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Decentralized renewable energy - an enabler for development in the agriculture sector in rural areas of Sub-Saharan Africa?

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Abstract:

The majority of the globally poor population, characterized by agricultural dependency as well as energy poverty, is located in Sub-Saharan Africa. Previous research states that energy benefits agriculture sectors. One reason why the agrarian society lacks access to electricity is because of the insufficient infrastructure in the remote areas. Therefore, this paper aims to investigate whether off-grid solar photovoltaics could possibly be a suitable way to make electricity available for a larger number of people in Sub-Saharan Africa, in order to increase agricultural production. Based on the theory by Solow and Swan (1956), we treat electricity as a new technological change in the production function, which underlies the regression models in the study. We use state-level panel data between the years 2000 and 2021 for all African countries and divide the sample into a subsample only containing Sub-Saharan countries. Our results could not estimate any statistically significant impact of installed capacity of off-grid solar photovoltaics on rural electrification as well as agriculture production. This contradicts the findings in previous literature. To capture the causal effect of off-grid electricity on agriculture outcome in rural areas, further research using data on a micro level instead of macro could be a more suitable way.

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List of acronyms

CSE	Clustered Standard Errors
FE	Fixed Effects
GDP	Gross Domestic Product
MW	MegaWatt
OLS	Ordinary Least Squares
OVB	Omitted Variables Bias
PV	Photovoltaic
SSA	Sub-Saharan Africa
SDG 7	Sustainable Development Goal 7
TFP	Total Factor Productivity
USD	American Dollar

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1. Introduction

Electricity is well known to be an enabler for development, and a crucial component for modern economic activity. Despite this, 759 million people around the globe still lacked access to electricity in 2019, with three quarters living in Sub-Saharan Africa (SSA) (United Nations, 2021a). Globally, people suffering from energy poverty are mainly found in rural areas (United Nations, n.d.b). Sub-Saharan Africa is not an exception. In 2020, as much as 71 percent of the rural population were lacking access to electricity (World Bank, 2022b).

The importance of increasing the availability of electricity for the world's population has been emphasized and received more attention during recent years. In 2015, The United Nation highlighted the importance of access to electricity for development by addressing the United Nation Sustainable Development Goal 7 (SDG 7) (United Nations, 2021a). According to the United Nation SDG 7, an important challenge to create sustainable development is to "ensure access to affordable, reliable, sustainable and modern energy for all". To achieve this, the United Nations underlines that a substantial increase of the share of renewable energy in the global energy mix is of importance (The United Nations, 2015). Renewable energy solutions can be an attractive way of counteracting energy poverty in rural communities. Rural areas have, to a lower extent, access to infrastructure such as the national electrical grid system (IFC, 2019). In Africa, a majority of the households without access to the national grid live in rural areas (ibid.). Decentralized renewable energy technologies such as off-grid solar photovoltaic (PV) may therefore be a good option for Sub-Saharan Africa to power their rural areas in a self-sufficient way. With Africa's large amount of sun-hours (Global Solar Atlas, 2022), the continent provides great potential for solar power.

The availability of electricity facilitates the everyday life of rural households (CEDRO, 2016). For example, electricity can provide households with lightning which allows people to shift their household chores to the evening, and thus extend the time to do other chores during the day (ibid.). Electricity can also be applied in sectors that provide livelihoods to rural communities (Palit et al., 2015). In Sub-Saharan Africa, a majority of the people living in the electricity poor rural areas, are working in the agrarian sector or are reliant on household farming. Since many of the households are engaged in agriculture, there is a great dependence on agriculture for sustenance (IFC, 2019). According to IRENA (2019a), decentralized renewable energy solutions can provide several benefits along the agriculture production chain. In an ecologically sustainable way, off-grid renewables can increase energy security, productivity, and overall socio-economic growth in the rural communities (ibid.).

Our aim with this research is to investigate whether off-grid solar photovoltaics is an enabler for providing energy to rural areas in Sub-Saharan Africa. This paper also investigates whether rural electrification can spur growth in the agriculture sector in terms of agriculture output. Based on the production function by Solow and Swan (1956), we run linear regression models to explore how technological improvements in terms of electrification can affect the efficiency of existing inputs in the agriculture process. Thus, increase the level of production in the sector. With low access to the electrical grid system in the rural areas of SSA (IFC, 2019), and with a rapid growth of solar PV capacity, we chose to focus on off-grid solar PV as the source of electrification in our study.

Based on annual state-level panel data from all 54 African countries between the years 2000 to 2021, we explore the association between rural electrification and agriculture output. The emphasis of this research is rural areas in Sub-Saharan Africa, where access to electricity is at globally low levels, and the main source of employment is within the agriculture sector. In our subsample with Sub-Saharan countries we have chosen to exclude Mauritius, Seychelles and South Africa. The countries were excluded since they, throughout the chosen time period, show a high and stable degree of access to electricity for the rural population and a low dependency on agriculture.

Firstly, we explore if off-grid solar photovoltaics can increase access to electricity in rural areas that have limited access to the national electrical grid system. Then on, we can investigate whether off-grid energy systems can be a suitable way to electrify the agriculture dependent areas of SSA. Secondly, we analyze if access to electricity, provided by all energy sources, could spur agriculture production. Lastly, we specifically examine the relationship between increased installations of off-grid solar PV technologies in SSA and agriculture production. The outcomes of the second and third research questions are compared and used to draw conclusions whether off-grid energy power is a suitable way of providing electricity in the agricultural sectors.

The ambition for this bachelor thesis is to answer the following research questions:

1. To what extent can increased installations of off-grid solar PV generate higher levels of access to electricity for the rural population in Sub-Saharan Africa?

2. Could an increased access to electricity for the rural population generate a higher level of agricultural output in Sub-Saharan Africa?

3. Could an increased installed electricity capacity of off-grid solar PV generate higher levels of agriculture output in Sub-Saharan Africa?

Previous studies have investigated the relationship between access to electricity and agriculture output. To our knowledge, there has not been any research of the impact of decentralized renewable sources on agricultural production. Thus, our aim is to fill the gap of already existing literature. Even though previous studies have found a significant relationship between rural electrification and agricultural production, our models used to investigate the research questions show estimates very close to zero and therefore negligible. The reason might be due to the fact that the indicators in the models are not able to capture the impact of variations in electrification in rural areas on agriculture output on a macro level.

1.1 Background

To gain an insight into how renewable energy can contribute to the electrification of rural areas in an environmentally friendly way, an understanding of the concept of the energy sector is required and will be presented in this part of the thesis. This section also aims to provide an overview of the agriculture sector in Sub-Saharan Africa and how electricity can be applied in the agriculture value chain.

Renewable energy refers to energy that is produced from the Earth's flow sources which emits less amount of greenhouse gases compared to fossil fuels (United Nations, n.d.a). Since the Earth provides different types of natural resources, there is a wide variety of different technologies for extracting renewable energy. The most common types of renewable energy technologies are solar power, wind power and hydropower (ibid.).

The latest report from the Intergovernmental Panel on Climate Change (IPCC, 2022) points out the adverse consequences of climate change on countries in Sub-Saharan Africa. It is clear that the impacts are already affecting the most vulnerable people of the world who, at the same time, are struggling adapting to the effects. Increased global warming leading to extreme weather events have exposed millions of people to both food and water insecurity, with the largest effects observed in many locations in SSA. Renewable energy sources, such as solar PV, can provide energy in an ecologically sustainable way. Solar energy both provides energy security and enables adaptation to climate change. An expanded use of solar PV contributes to reducing greenhouse gases emissions as well as reliable energy sources to the population. The authors of the report also underline the increased risk of malnutrition for small-scale food producers and low-income households as a result of sudden losses in food production. The consequences risk pushing poor households into persistent poverty traps (ibid.).

Africa is a continent with a great amount of renewable resources (IRENA, 2016c). Historically, hydropower has been the most common source of renewable energy generation in Africa. But with a great potential for solar photovoltaics, due to price reductions and the high abundance of sun-light, the continent has recently shifted into increasing its amount of solar power in the renewable energy mix. From the end of 2009 to the beginning of 2015, the price of solar PV modules fell by 80 percent (ibid.). Solar PV cells transform sunlight into electricity energy (EIA, 2022). Electricity from solar PV can be generated both on- and off-grid. Off-grid systems refer to electricity generating power plants that are not connected to the national electricity grid system in a country (IRENA, 2018). Off-grid solutions have rapidly increased in Africa. Between the years 2011 and 2019, the number of people served by off-grid solutions grew from two million to nearly 60 million people. The main reason for this increase is installations of off-grid solar solutions (ibid.).

Implementation of off-grid solar PV has increased worldwide during recent years, driven by improved technology, supportive policies, decreasing costs and regulations about environmental impacts (IRENA, 2018). It comes in different constructions. Everything between small standalone systems, such as solar home systems[1], to larger mini-grids[2] (IRENA, 2018). According to IRENA and AfDB (2022), both standalone systems and

[1] Solar home systems refer to off-grid energy generation systems that can provide electricity at a household level for lightning and basic electricity needs (IRENA, 2016a).
[2] Mini-grids, also known as microgrids, refer to interconnected small-scale electricity generators, which together form a smaller electricity network decentralized from the national grid. These generate electricity at a local level, to a smaller customer group (UNIDO, 2021; IRENA, 2016a).

mini-grids are cost-effective ways to provide rural areas with energy where grid infrastructure may be lacking. Mini-grids can also be connected to the main national grid (IRENA 2019b), and therefore provide electricity to rural areas during the waiting period until the expansion of the national grid reaches those areas.

Between the years 2016 and 2019, about 8.5 million people in Sub-Saharan gained access to electricity through solar home systems (IRENA, AfDB, 2022). Today, approximately 1 500 mini-grids are generating electricity and 4 000 more are planned to be installed in the future. Africa accounted for 70 percent of the global investments in the off-grid energy sector between the years 2010 and 2020. 74 percent of the total investments was in solar home systems and 16 percent in mini-grids, driven by a push of using the energy for commercial and industrial purposes. However, today's level of investments in off-grid energy sources is not close to what is needed to reach global electrification by 2030 (ibid.). Since agriculture activities in Sub-Saharan Africa operate in rural areas with low access to electricity, the agriculture sector is also characterized by energy poverty. The agriculture sector therefore remains under-mechanized, due to low access to electrical appliances that could have streamlined the agri-processes (IFC, 2019). In comparison to agriculture in developed countries, the sector in SSA is more labor intensive. In Sub-Saharan Africa, a majority of its land is tilled, plowed, and weeded by human- or animal power. The efficiency could increase by up to five times or more by using machinery in the process (Ibid.).

