energy in the context of providing modern energy services in rural areas, as "one that involves the application of energy derived mainly from renewable resources to create goods and/ services either directly or indirectly for the production of income or value". It is expected that the productive use of energy results in increased rural productivity, higher economic growth, increase in rural employment which will raise incomes and also reduce the migration of the rural poor to urban areas (Cabral et al., 2005). Electrification gives birth to industries which may or may not use agricultural output, bring about innovation and this will provide more jobs as a result of labour diversification and snowball into economic growth and social development (Pueyo & Maestre, 2019).

In a study that focused on agriculture as a consumer and producer of different forms of energy, Bhatia (1985) explains the trends in energy use in agriculture in developing countries in southern Asia at the global, national and farm levels. Developing countries in South Asia such as Nepal, India and Bangladesh have increased their use of energy on their farms. He concludes that if additional output is to be obtained from the given land resources that are fixed, then the commercial energy intensity of agricultural production in developing countries should increase significantly. Studies on the effect of electrification on agricultural productivity in developing countries focus on several indicators of agricultural productivity and outputs. Some indicators considered include output prices, input prices, agricultural outputs, total factor productivity and share of agriculture in gross domestic product (Khandker & Koolwal, 2010; Binswanger et al., 1993; Mundlak, 2002; Lio & Liu, 2008).

Khandker & Koolwal (2010) found in Bangladesh that, electricity increases agricultural output, wages as well as the other indicators considered in their study. They also find that with greater electrification, it is possible to raise agricultural productivity which in turn improves

Table 1
Summary of literature review.

Author	Country	Agric output/ productivity indicator	Infrastructure indicator	Effect ⁸
(Assunção et al., 2017)	Brazil	Agric Productivity	Electricity	0.107***
(Khandker & Koolwal, 2010)	Bangladesh	Agric output	% of household with electricity	0.151
		Agric price	% of household with electricity	0.057***
		Agric transport costs	% of household with electricity	0.43***
(Chen & Ding, 2007)	China	Total Factor productivity of beans	Electricity consumption per capita	-0.132**
(Fan & Zhang, 2004)	China	Agric output	Electricity per machinery	0.115**
(Binswanger et al., 1993)	India	Crop price (International)	Electricity	0.028*
		Crop price (Domestic)	Electricity	0.031*
(Mundlak, 2002)	Thailand	Agric GDP	Electricity	0.045*
(Lio & Liu, 2008)		Agric Productivity	Institutions	0.383***

*** p<0.01, ** p<0.05, * p<0.1.

⁸ These effects show the impact of electrification on the listed agricultural output/productivity indicators for the respective literatures.

output even though the effect is weak. With the combination of other investment in fixed capital, the effect of electrification on productivity in agriculture is expected to increase. Binswanger et al. (1993) studied the impact of electrification on investment in fixed capital (pumps) in India. They concluded that the effect was significant, and it contributed to an increase in investment levels by 28%.

In some studies, the results of access to electricity have been conflicting. Lee et al, (2020) find that in rural communities, unlike the households that were willing to connect when the price was high, households that were willing to be connected the grid when it was free did not get a lot of economic benefits from electrification. Other conflicting results pertain to income, education and time use. In their paper, Peters & Sievert (2016) did not find positive outcomes on the effect on income and education. In relation to time use among school children, spending time in the evening for schoolwork is done at the expense of daytime studying and other chores. In a systematic review by Jeuland et al, (2021) which focuses on the impacts of energy technologies reveals that in the literature, the evidence that access to modern energy services improves environmental and development outcomes is not a strong one.

In a systematic review of the literature by Knox et al. (2013), they principally focus on rural electrification and its impact on agricultural productivity and other agricultural indicators. The sample they targeted were the agricultural and rural communities including farming on the field, at district and national level in developing countries. One of the interventions the various literature covered was infrastructural development which includes rural electricity supply. The outcomes of the studies showed effects on poverty reduction, agricultural wage, agricultural and rural GDP, agricultural productivity energy and agricultural input consumption. The method they used was a systematic review protocol they drafted³. Concerning electricity and agricultural output, although limited, they find positive impacts of electrification especially on poverty reduction.

In the recent past decades, China has embarked on rural electrification programs which have been successful, and the country has

reached almost 100% electrification rate (Bhattacharyya & Ohiare, 2012). This endeavour has resulted in an increase in agricultural income in some targeted villages (Ding et al., 2018). In other studies, in China, however, electricity investment produced lower returns in GDP in both agricultural and non-agricultural sectors (Fan et al., 2002; Fan, Zhang, et al., 2004). Results from Thailand showed that investment in electricity yields higher returns in agricultural productivity. The impacts of electricity, roads and education come from growth in agricultural employment productivity rather than increasing agricultural productivity. The expenditure of the Thai government on rural electricity has the greatest impacts on poverty reduction (Fan et al., 2004; Knox et al., 2013). Table 1 shows a summary of the result of related studies dealing with the role of electrification on the agricultural sector.

The allocation of resources in an economy to a large extent depends on the ideology and preference of the government. Governance can be regarded as the traditions and institutions by which authority in a country is exercised (Kaufmann et al. 2005; Lio & Liu, 2008). Following Kaufmann et al. (2005) and Méon & Weill (2005), governance can be divided into three categories. The first category is referred to as the “respect for the institutional framework”. This has to do with the respect that citizens and the state have for the institutions that govern economic and social interactions among them. The second category is known as “the quality of government action”. It is the capacity of the government to effectively formulate and implement sound policies. The final category “selection of the authority” which is concerned with the process by which governments are selected, monitored and replaced (Lio & Liu, 2008).

Some of the challenges that surround rural electrification include inadequate policies, weak institutional frameworks and limited financing (Haanyika, 2006). According to Haanyika (2006), in order to overcome this challenge, market-based reforms in the power sector have been introduced in the last decade and this has affected the institutional and financing arrangement for rural electrification. By this, Haanyika (2006) draws linkages between rural electrification and institutions. The author finds that the reforms have affected the rate and affordability of electricity. Supportive policies and institutional infrastructure have brought forth more than double agricultural productivity since the 1960s in many regions of the world (Namara et al., 2010). Lio & Liu (2008) test the hypothesis that better governance fosters agricultural productivity. Their study examines a cross-national analysis of governance and agricultural productivity. They indicate that by driving agricultural capital accumulation, better governance can indirectly improve agricultural productivity.

Although most previous studies are looking at the effect of electrification and institutions on agricultural output, very little has been on Sub-Saharan Africa (SSA). While there is a large literature estimating the effects of electrification in agriculture, credible estimates of the effect of electrification on agricultural output are sparse. Considering the different climates as measured by variables such as temperature and rainfall, the results of the studies done in other non-African developing countries cannot be extended in the Sub-Saharan context. In addition, as the quality of institution of countries determines resource allocation, it is imperative to investigate whether or not the relationship between rural electrification and agricultural is conditional on the quality of institution. From the existing literature, not much is known about the interaction between electrification and factor inputs. Sims and Kienzle (2006), stipulate that mechanization of the agricultural sector is expected to increase the marginal to returns of the traditional factor inputs, that is, labour, land and capital. Based on this we systematically investigate this assertion by interacting electrification and factor inputs (that is, labour, land and capital). We consider the points listed above as our consideration to the literature.

³ CEE protocol 11-007.CEE: www.environmentalevidence.org/SR11007.html

3. Methodology

3.1. Theoretical framework and Empirical model

Using the production function approach, we draw the link between agricultural output and electrification. Following Adom et al., (2018), Barrios, Ouattara, & Strobl, (2008) and Kahsay & Hansen, (2016), we adapt the Cobb-Douglas production function where agricultural output is a function of labour, capital, land and other variables such as rainfall and temperature. The equation is shown below:

$$Y = AL^{\alpha_1} K^{\alpha_2} N^{\alpha_3} T^{\alpha_4} R^{\alpha_5} \exp^{\theta \text{time}} \tag{1}$$

where (Y) is the agricultural sector output, (A) is a measure of total factor productivity efficiency, (L) denotes labour, (K) is the capital invested, (N) land, (T) temperature and (R) rainfall. The time trend accounts for the natural increasing trend in output but is also a proxy for impact of technical change on agricultural output.

