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Unmasking the Mystery of the Varying Benefits from Electrification

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Abstract

The evidence demonstrating the welfare impacts of electrification in Sub-Saharan Africa remains weak and inconsistent, leading some to assert that emphasis on access, in and of itself, is misplaced and that more should be done to identify the complementary conditions that are needed to deliver the anticipated economic growth and improved welfare outcomes. This project seeks to contribute to this debate, by focusing on the impacts of Uganda's electrification efforts. Difference-in-difference estimation with fixed effects on five waves of Uganda National Panel Survey data is employed to characterize both the average and heterogeneous impacts of electrification. The findings show that access to grid connectivity increases the number of work hours, female employment, household expenditure, and certain educational outcomes. There was an increase in the number of girls who sat for final exams; however, there was no significant impact on the proportion of girls who passed with grades in the first division of their final year national examinations. The time effects are significant for all socioeconomic variables, underscoring that the welfare improvement impact of clean energy access may not occur immediately.

Keywords: electrification; Uganda; clean energy; gender; girls' education

JEL Codes: O13, O18, Q40, Q48

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Unmasking the mystery of the varying benefits from electrification

Abstract

The evidence demonstrating the welfare impacts of electrification in Sub-Saharan Africa remains weak and inconsistent, leading some to assert that emphasis on access, in and of itself, is misplaced and that more should be done to identify the complementary conditions that are needed to deliver the anticipated economic growth and improved welfare outcomes. This project seeks to contribute to this debate, by focusing on the impacts of Uganda's electrification efforts. Difference-in-difference estimation with fixed effects on five waves of Uganda National Panel Survey data is employed to characterize both the average and heterogeneous impacts of electrification. The findings show that access to grid connectivity increases the number of work hours, female employment, household expenditure, and certain educational outcomes. There was an increase in the number of girls who sat for final exams; however, there was no significant impact on the proportion of girls who passed with grades in the first division of their final year national examinations. The time effects are significant for all socioeconomic variables, underscoring that the welfare improvement impact of clean energy access may not occur immediately.

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1 Background

Globally, more than 1.1 billion people in the developing world lack access to electricity; more than half of them live in Sub-Saharan Africa (SSA), where the electrification rate stands at only 14% (Lenz et al., 2017). These low access rates, together with the unaffordability of modern fuels, mean that households continue to rely extensively on traditional sources of fuel, i.e., fuel wood, charcoal, kerosene, and dung, for lighting, heating, and cooking (Jeuland and Pattanayak, 2012). The use of traditional fuels causes indoor air pollution, which results in child and adult morbidity and mortality, especially among women and girls, who are primarily responsible for cooking (Dasgupta, et al., 2004; Cecelski, 2005). Prior work has found a significant and negative relationship between traditional biomass fuel use and life expectancy (with a larger effect on females), irrespective of income level (Cecelski, 2005). Fuel choice and sourcing is also mediated by gender and intra-household bargaining power, since women face distinct challenges and opportunities related to their traditional roles, household responsibilities, and social and economic status (Brown and Lankford, 2015; Oliver et al., 2019). Rural households (usually women and girls) devote many hours to gathering and preparing fuel for domestic use, while poor urban households (often female-headed) purchase polluting fuels owing to their lower prices. Provision of modern energy therefore affects women and men differently (Clancy, et al., 2003).

Cognizant of the adverse effects of dirty energy use on the one hand, and the benefits of clean energy on the other hand, governments, and development partners in many low- and middle-income countries – including Uganda – are increasingly prioritizing a range of interventions to expand access to modern energy (van de Walle et al., 2015; Okoboi and Mawejje, 2016). Many electrification programs, for example, are motivated by the belief that clean energy is a critical spur to development, as evidenced by the strong national-level correlations between electricity and overall energy use, and between electricity and the economic value of national output (van Bentham, 2015). At a micro-level, electricity access has been argued to be pivotal for raising households' standard of living, and for human capital accumulation through improved education and health (Zahnd and Kimber, 2009; Cook, 2011; Khandker et al., 2013), reducing coping costs, i.e., the cost of treatment of respiratory diseases resulting from use of traditional fuels (Barron & Torero, 2017), and enhancing agricultural productivity and enabling small- and medium-scale enterprise growth (Cabraal et al., 2005). It is expected that, once households and businesses connect to the grid, they will receive a range of improved energy services (Jeuland et al., 2019).

Microenterprise development is seen as a key to ongoing socioeconomic transformation efforts, particularly in Sub-Saharan Africa, where most people live on less than US $2 a day (Bruton et al., 2013; George et al., 2016; Khavul and Bruton, 2013). However, evidence in the development economics literature indicates that infrastructure is one key binding constraint to any form of enterprise development (Harrison et al., 2014). Provision of infrastructure, such as grid electricity and roads, is therefore critical to overall social welfare improvement (Parikh et al., 2015). In an investigation of village-level effects of grid connectivity in India, Van de Walle et al. (2016) found that electrification resulted in significant consumption gains for households that connected to the grid. Khandker et al. (2012) found that rural electrification improves labour supply, education opportunities, and overall welfare of grid-connected communities. In addition, there are reports of increases in labour productivity for women (see Grogan and Sadanand, 2013; Khandker et al., 2012; van de Walle et al., 2016).