Electricity generated from renewable sources can be applied in the agriculture process in several ways (IRENA & FAO, 2021). For instance, in the primary production stage, solar PV can be used to power electrical water pumps for irrigating crops. Today, most agriculture in SSA is rain-fed. With increasing changes in rain-patterns due to climate change, improvement in irrigation technology is of importance for water supply to ensure food security, generate reliable yields and improve agriculture productivity (IPCC, 2022; IRENA & FAO, 2021). In the post-harvest stage, solar PV can generate energy for cooling and refrigeration (IRENA, 2016c). Energy from mini-grids are being used in the processing stage, to electrify grain milling, threshing and oil-pressing machinery. It can also provide electricity for electric fences, egg incubators and lights for night fishing (IRENA & FAO, 2021; IFC, 2019).

Sub-Saharan Africa accounts for one of the highest levels of extreme poverty, with over 38 percent of the population living below the poverty headcount ratio of 1.90 American dollar (USD) a day (World Bank, 2019b). According to Castañeda et al. (2016), most of the severely poor people live in rural areas, and are engaged in the agriculture sector. Since more than half of the total employment in SSA is within the agriculture sector, (World Bank, 2019a), an increase in productivity in the agriculture sector could be a powerful tool to the overall socioeconomic development in the area. A way to increase economic growth, reduce poverty and ensure food security (Castañeda et al., 2016). The World Bank (2022c) highlights the importance of the agriculture sector contributing to economic growth in developing countries. In Sub-Saharan Africa, agricultural activities contribute to 18.5 percent of the total Gross Domestic Product (GDP) (World Bank, 2022e), unlike in the global economy where only approximately four percent of total GDP comes from the agriculture sector (World Bank, 2022d). At the same time, only four percent of the total global energy consumption is used in the agricultural sector in Africa (IRENA, AfDB, 2022).

2. Literature review

This section of the thesis presents an overview of previous research and literature, discussing advantages as well as limitations of implementing renewable energy in rural areas of developing countries.

According to Kanagawa and Nakata (2008) and Shahidur, Douglas and Hussain (2013), the socio-economic outcomes of an increased access to electricity are for instance improved health, education and gender equality. As a result of improvements of the electrical availability, long-term welfare and poverty reduction can be achieved (ibid.). Kumar and Kumar (2013) investigate the relationship between increased energy per capita and the level of production output as the measurement of GDP per worker. The authors found a causal positive relationship between increased energy per capita and GDP growth in both South Africa and Kenya.

Off-grid solar power is potentially a cost-effective alternative to cover basic electricity needs at a village level in countries in Sub-Saharan Africa (Palit et al., 2015). The authors examine the implementation of power supply in villages in Kenya in the form of decentralized solar

PV applications. Their research shows that the implementation of off-grid solar energy technologies, at remote village levels, can contribute to economic sustainability. They highlight the importance of an engaged follow-up and a flexible socio-technical design, which enables improvements after implementation, in order for projects to be able to achieve the outcome of economic sustainability. Rural areas, with the same characteristics as the remote areas of Kenya, can benefit from the application of off-grid solar technologies, but further research is needed on how the off-grid energy solutions can be adopted in order for implementation to be successful in other geographical areas (ibid.). However, Lee, Miguel and Wolfram (2020) highlight the advantage of on-grid connected energy systems since it can provide a higher extended use of electrification.

Previous research has shown that increased access to electricity in rural areas can improve labor productivity and stimulate growth in the agricultural sector. In a study by Amuakwa-Mensah and Surry (2022), the authors examine, using panel data from Sub-Saharan Africa between 1990 and 2016, the relationship between access to electricity in agrarian areas and agriculture output at a macro level. The study measures the effect of electrification on agriculture output, both in the terms of the share of output in GDP and the share of output per worker. In both cases, there is a significant positive relationship between electrification of rural areas and agricultural output as the share of GDP. This can demonstrate that increased access to electricity in rural areas also has the ability to improve the quality and efficiency of input factors in agricultural activities. However, the study also shows that institutional quality is decisive for how positive the effect of electrification has on agricultural productivity. Countries with better institutional quality will likely benefit from greater effects on their agricultural productivity than countries with poorer institutional quality (ibid.).

Since increasing fuel prices and unreliable electricity supply are threatening agricultural production, Hossain, Hassan, Ahmmed and Islam (2014) analyze whether solar pumps could be an environmentally friendly alternative to the electric motor operated pumps for irrigated crops in Bangladesh. The authors found solar pumps to be an economically and ecologically sustainable way for the cultivation of crops (ibid.). However, Chen and Ding (2007) study the role of infrastructure on total factor productivity (TFP) in Chinese agriculture. They found that agriculture electricity consumption per capita has a statistically significant and negative effect on agricultural bean production on a 95-percent confidence level. The authors state that the impact of electrification on agriculture TFP may result in different outcomes depending on the type of crop and its physical geographical variation.

According to Sims and Kienzle (2006), improving agricultural labor productivity through power technologies is a key input in any farming system. In Sub-Saharan Africa, the most significant power source for small-scale farmers are human muscles. Nonetheless, since the rural population in those regions are characterized by extreme poverty and severe famine, households commonly lose labor as a result of disease, death or migration. To increase labor productivity, labor saving technologies are needed. However, they require time to adapt to technological changes and money to implement new technologies (ibid.).

Besides the developing world, Lewis and Severnini (2020) study the relationship between electrification and American farm households during the time period from 1930 to 1960. The authors found that rural electrification, in the short-run, had a greater impact on agriculture compared to the non-agricultural economy in the United States. Electrification in rural areas increased employment in agriculture, rural farm population and rural property values. The benefits from investing in electrification were larger than the costs. In the long-term, early electrification of rural areas led to overall economic growth (ibid.). Likewise, Edson and Joshua (2020) found that the main driver for economic growth in the United States was the expansion of the agriculture sector in remote areas.

Solar home systems have shown to generate social, economic and environmental benefits (CEDRO, 2016). Solar energy power can be used for lighting in the evening which enables longer working hours for small businesses activities which improve development and living standards (ibid.). Additionally, Lee, Miguel and Wolfram (2020) state that providing access to electricity in order to increase light hours can extend the amount of time spent on farming activities. Even though installed off-grid solar capacity has been rising rapidly across lower middle income countries in Africa, it has been shown to be unclear whether it has fulfilled to meet the actual needs of the end users (Jeuland et. al., 2021). The positive outcomes from electrification, such as increased productivity in income generating sectors, have been limited due to the off-grid solar solutions not meeting the requirements of being affordable and economically sustainable for its customers (ibid.).

Applications of solar energy are shown to have positive effects along the agricultural food chains. Off-grid solar energy can be used to power water pumps for irrigating crops which is a technology called solar irrigation (IRENA, 2016c). Solar irrigation has generated improved results for growth in the agricultural sector since it enables farmers to grow crops in the dry season (IRENA & FAO, 2021). In India, farmers' incomes increased by 50 percent by using solar irrigation, instead of rain-fed irrigation. Likewise, in Rwanda, solar irrigation pumps have increased the yield of small farmers by one-third. By changing from water energy to solar irrigation, excessive extraction of groundwater can be avoided. Additionally, according to the authors, solar-based irrigation could be a cost-effective substitute for fossil fuels.

However, in the Sub-Saharan region, implementing new technology into the agriculture sector has been hindered by poor institutions and insufficient information about the local environment (Sims & Kienzle, 2006). The authors therefore suggest the importance of a well-implemented strategy where all the main characters within the economy are involved in the planning process. The farmers' actual needs should play the key role in the policy of agricultural development. Sims and Kienzle highlight that new technologies enable traditional production inputs, such as labor and capital, in the agricultural process to become more effective. Based on this assumption, we further investigate how new implementations, in terms of electricity, can generate agricultural development through factor inputs in the production chain, discussed in accordance with the Solow-Swan (1956) production model presented in the next chapter.

3. Theoretical framework

This chapter presents the concept of the theories, which have provided guidance in creating the empirical method and in interpreting the results of the impact of electrification on agricultural production in SSA. Furthermore, the previous arguments about the strengths and weaknesses regarding the chosen theories are discussed.

3.1 The Solow-Swan model

The Solow-Swan model was developed by the economists Robert Solow and Trevor Swan in 1956 (Barro & Sala-i-Martin, 2004, p. 17). The Solow-Swan model is based on the Keynesian Harrod-Domar model of economic growth. In both of the theories, the neoclassical aggregate production function plays the central role. However, according to Barro and Sala-i-Martin, the difference between the two models is that the Harrod-Domar theory draws attention to the more malfunctional factors contributing to growth. In the Harrod-Domar model, the only factor which contributes to economic growth is capital as long as there is enough labor to use the capital. This assumption has been criticized by different neoclassical economists, among Robert Solow and Trevor Swan. Solow and Swan further developed the model by adding labor as a factor of production without using fixed ratios of capital and output. According to the Solow-Swan theory, the factors contributing to increased production are capital accumulation and population growth driven by technological progress (ibid.).

Acemoglu (2009, p. 26) describes the Solow-Swan model as a simple and abstract approach of how a complex economy moves towards growth. The theory has been criticized for being too simple or too abstract since actors within an economy do not always operate according to the model. Firms, households and individuals play different roles and have various abilities in the community, acting in different sectors with numerous social interactions. Acemoglu reminds us of the model's simplicity and ignorance of the complications within the economy. The Solow-Swan model will therefore only be seen as a starting point for our analysis. In previous studies, economists are using the Solow-Swan production model to estimate growth by analyzing only one separate factor, such as capital, labor or technological change in the production process (Barro & Sala-i-Martin, 2004). Likewise, in our thesis, the model is used to estimate the separate effect of implementing new technology into the agriculture sector to determine whether it increases agricultural production, which contributes to a larger part of the GDP outcome in Sub-Saharan Africa (World Bank, 2022e).