The total factor productivity could be expressed as an exponential function of institutional quality (Adom and Amuakwa-Mensah, 2016; Amuakwa-Mensah et al., 2018) and other factors which could lead to enhancement of the traditional factors such as electrification and knowledge accumulation. Thus, total factor productivity can formally be presented as;

$$A = \exp^{(\beta_1 E + \beta_2 INS)} = \exp^{\beta_1 E + \beta_2 INS} \tag{2}$$

where (E) represent electrification rate and INS is a measure of the quality of political institutions. According to Lio & Liu (2008), political institution fosters agricultural productivity. By substituting equation (2) into equation (1), we derive an expression where agricultural output is a function of electrification, institutional quality and the traditional factor inputs, as shown in equation (3);

$$Y = \exp^{(\beta_1 E + \beta_2 INS)} L^{\alpha_1} K^{\alpha_2} N^{\alpha_3} T^{\alpha_4} R^{\alpha_5} \exp^{\theta \text{time}} \tag{3}$$

To estimate equation (3), we linearize it by taking the natural log of the equation to get equation (4). The new equation becomes the baseline production function that is shown below.

$$\ln Y = \alpha_0 + \alpha_1 \ln L + \alpha_2 \ln K + \alpha_3 \ln N + \alpha_4 \ln T + \alpha_5 \ln R + \beta_1 E + \beta_2 INS + \theta \text{Time} \tag{4}$$

Following Adom et al., (2018), Barrios et al., (2008) and Kahsay & Hansen, (2016), equation (4) is transformed into a baseline panel fixed effect model that will be estimated. Thus, we include a variable that captures country-specific time-invariant effects (μ_i) and time trend as a proxy to take into account the effect of technological change and a natural increasing trend in output (θTime). In order to obtain the elasticity of agricultural output with respect to electrification rate, we replaced the actual variable with its log-transformation in the model. Finally, an error term (ε_{it}) is introduced, which accounts for other unobserved variables which might explain the variable of interest. This resolves into a new econometric model as Equation (5):

$$\ln Y_{it} = \alpha_0 + \alpha_1 \ln L_{it} + \alpha_2 \ln K_{it} + \alpha_3 \ln N_{it} + \alpha_4 \ln T_{it} + \alpha_5 \ln R_{it} + \alpha_6 \ln E_{it-1} + \alpha_7 \ln INS_{it-1} + \mu_i + \theta \text{Time} + \varepsilon_{it} \tag{5}$$

In Equation (5), electrification and institution are included as lagged variables. The idea here is that access to electrification in the current period will have an effect on the next periods' agricultural output. In the same vein, access to electrification in the previous period reveals its effect in the current period. The institutional quality of an economy determines how they allocate resources like electrification across the country. To this end, the model is estimated using the institutional quality as a lagged variable. While electrification is expected to correlate with agricultural sector output, to some extent the effect of electrification is dependent on the quality of an institution of a country (Haanyika, 2006). As a result, we introduce an interaction term between electricity

and institutional quality in Equation (6):

$$\ln Y_{it} = \alpha_0 + \alpha_1 \ln L_{it} + \alpha_2 \ln K_{it} + \alpha_3 \ln N_{it} + \alpha_4 \ln T_{it} + \alpha_5 \ln R_{it} + \alpha_6 \ln E_{it-1} + \alpha_7 \ln INS_{it-1} + \alpha_8 \ln INS_{it-1} * \ln E_{it-1} + \mu_i + \varphi_t + \varepsilon_{it} \tag{6}$$

where φ_t is the time-varying effect common to all countries that capture factors such as technological progress.

From equation (6), the marginal effect of electrification on agricultural output is derived as;

$$\frac{\partial \ln Y_{it}}{\partial \ln E_{it-1}} = \alpha_6 + \alpha_8 \ln INS_{it-1} \tag{7}$$

The quality of institutions reinforces the expected positive relationship between electrification and agricultural output if α_8 is positive. However, in the case where α_8 is negative, it reduces the positive relationship between electrification and agricultural output. The total effect of electrification on agricultural output will be the coefficient of the electrification (α_6) (when significant) if the interaction between electrification and institutional quality is not significant. However, when both electrification and its interactions with institutions are significant, the total effect of electrification on agricultural output is evaluated at the mean of institutional quality⁴.

According to Sims and Kienzle (2006), mechanization of the agricultural sector is expected increase the marginal returns of the traditional factor inputs, that is, labour, land and capital. Based on this we systematically investigate this assertion by interacting electrification and factor inputs (that is, labour, land and capita) as show in equations (8a) to (8c);

$$\ln Y_{it} = \alpha_0 + \alpha_1 \ln L_{it} + \alpha_2 \ln K_{it} + \alpha_3 \ln N_{it} + \alpha_4 \ln T_{it} + \alpha_5 \ln R_{it} + \alpha_6 \ln E_{it-1} + \alpha_7 \ln INS_{it-1} + \gamma_1 \ln L_{it} * \ln E_{it-1} + \mu_i + \varphi_t + \varepsilon_{it} \tag{8a}$$

$$\ln Y_{it} = \alpha_0 + \alpha_1 \ln L_{it} + \alpha_2 \ln K_{it} + \alpha_3 \ln N_{it} + \alpha_4 \ln T_{it} + \alpha_5 \ln R_{it} + \alpha_6 \ln E_{it-1} + \alpha_7 \ln INS_{it-1} + \gamma_2 \ln K_{it} * \ln E_{it-1} + \mu_i + \varphi_t + \varepsilon_{it} \tag{8b}$$

$$\ln Y_{it} = \alpha_0 + \alpha_1 \ln L_{it} + \alpha_2 \ln K_{it} + \alpha_3 \ln N_{it} + \alpha_4 \ln T_{it} + \alpha_5 \ln R_{it} + \alpha_6 \ln E_{it-1} + \alpha_7 \ln INS_{it-1} + \gamma_3 \ln N_{it} * \ln E_{it-1} + \mu_i + \varphi_t + \varepsilon_{it} \tag{8c}$$

From equations (8a) to (8c), we can compute the marginal effect or elasticity of each factor input by finding the partial derivative with respect to the natural log of the factor input. That is,

$$\text{Labour : } \frac{\partial \ln Y_{it}}{\partial \ln L_{it}} = \alpha_1 + \gamma_1 \ln E_{it-1} \tag{9a}$$

$$\text{Capital : } \frac{\partial \ln Y_{it}}{\partial \ln K_{it}} = \alpha_2 + \gamma_2 \ln E_{it-1} \tag{9b}$$

$$\text{Land : } \frac{\partial \ln Y_{it}}{\partial \ln N_{it}} = \alpha_3 + \gamma_3 \ln E_{it-1} \tag{9c}$$

Fixed effect models may not be an appropriate estimation technique because of country-specific heterogeneities, the presence of serial correlation (due to long time period), and potential endogeneity problem associated with electrification. As a result, our empirical models are estimated by employing Fully Modified Ordinary Least Squares (FMOLS) model developed by Phillips & Hansen, (1990) to account for the potential serial correlation associated with the long time period and endogeneity. FMOLS is a semi-parametric model that is robust to endogeneity and serial correlation problems. Also, it provides consistent

⁴ The institutional quality variable shows which countries are more democratic in their governance. Governance can be regarded as the traditions and institutions by which authority in a country is exercised (Kaufmann et al. 2005; Lio & Liu, 2008). When unfavorable authority is exercised in any country, it affects the productivity negatively. In this context, if the traditions and institutions do not favor agricultural activities, there will be a slack in agricultural output.

Table 2
Definition of main variables and their data sources

Variables	Description	Source	Expected sign	(1) N	(2) Mean	(3) SD	(4) Min	(5) Max
<i>Dependent variables</i>								
Agricultural output (y/gdp)	Ratio of total agriculture output to gross domestic product ⁹	WDI		943	0.259	0.160	0.008	0.709
Output per labour (ypercapita)	Agriculture output (value added) per worker ¹⁰	WDI		935	1574.67	1914.32	165.81	14476.11
<i>Explanatory variables</i>								
Labour (L)	Employment in agriculture (% of total employment)	WDI	+	1,109	60.06	22.01	4.6	92.84
Capital (K)	Net capital stock in agriculture	FAOSTAT	+	858	2812.24	6579.76	6.06	64171.71
Land (N)	Total agricultural land (% of total land)	WDI	+	1,129	47.95	19.396	8.04	82.67
Electrification (E)	Proportion of rural households that have access to grid electricity in the country	(Aklin et al., 2018)	+	996	14.14	19.32	0.01	100
Polity2 (INS)	Institutions measured as Democracy index between -10 and 10. The index is transformed to range between 0 and 1.	Polity IV Project ¹¹	+/-	1,107	0.533	0.286	0	1
<i>Climate variables</i>								
Temperature(T)	Mean annual temperature for each country in °C	WBCKCKP ¹²	+/-	1,150	24.80	3.18	12.63	29.54
Rainfall (R)	Total annual rainfall for each country in mm	WBCKCKP	+/-	1,150	1035.3	613.60	66.03	3282.24

Source: Own computation and compilation.

⁹ Agriculture output corresponds to ISIC divisions 1-5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production. Value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs.

¹⁰ Calculated by dividing Agriculture output (value added) by the number employed in the agricultural sector.

¹¹ <http://www.systemicpeace.org/polity/polity4.htm>

¹² World Bank Climate Change Knowledge Portal

and efficient estimates even in the absence of cointegration relation (see Phillips, 1995). In spite of the advantages of the FMOLS method, it is likely that the potential endogeneity associated with electrification rate could still persist. As a result, we are careful in claiming causal effect of electrification rate on agricultural output in the interpretation of our result. In order to address potential outliers, we log-transformed variables in the empirical model.

3.2. Data and data sources

This paper uses unbalanced panel data for 43 Sub-Saharan African countries for the period 1990-2016⁵. Table 2 gives a description, data sources and the expected signs of the variables used in this paper. The outcome variable of interest is agricultural output measured as a ratio of total agricultural output to gross domestic product is sourced from the World Bank Development Indicators (WDI). Given the heterogeneity of the countries in terms of economy size, we opted for the ratio of total agriculture output to gross domestic product instead of total agricultural output. In addition, we also considered agricultural output per worker (labour) as an outcome variable to measure labour productivity.

In our production function, we consider the three traditional factors of production, land, capital and labour. *Labour* is the number of people employed in the agricultural sector as a proportion to total employment in each country. It is anticipated that if there are more people employed by agriculture, output will increase. Adom et al. (2018) in their paper concluded that labour has a positive significant effect on agricultural production in Africa. Total agricultural *land* is measured as the share of land used in the agricultural sector relative to total land size of a country. As one of the factors of production, the size of land is expected

to have a significant effect on output as it a primary necessity in agriculture. The bigger the size of the land, the more the agricultural output. However, land litigations in many parts of the continent may give rise to scarcity of land in the future and hence affecting the productivity and output in the agricultural sector (Adom et al., 2018). *Capital* is measured as the net capital stock in agriculture by the physical investment in the sector. We retrieved this variable from FAOSTAT. The amount and quality of capital invested in agriculture also determine how large or small the output will be. Good capital investment will facilitate agricultural output.