Grid connectivity impacts education through several mechanisms. For example, total school enrolment may increase if electrification results in income gains at a household level, releasing children from child labour market activities into school. On the other hand, the opportunities that emerge with grid connectivity often raise wages, which may inadvertently draw children out of school and into the labour force. Grid connectivity may change the education production function, say, through lighting or computing facilities in schools. These may improve the quality of learning both at school and home. Reliable grid connectivity that ensures constant lighting and helps learners develop more effective study habits. Furthermore, if electrification improves learner performance, it can affect the both the extensive margin of schooling (as learners stay longer in school) and the intensive margin (as it provides the necessary conditions for pupils to properly utilise their time at school – learning computer skills or watching informative videos in class or in the library). This has a positive effect on enrolment in the upper grades. Lipscomb et al. (2013) find that rural electrification increases the years of school attendance. Human capital improvements, in turn, may help youth and women tap into improved employment opportunities, especially for non-farm employment (Dinkelman, 2011; Fetter and Usmani, 2019; Gibson and

Olivia, 2010). However, while access to energy has been found to correlate with a number of key social and economic indicators of special importance to women, there has been only limited gender disaggregation of impacts in prior studies (Cecelski, 2005; Rathi and Vermaak, 2018; Jeuland et al., 2019). This limits our ability to draw conclusions about the relationship between energy interventions and SDG 5, which emphasizes gender equity and empowerment. Our project aims to provide new evidence related to this key information gap.

1.1 Policy context

Because energy poverty stifles development, electrification, supported by clean energy solutions, is a high priority goal for many developing countries. Uganda is no exception; the bulk of the population currently relies on traditional, highly polluting sources of fuel for lighting, heating, and cooking. The attendant time and health burdens are especially heavy for women and children. Electrification promises improvements in access to information about health and family planning, domestic productivity, children's study opportunities, small-scale household production, and general household welfare (Köhlin et al., 2011; ADB, 2010). In 2018, the government of Uganda, with funding from the African Development Bank and other partners, launched the 'last-mile' connectivity component under the Uganda Rural Electricity Access Project. The objective of the project is to provide reliable and affordable electricity to rural households, public institutions, and small and medium-sized enterprises. The project meets the cost of extending the grid up to a beneficiary's property, but requires them to meet the cost of wiring up their property prior to receiving that 'last-mile' service. Overall, the scheme was expected to significantly contribute to meeting the country's National Development Plan goal of "increasing electricity access to 60 percent of the population." However, although the overall national electricity access rate has increased to 57 percent (including both grid and off-grid sources), household-level grid connectivity stands at 19 percent (UBOS, 2021). In this project, we consider the various potential impacts of the ongoing electrification effort in the Ugandan context.

The focus of the paper speaks to the global UN Sustainable Development Goals No.7 (*"Ensuring access to affordable, reliable, sustainable and modern energy for all"*) and No. 5 (*"Achieving* *gender equality and empower all women and girls"*) (United Nations, 2015)). It is also responsive to Uganda's national priorities. The government has undertaken several energy sector reforms with a view to satisfying the increasing energy needs of the economy and the general population (Mawejje et al., 2014; Okoboi and Mawejje, 2016). Nonetheless, given the costly nature of energy investments, the record of mixed impacts in other settings (Bernard, 2012; Köhlin et al., 2011; Lenz et al., 2017), and the multiplicity of channels through which their impacts may or may not materialize, it is important to establish the impacts on well-being and economic development. The mixed evidence in the literature highlights the limits of generalizing across settings and countries, and the imperative for country-specific studies (Saing, 2017).

1.2 Hypotheses

The following specific hypotheses were tested:

i) Connectivity of households/communities to the grid is driven by household characteristics.

ii) Expansion of grid electricity results in improved socioeconomic outcomes at a community and household level on average.

iii) The impacts of grid electrification vary across local socioeconomic and community conditions.

We first investigated the drivers of connectivity to the grid. Second, using a difference-in-differences identification strategy, we examined the impact of grid connectivity on selected socioeconomic outcomes: first at a household level, and second at a community level. Household-level outcomes were analysed with respect to household-specific connectivity to electricity, while community-level outcomes focused on community-level connectivity and community-level outcomes, i.e., school enrolment and academic performance. The latter is critical given that a) there may be complementary effects between household and community use of electricity, and b) connection of public services to the grid is highlighted in the Government's electrification strategy plan (2013-2022), though impacts on public service quality have rarely been studied (Jeuland et al., 2019). In all our analyses, the availability of complementary infrastructure features prominently, as this was a key motivation of the electrification strategy. Given that considerable evidence shows the impacts of electrification are small or absent in the case of Africa (see Chaplin et al., 2017; Lee et al., 2020b; Lenz et al., 2017), we hypothesize that the availability of complementary infrastructure may play an important role in mediating the welfare impacts of electrification.

2 Literature review

The literature on the socioeconomic impacts of electrification highlights a wide range of benefits (Lenz et al., 2017; Peters and Sievert, 2016). In certain contexts, electrification supports the creation of home-based enterprises with longer hours for productive work (Alby et al., 2013; Binswanger et al., 1993; Rud, 2012). Productivity-related increases in income in the longer term also have been linked to improved lighting, which enhances the return on education (ESMAP, 2003).