3.1.1 The neoclassical aggregate production function

The aggregate production function at time t can be expressed as

$$Y(t) = F(K(t), L(t), A(t)),$$

where $Y(t)$ is the total amount of production, $K(t)$ is the capital stock, $L(t)$ is total employment, and $A(t)$ is technology (Acemoglu, 2009, p. 28). The capital stock corresponds to the quantity of equipment and machines used in production. Employment can be measured in the numbers of employees. The aggregate production function underlies the basis for the regression equations used in this thesis. $Y(t)$ is the total amount of agricultural production,

$K(t)$ is the net capital stock invested in the agriculture sector, along with $L(t)$ representing employment in the same sector. In our second regression equation (2), $A(t)$ presents the technological change in the form of access to electricity by the rural population and in the third regression model (3), $A(t)$ corresponds to the installed capacity of off-grid solar PV. According to Acemoglu, the major assumption of the aggregate production function is that technology is publicly available, and its use of one individual does not inhibit or prevent the use of another. The same approach will underlie our analysis.

There are four standard assumptions of the aggregate production function (Barro & Sala-i-Martin, 2004, p. 27-28). Firstly, the production function is differentiable and takes nonnegative values of the input factors as well as nonnegative levels of outputs. Furthermore, the marginal products are also positive which means that the level of production increases with the amount of inputs. However, the marginal products of both capital and labor are diminishing. This indicates that increasing the input factors will come to a point where they increase the output by less, holding everything else constant. This property is sometimes also referred to as “diminishing returns” to capital and labor. The fourth and last assumption is that there are constant returns to scale in capital and labor which means that the input factors increase at the same rate as their outputs (ibid.).

3.1.2 Solow model with technological progress

According to Acemoglu (2009, p. 56), there is no doubt that the ability to develop new techniques into human society has increased excessively during the past 200 years. Today, new technologies are implemented by both firms and individuals to produce goods as well as services more effectively (ibid.). As previously presented, one of the major assumptions in the Solow-Swan model is the diminishing returns of capital and labor inputs. To allow the economy to still grow in the long-term, technological progress is of importance to escape the diminishing returns (Barro & Sala-i-Martin, 2004, p. 51-52).

In order to show how technological change affects the traditional input factors in the production function, Acemoglu (2009, p. 57) uses a balanced growth model. In a balanced growth model, all variables within the economy grow at a constant rate. For instance, the capital-output ratio and factor shares remain constant. However, we are aware of the fact that this is only a simplification of an economy and that the share of different sectors within the economy vary over time. Nevertheless, a balanced growth model provides a good approximation of reality and is a useful instrument to analyze the impact of technological change in the agriculture sector discussed in this study. In the next sections we assume that technology improves the factors in the balanced growth model exogenously in two of the popular definitions produced by Robert Solow (1969) and Roy Harrod (1942) (Barro & Sala-i-Martin, 2004, p. 52).

3.1.2.1 Capital-augmenting progress

According to Solow (1969), a higher value of technological change $A(t)$ is equivalent to the economy having more capital and is presented in accordance with the following equation

$$\overline{F}(K(t), L(t), A(t)) = F[A(t)K(t), L(t)],$$

and is also called Solow-neutral technological progress (Acemoglu, 2009, p. 58). A higher $A(t)$, which in our regression models represents electricity, corresponds to a larger level of effective capital. The capital in our analysis is the net capital stock invested in the agriculture sector. As seen in Figure 1, the isoquant is shifting inward as a result of the level of $A(t)$ being doubled (ibid.).

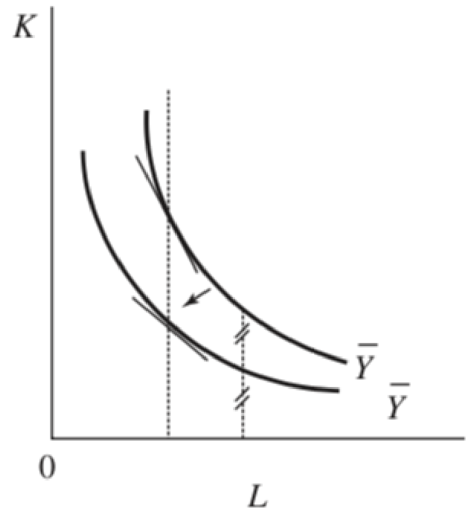

Figure 1: Solow-neutral technological progress.
Source: Acemoglu (2009, p. 59)

A technological improvement increases output in the same way as an increase in the stock of capital (Barro & Sala-i-Martin, 2004, p. 52-53).

3.1.2.2 Labor-augmenting progress

Secondly, technological improvements into the production function was implemented by Harrod (1942) and is referred to as the Harrod-neutral technological progress (Acemoglu, 2009, p. 59). A higher level of technology $A(t)$ is equal to if the economy had more labor and is shown in the following equation

$$\bar{F}(K(t), L(t), A(t)) = F[K(t), A(t)L(t)].$$

In our regression models, $A(t)$ is electricity and $L(t)$ is employment in the agriculture sector. $A(t)L(t)$ therefore reflects a more effective labor input. $A(t)$ raises production in the same way as an increase in the stock of labor and thus corresponds to an inward shift of the isoquant as is seen in Figure 2 (Barro & Sala-i-Martin, 2004, p. 52-53).

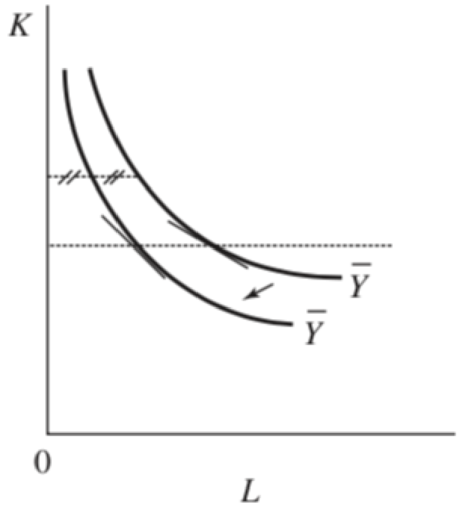

Figure 2: Harrod-neutral technological progress.
Source: Acemoglu (2009, p. 59)

Acemoglu (2009) points out that in practice technological change can be a mixture of both capital-augmenting and labor-augmenting. However, Acemoglu along with Barro and Sala-i-Martin (2004) highlight the government policies' and institutions' roles as determinants of differences in the level of technology and adaptation possibilities. For instance, failures to protect property rights and higher levels of corruption, can hinder new technological implementations and improvements.

4. Data

This chapter is dedicated to the data used in this study, explaining the data sources, presenting all the included indicators and motivating the chosen dependent, independent and control variables.

4.1 Data description

For this research, data regarding electricity and relevant characteristics of the countries of Africa, which can affect the level of electrification of rural areas and development in the agriculture sector, is necessary. We have collected annual panel data from all 54 African countries from the year 2000 to 2021. Since decentralized renewable energy technologies are a relatively new phenomenon, data from earlier than the year of 2000 would not be sufficient for this study and thus contain a large proportion of missing values. We use state-level panel data because of its large sample size. Furthermore, we divide the countries into a subsample which contains the Sub-Saharan region. Since Mauritius, Seychelles and South Africa have had a higher level of access to electricity in rural areas as well as lower dependency on agriculture during the time period, we chose to exclude them from our subsample. The division of the countries are shown in Appendix A.

Data on agriculture activity as well as socio-economic and governance indicators are collected from the World Bank Databank. The data source for the variable access to electricity is the World Bank Global Electrification Database from "Tracking SDG 7: The Energy Progress Report" which is led cooperatively by the International Energy Agency (IEA), the United Nations Statistics Divisions (UNSD) and the World Health Organization (WHO). Data on agricultural variables are derived from World Bank National Accounts data and Organization for Economic Co-operation and Development (OECD) National Accounts data files. The World Bank collects data on employment from the International Labor Organization (ILOSTAT) database, and data on rural population is based on estimates from the United Nations Population Division's World Urbanization Prospects: 2018 Revision. The Worldbank gathers data on governance variables from the Worldwide Governance Indicators (WGI).

Additionally, we collected data from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) and International Renewable Energy Agency (IRENA). The

FAOSTAT presents data on the indicator agricultural net capital stock and IRENA provides data on countries' investments, installations and generations of renewable energy sources. Still, we are aware of the fact that some developing countries lack available and registered data. Missing data implies that the sample size will be reduced which can indicate measurement errors in the indicators (Cameron & Trivedi, 2005, p. 46). For instance, data on countries' installations of off-grid solar PV is missing for several African countries (see Figure 4 in Appendix C).

A summary of our variables and their sources is shown in Table 1. Additionally, descriptive statistics for each of the variables are presented in Table 2. It includes the number of observations, the mean values, the standard deviations, the minimum value and the maximum value for both Africa and the subsample.

Table 1: Variables.

Variable name (unit)	Type of variable	Source
Access to electricity, rural (% of rural population)	Dependent variable / Independent variable	World Bank Database
Agriculture, forestry, and fishing, value added (constant 2015 USD)	Dependent variable	World Bank Database
Off-grid installed capacity of solar photovoltaics (MW)	Independent variable	IRENA
Rural population (total amount of people living in rural areas)	Control variable	World Bank Database
Employment in agriculture (% of total employment)	Control variable	World Bank Database
Labor force (total amount of people in the labor force)	Control variable	World Bank Database
Net capital stock agriculture, forestry, and fishing (constant 2015 USD)	Control variable	FAOSTAT
GDP per capita (constant 2015 USD)	Control variable	World Bank Database
Government effectiveness (scale from 1 to 10)	Control variable	World Bank Database

4.2 Dependent and independent variables

To estimate the changes in the dependent variable access to electricity by the rural population, we use installed capacity of off-grid solar PV as an independent variable. Off-grid solar PV is also the independent variable in the third regression model when estimating its impact on the dependent variable agriculture outcome. The off-grid solar PV indicator will be used as the technological change $A(t)$ based on the theoretical framework and is in the unit Megawatt (MW) (IRENA, 2022b). The data represents the maximum net generating capacity of power plants installations that use solar energy to produce electricity (ibid.). There are different data indicators on off-grid solar photovoltaic produced by IRENA, such as investments in energy sources and electricity generation. The reason why we chose installed capacity as the variable of interest is due to the fact that the indicator, to a greater extent, mirrors the increased supply of electricity in comparison with the level of investments. Additionally, generation depends on the electricity demand (IRENA, 2022a), and does not reflect the potential increase in access to electricity which we want to investigate.