We also control for *institutional quality* (Polity2) measured as a democracy index which ranges between -10 and 10, where -10 indicates the worst institutional quality and 10 is the best. Good institutional quality implies a stable economy since the basic needs of the people are attended to. Institutional quality is dependent on the style of governance of a country. In our estimations, we rescaled this index to be between 0 and 1 for ease of interpretation of our results. The mean value of the transformed institutional quality index as presented in Table 2 is 0.533 which reflects relatively poor institutions in the region.

The climate variables we control for are *temperature* and *rainfall*, sourced from the World Bank Climate Change Knowledge Portal (WBCKCKP). Climate is an important factor in agricultural productivity. There are some crops that only thrive or grow in certain regions because of the temperature and amount of rainfall. It should be noted that the different regions of SSA have different climates and hence the amount of rainfall and temperature varies across countries. Temperature is calculated as the annual mean in degree celsius (°C) for each country. It is calculated as an average because of its variations throughout the year. According to WBCKCKP, the maximum temperature for the region is 29.54 °C. Most SSA countries have warmer temperatures most of the year. Rainfall is measured as the total amount of rain annually for each country. Too much rain causes flooding, in the same vein, high temperature causes drought and results in little or no agricultural output. Bad weather conditions cause agricultural output to decline but a good combination of temperature and rainfall in their right proportions is a tool for agricultural output increase. Climate is however, a natural occurrence and every country have its unique climate. This implies that agricultural productivity is also dependant on a country's climate which also differs across the region. Rainfall and changes in temperature are not under the control of the farmers, hence making them risk variables.

⁵ The countries include Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros Island, Republic of Congo, Côte d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe. The panel is unbalanced because observations are missing for some countries over some years. São Tomé and Príncipe and Seychelles eventually drop out of the estimation because they have no data on institutions for the period of study.

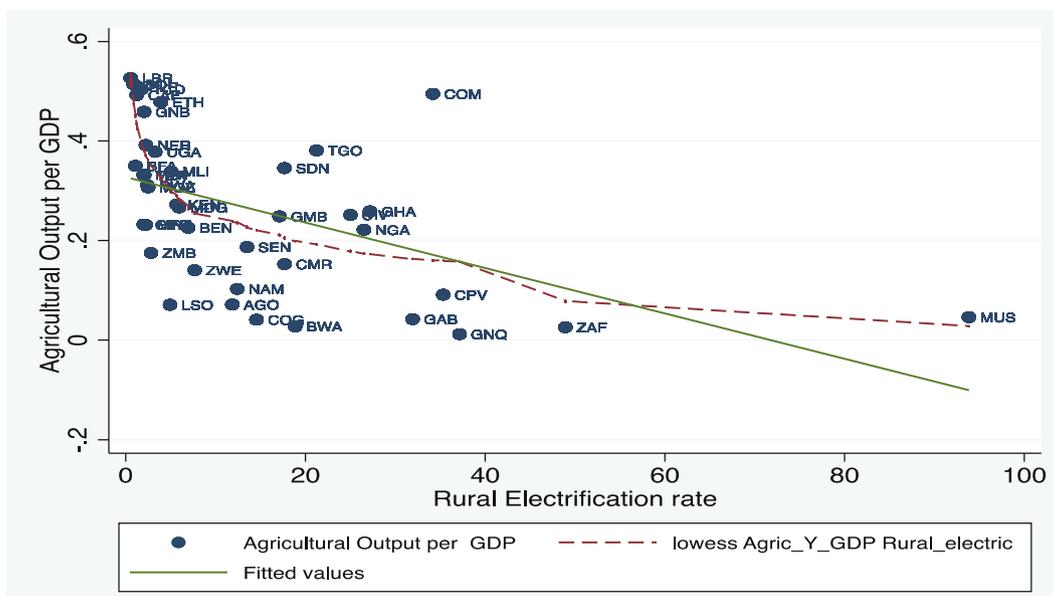


Fig. 2. Relationship between rural electrification rate and gross agricultural output per GDP.(Angola (AGO), Benin (BEN), Botswana (BWA), Burkina Faso (BFA), Burundi (BDI), Cameroon (CMR), Cape Verde (CPV), Central African Republic (CAF), Chad (TDC), Comoros Island (COM), Republic of Congo (COG), Côte d'Ivoire (CIV), Equatorial Guinea (GNQ), Eritrea (ERI), Ethiopia (ETH), Gabon (GAB), The Gambia (GBM), Ghana (GHA), Guinea (GIN), Guinea-Bissau (GNB), Kenya (KEN), Lesotho (LSO), Liberia (LBR), Madagascar (MDG), Malawi (MWI), Mali (MLI), Mauritania (MRT), Mauritius (MUS), Mozambique MOZ, Namibia (NAM), Niger (NER), Nigeria (NGA), Rwanda (RWA), Senegal (SEN), Sierra Leone (SLE), Somalia (SOM), South Africa (ZAF), Sudan (SDN), Tanzania (TZA), Togo (TGO), Uganda (UGA), Zambia (ZMB) and Zimbabwe (ZWE)).

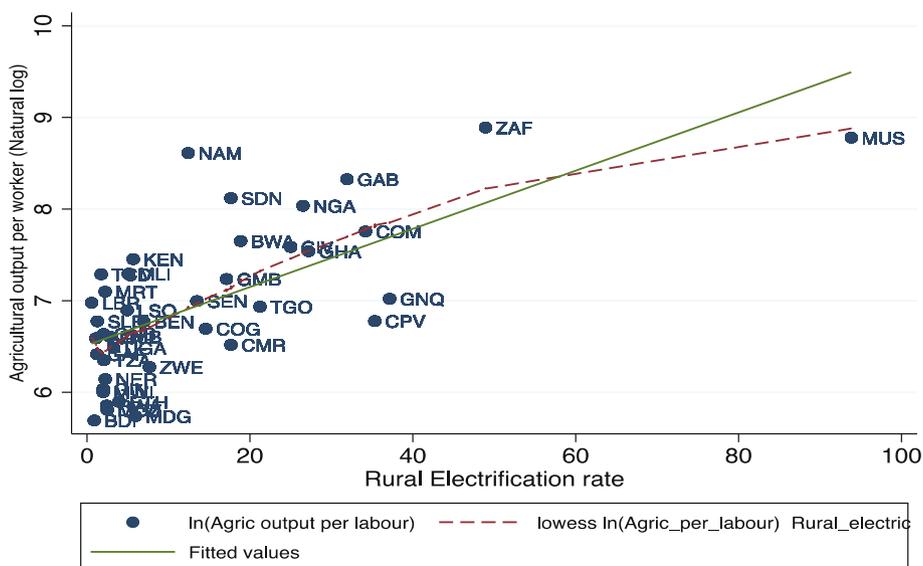


Fig. 3. Relationship between rural electrification and output per labour.

The variable of interest in this paper is *electrification* and its association with agricultural output/productivity. Electrification is measured as the percentage of rural households with access to grid electricity as measured and is obtained from Aklın, S. P., & Urpelainen, (2018). From the data, access to grid electricity is between 0.01 and 100 and on average, 14.14% of rural households have access to electricity. Here again, since only a few rural communities (e.g. Mauritius and Cabo Verde) have between 60 and 99.7 access to electrification on average, the other countries lacking in rural electrification overshadow the former. As a robustness check we used total electrification rate (rural plus urban) in our econometrics analysis. The supply chain of agricultural products extends beyond rural areas and as such we expect similar

results of the association between electrification and agricultural output, in the case of rural and total electrification access rate, if our results are externally valid. We carried out sensitivity analysis by re-estimating our models based on sub-samples of our data considering the quartiles of the population size of countries.

3.2.1. Relationship between dependent variables and rural electrification

Figs. 2 and 3 show the relationship between the means of agricultural output per GDP and agricultural output per worker, on the one hand,

Table 3
Unit root test.

	ADF		Phillips-Perron	
	Inverse logit	Modified inv. chi-squared	Inverse logit	Modified inv. chi-squared
Ln(y/gdp)	-7.72***	10.17***	1.025	-0.0196
Δ LnY	-37.25***	61.03***	-44.68***	74.69***
Ln(ypercapita)	-7.33***	8.91***	1.61	0.0996
Δ Ln(ypercapita)	-37.43***	61.43***	-44.48***	74.31***
lnL	-2.91***	5.23***	4.721	-2.932
Δ lnL	-31.48***	50.42***	-30.29***	48.45***
lnN	-9.86***	13.017***	0.024	2.497***
Δ lnN	-32.09***	51.60***	-30.68***	49.24***
lnK	-4.414***	4.671***	5.314	-2.993
Δ lnK	-27.33***	43.20***	-25.28***	39.56***
lnT	-11.52***	15.22***	-11.52***	15.22***
lnR	-39.54***	64.995***	-39.536***	64.995***
lnE_1	-30.81***	50.29***	-30.813***	50.29***
lnET_1	-43.92***	73.88***	-43.92***	73.88***
Ins_1	-16.63***	27.33***	-16.627***	27.331***
lnET_1*Ins_1	-14.65***	25.65***	-14.649***	25.648***

*** p<0.01, ** p<0.05, * p<0.1.

Table 4
Relationship between electrification, and agricultural output per GDP and labour efficiency-Fully Modified OLS