Given the considerable time generally allocated to fuel collection, women are especially likely to be the beneficiaries of electrification that replaces reliance on traditional fuels. In addition, labour-saving technologies in grid-connected households can decrease both the effort and time required for women to complete household chores. This in turn can increase female employment opportunities, either outside the home or in microenterprises (Dinkelman, 2011). Dinkelman (2011) and Grogan and Sadanand (2013) found that electrification had positive effects on female employment in South Africa and in Nicaragua, with the probability of women working outside the home having increased by approximately 9 percent in South Africa and 23 percent in Nicaragua. In their study of the impact of electricity infrastructure on gender and poverty in Indian slums, Parikh et al. (2015) find positive effects on literacy, income, and health, and focus especially on benefits to women.

However, electrification's impacts on productivity, firm performance and employment are highly mixed. Much of the positive evidence has been derived from Asia and Latin America (Kanagawa and Nakata, 2008; Khandker et al., 2012, 2013; van de Walle et al., 2015. Studies on India, Kenya, Nicaragua, and South Africa found positive impacts (Dinkelman, 2011; Gibson and Olivia, 2010; Grogan and Sadanand, 2013; Kirubi et al., 2009; Rud, 2012). In more remote and less developed areas in sub-Saharan Africa, the results have been mixed or dismal (Bos et al., 2018; Bernard, 2012; Grimm et al., 2013; Neelsen and Peters, 2011; Peters et al., 2011; Peters and Sievert, 2016; Lenz et al., 2017).

Where electrification has affected labour market outcomes, it has been observed through four potential channels. First, household electrification can increase the total number of productive hours available for individuals to engage in different enterprises (Barnes et al., 2003; Bensch et al., 2013). Although traditional lighting sources can be used, the quality of light produced is inferior to electrical lighting. Second, street lighting provides safety for entrepreneurs and their clients, extending work hours and attracting more customers (De Groot et al., 2017). This effect has a vital gender component, as evidence shows the role of street lighting in increasing women's perception of safety (Cabraal et al., 2005; Barnes et al., 2003; Bensch et al., 2013). Third, having access to electricity creates opportunities to generate income within the home and may allow for new employment opportunities outside of the home, thus potentially increasing both self-employment and labour demand (Dasso and Fernandez, 2015; Chowdhury, 2010; van de Walle, 2013). Fourth, electrification may result in a shift from agricultural to non-agricultural activities that are typically associated with an increase in productivity and income (Torero, 2015). This is relevant to Uganda and the many other African countries whose economies remain predominantly agricultural.

The lack of consistent and positive evidence of impacts, especially in sub-Saharan Africa, may be a result of variation in electricity use, which in turn is driven by a wide range of socioeconomic factors. Rao (2013) and Rathi and Vermaak (2018) contend that the empirical evidence has not focused sufficiently on the complex linkages among electrification, channels of impact, and development outcomes. For rural electrification to generate income, time savings, and human capital development, households (as well as firms and infrastructural institutions) must be able to afford to connect to the grid, acquire appliances, and pay electric bills. This relates very closely to complementary conditions such as access to infrastructure, markets, and income-generating opportunities.

In their study of electrification in India, Fetter and Usmani (2019) note that electrification had no discernible impact on welfare outcomes in rural areas without production-enhancing infrastructure.

In areas where positive outcomes were apparent, the availability of non-farm work opportunities was often driven by the rise of electricity-intensive firms that complemented traditional, agricultural production processes. They thus conclude that electrification alone may not deliver the desired economic benefits, but rather that such investments should be made in settings where complementary infrastructure enables both firms and households to benefit from electrification. For example, empirical evidence has documented significant effects of electrification on knowledge about modern contraception, nutrition, and child health, but this depends both on television programming and on households' access to televisions (IEG, 2008; Peters and Vance, 2011). Furthermore, whether such time savings are reallocated to income generation or leisure depends on the availability of other economic opportunities (van de Walle et al., 2017). Similarly, modern lighting can facilitate longer hours of evening study. This may result in improvements in academic performance, but academic outcomes depend on many factors, including school quality and how a household allocates time between school and work (Cook, 2011; Gibson and Olivia, 2010).

The context-specific and region-specific nature of findings makes it difficult to generalize the effects of electrification from one developing country context to another. Our contribution is to explore the impacts on outcomes in Uganda, with a focus on educational outcomes.