The reason why we use off-grid installations of solar power systems and not on-grid is because of its availability for small-scale farmers who lack infrastructure in rural areas in the Sub-Saharan countries (Boccia et al., 2014). However, we are aware of the importance of having a mix of energy sources because of the different generation technologies (IRENA, 2020). Solar photovoltaic power plants can only provide energy during daytime. To ensure that energy supply meets demand, it is important to integrate both wind turbine and hydropower plants together with solar PV as well. The national grid can be accessible close to or in the urban sector and therefore rural people need to use off-grid alternatives to get access to energy sources (Boccia et al., 2014). Nonetheless, since Africa is the continent with the largest amount of solar resources, the focus in this paper is electricity generated by solar power sources.

In the first regression model, we use the indicator access to electricity, rural (% of rural population) as the explanatory variable while, in the second regression equation it is the independent variable. The variable contains the amount of rural population who have access to electricity provided by the total mix of energy sources, both on- and off-grid. The reason why we chose to include the variable in the second regression is to see the overall change in agriculture production by electricity in general in order to compare with the results from the last regression including only off-grid solar power.

Additionally, in the second and third regression models, the dependent variable is agriculture, forestry, and fishing value added (constant 2015 USD) representing the net output of the agricultural sector. We chose to have the indicator in constant terms with 2015 as the base year to adjust for the effect of inflation during the time period, a reasoning that goes for all the variables in constant terms. The time trends of the mean for the variables access to electricity and installed capacity of off-grid solar PV from the year 2000 to 2021, are shown in Figure 3 and 4 in Appendix C for the countries included in the subsample.

4.3 Control variables

In our analysis we will control for indicators which are likely to differ between the nations and have fluctuated during the time period in order to come closer to a causality statement. Even though 59 percent of the total population in Sub-Saharan countries lives in the rural sector, there are differences within the amount of rural populations between the countries included in the analysis (World Bank, 2022i). We therefore control for the rural population in our first linear regression model.

The second and the third regressions are based on the Solow-Swan model. Besides technological change, two important factors determining the level of production are the amount of labor and the amount of capital. To avoid omitted variable bias (OVB), we control for the amount of labor by including employment in agriculture. According to Solow and Swan, a higher proportion of employees in agriculture generate a higher level of output. Likewise, according to the theory, a higher level of capital within the agriculture sector generates a higher level of output. For both the employment and capital variable, there is a high positive correlation between the indicators and agricultural production in the dataset (see Table 6 in Appendix B). We therefore control for the amount of capital by including the variable net capital stock in agriculture, forestry, and fishing measured as the amount of physical investment in USD.

Economic well-being is controlled for by adding the logarithm of annual GDP per capita for each country. Even though the Sub-Saharan region accounts for two-thirds of the global extreme poor population (Lakner & Schoch, 2020), there is a significant heterogeneity between the communities in the region. In 2020, the GDP per capita was approximately 30 times higher in Equatorial Guinea compared to the one in Burundi (World Bank, 2022f). Since the dependent variable is agriculture output in constant terms, and not as a share of GDP, controlling for income differences are of importance. GDP per capita does not ultimately represent welfare or the level of a nation’s development and could be underestimated in low income countries who may have more informal economic activities (Fantom & Serajuddin, 2016). However, it has been proved to be a useful measurement for development because of its correlation with non monetary indicators, for instance life expectancy at birth and enrollment rates in school. GDP and population levels are also often available and registered data even for developing countries (ibid.).

According to the economists Acemoglu, Barro and Sala-i-Martin along with the research presented in the literature review, variations in policies and institutions hinder countries from adapting to new technology. Therefore, we include the Government effectiveness index as a control variable which proxies for institutional quality. The indicator is based on estimates on the perceptions of the quality of governmental actions (World Bank, 2022g). For instance the quality of public services and the quality of policy formulation along with application, but also the reliability of the government's commitment to such policies. The countries have been given scores between minus 2.5 and 2.5, where minus 2.5 indicates the lowest level of government effectiveness and 2.5 the highest level. We have chosen to rescale this index to a range between zero and ten to simplify the interpretation of the variable. The variable is positively correlated (see Table 6 in Appendix B) with both access to electricity as well as installations of off-grid solar PV which is in line with the reasoning from the theory and previous literature.

4.4 Descriptive statistics

Table 2 illustrates an overview of the statistics for both Africa and the subsample, including Sub-Saharan countries except Mauritius, Seychelles and South Africa. The indicators presented are the outcome variables, the explanatory variables and the control variables used in the study.

Table 2: Descriptive statistics of the variables.

Variable (unit)	Obs	Mean	Std. Dev	Min	Max
Access to electricity, rural (% of rural population)					
Africa	980	43.08	29.08	1.27	100
Sub-Saharan Africa	835	34.38	13.73	1.27	95.53
Agriculture, forestry, and fishing, value added (constant 2015 USD)					
Africa	969	5.92e+09	1.31e+10	2.40e+07	1.20e+11
Sub-Saharan Africa	829	5.28e+09	1.33e+10	2.50e+07	1.20e+11
Off-grid installed capacity of solar photovoltaic (MW)					
Africa	744	10.13	36.63	0.001	423
Sub-Saharan Africa	658	6.83	12.48	0.001	135.57
Rural population (total amount of people living in rural areas)					
Africa	1 071	1.20e+07	1.75e+07	40 045	9.90e+07
Sub-Saharan Africa	911	1.19e+07	1.79e+07	56 206	9.90e+07
Employment in agriculture (% of total employment)					
Africa	1 007	49.25	21.87	4.6	91.48
Sub-Saharan Africa	874	53.80	19.35	10.6	91.48
Labor force (total amount of people in the labor force)					
Africa	1 060	7 501 282	1.03e+07	44 469	6.20e+07
Sub-Saharan Africa	920	7 025 057	1.04e+07	44 469	6.20e+07
Net capital stock agriculture, forestry, and fishing (constant 2015 USD)					
Africa	1 040	6 304.23	19 122.13	5.44	194 296.1
Sub-Saharan Africa	889	5 058.88	20 024.07	5.44	194 296.1
GDP per capita (constant 2015 USD)					
Africa	1 035	2 324.705	2 803.141	258.629	16 438.6
Sub-Saharan Africa	875	1 683.743	2 139.089	258.629	16 438.6
Government effectiveness (scale from 0 to 10)					
Africa	1 017	4.84	1.81	0	10
Sub-Saharan Africa	865	4.52	1.58	0	9.06

Sub-Saharan Africa refers to the subsample only including Sub-Saharan countries except Mauritius, Seychelles and South Africa.

On average, access to electricity by the rural population is higher for all African countries compared to the Sub-Saharan region during the 20 year period. Furthermore, there is a large variation between the country with the highest value of having 100 percent access to electricity compared to another country having only 1.27 percent access in rural areas. The nations contributing to the mean of almost having only one percent access to electricity during the time period are Angola, Burkina Faso, Burundi, Central Africa and the Republican Democratic of the Congo (see Figure 3 in Appendix C).

The table shows that about half of the total employment in Africa is within the agriculture sector. Regarding the subsample, the average mean is slightly higher at approximately 54 percent which indicates that the subsample is more economically dependent on the agriculture sector. However, the average mean of the agriculture output in constant 2015 USD is lower in the Sub-Saharan region compared to the average mean of all African countries. Likewise, the average mean of the invested capital stock in the agrarian sector is lower in SSA compared to the average mean in Africa. Even though the average mean of employment is larger in SSA, both output and capital invested in the sector is lower compared to the African continent.

Like the access to electricity, there is a large variance between the lowest and the highest value for several indicators including in the research. The installed capacity of off-grid solar PV is almost zero MW in some African countries compared to over 400 MW in others. For a non-Sub-Saharan country, the highest value is four times larger compared to the highest value in the subsample. This may have an impact on the differences in the regression results for Africa and the subsample (see Table 3 and Table 5). However, during the last 20 years, installations of off-grid solar PV took off around the year of 2015 for several countries in our subsample (see Figure 5 in Appendix C). Some of the countries which have shown an increased installation of off-grid solar power are Benin, Burkina Faso, the Republican Democratic of the Congo, Kenya, Mali and Sudan.

The average mean of government effectiveness is 4.84 for all African countries and 4.52 for the subsample which reflects, on average, poor institutions and governance policies of the African continent. According to Acemoglu (2009), weak institutions hinders adoption of new technology. Previous literature has also shown that low quality institutions can reduce the positive effects of electrification on agriculture output. The fact that Africa and SSA, on average, have relatively poor institutions may reflect that they will find it more difficult to adopt new technology for electrification effectively in the agriculture sector.

5. Econometric methods

This chapter presents the methodology of the study and a more in-depth explanation of the three linear regression models used to answer the research questions. We explain the reasoning behind the chosen research approach and the different parts included in the regression equations.

5.1 Methodology

In our thesis, we use pooled ordinary least squares (OLS) and fixed effects (FE) models to estimate the variation in the dependent variables due to variations in the variables of interest (Cameron & Trivedi, 2005, p. 211). The pooled OLS estimator reflects the relationship between the variable of interest and the outcome variable and seeks to minimize the total squared errors. In the first regression we estimate the effect of installed capacity of off-grid solar PV on access to electricity on a rural population level. Secondly, we estimate the effect of access to electricity on agricultural production. The third and last linear regression model estimates the impact of installed capacity of off-grid solar PV on agricultural production.

Acemoglu (p. 83) highlights the risk of the independent variable being endogenous and thus creating a bias in the pooled ordinary least square estimator. We therefore include control variables and use a country fixed effect (FE) model to support the independent variable to OVB. The country (FE) model removes variation between countries in order to focus on the changes over time. It allows us to explore the relationship between the explanatory variable and the dependent variable within the countries (ibid., p. 85). For instance political differences or attitudes towards installations of off-grid solar PV.

Furthermore, we use time as a control variable to control for the linear time trend. Since we aim to measure if more of the independent variable results in more of the dependent variable, we need to rule out the possibility that the association between the two variables only is due to a common growth trajectory. Therefore we control for the time trend which is common for all countries. However, including control variables and a country FE model will not eliminate all OVB. Cameron and Trivedi (2005, p. 75) describe the importance of including clustered standard errors (CSEs). Since we use panel data, observations within the sample are likely to be related to each other and may be subdivided into smaller groups (clusters) in a natural way. We therefore also include CSEs to account for correlation in the error term within the cluster. We cluster at a country level to adjust for correlation within countries over time.