VARIABLES	Rural Electrification				Total Electrification (Robustness Test)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Ln(y/gdp)	0.071***	0.039***	-1.280***	-1.290***	0.111***	0.096***	-1.207***	-1.211***
lnL	(0.007)	(0.008)	(0.017)	(0.009)	(0.009)	(0.008)	(0.013)	(0.012)
lnN	0.220***	0.017	0.663***	0.678***	0.241***	0.053*	0.766***	0.703***
lnK		0.013***		0.063***		0.017***		0.067***
lnT	0.837***	0.904***	1.218***	1.144***	0.813***	0.910***	1.342***	1.149***
lnR	(0.094)	(0.107)	(0.232)	(0.131)	(0.127)	(0.122)	(0.195)	(0.177)
lnE_1	0.025***	0.001	0.098***	0.085***	0.036***	0.016*	0.136***	0.102***
Ins_1	(0.007)	(0.008)	(0.017)	(0.010)	(0.010)	(0.009)	(0.015)	(0.013)
lnET_1	0.006***	0.011***	0.034***	0.013***				
	(0.001)	(0.002)	(0.003)	(0.002)				
Constant	0.058***	-0.005	0.052***	-0.063***	0.053***	-0.040***	0.073***	-0.073***
	(0.007)	(0.010)	(0.017)	(0.012)	(0.009)	(0.012)	(0.014)	(0.016)
					0.008***	0.014***	0.030***	0.009**
					(0.002)	(0.003)	(0.004)	(0.004)
Observations	-6.457***	-5.679***	4.287***	4.232***	-6.707***	-6.198***	2.812***	3.589***
R-squared	(0.326)	(0.381)	(0.796)	(0.464)	(0.432)	(0.438)	(0.661)	(0.625)
Country FE	847	690	833	676	868	697	854	683
Trend	0.938	0.955	0.856	0.900	0.937	0.957	0.863	0.896
Adjusted R-squared	YES	YES	YES	YES	YES	YES	YES	YES
Long Run SE	YES	YES	YES	YES	YES	YES	YES	YES
Bandwidth(neweywest)	0.934	0.952	0.848	0.893	0.934	0.955	0.855	0.889
	0.0289	0.0288	0.0701	0.0349	0.0402	0.0337	0.0613	0.0480
	453.3	253.6	134.2	434.9	213.8	183.3	213.1	243.2

Note: The dependent variables are the natural log of agricultural output per labour (Ln(ypercapita) and natural log of agricultural output per GDP (y/gdp). LnE_1 is one-year lag of natural log of rural electrification rate and lnET_1 is one-year lag of total electrification rate. lnL, lnN, lnK, lnT and lnR is natural logs of labour, land, capital, temperature and rainfall, respectively. Ins_1 is one-year lag of institutional quality. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

and the mean of rural electrification rate for SSA between 1990 and 2016. These relationships are shown by a scatter plot, fitted linear lines and the LOWESS⁶ curve. From Fig. 2, most of the countries have the lowest electrification; clustered between 0 and 20 per cent and their mean share of agricultural output in GDP ranges between 20 to 60 per cent. Liberia, Burundi, Sierra Leone and Chad have the highest mean share of agricultural output in GDP of about 50% but with low rural electrification rate. Mauritius (MUS) has the highest mean of the rural household electrification percentage (that is, 94%) followed by South

⁶ LOWESS (Locally Weighted Scatterplot Smoothing) generates a smooth line through a scatter plot to show the relationship between variables and foresee trends.

Africa (49%) but their agricultural output share in GDP is rather low.

The fitted linear line and LOWESS curve in Fig. 2 show a negative correlation between agricultural output to GDP ratio and rural electrification rate. The econometric results will throw more light on this relationship. Fig. 3 shows the relationship between the natural log of agricultural output per labour and rural electrification rate. The average of the mean of output per labour is US\$1575. South Africa has the largest mean of agricultural output per labour at US\$7257 and Burundi records the country with the lowest mean of about US\$297⁷. The fitted line and the Lowess curve show a positive relationship between rural electrification and agricultural output per labour.

⁷ These figures are in anti-log.

Table 5
FMOLS model for electrification and institution interaction

VARIABLES	Rural Electrification				Total Electrification (Robustness Test)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
lnE_1	Ln(y/gdp) 0.000 (0.002)	Ln(y/gdp) -0.019*** (0.003)	Ln(ypercapita) 0.035*** (0.004)	Ln(ypercapita) -0.009** (0.004)	Ln(y/gdp) 0.043*** (0.014)	Ln(y_gdp) -0.448*** (0.028)	Ln(ypercapita) 0.194*** (0.023)	Ln(ypercapita) -0.130*** (0.041)
Ins_1	0.047*** (0.008)	-0.075*** (0.011)	0.059*** (0.014)	-0.116*** (0.016)				
lnE_1*Ins_1	0.010*** (0.003)	0.050*** (0.004)	-0.002 (0.005)	0.037*** (0.006)				
lnET_1					0.006** (0.003)	-0.065*** (0.006)	0.049*** (0.004)	-0.002 (0.009)
lnET_1*Ins_1					0.004 (0.005)	0.146*** (0.009)	-0.048*** (0.008)	0.021 (0.014)
Constant	-6.522*** (0.352)	-5.705*** (0.372)	4.278*** (0.593)	4.120*** (0.508)	-6.746*** (0.358)	-5.566*** (0.424)	2.973*** (0.573)	3.629*** (0.631)
Total effect lnE_1(or lnET_1)	0.010*** (0.003)	0.007*** (0.002)	0.035*** (0.004)	0.0104*** (0.0025)	0.006** (0.003)	0.013*** (0.003)	0.023*** (0.0034)	0.009** (0.005)
Observations	847	690	833	676	868	697	854	683
R-squared	0.943	0.956	0.872	0.914	0.937	0.960	0.888	0.902
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Trend	YES	YES	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Adjusted R-squared	0.940	0.953	0.864	0.908	0.934	0.957	0.881	0.895
Long Run SE	0.0311	0.0281	0.0521	0.0382	0.0333	0.0325	0.0530	0.0483
Bandwidth(neweywest)	337.5	251.9	241.4	308.5	326	166.3	260.1	188.2

Note: The dependent variables are the natural log of agricultural output per labour (Ln(ypercapita) and natural log of agricultural output per GDP (y/gdp). lnE_1 is one-year lag of natural log of rural electrification rate and lnET_1 is one-year lag of total electrification rate. Ins_1 is one-year lag of institutional quality. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

4. Results and discussion

This section presents the econometric results using Fully Modified OLS (FMOLS). All the models are estimated by alternating the inclusion of capital in the final estimation because not all SSA countries have data on capital. Also, the data on capital starts from 1995, instead of 1990 like the other variables. Hence the number of observations drops when capital is included in the model. In addition, the models are estimated with time trend and country fixed effect. The correlation matrix in Table A1 (see appendix) shows a weak correlation among the independent variables of interest, i.e. rural electrification and institution with other variables, hence multicollinearity is not an issue in the econometrics model. Given the long time period of the panel data used in this paper, a panel unit root test is carried in Table 3 based on panel Augmented dickey fuller (ADF) and Phillip-Perron (PP) tests. Using both tests as a decision criteria, agricultural output per GDP, agricultural output per labour, labour and capital are not stationary at level. They become stationary after first difference. Thus, we used FMOLS in our econometrics estimation to address the potential serial correlation.

4.1. Electrification and agricultural output

The relationship between electrification and agricultural output is estimated using FMOLS and the results are presented in Table 4. The variables *lnE_1* and *lns_1* are the one-year lagged period of the log of rural electrification and institutional quality respectively. The other explanatory variables expressed in logarithms imply that their coefficients are elasticities. The models account for time trends and country fixed effect.

For each of the two models, i.e. agricultural output per GDP model and agricultural output per labour models, we provide two estimations, one with capital and the other without capital. In all the models, rural electrification coefficients are significant. Thus, a 10% increase in rural electrification could be associated with about 0.06 or 0.1 percentage point increase in agricultural output to GDP ratio as shown in columns 1 and 2 of Table 4. The positive correlation between rural electrification and agricultural output to GDP ratio suggests that an increase in rural household’s access to electricity could spur growth in agricultural

output. Our results corroborate that of the [Khandker & Koolwal \(2010\)](#) and [Mundlak \(2002\)](#). Findings by [Khandker & Koolwal \(2010\)](#) show a weak but positive effect of electrification on agricultural output. Similarly, [Mundlak \(2002\)](#) showed that an investment in electrification has a strong correlation with agricultural growth. Our results also show a positive association between rural electrification and labour productivity (agricultural output per labour). From columns 3 and 4 of Table 4, a 10% increase in rural electrification is associated with 0.34% or 0.13% increase in labour productivity. As communities in rural areas have access to electricity, it complements existing factor inputs and makes labour more productive ([Knox et al., 2013](#)). [Assunção et al. \(2017\)](#) found a significant relationship between electrification and agricultural output per labour.

We test the robustness of this results by replacing rural electrification with total electrification rate which comprises of both rural and urban electrification. This is informed by the fact that the supply chain of agricultural products extends beyond rural areas as the bulk of trading and processing of agricultural products also take place in urban areas. Therefore, an increase in demand for agricultural products from both urban and rural centers could stimulate production in the subsequent year. As a result, if rural electrification drives agricultural output then we expect total electrification rate to follow similar direction. The results from the estimation using total electrification in place of rural electrification can be seen in columns 5 to 8 in Table 4. We find positive association between total electrification and agricultural output (that is, agricultural output to GDP ratio and agricultural output per capita). In the case of agricultural output to GDP ratio, we find the correlation between total electrification and agricultural output is relatively higher than that of rural electrification and agricultural output. However, the marginal effect of total electrification with respect to agricultural output per worker is lower than that of rural electrification.