3 Methodology

3.1 Conceptual and econometric framework

As earlier noted, there are multiple channels through which electrification can affect household welfare, including income and consumption, education, and health (Khandker et al., 2013; Lenz et al., 2017; Saing, 2017; Peters and Sievert, 2016). It is therefore critical to consider what happens after a community gains access to electricity. In most cases (e.g., for grid electrification and mini-grid interventions), only a subset of households, firms, and institutions (schools, health centres, businesses), public and private, are connected. With decentralized off-grid solutions, the choice to connect is even more individualized. Many individual agents may not connect, owing to the high perceived connection costs, low affordability of a new connection, or low perceived benefits from the specific energy solution being offered. In our first analysis, we examine the determinants of connectivity status over time within communities with nonzero electricity access, by estimating the following empirical model for each individual wave in our data set. Formally:

$$y_{ij} = \beta_0 + \beta_1 X_{ij} + \beta_2 Z_j + \varepsilon_{ij} , \qquad (1)$$

where y_{ij} is an indicator that is equal to 1 if household i in community j has access to grid electricity, and 0 otherwise; X_{ij} is a vector of household characteristics (including gender of the household head and other proxies for greater female bargaining power, e.g., number of adult women in the household, number of women earning income in the household); Z_j is a vector of community characteristics; and ε_{ij} is an individual-specific error term. The model was estimated using OLS with standard errors clustered at the community level. The purpose of the wave-by-wave analysis is to determine if the set of such individual and community determinants evolves over time, as would be expected when electricity access increases.

In the next step, we identify the average impacts of electricity access, using a difference-in-difference fixed effects model with the following specification:

$$y_{ijt} = \beta_0 + \gamma_1 E_{ijt} + \beta_1 X_{ijt} + \beta_2 Z_{jt} + \omega_{ij} + \varepsilon_{ijt} \qquad (2)$$

where all variables are now time-varying and subscripted by time t, and where y_{ijt} is an outcome of interest; E_{ijt} is a binary indicator that denotes an electricity connection for household i in community j at time t; E_{jt} represents the fraction of connected households in the community; and ω_{ij} is the household-level fixed effect.

For the heterogeneity analysis, we analyse the influence of two variables related to our hypotheses about complementary infrastructure and conditions, i.e., initial community access to grid energy (electricity in the first wave of the panel), and an index was constructed from variables representing market connectivity using polychoric principal components analysis (Kolenikov and Angeles, 2009). The model is specified as follows:

$$y_{ijt} = \beta_0 + \alpha I_{jt} + \gamma_1 E_{ijt} + \beta_1 X_{ijt} + \beta_2 Z_{jt} + \omega_{ij} + \varepsilon_{ijt}; \qquad (3)$$

where all variables are as previously defined, except for I_{jt}, which is an indicator representing infrastructure in community j.

Finally, we analyse the impact of electrification from a gender perspective. This analysis was undertaken for the education and labour market outcomes, namely: employment, number of hours worked and academic performance. In each case, the variable of interest was the electrification status of the household or community. Formally:

$$y_{ijt} = \theta E_{ijt} + \beta_1 X_{ijt} + \varepsilon_{ijt} \ , \qquad (4)$$

y_{ijt} is the outcome of interest (employment status, hours worked, and academic performance), E_{ijt} is a dummy variable for electricity access, X_{ijt} is the vector of covariates, and ε_{ijt} is a random error term. This model was used to estimate the causal effect of electrification status on education and labour market outcomes for individual household members. Given the potential for endogeneity, the analysis was undertaken using fixed effects estimation.

3.2 Data

The Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) panel data spanning 2009-2016 was used. This survey was implemented by the Uganda Bureau of Statistics (UBOS) in conjunction with the World Bank. The baseline was taken at the 2009/10 level of electrification and was representative at the national and regional level. The survey enrolled approximately 3,200 households from 320 Enumeration Areas originally sampled for another survey in 2005/06. In 2013/14, one-third of the original EAs were permanently rotated out of the sample and replaced with 100 new EAs, resulting in a final sample of 3,119 households. The 2015/16 sample followed the 2013/14 sample, including split-off tracking. The LSMS-ISA data for Uganda has three key modules and provides a rich dataset including socioeconomic, environmental and infrastructure characteristics at the household and community level. The data therefore allows for the estimation of the impacts of electrification on several electrification-related outcomes that are of interest to the government of Uganda, as well as highlighting the role of complementary infrastructure.

4 Empirical results

4.1 Descriptive statistics

The results from the mean difference analysis for the socioeconomic characteristics of households by grid-connectivity status show that most of the household characteristics do differ significantly, except for the number of rooms in the dwelling and the marital status of the household head (Table 1). It is important to note the differences in per capita household expenditure, ownership of enterprises, number of weekly work hours, and employment of household members. Whilst per capita expenditure per adult equivalent has been rising generally, the level of the increase has varied significantly across the two categories of households, increasing by close to 60% and 50% in grid-connected and non-grid communities respectively between 2009 and 2016. The level of per capita expenditure per adult equivalent in 2016 was equivalent to approximately $1400 and $500 in grid connected and off-grid communities respectively.