Before we run the regressions we transform the dependent variable into a lead indicator in the first and third regression equations including the variable of installed capacity of off-grid solar PV. It is plausible to assume that the current effect on the dependent variable is due to changes in installations from the previous year and when we include the lead, the movements of the two variables are more closely aligned. Furthermore, since the variable of installed off-grid solar PV, rural access to electricity, rural population, agricultural net capital stock, employment in agriculture along with GDP per capita have a highly skewed distribution, we apply the logarithm of the variables to improve the fitting of the linear regression models.

5.2 Regressions

To answer the research questions, the following linear regression model equations (1), (2) and (3) are run and the outcomes of running the regressions are presented in the next chapter.

$$log(Access\ to\ electricity)_{it+1} = \beta_0 + \beta_1 * log(SolarPV)_{it} + \beta_2 * log(Ruralpopulation)_{it} + \beta_3 * log(GDPpc)_{it} + \beta_4 * Governmenteffectiveness_{it} + \beta_5 * Time + \beta_6 * FE_{country} + u_{it} \quad (1)$$

$$log(Agriculture\ output)_{it} = \beta_0 + \beta_1 * log(Accesstoelectricity)_{it} + \beta_2 * log(Employment)_{it} + \beta_3 * log(Capitalstock)_{it} + \beta_4 * log(GDPpc)_{it} + \beta_5 * Governmenteffectiveness_{it} + \beta_6 * Time + \beta_7 * FE_{country} + u_{it} \quad (2)$$

$$log(Agriculture\ output)_{it+1} = \beta_0 + \beta_1 * log(SolarPV)_{it} + \beta_2 * log(Employment)_{it} + \beta_3 * log(Capitalstock)_{it} + \beta_4 * log(GDPpc)_{it} + \beta_5 * Governmenteffectiviness_{it} + \beta_6 * Time + \beta_7 * FE_{country} + u_{it} \quad (3)$$

β is the value of the coefficients of the variables. In the first (1) and the second model (2), the variable of access to electricity contains the access to electricity by the rural population as the share of rural population having access to electricity multiplied by rural population in order to get the variable in constant terms. Additionally, the control variable for employment in the agriculture sector has also been transformed into constant terms by multiplying the indicator by the total labor force. With this choice of regression models, the beta coefficients can be interpreted as the elasticity between the dependent and independent variables.

In the next chapter we present the results. We observe the variations of the coefficients of the variable of interest as they change and if they stay statistically significant when adding the country FE model, country CSEs, the control variables and controlling for the linear time trend. By adding control variables we are able to draw conclusions about how much of the impact on the dependent variable that is shared.

6. Results

The results from the regressions are divided into three parts. The first part (6.1) shows the impact on rural electrification by installed capacity of off-grid solar PV. The second part (6.2) presents the impact of access to electricity on agriculture output in rural areas. Lastly, the third part (6.3) shows the effect on agriculture output with the installed off-grid solar PV as the variable of interest. The results represent the estimates for both all African countries and the subsample.

6.1 The effect of off-grid solar PV on the access to electricity

Table 3 illustrates the coefficient outputs of running the regression (1). At first, we run the regression with only the explanatory variable (a) and thereafter add country FE (b), control for the linear time trend (c) and country CSEs (d). Secondly, we run regressions in the same way but also with the control variables: (e), (f), (g) and (h).

Table 3: The effect of off-grid solar PV on the access to electricity by the rural population.

$log\ Access\ to\ electricity_{t+1}$	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Log Off-grid solar PV								
Africa	0.35***	0.18***	0.06***	0.06	0.06***	0.05***	0.02	0.02
Sub-Saharan Africa	0.26***	0.18***	0.03*	0.03	0.06***	0.05**	0.01	0.01
Log Rural population								
Africa					1.07***	3.82***	3.06***	3.06***
Sub-Saharan Africa					0.98***	4.00***	3.03***	3.03***
Log GDP per capita								
Africa					0.92***	0.16	-0.17	-0.18
Sub-Saharan Africa					0.75***	0.21	0.05	0.05
Government effectiveness								
Africa					0.14***	-0.02	-0.07	-0.07
Sub-Saharan Africa					0.11***	-0.07	-0.003	-0.003
Time								
Africa			0.06***	0.06***			0.03***	0.03**
Sub-Saharan Africa			0.08***	0.08***			0.04***	0.04**
Constant								
Africa	18.24***	12.24***	-105.13***	-105.13***	-5.69***	-42.46***	-98.28***	-98.28***
Sub-Saharan Africa	17.96***	17.94***	-142.98***	-142.98***	-2.96***	-45.11***	-109.50***	-109.50***
FE country	*NO*	*YES*	*YES*	*YES*	*NO*	*YES*	*YES*	*YES*
Control for time trend	*NO*	*NO*	*YES*	*YES*	*NO*	*NO*	*YES*	*YES*
CSEs country	*NO*	*NO*	*NO*	*YES*	*NO*	*NO*	*NO*	*YES*
Observations								
Africa	522	522	522	522	496	496	496	496
Sub-Saharan Africa	454	454	454	454	434	434	434	434

$* \ p < 0.1,\ \ ** \ p < 0.05\ and\ \ *** \ p < 0.01$

Sub-Saharan Africa refers to the subsample only including Sub-Saharan countries except Mauritius, Seychelles and South Africa.

As shown in Table 3, installed capacity of off-grid solar PV is positively correlated with access to electricity in rural areas of Africa and in our subsample (a). When we add control variables, a country fixed effect model and country clustered standard errors, the variation in the explanatory variable is estimated to have a very small impact on the outcome variable and loses its statistical significance.

6.2 The effect of access to electricity on agriculture output

Table 4 describes the coefficient outputs of running the regression (2). The regressions are run in the same way as presented previously for Table 3.

Table 4: The effect of access to electricity by the rural population on agricultural output.

Log Agriculture output	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Log Access to electricity								
Africa	0.75***	0.16***	0.01	0.01	0.08***	-0.01	-0.03***	-0.03**
Sub-Saharan Africa	0.76***	0.15***	0.003	0.003	0.05***	-0.01	-0.03***	-0.03*
Log Empl. in agri.								
Africa					0.34***	0.28***	0.23***	0.23*
Sub-Saharan Africa					0.34***	0.38***	0.30***	0.30**
Log Net cap. stock.								
Africa					0.55***	0.26***	0.18***	0.18**
Sub-Saharan Africa					0.57***	0.25***	0.19***	0.19**
Log GDP per capita								
Africa					-0.08**	0.63***	0.41***	0.40***
Sub-Saharan Africa					-0.11***	0.58***	0.43***	0.43***
Government effectiveness								
Africa					0.001	-0.01	0.01	0.01
Sub-Saharan Africa					0.03**	0.01	0.02*	0.02
Time								
Africa			0.03***	0.03***			0.01***	0.01***
Sub-Saharan Africa			0.03***	0.03***			0.01***	0.01*
Constant								
Africa	7.84***	18.40***	-32.40***	-32.40***	10.06***	9.76***	-16.29***	-16.29
Sub-Saharan Africa	7.67***	18.48***	-33.51***	-33.51***	10.56***	8.18***	-11.89***	-11.89
FE country	*NO*	*YES*	*YES*	*YES*	*NO*	*YES*	*YES*	*YES*
Control for time trend	*NO*	*NO*	*YES*	*YES*	*NO*	*NO*	*YES*	*YES*
CSEs country	*NO*	*NO*	*NO*	*YES*	*NO*	*NO*	*NO*	*YES*
Observations								
Africa	784	784	784	784	708	708	708	708
Sub-Saharan Africa	658	658	658	658	606	606	606	606

$* \ p < 0.1, \ ** \ p < 0.05 \ and \ *** \ p < 0.01$
Sub-Saharan Africa refers to the subsample only including Sub-Saharan countries except Mauritius, Seychelles and South Africa.

In Table 4, we notice a positive correlation between access to electricity by the rural population and agricultural production (a). When running the full regression model the estimator switches sign and is now estimated to have a negative impact on the dependent variable. On average, one percent increase in the access to electricity in rural areas indicates, on average, 0.03 percent decrease in agriculture output for all African countries and the subsample (h). Although the coefficient is statistically significant on a 95-percent level, respectively on a 90-percent level, the estimator is approximately zero. Given this, its effect can be considered negligible.

6.3 The effect of installed off-grid solar PV on agriculture output

Table 5 presents the coefficient outputs of running the regression (3). The regressions are run in the same way as described previously for Table 3 and 4.

Table 5: The effect of installed off-grid solar PV on agricultural output.

$Log\ Agriculture\ output_{t+1}$	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Log Off-grid solar PV								
Africa	0.28***	0.06***	0.004	0.004	0.03**	0.004	-0.01*	-0.01
Sub-Saharan Africa	0..23***	0.06***	0.01	0.01	0.03**	0.01	-0.004	-0.01
Log Empl. in agri.								
Africa					0.34***	0.30***	0.25***	0.25
Sub-Saharan Africa					0.34***	0.35***	0.50***	0.29*
Log Net cap. stock.								
Africa					0.60***	0.30***	0.21***	0.21**
Sub-Saharan Africa					0.59***	0.29***	0.34***	0.22**
Log GDP per capita								
Africa					-0.09***	0.60***	0.48***	0.48**,
Sub-Saharan Africa					-0.11***	0.51***	0.30***	0.45**
Government effectiveness								
Africa					0.05***	-0.001	0.02*	0.02**
Sub-Saharan Africa					0.07***	0.02	0.05***	0.03
Time								
Africa			0.03***	0.03***			0.01***	0.01
Sub-Saharan Africa			0.02***	0.02***			0.01***	0.01
Constant								
Africa	21.48***	21.53***	-33.40***	-33.40***	10.95***	9.32***	-15.09***	-15.09
Sub-Saharan Africa	21.39***	21.40***	-28.33***	-28.33*	11.08***	8.88***	-6.55	-12.65
FE country	*NO*	*YES*	*YES*	*YES*	*NO*	*YES*	*YES*	*YES*
Control for time trend	*NO*	*NO*	*YES*	*YES*	*NO*	*NO*	*YES*	*YES*
CSEs country	*NO*	*NO*	*NO*	*YES*	*NO*	*NO*	*NO*	*YES*
Observations								
Africa	614	614	614	614	558	558	558	558
Sub-Saharan Africa	540	540	540	540	497	497	497	497

$* \ p < 0.1, \ ** \ p < 0.05\ and\ *** \ p < 0.01$

Sub-Saharan Africa refers to the subsample only including Sub-Saharan countries except Mauritius, Seychelles and South Africa.