For the other variables in our model, we find that institutional quality has significant positive association with agricultural output per GDP as shown in column 1 of Table 4. A unit increase in institutional quality could drive agricultural output per GDP by 5.8%. Our result is consistent with that of [Méon & Weill \(2005\)](#), [Fulginiti et al., \(2004\)](#) and [Lio & Liu \(2008\)](#). [Méon & Weill \(2005\)](#) in their study find that a relatively good institutional quality brings about higher output in

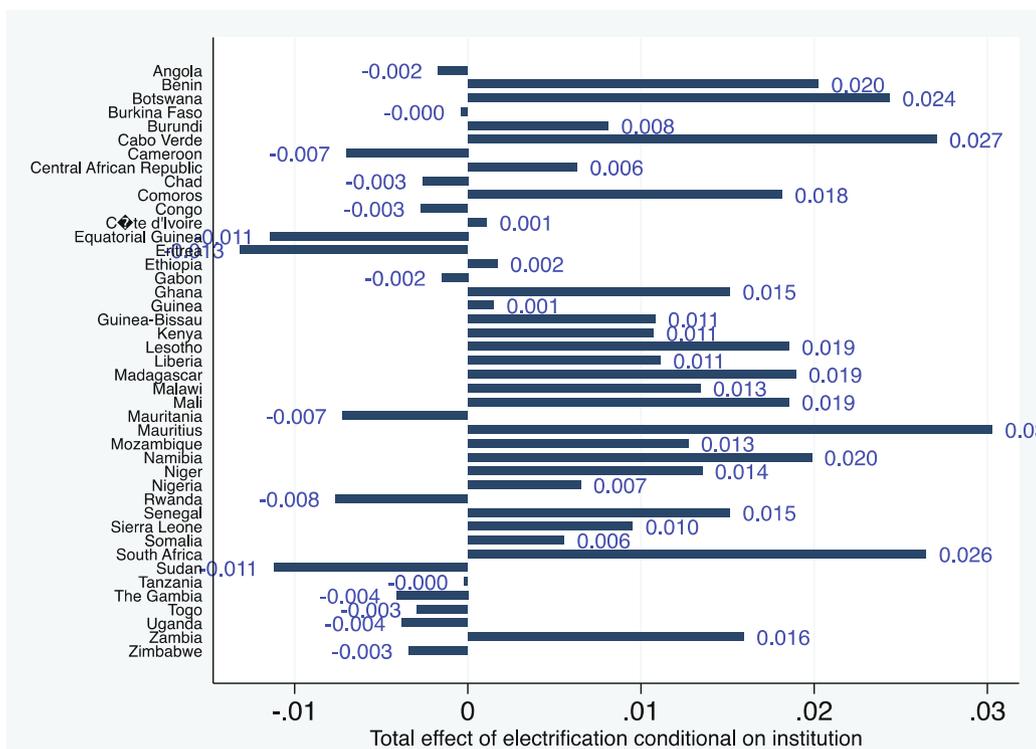


Fig. 4. Total Effect of rural electrification on agricultural output per GDP by country.

agriculture. Lio & Liu (2008) discovered a positive indirect significant effect of institutions on agricultural output. They also claim that given that if the level of education and climate are the same for each country, then better governance will definitely increase agricultural productivity. Similarly, Fulginiti et al., (2004) conclude that SSA countries with

higher political rights and civil liberties have high agricultural productivity. Our result for agricultural output per labour is consistent with that of Fulginiti et al., (2004) as improved institutional quality is associated with higher labour productivity in the agricultural sector as shown in column 3 of Table 4. However, when we control for capital in

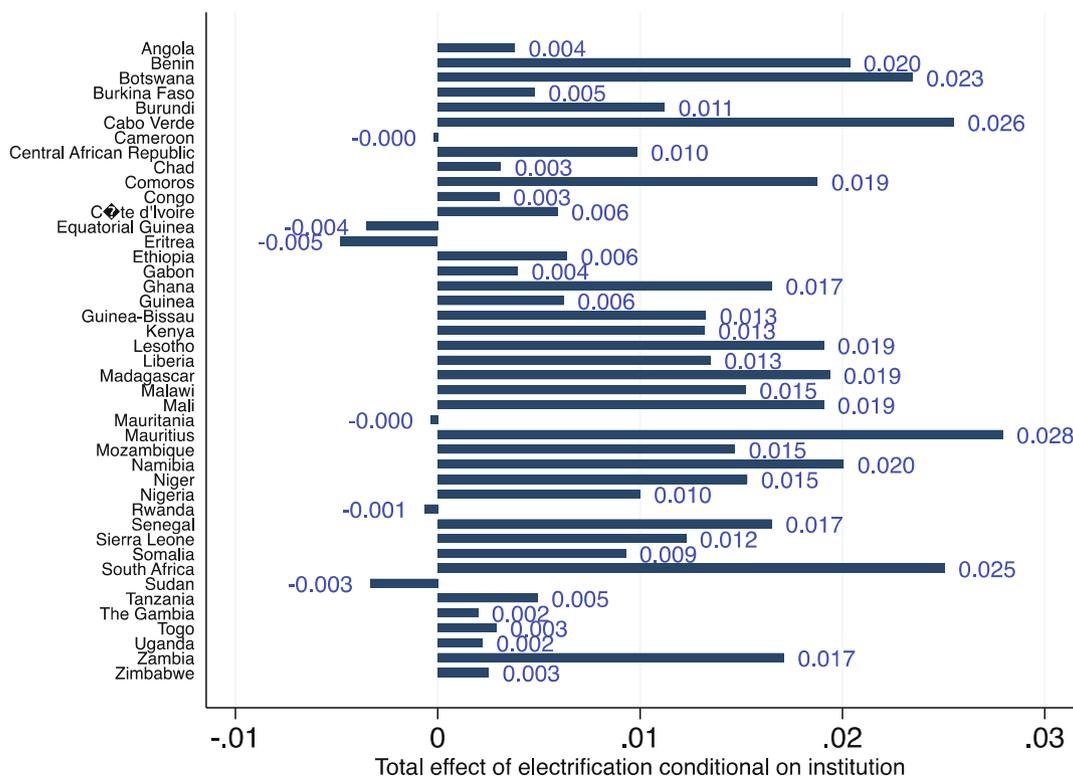


Fig. 5. Total effect of rural electrification on agricultural output per labour by country.

Table 6
FMOLS model for rural electrification and factor inputs interaction.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Ln(y/gdp)	Ln(y/gdp)	Ln(y/gdp)	Ln(y/gdp)	Ln(y/gdp)
lnE_1	0.048*** (0.014)	0.151*** (0.012)	0.086*** (0.005)	0.154*** (0.010)	-0.001 (0.005)
lnL	0.100*** (0.014)	0.139*** (0.011)			
lnE_1*lnL	-0.010*** (0.003)	-0.034*** (0.003)			
lnN			0.224*** (0.016)	0.042* (0.025)	
lnE_1*lnN			-0.023*** (0.001)	-0.039*** (0.003)	
lnK					0.009** (0.005)
lnE_1*lnK					0.002** (0.001)
Constant	-6.605*** (0.450)	-6.136*** (0.335)	-6.150*** (0.253)	-5.379*** (0.364)	-5.542*** (0.393)
Total effect lnE_1	0.008*** (0.002)	0.017*** (0.002)	0.0007 (0.001)	0.008*** (0.002)	0.0127*** (0.002)
Total effect lnL	0.083*** (0.011)	0.084*** (0.008)			
Total effect lnN			0.187*** (0.016)	-0.022 (0.025)	
Total effect lnK					0.0126*** (0.004)
Observations	847	690	847	690	690
R-squared	0.944	0.959	0.943	0.962	0.961
Country FE	YES	YES	YES	YES	YES
Trend	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES
Adjusted R-squared	0.941	0.956	0.939	0.959	0.959
Long Run SE	0.0396	0.0252	0.0224	0.0275	0.0295
Bandwidth(neweywest)	190.6	476.7	775.5	307.3	271

Note: The dependent variables are the natural log of agricultural output per labour (Ln(ypercapita) and natural log of agricultural output per GDP (y/gdp). lnE_1 is one-year lag of natural log of rural electrification rate. lnL, lnN, lnK, lnT and lnR is natural logs of labour, land, capital, temperature and rainfall, respectively. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

our model, the relationship is reversed to negative (see column 4 of Table 4). For this model, we have missing observations and this could drive our result.

Our results show that labour significantly increases agricultural output per GDP but reduces its productivity (see Table 4). The negative correlation of labour with its efficiency is not surprising due to the functional form used (Cobb-Douglas function) and it is also explained by the diminishing marginal returns. Similarly, land and capital significantly increase agricultural output per GDP and agricultural output per worker. The effect of weather variables (temperature and rainfall) on agricultural output is significantly positive. Given the type of weather in SSA, most of the crops thrive in warm weathers and raining seasons. A good combination of favourable temperature and amount of rainfall boost agricultural output and efficiency output. High temperatures compensated with rainfall and vice versa, facilitates agricultural output. The results we find for labour, land and capital agree with Adom et al., (2018); Alene, (2010) and Barrios et al. (2008). They also find that the effect of these factors on agricultural output is positive and significant. On climate, Barrios et al., (2008) find that the evolution of agricultural output is as a result of rainfall and temperature. Their study shows that temperature has a negative effect on agricultural productivity whereas rainfall increases agricultural productivity.