Table 1: Households' socioeconomic characteristics by grid connectivity

	UNPS Wave (2009/10)			UNPS Wave III (2011/12)			UNPS Wave III (2015/16)		
Variables	Grid	Non-grid	Diff	Grid	Non-grid	Diff	Grid	Non-grid	Diff
Grid connected	0.337	0.663		0.337	0.663		0.351	0.648	
Socioeconomic characteristics									
Per capita expenditure (UGX '000)	3,160,784	916,493.2	-2,244,291***	4,267,687	1,223,479	-3,044,209***	4,897,175	1,737,471	-3159704***
Average household size	4.595	5.326	0.731***	4.25	5.105	0.855***	3.586	4.415	0.829***
Age of household head	41.89	46.04	4.147***	43.47	47.68	4.213***	41.421	46.923	5.501***
Female household head	0.230	0.271	0.041*	0.228	.242	0.014	.282	0.264	-0.017
Head education (years)	11.88	8.41	-3.47***	11.43	8.522	-2.915***	12.447	8.726	-3.721***
Marital status of head	0.641	0.677	0.0350	.595	0.632	0.037	.582	0.599	0.017
Adult females per household	1.327	1.188	-0.138**	1.244	1.148	-0.095**	.342	0.345	0.003
No. of females with an income (%)	0.657	0.848	0.191***	.796	0.870	0.0739*	.78	0.839	0.059*
Ownership of enterprise	0.771	0.599	-0.171***	1.289	1.162	-0.126**	.612	0.425	-0.186***
Employment	0.408	0.250	-0.158***	.412	0.212	-0.200***	0.437	0.212	-0.224***
Weekly work hours	39.46	23.78	-15.67***	41.01	22.88	-18.12***	42.708	22.961	-19.747***

Source: Authors' own computations

In Table 2, the results show significant differences in the quality of amenities such as source of drinking water, toilet type, wall, floor, and roofing material. Grid-connected households are more likely to report ownership of an enterprise, which is an indicator of engagement in income-generating activities beyond agriculture; i.e., grid connectivity affects the reported non-agricultural economic activities in which households engage. Furthermore, grid-connected household members reported a significantly higher number of weekly work hours. It is important to note that grid connectivity creates avenues for income generation late into the evening hours, periods which are typically unavailable to households unconnected to the non-grid. Microenterprise activities include grocery sales, hair dressing, restaurants and cafes, bars, tailoring, cell phone-based money-transfer services, cell phone charging, computer services, and video halls. These benefit from the increased hours of operation enabled by grid connectivity. Given that most people are actively involved in a variety of economic activities during the day, the evenings tend to be busy in community trading centres when more customers get the opportunity to be served after hours. For this reason, grid electricity provision allows microenterprises the option of longer evening hours than would otherwise be the case. Trading centres are an important part of community life in many parts of Africa, providing not only the day-to-day household essentials and services, but also entertainment and socialization, all of which are critical to overall welfare.

Despite the potential benefits from grid connectivity, the results show that community connectivity stands at 35%. In Table 4, the level of household-level connectivity stands at 15%. Most of the households use kerosene for lighting, while the use of solar power stands at 11%. While it was expected that areas not connected to the grid would utilise other clean energy options such as solar energy, the transition to non-grid clean energy is yet to take root significantly. However, there appears to be progress in the use of solar energy. In 2009, less than 1% of sampled households reported using solar energy; this number has since risen to the current 11%. There is evidence that households combine multiple energy sources, both for lighting and cooking. The results show the use of firewood as the main household energy source for cooking (approximately 80% of all households reportedly use it).

Table 2 presents ownership of electric appliances and other household assets. There are significant differences regarding the ownership of appliances and assets between households by grid connectivity status. This trend in ownership goes beyond appliances that require electricity, pointing to wider wealth and income differences. For instance, there are significant differences in the ownership of not only motorcycles but bicycles as well. Households that are not connected to the grid have higher ownership of motorcycles, perhaps highlighting this as a response to the infrastructure deficit in their communities. In Uganda, motorcycles are used as a quick means of transport in the absence of motor vehicles.

Mobile phones and radios are the two most possessed and used technologies regardless of community connectivity to the grid. It should be noted that mobile phone usage requires charging with electricity. In this case, households that have no direct connection to the grid use charging points in trading centres within or outside communities (as the distances between communities are not extremely large) or use mini-solar-based charging technologies. On the other hand, radios use both solar and cell batteries. In terms of TV and computer ownership, households differ significantly, computers being generally less common than TVs. While there is a statistically significantly higher usage of TVs or computers in grid-electrified households, even in areas without connectivity, some households do possess these appliances and use batteries to operate them.