As shown in Table 5, there is a positive correlation between the variable of interest and the dependent variable (a). However, when we add control variables and a country fixed effect model, the estimator becomes negative and nearly zero (g). The coefficient has a statistically significant impact on agricultural production on a 90-percent confidence level in Africa. On average, if installations of off-grid solar PV increased by one percent, agriculture output can be estimated to decrease by 0.01 percent. For the subsample the magnitude of the estimator is even closer to zero and also statistically insignificant. Furthermore, when we add country clustered standard errors the estimator loses its statistical significance for both Africa and the subsample.

7. Discussion

Our aim with this thesis is to investigate the relation between installations of off-grid solar PV and electrification of rural areas and the agriculture sector in Sub-Saharan Africa. In this section we discuss the research questions based on previous research, theoretical framework and the results from the regression outputs.

7.1 Off-grid solar PV in rural areas of SSA

The first research question is: "To what extent can increased installations of off-grid solar PV generate higher levels of access to electricity for the rural population in Sub-Saharan Africa?". To start with, our results show a positive correlation between installations of off-grid solar power and access to electricity at a rural population level. However, we cannot state a statistically significant effect of increased installed capacity of off-grid solar PV on rural access to electricity based on our results. Previous research has shown that off-grid solar PV systems can provide electricity to areas not connected to the national grid (Satpathy & Pamuru, 2021). Additionally, Palit et al. (2015) showed that off-grid solar power can cover basic electricity needs in villages in Sub-Saharan Africa. Off-grid solar PV solutions could therefore be an enabler to reach SDG 7: "ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations, 2021a), in order to fight energy poverty. Including solar PV in the mix of energy sources is also important to reduce GHG emissions. According to IPCC (2022), the effect of climate change leads to severe consequences such as food and water insecurity for the rural population in SSA.

There could be many reasons as to why the estimator loses its significance when using the full linear regression model. The dependent variable in the model measures access to electricity provided by all different energy sources in rural areas, both on and off-grid. It is plausible to assume that our independent variable therefore stands for a small share of the total mix of energy sources contributing to an increasing access to electricity by the rural population. Our independent variable may therefore have a positive effect on rural electrification, but in relation to the other energy sources, off-grid solar PV provides a too small part of the total share in order to see a statistically significant positive effect on a macro level. Furthermore, the independent variable contains a lot of missing values (see Figure 4 in Appendix C) which leads to a smaller sample size. This implies that the variable of interest has a measurement error which may have decreased the explanatory power of the estimator.

7.2 The association between electricity and the agriculture sector

Secondly, the thesis aims to investigate the relation between access to electricity and the agriculture sector in Sub-Saharan Africa. The second research question is: "Could an increased access to electricity for the rural population generate a higher level of agricultural output in Sub-Saharan Africa?". We use the theoretical economic models by Solow and Swan to analyze the relationship of implementing new technology on agricultural production. According to the neoclassical aggregate production function, the total agricultural output is driven by the capital stock, the amount of employment and technological progress. Based on the Solow-Swan model we use Acemoglu's (2009) reasoning about "capital-augmenting" and "labor-augmenting" to see if new technology could increase the effectiveness of the input factors within the agricultural production chain. Electricity can be used throughout the different stages in the agricultural value chain (IRENA, 2016; FAO, 2021; IFC, 2019). For instance, it can be used for processing equipment such as grain milling machines (ibid.).

However, the impact of an increased access to electricity on agricultural production shown in our results is negative and approximately zero. This may imply that electricity provided to the rural population is not used for agriculture purposes, or is not effectively implemented in the agriculture value chain. Our findings contradict previous research. For instance, Amuakwa-Mensah and Yves Surry (2022) show a significant positive relationship between increased access to electricity and agriculture production in rural areas in Sub-Saharan Africa. One reason why the estimates show a negligible effect with the opposite sign, could be due to differences in our regression models. For instance, the different time-periods studied in the research or the different variables used to estimate changes for both agriculture output and electrification.

Lastly, our third research question is: “Could an increased installed electricity capacity of off-grid solar PV generate higher levels of agriculture output in Sub-Saharan Africa?”. The results in Table 5 are similar to those in Table 4 based on our second research question. Likewise, the coefficient of installed capacity of off-grid solar PV shows a negligible negative impact on agriculture output in Africa and for our subsample, the effect is insignificant. We can therefore not state any difference in the effect on electricity provided from all energy sources in relation to off-grid solar energy on agriculture output. Nor can we see any significant difference between Africa and our subsample. This may indicate that there are limitations in both models that do not capture the effect of electricity on agriculture production, both in the form of all energy sources, as well as decentralized solar energy.

Even though farmers get access to electricity, they will need complementary electrical equipment and machinery to be able to electrify the agricultural production chain. According to Sims and Kienzle (2006), adoption of new technologies requires both time and money. In the adoption phase of new electrical machinery, training on usage may be required for farmers only used to traditionally labor intensive farming. Investments in electrical machinery may also be too expensive for small-scale farmers without financial contribution from governments or aid organizations. This could hinder both the capital- and labor-augmenting progresses described by Solow (1969) and Harrod (1942). Additionally, rural households are characterized with high levels of poverty as well as high dependency on agriculture for livelihood. With high dependence on agriculture for subsistence, there may exist cognitive barriers for small farmers to implement new technology, as the impact may be unknown. Other variables which are hard to measure and therefore not included in the analysis are for instance attitudes towards new technologies and lack of knowledge about implementing them into the agricultural sector.

Furthermore, there is reason to believe that our data is only capable of capturing a small part of what can positively affect countries' total agricultural production. Our variable on agricultural production is the total output generated from agriculture activities. This also includes the industrialized part of agriculture. At the same time, our explanatory variables are focused on small-scale farmers. Access to electricity for the rural population and off-grid solar PV may increase production for small-scale farmers. For instance, water pumps electrified by off-grid solar energy have raised incomes for rural farmers in India by 50 percent, and increased yield for small farmers by one third in Rwanda (IRENA & FAO, 2021). Even though electricity can increase production for small-scale farmers, their share, which contributes to the total national output of agriculture production, may be very small in relation to the total share. This might be a reason why the results from the regression show a minimal effect, very close to zero, when examining this relationship at a macro level.

Additionally, another argument could be due to the fact that gaining access to electricity is not equivalent to adopting it in agricultural activities. For instance, it can spur growth in the overall economy by being used in other income generating activities instead. For instance, Kumar and Kumar (2013) find a causal positive relationship between increased energy per capita and GDP growth in both South Africa and Kenya. Additionally, there is a positive correlation between access to electricity for the rural population and GDP per capita (see Table 6 in Appendix B). Moreover, our variables of access to electricity and installed capacity of off-grid solar PV may capture a greater change in society that also affects agriculture production. Even though we have controlled for the countries' economic well-being in terms of GDP per capita, access to electricity may capture other unobserved development aspects not included in our regressions. As countries get more developed, it generally leads to less dependence on agriculture which may impact our results.

7.3 Further research

Even though we have included control variables, controlled for the linear time trend, used a country fixed effect model and added country clustered standard errors, more comprehensive econometric methods are needed to be able to state causality of the relationship. Moreover, to investigate this research topic further, we suggest studying the association between electrification in the agriculture sector on a micro level instead of a macro state-level. In order to capture how small-scale farmers possibly benefit from off-grid solar PV, the researcher could use household surveys in areas where farmers have access to off-grid solar power and are dependent on agricultural production. At the same time, the researcher could make similar surveys in areas where small-scale farmers lack access to electricity. After collecting data from the two sample groups, a difference-in-difference method could be used in order to claim causality of the impact of increasing installations of off-grid solar PV on access to electricity in rural areas and if it makes agricultural production more effective.

According to previous literature, it is unclear whether new implementations of technological investments reach the actual needs of its consumers. Additionally, the SSA region accounts for one of the highest levels of extreme poverty globally and according to Jeuland et al. (2021), it has been shown that the off-grid solar solutions have not always been affordable for its customers. It is therefore of importance to investigate how new technology such as off-grid solar PV can be both adopted and adapted in the agriculture sector in Sub-Saharan Africa in order to meet the necessities of the rural farmers. To overcome this problem, Sims and Kienzle (2006) highlight the importance of involving all the key players within the community in the policy making process. Therefore, small-scale farmers should play the main role in the policy making planning in order to investigate how off-grid energy solutions actually could be beneficial in the agriculture value chain.

8. Conclusion

This paper examines the relationship between rural electrification and agriculture output between the years 2000 and 2021 for all African countries. In order to get a closer look into the most energy poor and agriculture dependent countries, the sample was divided into a subsample containing only Sub-Saharan countries characterized by energy poverty and agriculture dependence. The research investigates if off-grid solar energy sources could electrify the rural areas of Sub-Saharan Africa, and whether it could spur agriculture production. To answer the research questions, we use linear regression models based on the theory of Solow and Swan (1956). New technologies can enable traditional production input factors in the agriculture process, such as capital and labor, to become more effective and increase agriculture output. New technology in this research was in the context of electricity and off-grid solar solutions.

In our study we were not able to find any statistically significant relationship between installed capacity of off-grid solar PV and rural electrification in Sub-Saharan Africa. Likewise, we could not conclude any statistically significant relationship between installed capacity of off-grid solar PV and agriculture output. Finally, our results showed that rural electrification provided by all energy sources had a statistically significant but negative impact on agriculture productivity. However, the estimated effect was approximately zero, which means that it can be seen as negligible. Off-grid solar PV only stands for a slight share of the country's total energy mix. Also, the data contains a lot of missing values which may have affected the significance of the results. Furthermore, the dependent variable of agriculture output may only capture a very small part of the extra production that electrification leads to. Off-grid solar PV and rural electrification is focused on small-scale farmers, and there is reason to believe that they only contribute to a smaller share of the total national agriculture output.

Even though we were not able to show any significant relationship between off-grid solar PV and agriculture output, one needs to remember the importance of increasing electricity access in developing countries by renewable resources, in order to achieve sustainable development and to reduce the energy sector's environmental impact. Both households and the agriculture sector in Sub-Saharan Africa are still characterized by energy poverty which hinder the ability of meeting basic needs as well as providing growth in agricultural production. Without consuming the Earth’s finite resources, solar energy power can increase energy security and spur overall socio-economic growth in the rural communities.