4.2. Interaction between rural electrification and institution

Our second hypothesis is to test the relationship between the interaction of rural electrification and institution (that is, lnE_1*Ins_1), and agricultural output. From Table 5, we have a positive relationship between the interaction of rural electrification and institution, and agricultural output, with estimates ranging from 0.01 to 0.05. This implies that the quality of institution complements the effect of electrification in

enhancing agricultural output. From columns 2 and 4 of Table 5, we find that the interaction relationship increases when capital is included in the model. In order to estimate the total marginal effect of electrification on agricultural output, we evaluate the expression in equation (7) at the mean of institutional quality.

$$\text{Recall from equation (7) that } \frac{\partial \ln Y_{it}}{\partial \ln E_{it-1}} = \alpha_6 + \alpha_8 \text{INS}_{it-1}$$

From Table 5, the direct relationship between electrification and agricultural output (that is, α_6) is positive in the models which excludes capital but turns negative when we include capital in the models. Since the coefficient of the interaction between electrification and institutional quality is positive, evaluating the total marginal effect expression in equation (7) at the mean of institutional quality gives a significant positive value as shown in Table 5. Given the mean institutional quality in the sample, a 10 per cent increase in rural electrification is associated with an increase in agricultural output per GDP by 0.07 percentage point (see the total effect in column 2 of Table 5) and an increase in agricultural output per worker by 0.1 percentage point (see the total effect in column 4 of Table 5). Based on our robustness test where we replace rural electrification with total electrification, the results are qualitatively similar.

Since the countries are heterogeneous in nature, we predicted each country's total marginal effect of electrification on agricultural output per GDP. Figs. 4 is derived from column 2 of Table 5 and it shows the total marginal effect of rural electrification on agricultural output per GDP in each country. Mauritius records the highest estimate of about 0.3 per cent with a 10 per cent increase in rural electrification. This high estimate is attributed to the fact that institutional quality index is the highest in Mauritius. The country with the lowest estimate is Eritrea (see Fig. 4). The total marginal effect for each country has been obtained assuming an average institutional quality index for each country and

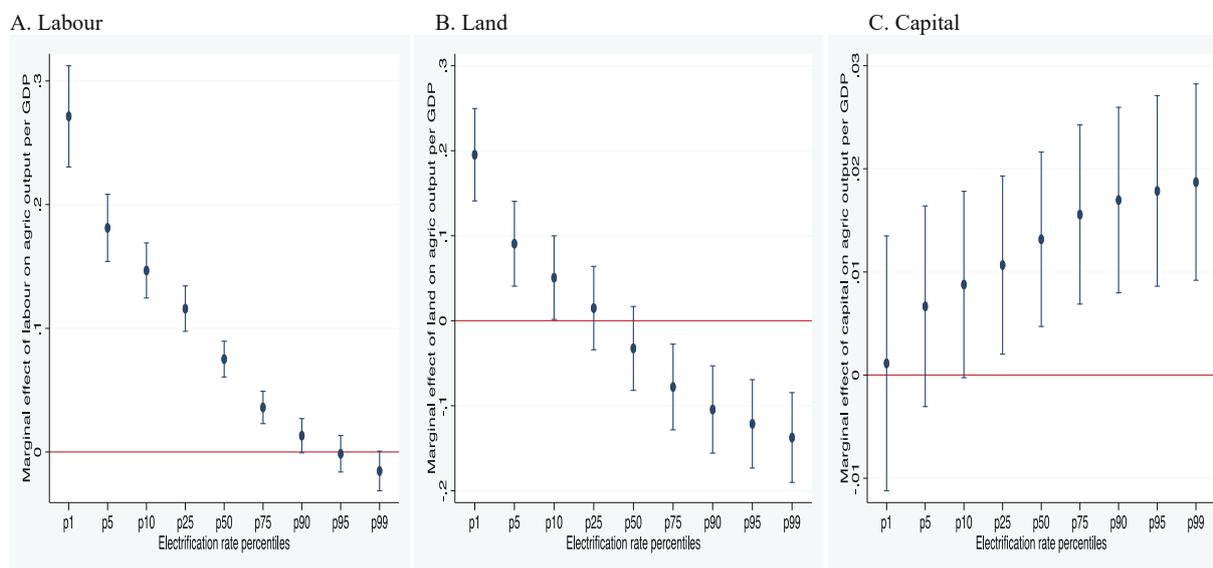


Fig. 6. Total effect of factor inputs conditional on electrification rate.

then applying equation (7). Fig. A2 in appendix calculates the total marginal effect on agricultural output per GDP using total electrification and it is derived from column 6 of Table 5. The result is qualitatively similar.

Fig. 5 shows the total effect of rural electrification on agricultural output per worker for each country, and it is derived from column 4 of Table 5. Here again, Mauritius records the highest estimate of about 0.28 per cent with a 10 per cent increase in rural electrification, followed by Cabo Verde with an effect of 0.26. From Figure 5 the relationship between electrification and productivity of labour is lowest in Equatorial Guinea, Eritrea and Sudan. Equatorial Guinea is known for violating human rights and a very weak democratic practise. Sudan mainly focuses on producing mineral resources and hence they do not focus on agriculture. Eritrea and Sudan have faced a series of famine and civil wars. The most performing sector in Eritrea is the mining sector. For these reasons, these countries have the lowest agricultural output and

hence the relationship between electrification and agricultural output per labour is also low.

4.3. Interaction between rural electrification and inputs

In Table 6 we investigate whether or not electrification enhances the relationship between factor inputs such as labour, land and capital, and agricultural output. Our results show that the interaction between rural electrification and labour have negative relationship with the share of agricultural output in GDP (see columns 1 and 2 of Table 6). This negative relationship could be attributed to the fact that labour move from agricultural activities to non-agricultural sectors as a result of electrification in the community. However, we find a positive direct relationship between labour (that is, α_1) and agricultural output per GDP as shown in (see columns 1 and 2 of Table 6). This direct association (that is, 0.1 and 0.139) is several times greater than the coefficient

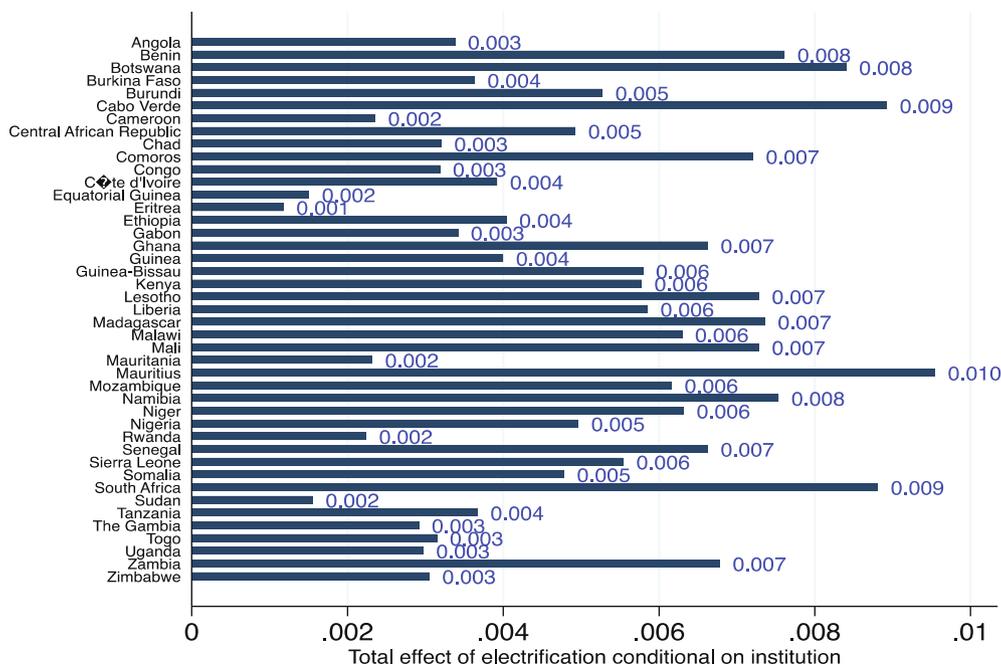


Fig. A2. Total Effect of total electrification on agricultural output per GDP by country.

Table 7

Relationship between electrification, and agricultural output per GDP and labour efficiency by population size quartile

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	lny_gpd	lny_gpd	lny_percapita	lny_percapita	lny_gpd	lny_gpd	lny_percapita	lny_percapita
	1 st Quartile				2 nd Quartile			
lnE_1	0.000 (0.003)	-0.020*** (0.005)	0.087*** (0.005)	-0.006 (0.005)	0.018*** (0.004)	0.030*** (0.003)	-0.021*** (0.005)	-0.043*** (0.003)
Ins_1	0.024* (0.014)	0.119*** (0.030)	-0.101*** (0.025)	-0.459*** (0.025)	-0.100*** (0.025)	-0.152*** (0.017)	-0.142*** (0.030)	-0.197*** (0.017)
Observations	212	149	211	148	201	179	202	180
Adjusted R-squared	0.926	0.963	0.853	0.942	0.933	0.963	0.832	0.848
Long Run SE	0.0254	0.0282	0.0454	0.0234	0.0524	0.0308	0.0641	0.0310
	3 rd Quartile				4 th Quartile			
lnE_1	0.017* (0.009)	0.025* (0.013)	0.047*** (0.013)	0.075*** (0.020)	-0.019*** (0.005)	0.006*** (0.002)	0.060*** (0.008)	0.090*** (0.003)
Ins_1	0.041 (0.048)	-0.106 (0.079)	0.068 (0.063)	-0.288** (0.114)	0.222*** (0.024)	0.058*** (0.008)	0.270*** (0.035)	0.196*** (0.015)
Observations	225	178	211	164	206	181	206	181
Adjusted R-squared	0.692	0.859	0.524	0.602	0.949	0.979	0.943	0.974
Long Run SE	0.0904	0.0860	0.119	0.121	0.0479	0.0124	0.0689	0.0235
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Trend	YES	YES	YES	YES	YES	YES	YES	YES

Note: The dependent variables are the natural log of agricultural output per labour (Ln(ypercapita) and natural log of agricultural output per GDP (y/gdp). lnE_1 is one-year lag of natural log of rural electrification rate. All models controlled for labour, land, temperature and rainfall. However, capital is only included in the columns with even numbering. Ins_1 is one-year lag of institutional quality. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

estimate of labour in our baseline model in Table 4 (that is, 0.071 and 0.039). This implies that though some labour will move from the agricultural sector to non-agricultural sector, those who remain in the sector are relatively more productive than before.