Table 2: Households' quality of housing and asset ownership by grid connectivity

	UNPS Wave (2009/10)			UNPS Wave III (2011/12)			UNPS Wave III (2015/16)		
Variables	Grid	Non-grid	Diff	Grid	Non-grid	Diff	Grid	Non-grid	Diff
Housing									
Quality of housing index	1.261	-0.193	-1.454***	1.152	-0.176	-1.328***	1.034	-0.185	-1.220***
More than two rooms	0.718	0.757	0.038	0 .500	0.549	0.049*	0.336	0.353	0.017
Quality wall	0.948	0.370	-0.578***	0.934	0.377	-0.557***	0.942	0.387	-0.554***
Quality roof	0.984	0.618	-0.365***	0.994	0.637	-0.357***	0.996	0.650	-0.345***
Quality floor	0.943	0.223	-0.720***	0.956	0.217	-0.738***	0.942	0.239	-0.702***
Quality toilet	0.544	0.486	-0.0585**	0.478	0.472	-0.005	0.986	0.791	-0.194***
Quality source of water	0.895	0.710	-0.184***	0.918	0.763	-0.155***	0.892	0.726	-0.165***
Asset ownership									
Asset Ownership index	1.409	-0.210	-1.620***	1.348	-0.204	-1.552***	1.216	-0.218	-1.434***
Ownership of appliances	0.682	0.113	-0.569***	0.520	0.044	-0.476***	0.532	0.016	-0.515***
Owns television	0.693	0.0393	-0.653***	0.779	0.033	-0.745***	0 .746	0.042	-0.703***
Owns a radio	0.810	0.634	0.657***	0.798	0.643	-0.155***	0.71	0.623	-0.086***
Owns motorcycle	0.138	0.057	-0.080***	0.100	0.071	-0.029*	0.132	0.095	-0.036**
Owns a motor vehicle	0.135	0.012	-0.123***	0.141	0.011	-0.130***	0.138	0.012	-0.125***
Owns a bicycle	0.232	0.436	0.203***	0.226	0.434	0.208***	0.206	0.409	0.203***
Owns a mobile phone	0.925	0.456	-0.469***	0.948	0.588	-0.359***	0.982	0.695	-0.286***
Owns a computer	0.140	0.009	-0.130***	0.125	0.004	-0.120***	0.136	0.004	-0.131***
Infrastructure index	0.489	-0.228	-0.718***	0.243	-0.060	-0.304***	0.465	-0.110	-0.576***

Source: Authors' own computations

Primary school enrolment is universal in Uganda, regardless of location. However, it is clear from Table 3 that children from grid-connected communities tend to stay in school longer, and perform better, than those from communities without grid connectivity. However, there was no significant difference between boys’ enrolment in some years of the study.

Table 3: Candidate enrolment and academic performance by community connectivity to the grid

	UNPS Wave I (2009/10)			UNPS Wave II (2011/12)			UNPS Wave III (2015/16)		
	Grid	Non-grid	Diff	Grid	Non-grid	Diff	Grid	Non-grid	Diff
Total number of candidates	51.845	24.261	-27.583***	46.448	44.927	-1.52	44.560	39.527	-5.033**
Number of boy candidates	22.840	14.434	-8.405***	23.425	22.473	-0.952	22.17	21.99	-.0179
Number of girl candidates	29.004	9.826	-19.178***	23.023	22.454	-0.568	22.388	17.534	-4.853***
Candidates in 1st grade (%)	0.0592	0.0092	-0.0499***	0.110	.044	-0.065***	.0845	0.0479	-0.0365***
Candidates in 2nd grade (%)	0.545	0.355	-0.189***	0.563	.536	-0.027***	.588	0.555	-0.032***
Candidates in 3rd grade (%)	0.395	0.635	0.239***	0.326	.418	0.092***	.326	0.396	0.069***
Proportion of girls in 1st grade	0.322	0.198	-0.123***	0.356	.230	-0.125***	.302	0.328	0.025
Proportion of girls in 2nd grade	0.461	0.289	-0.171***	0.436	.392	-0.043***	.460	0.380	-0.079***
Proportion of girls in 3rd grade	0.568	0.4319	-0.1369***	0.598	.521	-0.077	.521	0.464	-0.056***

Source: Authors' own computations

4.2 Household connectivity, energy expenditure and use

There was a modest (from 33% to 35%) expansion of grid connectivity at the community level between 2009 and 2016. However, household-level connectivity remains low at 15% – so low that between 60% and 86% of households reported using kerosene lamps as their source of lighting over the study period. Between 2009 and 2016, monthly household electricity expenditures declined from US $10.1 to approximately US $7.7 - a 25% decline, and yet this decline was associated with an increase in the number of hours which households reported having been connected to the grid (there are episodes of power shutdowns in different areas of the country for several reasons). This could partly be attributed to changes in energy tariff rates or changes in energy use.[1]

Table 4: Connectivity and energy use and expenditure

Variables	2009/10	2011/12	2015/16
Grid connectivity	0.133	0.131	0.151
	(0.34)	(0.337)	(0.359)
Grid energy (hours/day)	19.533	15.188	19.084
	(6.569)	(7.480)	(7.274)
Energy expenditure	30,923.8	30,561.241	23,764.975
	(38,838.66)	(35,682.179)	(18,088.130)
Energy source (Cooking)			
Electricity	0.013	0.009	0.008
	(0.112)	(0.092)	(0.088)
Firewood	0.783	0.797	0.791
	(0.412)	(0.402)	(0.407)
Crop residue	0.095	0.086	0.17
	(0.293)	(0.280)	(0.376)
Kerosene	0.077	0.052	0.038
	(0.266)	(0.222)	(0.190)
Cooking gas	0.006	0.004	0.009
	(0.078)	(0.065)	(0.093)
Charcoal	0.28	0.266	0.277
	(0.449)	(0.442)	(0.447)
Energy source (Lighting)			
Electricity	0.118	0.09	0.139
	(0.322)	(0.286)	(0.346)
Solar	0.01	0.019	0.118
	(0.101)	(0.135)	(0.322)
Kerosene	0.856	0.767	0.559
	(0.351)	(0.423)	(0.497)
Observations	2,940	2,809	3,302

Source: Authors' own computations

[1] The analysis is based on nominal expenditure data. However, electricity prices are denominated in US dollars and only converted into the domestic currency during bill payment. Given the fact that the domestic currency has consistently depreciated during the period under study, it means that the energy prices also have consistently been on the decline. See https://www.era.go.ug/index.php/tariffs/tariff-adjustment-methodology.