9. References

Acemoglu, D. (2009). *Introduction to modern economic growth.* New Jersey: Princeton University Press.

Africa Renewable Energy Initiative. (2015). *Transforming Africa towards a renewable energy powered future with access for all.* Available: http://www.arei.org/#actionplan [2022-04-19]

Ahmmed S., Hassan M.S., Hossain M.S., & Islam M.S. (2014). Solar pump irrigation system for green agriculture. *Agricultural Engineering International: CIGR Journal, 16*(4), 1-15. Available: https://cigrjournal.org/index.php/Ejounral/article/view/2836

Amuakwa-Mensah, S., & Surry, Y. (2022). Association between rural electrification and agricultural output: Evidence from Sub-Saharan Africa. *World Development Perspectives, 25.* https://doi.org/10.1016/j.wdp.2021.100392

Barro, R. J., & Sala-i-Martin, X. (2004). *Economic Growth* (2nd ed.). London: Massachusetts Institute of Technology.

Boccia, L., Faugno, S., Pindozzi, S., & Okello, C. (2014). Appraising Bioenergy Alternatives in Uganda Using Strengths, Weaknesses, Opportunities and Threats (SWOT)-Analytical Hierarchy Process (AHP) and a Desirability Functions Approach. *Energies*, *7*(3), 1171-1192. https://doi.org/10.3390/en7031171

Cameron, A. C., & Trivedi, P. K. (2005). *Microeconometrics Methods and Applications.* New York: Cambridge University Press.

Castañeda, A., Doan D., Newhouse D., Nguyen M.C., Uematsu H., & Azevedo J.P. (2016). Who Are the Poor in the Developing World? *Policy Research Working Papers.* https://doi.org/10.1596/1813-9450-7844

Chen, W., & Ding, Y. (2007). Total Factor Productivity in Chinese agriculture: The role of infrastructure. *Frontiers of Economics in China, 2*(2), 212-223. https://doi.org/10.1007/s11459-007-0011-3

Country Entrepreneurship for Distributed Renewables Opportunities (CEDRO). (2016). *Off-Grid Solar Home Systems as Part of Rural Electrification in Lebanon.* (Exchange Issue, 24). CEDRO. Available: https://data.unhcr.org/en/documents/details/66476 [2022-04-19]

Edson, S., & Joshua, L. (2020). Short- and long-run impacts of rural electrification: Evidence from the historical rollout of the U.S. power grid. *Journal of Development Economics, 143*(102412). https://doi.org/10.1016/j.deveco.2019.102412

Fantom, N., & Serajuddin, U. (2016). Classifying countries by income: A new working paper. *World Bank Blogs,* January 12.
https://blogs.worldbank.org/opendata/classifying-countries-income-new-working-paper [2022-04-15]

Global Solar Atlas. (2022). *Map.*
https://globalsolaratlas.info/map?c=13.325485,14.238281,4&s=11.502434,17.757812&m=site [2022-05-03]

International Finance Corporation (IFC). (2019). *The Market Opportunity for Productive Use Leveraging Solar Energy (PULSE) in Sub-Saharan Africa.*
https://www.lightingglobal.org/wp-content/uploads/2019/09/PULSE-Report.pdf

International Renewable Energy Agency (IRENA). (2022a). *Electricity generation (GWh) by Country/area, Technology, Grid connection and Year.*
https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__Power%20Capacity%20and%20Generation/ELECGEN_2022_cycle1.px/

International Renewable Energy Agency (IRENA). (2016a). *Innovation Outlook: Renewable Mini-grids.* Available:
https://www.irena.org/publications/2016/Sep/Innovation-Outlook-Renewable-mini-grids [2022-05-22]

International Renewable Energy Agency (IRENA). (2022b). *Installed renewable electricity capacity (MW) by Region/country/area, Technology, and Year.*
https://pxweb.irena.org/pxweb/en/IRENASTAT/IRENASTAT__Power%20Capacity%20and%20Generation/RECAP_2022_cycle1.px/

International Renewable Energy Agency (IRENA). (2018). *Measurement and estimation of off-grid solar, hydro and biogas energy.*
https://irena.org/-/media/Files/IRENA/Agency/Publication/2018/Dec/IRENA_Statistics_Measuring_offgrid_energy_2018.pdf

International Renewable Energy Agency (IRENA). (2016b). *Off-grid renewable energy in Africa.*
https://www.irena.org/-/media/Files/IRENA/Agency/Data-Statistics/Off-grid-renewable-energy-in-Africa.pdf?la=en&hash=0FEC28407B13C1A7AAD58F5AC28E295A4541EEA4

International Renewable Energy Agency (IRENA). (2019a). *Off-grid renewable energy solutions to expand electricity access: An opportunity not to be missed.* Available:
https://www.irena.org/publications/2016/Sep/Renewable-Energy-Benefits-Decentralised-solutions-in-agri-food-chain

International Renewable Energy Agency (IRENA). (2019b). *Innovation landscape brief: Renewable mini-grids.* https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Renewable_mini-grids_2019.pdf [2022-04-15]

International Renewable Energy Agency (IRENA). (2016c). *Solar PV in Africa: Costs and Markets,* https://www.africa50.com/fileadmin/uploads/africa50/Documents/Knowledge_Center/IRENA_Solar_PV_Costs_Africa_2016.pdf

International Renewable Energy Agency (IRENA). (2020). *The Renewable Energy Transition in Africa.* https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/March/Renewable_Energy_Transition_Africa_2021.pdf

International Renewable Energy Agency (IRENA). & The Food and Agriculture Organization of the United Nations (FAO). (2021). *Renewable energy for agri-food systems – Towards the Sustainable Development Goals and the Paris agreement.* https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2021/Nov/IRENA_FAO_Renewables_Agrifood_2021.pdf

International Renewable Energy Agency (IRENA). & African Development Bank (AfDB). (2022). *Renewable Energy Market Analysis: Africa and Its Regions.* https://www.irena.org/publications/2022/Jan/Renewable-Energy-Market-Analysis-Africa [2022-04-22]

Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate Change 2022 Impacts, Adaptation and Vulnerability Summary for Policymakers.* https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_FullReport.pdf

Jeuland, M., Fetter, T.R., Yating, L., Subhrendu, K.P., Usmani, F., Bluffstone, R.A., Chávez, C., Girardeau, H., Hassen, S., Jagger, P., Jaime, M.M., Karumba, M., Köhlin, G., Lenz, L., Litzow, E.L., Masatsugu, L., Naranjo, M.A., Peters, J., Qin, … Toman, M. (2021). Is energy the golden thread? A systematic review of the impacts of modern and traditional energy use in low- and middle-income countries. *Renewable and Sustainable Energy Reviews, 135*(110406). https://doi.org/10.1016/j.rser.2020.110406

Kanagawa, M., & Nakata, T. (2008). Assessment of access to electricity and the socio-economic impacts in rural areas of developing countries. *Energy Policy, 36*(6), 2016-2029. https://doi.org/10.1016/j.enpol.2008.01.041

Kumar, R. R., & Kumar, R. (2013). Effects of energy consumption on per worker output: A study of Kenya and South Africa. *Energy Policy, 62*, 1187-1193. https://doi.org/10.1016/j.enpol.2013.07.100

Lakner, C., & Schoch, M. (2020). The number of poor people continues to rise in Sub-Saharan Africa, despite a slow decline in the poverty rate. *World Bank Blogs,* December 16. https://blogs.worldbank.org/opendata/number-poor-people-continues-rise-sub-saharan-africa-despite-slow-decline-poverty-rate [2022-04-15]

Lee, L., Miguel, E., & Wolfram, C. (2020). Does household electrification supercharge economic development? *Journal of Economic Perspective, 34*, 122-144. https://doi.org/10.1257/jep.34.1.122

Lewis, J., & Severnini, E. (2020). Short- and long-run impacts of rural electrification: Evidence from the historical rollout of the U.S. power grid. *Journal of Development Economics, 143.* https://doi.org/10.1016/j.jdeveco.2019.102412

Palit, D., Rohracher, H., Ulsrud, K., & Winther, T. (2015). Village-level Solar Power in Africa: Accelerating access to electricity services through a sociotechnical design in Kenya. *Energy Research & Social Science, 5,* 34-44. https://doi.org/10.1016/j.erss.2014.12.009

Satpathy, R., & Pamuru, V. (2021). Chapter 7 - Off-grid solar photovoltaic systems. In R. Satpathy & V. Pamuru, *Solar PV Power* (p. 267-315). Academic Press. https://doi.org/10.1016/B978-0-12-817626-9.00007-1

Shahidur, K., Barnes, D., & Samad, H. (2013). Welfare Impacts of Rural Electrification: A Panel Data Analysis from Vietnam. *Economic Development and Cultural Change, 61*(3), 659-692. https://doi.org/10.1086/669262

Sims, B.g., & Kienzle, J. (2006). *Farm power and mechanization for small farms in sub-Saharan Africa* (Agricultural and food engineering technical reports, 1814-1137). FAO. https://www.fao.org/publications/card/en/c/6e76ecd0-1097-588c-ab99-7c5d29a6d055/

The Food and Agriculture Organization of the United Nations. (FAO). (2022). *STATUS OF DIGITAL AGRICULTURE IN 47 SUB-SAHARAN AFRICAN COUNTRIES.* https://www.fao.org/3/cb7943en/cb7943en.pdf

The World Bank. (2022a) *Access to electricity, rural (% of rural population).* https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS [2022-04-15]

The World Bank. (2022b). *Access to electricity, rural (% of rural population) - Sub-Saharan Africa.* https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS?locations=ZG [2022-04-15]

The World Bank. (2022c). *Agriculture and Food.* https://www.worldbank.org/en/topic/agriculture/overview#1 [2022-04-21]

The World Bank. (2022d). *Agriculture, forestry, and fishing, value added (% of GDP).* https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?view=chart [2022-04-25]

The World Bank. (2022e). *Agriculture, forestry, and fishing, value added (% of GDP) - Sub-Saharan Africa.* https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=ZG&view=chart [2022-04-25]

The World Bank. (2022f). *GDP per capita (current USD) - Sub-Saharan Africa.* https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=ZF [2022-04-28]

The World Bank. (2019a). *Employment in agriculture (% of total employment) (modeled ILO estimate) - Sub-Saharan Africa.* https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=ZG [2022-04-15]