Similarly, we find the relationship between the interaction between land and rural electrification, and agricultural output is negative (see columns 3 and 4 of Table 6). Nonetheless, the direct relationship between labour (that is, α_3) and agricultural output per GDP is positive. In the case of capital, we find both the direct relationship and its interaction with rural electrification on agricultural output per GDP is positive. This implies that rural electrification reinforces the positive relationship of capital with agricultural output per GDP. Our results in Table 6 are qualitatively similar when we use total electrification rate instead of rural electrification rate as shown Table A2 in the appendix, albeit, the direct effect of capital which is positive.

To compute the total marginal effect of each factor input on agricultural output per GDP, we evaluate equations (9a-9c) at the mean of the natural log of rural electrification, as shown below;

Recall that:

$$\text{Labour : } \frac{\partial \ln Y_{it}}{\partial \ln L_{it}} = \alpha_1 + \gamma_1 \ln E_{it-1} \tag{9a}$$

$$\text{Capital : } \frac{\partial \ln Y_{it}}{\partial \ln K_{it}} = \alpha_2 + \gamma_2 \ln E_{it-1} \tag{9b}$$

$$\text{Land : } \frac{\partial \ln Y_{it}}{\partial \ln N_{it}} = \alpha_3 + \gamma_3 \ln E_{it-1} \tag{9c}$$

We find that the total marginal effect of each factor input on agricultural output per GDP positive. A 10% increase in labour, capital and land could be associated with about 0.8, 1.9 and 0.1 percentage point increase in agricultural output per GDP, respectively. In order to investigate the sensitivity of the marginal effect of each factor input on agricultural output, to the rate of electrification, we re-evaluate equations (9a-9c) by considering different percentiles of electrification rates. The results of the estimations are shown in Fig. 6. From panel A of Fig. 6, we find a significant positive marginal effect of labour until the 90th percentile of electrification rate. However, this marginal effect shows a decreasing trend. In the case of the marginal effect of land, we find a positive significant relationship until the 10th percentile of electrification rate and a negative significant relationship from the 75th percentile onwards. Generally, the marginal effect of land shows a decreasing trend

along electrification rate percentile (see panel B in Fig. 6). However, the marginal effect of capital shows a positive relationship and an increasing trend along the electrification rate percentile, albeit, significant from the 10th percentile and above (see panel C in Fig. 6).

4.4. Sensitivity analysis

As the countries in our data have varying size in terms of population, we re-estimate our models for different sub-samples based on the countries' population size. We divide our data into four sub-samples using the quartiles of the population size of countries. Based on the descriptive statistics, the 1st quartile comprises of countries with average population size less than 1.94 million, 2nd quartile comprises of countries with population size from 1.94 million to 8.54 million, 3rd quartile comprises of countries with population size from 8.541 million to 17.25 million, and the 4th quartile comprises of countries with population size above 17.25 million, during the periods of our dataset⁸. The results for the sensitivity analysis based on population size quartiles are shown in Tables 7, 8 and 9. We present only the variables of interest in the tables.

From Table 7, we find heterogeneous relationship between rural electrification and agricultural output across population size quartile sub-samples. Considering the models that control for capital in the specification, the result shows a significant positive relationship between electrification and agricultural output per GDP for all population size quartiles, except for the 1st quartile which showed a negative relationship. In the case of the relationship between electrification and agricultural output per labour, we find a significant positive relationship for the 3rd and 4th quartiles and a negative relationship for the 2nd

⁸ Countries in each quartile are as follow; 1st quartile: Botswana, Cape Verde, Comoros Island, Equatorial Guinea, Gabon, The Gambia, Guinea-Bissau, Lesotho, Mauritius, Namibia, São Tomé and Príncipe, and Seychelles; 2nd quartile: Benin, Burundi, Central African Republic, Republic of Congo, Eritrea, Liberia, Rwanda, Mauritania, Sierra Leone, Somalia and Togo; 3rd quartile: Angola, Burkina Faso, Cameroon, Chad, Guinea, Malawi, Mali, Niger, Senegal, Zambia and Zimbabwe; 4th quartile: Côte d'Ivoire, Ethiopia, Ghana, Kenya, Madagascar, Mozambique, Nigeria, South Africa, Sudan, Tanzania and Uganda. The panel within each quartile is unbalanced because observations are missing for some countries over some years. São Tomé and Príncipe and Seychelles eventually drop out of the estimation because they have no data on institutions for the period of study.

Table 8
FMOLS model for electrification and institution interaction by population size quartile

Variables	(1) lny_gpd	(2) lny_gpd	(3) lny_percapita	(4) lny_percapita	(5) lny_gpd	(6) lny_gpd	(7) lny_percapita	(8) lny_percapita
	1 st Quartile				2 nd Quartile			
lnE_1	0.082*** (0.027)	0.232*** (0.029)	-0.062** (0.027)	-0.419*** (0.037)	0.001 (0.007)	-0.008 (0.007)	0.022*** (0.007)	-0.025*** (0.008)
Ins_1	0.297*** (0.093)	1.106*** (0.114)	-0.587*** (0.091)	-2.078*** (0.146)	-0.109*** (0.028)	-0.193*** (0.023)	-0.119*** (0.028)	-0.181*** (0.029)
lnE_1*Ins_1	-0.095*** (0.031)	-0.301*** (0.034)	0.172*** (0.031)	0.493*** (0.043)	0.034*** (0.012)	0.084*** (0.012)	-0.086*** (0.012)	-0.038** (0.015)
Total effect lnE_1	0.0195** (0.008)	0.035*** (0.0077)	0.051*** (0.008)	-0.096*** (0.010)	0.015*** (0.005)	0.037*** (0.005)	-0.016*** (0.0046)	-0.042*** (0.005)
Observations	212	149	211	148	201	179	202	180
Adjusted R-squared	0.929	0.960	0.839	0.948	0.937	0.953	0.839	0.875
Long Run SE	0.0501	0.0247	0.0494	0.0318	0.0583	0.0403	0.0587	0.0491
	3 rd Quartile				4 th Quartile			
lnE_1	0.105*** (0.014)	0.171*** (0.034)	0.180*** (0.023)	0.324*** (0.047)	-0.067*** (0.007)	-0.108*** (0.007)	0.000 (0.010)	-0.070*** (0.014)
Ins_1	0.140*** (0.044)	0.088 (0.087)	0.195*** (0.064)	0.051 (0.112)	0.074*** (0.025)	-0.270*** (0.021)	0.080** (0.037)	-0.264*** (0.045)
lnE_1*Ins_1	-0.160*** (0.022)	-0.203*** (0.042)	-0.229*** (0.033)	-0.325*** (0.057)	0.111*** (0.011)	0.181*** (0.010)	0.141*** (0.016)	0.254*** (0.021)
Total effect lnE_1	0.024*** (0.008)	0.069*** (0.016)	0.065*** (0.012)	0.160*** (0.022)	-0.007 (0.0048)	-0.011*** (0.003)	0.076*** (0.009)	0.066*** (0.005)
Observations	225	178	211	164	206	181	206	181
Adjusted R-squared	0.731	0.844	0.531	0.671	0.956	0.983	0.932	0.979
Long Run SE	0.0805	0.0842	0.115	0.101	0.0410	0.0175	0.0603	0.0368
Country FE	YES	YES	YES	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES	YES	YES	YES
Trend	YES	YES	YES	YES	YES	YES	YES	YES

Note: The dependent variables are the natural log of agricultural output per labour (Ln(ypercapita) and natural log of agricultural output per GDP (y/gdp). LnE_1 is one-year lag of natural log of rural electrification rate. All models controlled for labour, land, temperature and rainfall. However, capital is only included in the columns with even numbering. Ins_1 is one-year lag of institutional quality. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

quartile. Our results show a significant positive relationship between institutional quality and agricultural output per GDP, within the 1st and 4th quartile sub-samples, however, a negative relationship for the 2nd quartile.

In Table 8, we show the relationship between the agricultural output and the interaction between rural electrification and institutional quality across different population size quartiles. Similarly, our results show heterogenous relationship across population quartile sub-samples. In the case of agricultural output per GDP, we find a significant positive relationship with the interaction between electrification and institutional quality for the 2nd and 4th quartile sub-samples. However, a negative relationship between agricultural output per GDP and electrification-institutional quality interaction is observed for the 1st and 3rd population quartile sub-samples.

In relation with agricultural output per labour, we find a significant negative relationship with the interaction between electrification and institutional quality for the 1st and 4th quartile. However, a positive relationship between agricultural output per labour and electrification-institutional quality interaction is observed for the 2nd and 3rd population quartile sub-samples.