4.3 Determinants of connectivity status

The results of the analysis on the determinants of household connectivity are presented in Table 5. Across all specifications, we find that household income, mirrored by per capita household expenditure per adult equivalent, is an important determinant of household connectivity across the waves.

Table 5: Determinants of household-level grid connectivity status within communities over time

	(1)	(2)	(3)	(4)	(5)
Variables	2009	2010	2011	2013	2015
Per capita expenditure	0.0394**	0.0451*	0.0577*	0.0354*	0.0503**
	(3.04)	(2.45)	(2.43)	(2.37)	(2.82)
Female head of household	-0.000403	0.00815	-0.00702	0.0419*	0.0469*
	(-0.02)	(0.29)	(-0.16)	(2.14)	(2.20)
Age of head of household	-0.0500*	-0.0754*	0.0319	-0.0141	0.0308
	(-2.11)	(-2.13)	(0.66)	(-0.67)	(0.98)
Marital status	-0.00466	0.00291	-0.000213	-0.00299	0.0100
	(-0.31)	(0.13)	(-0.01)	(-0.19)	(0.52)
Household size	-0.0104***	-0.0136***	-0.0135*	-0.00729*	-0.0111**
	(-3.54)	(-3.38)	(-2.36)	(-2.40)	(-2.76)
No. of females>18	0.0643***	0.0691**	0.0744*	0.0536***	0.0806***
	(4.09)	(3.15)	(2.37)	(3.60)	(4.62)
No. of employed females	0.0216	0.0542*	0.0240	0.0348*	0.0734***
	(1.43)	(2.33)	(0.85)	(2.34)	(4.20)
Years of schooling	0.00463	-0.00216	-0.00424	0.0108***	0.0115***
	(1.81)	(-0.62)	(-0.78)	(4.22)	(4.06)
Enterprise ownership	-0.0113	-0.00300	-0.0262*	0.0195	0.0317
	(-1.22)	(-0.31)	(-2.03)	(1.54)	(1.65)
Infrastructure index	0.158***	0.194***	0.180***	0.193***	0.164***
	(14.99)	(13.04)	(8.31)	(17.06)	(11.48)
Asset index	0.146***	0.180***	0.162***	0.183***	0.151***
	(13.08)	(11.41)	(7.31)	(15.70)	(10.43)
Housing index	0.0450***	0.0233*	0.0358**	0.0211*	0.0378***
	(4.97)	(2.18)	(2.71)	(2.45)	(3.59)
Constant	-0.251	-0.197	-0.758*	-0.415	-0.837**
	(-1.33)	(-0.72)	(-2.02)	(-1.86)	(-2.99)
Observations	2,763	2,882	2,577	2,819	3,299

Notes: OLS estimation with standard errors clustered at the community-level.
***, **, * respectively denote significance at 1%, 5% and 10%
Source: Authors' own computations

The results show that the household grid connectivity is strongly influenced by several economic and non-economic factors, conditional on living in a grid-connected community. Connectivity is positively and significantly influenced by ownership of an enterprise, the asset index, and the quality of housing index, and negatively influenced by household size. This points to the role of income and wealth in driving the likelihood of being connected to the grid. Previous studies in

Ethiopia, Kenya, and Bangladesh (respectively, Wassie et al., 2021; Guta, 2018; Lay et al., 2013; Komatsu et al., 2011) had reported that the likelihood of clean energy adoption varied positively and significantly with household income.

Even if electricity supply were extended via the national grid to grant near-universal access, households would still face individual costs of connecting to the grid. Based on differences in household income, we expect heterogeneity in the drivers of grid connectivity. We therefore analyse the effects of household income, and also the effects of other variables that influence households' abilities to connect. Household characteristics certainly appear to affect connectivity to the grid. The coefficients of the household characteristics are within the same ranges across the five panel waves. Household size is negatively associated with grid connectivity. This is perhaps a reflection of the burden that a large household places on income and expenditure decisions, undercutting the chances of access to clean energy, or perhaps a reflection of larger families in rural areas. The quality of housing appears to have a strong relationship with connectivity to the grid, with higher-quality dwellings having a positive and high correlation with connectivity. Several characteristics of the household head influence electricity expenditure. The household head's years of schooling are positively correlated with grid connectivity. Similarly, the number of household assets, presence of community infrastructure, and the number of adult female members in the household all significantly and positively influence a household's connectivity to the grid.

4.4 Difference-in-difference estimation of the impacts of electricity access

In this section, we employ a difference-in-difference estimation to analyse the effect of grid connectivity on the four socioeconomic outcomes of interest, namely household per capita expenditure per adult equivalent, enrolment of pupils in candidate classes, the number of girls sitting for the final primary school examination, and the proportion of girls who passed in grade one. Difference-in-differences analysis allows one to assess the effect of a treatment on the path of change of a community (Gelman and Hill, 2007). To measure the effect of grid connectivity reliably, and to be able to make causal statements, we use a control community as a counterfactual. The differences between the two communities should be unaffected if the intervention has no effect. If differences change, however, we can be confident this is the effect of the intervention.