The World Bank. (2022g). *GovData360 - Government effectiveness.* https://govdata360.worldbank.org/indicators/h580f9aa5?country=BRA&indicator=388&viz=line_chart&years=1996,2020 [2022-04-28]

The World Bank. (2022h). *How does the World Bank classify countries?* https://datahelpdesk.worldbank.org/knowledgebase/articles/378834-how-does-the-world-bank-classify-countries [2022-04-22]

The World Bank. (2019b). *Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population) - Sub-Saharan Africa.* https://data.worldbank.org/indicator/SI.POV.DDAY?locations=ZG [2022-04-15]

The World Bank. (2022i). *Rural population (% of total population) - Sub-Saharan Africa.* https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=ZG [2022-04-15]

The United Nations. (n.d.a) *Renewable energy – powering a safer future.* https://www.un.org/en/climatechange/raising-ambition/renewable-energy [2022-05-22]

The United Nations. (n.d.b). *Ensure access to affordable, reliable, sustainable and modern energy for all.* https://unstats.un.org/sdgs/report/2019/goal-07/ [2022-04-29]

The United Nations. (2021a). *Goals 7 Ensure access to affordable, reliable, sustainable and modern energy for all.* https://sdgs.un.org/goals/goal7 [2022-04-29]

The United Nations. (2021b). *The Sustainable Development Goals Report 2021.* https://unstats.un.org/sdgs/report/2021/ [2022-04-29]

The United Nations. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development.* https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E [2022-04-29]

Torero, M. (2015). *The Impact of Rural Electrification: Challenges and Ways Forward.* Food and Agriculture Organization of the United Nations. https://doi.org/10.13140/2.1.2543.2641

U.S. Energy Information Administration. (2022). Solar explained - Photovoltaics and electricity. https://www.eia.gov/energyexplained/solar/photovoltaics-and-electricity.php [2022-05-15]

United Nation Industrial Development Organization (UNIDO). (2021). *What's so important about mini-grids?* https://www.unido.org/stories/whats-so-important-about-mini-grids [2022-05-15]

United Nations Statistics Division. (2019). *7 Affordable and clean energy.* https://unstats.un.org/sdgs/report/2019/goal-07/ [2022-04-29]

Appendices

Appendix A

List of African countries included in the subsample

Angola	Eswatini	Niger
Benin	Ethiopia	Nigeria
Botswana	Gabon	Rwanda
Burkina Faso	Gambia	Sao Tome and Principe
Burundi	Ghana	Senegal
Cape Verde	Guinea	Sierra Leone
Cameroon	Guinea-Bissau	Somalia
Central Africa	Kenya	South Sudan
Chad	Lesotho	Sudan
Comoros	Liberia	Tanzania
The Democratic Republic of the Congo	Madagascar	Togo
Republic of the Congo	Malawi	Uganda
Côte d'Ivoire	Mali	Zambia
Djibouti	Mauritania	Zimbabwe
Equatorial Guinea	Mozambique	
Eritrea	Namibia	

List of African countries excluded in the subsample

Algeria	Mauritius	South Africa
Egypt	Morocco	Tunisia
Libya	Seychelles	

Appendix B

Table 6: Correlations between dependent, independent and control variables.

	Employment in agriculture (total amount of labor in agriculture sector)	Rural population (total amount of people living in rural areas)	Net capital stock agriculture, forestry, and fishing (constant 2015 USD)	GDP per capita (constant 2015 USD)	Government effectiveness (scale from 1 to 10)
Access to electricity, rural population	0.4605	0.7042	0.6032	0.0512	0.1103
Off-grid installed capacity of solar PV (MW)	0.0400		0.1447	0.0633	0.0471
Agriculture, forestry, and fishing, value added (constant 2015 USD)	0.5939		0.9635	-0.0246	-0.0506

Table 7: Correlations between dependent and independent variables.

	Access to electricity, rural population	Off-grid installed capacity of solar PV (MW)	Agriculture, forestry, and fishing, value added (constant 2015 USD)
Access to electricity, rural population	1		
Off-grid installed capacity of solar PV (MW)	0.1708	1	
Agriculture, forestry, and fishing, value added (constant 2015 USD)	0.7053	0.1820	1

Appendix C

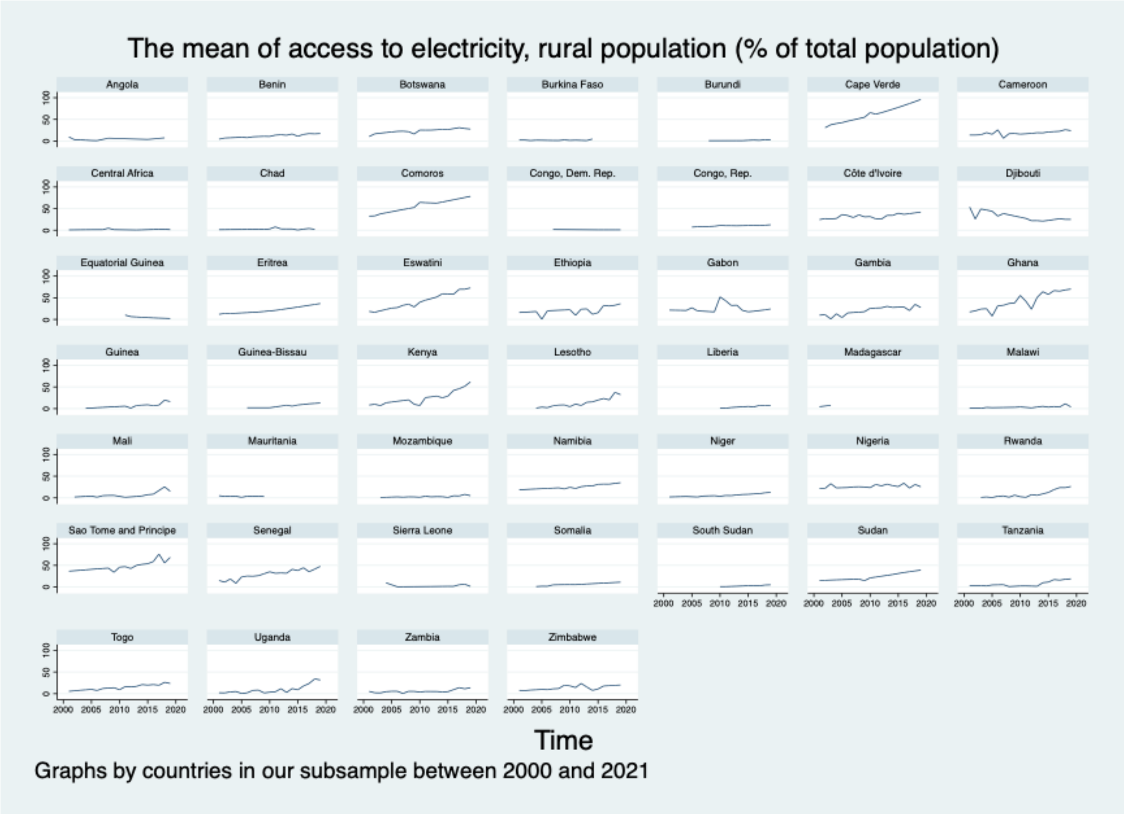

Figure 3: Time trends for the mean of access to electricity on a rural population level.

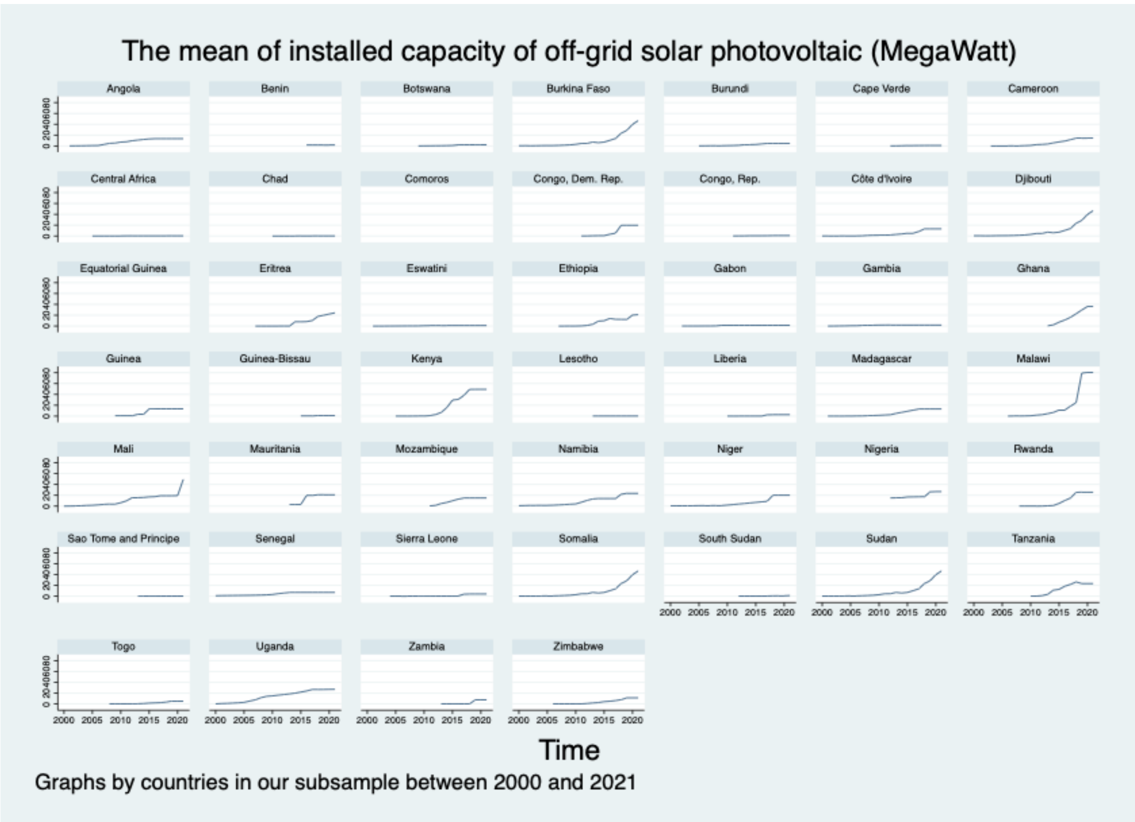

Figure 4: Time trends for the mean of installed capacity of off-grid solar PV (MW).