Table 9 shows the relationship between agricultural output and the interaction between electrification and factor inputs (that is, labour, land and capital). The results show heterogenous relationship across sub-samples. In the case of labour-electrification interaction, we find significant positive relationship with agricultural output per GDP for all sub-samples, except for the 2nd quartile sub-sample which showed a negative relationship. The results of the relationship between agricultural output per GDP and land-electrification interaction show a positive relationship for the 1st and 3rd quartile sub-samples and a negative relationship for the 2nd and 4th quartile sub-samples. The results from the interaction between capital and electrification show a different pattern in relation with agricultural output per GDP. We find that, whereas the relationship between agricultural output and capital-electrification interaction shows significant negative relationship for the lower quartiles (1st and 2nd) sub-samples, positive relationship is

observed for the upper quartiles (3rd and 4th) sub-samples.

Our sensitivity analysis so far demonstrates that the size of countries in terms on population has implication on the relationship between rural electrification and agricultural output in sub-Saharan Africa.

5. Conclusions

This study presented the results of the association between rural electrification and agricultural output at the macro level using panel data on Sub-Saharan African countries from 1990 to 2016. We employed FMOLS with time trend and country fixed effect in our econometrics estimation to address potential serial correlation. Our study sought to investigate the following; i) the correlation between rural electrification and agricultural output, measured as agricultural output per GDP and agricultural output per worker, ii) whether the relationship between rural electrification and agricultural output is conditional on the level of institutional quality of a country, and iii) whether electrification enhances the marginal effect of factor inputs.

We observed a positive significant association between rural electrification and agricultural output measured as the share of agricultural output in GDP and agricultural output per worker. This suggests that an increase in rural household's access to electricity could spur growth in agricultural output. The improvement in labour productivity in agricultural sector resulting from rural electrification could imply the complementary role of electrification in enhancing the efficiency of existing factor inputs. In addition, our results show that the relationship between rural electrification-institutional quality interaction and agricultural output is positive and it ranges from 0.01 to 0.05. Thus, the total effect of electrification is conditional on the quality of institution of a country. This denotes that countries with good institutions are likely to augment the positive relationship between electrification and agricultural output. As rural electrification encourages labour movement from agricultural sector to non-agricultural sector, our results show a negative relationship between rural electrification-labour interaction and agricultural output. However, we find a higher positive direct relationship

Table 9
FMOLS model for rural electrification and factor inputs interaction by population quartile

Variables	(1) lny_gdp 1 st Quartile	(2) lny_gdp 2 nd Quartile	(3) lny_gdp 3 rd Quartile	(4) lny_gdp 4 th Quartile
Electrification and labour interaction				
lnE_1	-0.600*** (0.103)	0.291*** (0.081)	-0.941*** (0.221)	-0.747*** (0.110)
lnL	-0.326*** (0.074)	0.258 (0.161)	-0.016 (0.074)	-0.669*** (0.118)
lnE_1*lnL	0.142*** (0.027)	-0.067*** (0.020)	0.244*** (0.056)	0.160*** (0.025)
Total effect lnE_1	-0.087*** (0.015)	0.011 (0.008)	0.077*** (0.0196)	-0.117*** (0.014)
Observations	149	179	178	181
Adjusted R-squared	0.945	0.932	0.791	0.959
Long Run SE	0.0822	0.0750	0.0994	0.0397
Electrification and land interaction				
lnE_1	-0.423*** (0.077)	0.226*** (0.033)	-0.953*** (0.277)	0.511*** (0.052)
lnN	0.997*** (0.234)	0.175* (0.101)	-0.970*** (0.267)	-1.906*** (0.131)
lnE_1*lnN	0.086*** (0.018)	-0.058*** (0.009)	0.281*** (0.079)	-0.145*** (0.014)
Total effect lnE_1	-0.120*** (0.018)	0.010 (0.007)	0.067*** (0.020)	-0.077*** (0.007)
Observations	149	179	178	181
Adjusted R-squared	0.938	0.928	0.729	0.943
Long Run SE	0.0792	0.0690	0.106	0.0489
Electrification and capital interaction				
lnE_1	0.244*** (0.052)	0.272*** (0.044)	-0.289** (0.121)	-0.305*** (0.048)
lnK	0.358*** (0.066)	-0.136*** (0.019)	-0.277*** (0.038)	-0.053*** (0.023)
lnE_1*lnK	-0.092*** (0.014)	-0.046*** (0.008)	0.046** (0.018)	0.035*** (0.006)
Total effect lnE_1	-0.216*** (0.029)	-0.001 (0.008)	0.037** (0.018)	-0.013 (0.011)
Observations	149	179	178	181
Adjusted R-squared	0.939	0.913	0.867	0.985
Long Run SE	0.0976	0.0732	0.111	0.0841
Country FE	YES	YES	YES	YES
Trend	YES	YES	YES	YES
Controls	YES	YES	YES	YES

Note: The dependent variables are the natural log of agricultural output per labour (Ln(ypercapita) and natural log of agricultural output per GDP (y/gdp). lnE_1 is one-year lag of natural log of rural electrification rate. All models controlled for labour, land, temperature, rainfall, capital and institutional quality. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

between labour and agricultural output per GDP, implying a higher productivity for those labour who remain in the sector. Similar result was found for the interaction between land and rural electrification. For capital, our result concludes that the rural electrification reinforces the positive relationship between capital and agricultural output per GDP. Our sensitivity analysis shows heterogeneous relationship between rural

electrification and agricultural output across population size quartiles subsamples. Given potential confounding factors that could drive both electrification and agricultural output, we seek not to claim causality in this study. As such the effects discussed in this study are correlation.

As countries in SSA are on the path of strengthening their institutions and expansion of electricity infrastructure, there is the tendency of growth in all sectors of the economy including the agricultural growth. However, our results show movement of labour and land from agricultural sector to non-agricultural sectors. This means that in order to sustain the expansion of agricultural output, governments should endeavor to put in place innovative policies to increase production as labour and land are likely to reduce in the agricultural sector has a result of electricity expansion.

In conclusion, every Sub-Saharan country is unique in every way. The differences in culture, government and agricultural focus go a long way to determine how each country puts electricity to use. It is also noteworthy that some of the policies that will be considered in one country may not be externally valid for other countries. For example, some agricultural policies that will be working well for Ghana may not be ideal for South Africa or Botswana. Even though this study looks at Sub-Saharan Africa as a whole, the region is made up of different countries with their individual governments and hence institutional quality are also different. This implies that future research could focus on country specific time series analysis to consider the short and long-run relationship between electrification and agricultural output. Such analysis would require a time-series data covering over forty years.

CRedit authorship contribution statement

Salome Amuakwa-Mensah: Conceptualization, Data curation, Formal analysis, Investigation, Software, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Yves Surry:** Supervision, Conceptualization, Investigation, Writing – review & editing.

Declaration of Competing Interest

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

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Appendix

(See [Table A1](#) and [A2](#))

Table A1
Correlation Matrix

	Ln(y/gdp)	lnypercapita	lnL	lnN	lnK	lnT	lnR	lnE_1	lns_1
Ln(y/gdp)	1								
lnypercapita	-0.46***	1							
lnL	0.67***	-0.76***	1						
lnN	0.12***	0.04	-0.16***	1					
lnK	0.02	0.15***	-0.14***	0.27***	1				
lnT	0.39***	0.07**	0.30***	-0.21***	0.09***	1			
lnR	0.10***	-0.21***	-0.02	-0.09***	0.01	-0.06***	1		
lnE_1	-0.54***	0.598***	-0.52***	0.05	0.20***	-0.03	0.07**	1	
lns_1	-0.21***	0.26***	-0.39***	0.12***	0.029	-0.21***	-0.03	0.16***	1

*** p<0.01, ** p<0.05, * p<0.1

Table A2
 FOLS model for total electrification and factor inputs interaction

Variables	(1) Ln(y/gdp)	(2) Ln(y/gdp)	(3) Ln(y/gdp)	(4) Ln(y/gdp)	(5) Ln(y/gdp)
lnET_1	0.165*** (0.012)	0.492*** (0.024)	0.266*** (0.013)	0.497*** (0.019)	-0.085*** (0.013)
lnL	0.242*** (0.011)	0.491*** (0.021)			
lnET_1*lnL	-0.036*** (0.003)	-0.112*** (0.006)			
lnN			0.390*** (0.023)	0.382*** (0.031)	
lnET_1*lnN			-0.066*** (0.003)	-0.125*** (0.005)	
lnK					-0.088*** (0.009)
lnET_1*lnK					0.035*** (0.002)
Constant	-7.150*** (0.225)	-7.646*** (0.387)	-6.764*** (0.361)	-7.069*** (0.412)	-6.396*** (0.431)
Observations	868	697	868	697	686
R-squared	0.940	0.959	0.946	0.961	0.963
Country FE	YES	YES	YES	YES	YES
Trend	YES	YES	YES	YES	YES
Controls	YES	YES	YES	YES	YES
Adjusted R-squared	0.936	0.956	0.942	0.958	0.961
Long Run SE	0.0207	0.0293	0.0336	0.0316	0.0318
Bandwidth(neweywest)	940.6	237.3	293.4	198	200.7

Note: The dependent variables are the natural log of agricultural output per labour (Ln(ypercapita) and natural log of agricultural output per GDP (y/gdp). lnE_1 is one-year lag of natural log of rural electrification rate and lnET_1 is one-year lag of total electrification rate. lnL, lnN, lnK, lnT and lnR is natural logs of labour, land, capital, temperature and rainfall, respectively. Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1.

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