We examine whether community-level grid access results in significant variation in the selected socioeconomic outcomes. The results in Table 6 show a significant difference in household expenditure and in the total number of girl candidates sitting for the Primary Leaving Examination. However, electrification yielded no significant change in the proportions of female candidates passing grade one. The difference-in-difference analysis of household expenditure and girl candidate enrolment shows significant changes in differences between the grid-connected communities and the control community across the three waves of the survey (Table 5). The coefficient for the ATET is highly significant, implying that community-level grid connectivity had a positive impact on the socioeconomic indicators for the connected households than would have been the case in its absence. All the models include the control variables as specified in the previous estimations.

Table 6: Socioeconomic impact of community-level grid connectivity

	(1) Per capita expenditure	(2) Total enrolment	(3) Female enrolment	(4) Academic performance
ATET	0.239***	0.265*	0.519**	-0.086
	(0.096)	(0.416)	(0.204)	(-0.092)
DID	0.2641***	0.308**	0.562***	-0.028
	(0.011)	(0.134)	(0.191)	(0.098)
Time	0.339***	0.170***	0.279***	0.065*
	(17.94)	(6.97)	(8.14)	(2.04)
Constant	13.51***	3.308***	2.443***	0.278***
	(1103.07)	(225.21)	(117.97)	(10.89)
Controls	Yes	Yes	Yes	Yes
Observations	7,937	6,989	6,918	6,013

Notes: Estimation with standard errors clustered at the community-level.
***, **, * respectively denote significance at 1%, 5% and 10%
Source: Authors' own computations

We analyse the effects of community-level grid connectivity and test for impacts of electrification via each of the potential channels discussed in Section 3. We estimate Equations (3) and (4) using outcome variables from three broad categories: female employment, number of work hours per week, household consumption, and education. Each regression is estimated using community-level fixed effects.

Table 7: Impact of initial community-level access to grid electricity

	Per capita expenditure	Total enrolment	Academic performance
Year of connectivity	0.117***	-0.0235	0.0716***
	(3.90)	(-0.63)	(3.86)
Connectivity dummy	-0.168	-0.128	-0.186**
	(-1.83)	(-0.61)	(-2.67)
Baseline connectivity status	0.422***	0.573	0.178
	(3.42)	(1.92)	(1.93)
Age of head of household	0.0788	-0.0540	-0.00176
	(1.79)	(-0.65)	(-0.04)
Female head of household	0.0179	0.0294	-0.0328
	(0.46)	(0.36)	(-0.94)
Marital status	-0.0541	-0.113	-0.00992
	(-1.35)	(-1.51)	(-0.31)
Household size	-0.111***	-0.0231*	-0.00418
	(-19.23)	(-2.38)	(-0.80)
No. of females>18	0.0174	0.0662	0.0126
	(0.82)	(1.73)	(0.71)
Years of schooling	0.0282***	0.0171*	-0.00432
	(7.09)	(2.41)	(-1.14)
Enterprise ownership	0.106***	0.0866***	-0.00915
	(7.44)	(3.38)	(-0.74)
Infrastructure index	0.0435***	0.103***	0.00725
	(3.76)	(4.99)	(0.67)
Asset index	0.269***	0.0938***	-0.00429
	(14.88)	(3.35)	(-0.30)
Housing index	0.179***	0.127***	0.0947***
	(12.23)	(4.44)	(7.38)
Constant	13.67***	3.456***	0.306
	(77.29)	(10.55)	(1.87)
Observations	7,930	6,873	6,011

Notes: Estimation with standard errors clustered at the community-level.
***, **, * respectively denote significance at 1%, 5% and 10%
Source: Authors' own computations

We estimated the fraction of households with connectivity to the grid as one of the independent variables. Table 7 reports the corresponding regression results. First, we tested the impact of a community's initial grid connectivity on education and household expenditure. We estimated Equation (3) using community level school enrolment and performance in the final year national examinations. The dependent variables are total enrolment in the final year class, the proportion of girls who passed in the first division of the final year national examinations, and per capita household expenditure. We tested three explanatory variables: the year in which a community was connected to the grid, connectivity at the baseline (2009), and overall connectivity status. The results, in Table 7, show that, while connectivity had no statistically significant effects on enrolment, the year in which the community was connected to the grid had a strong and significant impact on the performance of girls in the first division and on household consumption expenditure. The baseline connectivity status had a significant impact on household expenditure. These findings suggest that grid connectivity can contribute to female education and household consumption.

Finally, we tested for the effects of household grid connection on female employment by estimating Equation (4), the dependent variables being the total number of female household members who reported being employed, and the log of weekly work hours. Initial community access to modern energy was measured by determining the fraction of households using LPG or kerosene or having electricity in the first wave of the panel. The infrastructural index was constructed from variables representing community accessibility and supportive infrastructure. We found that the proportion of households that are connected to the grid increased the share of women's employment by a mean of 37 percent (Table 8).

Table 8: Gender and employment impacts of household on-grid electrification

	No of employed females	Log of work hours
Proportion of grid connected households	0.369***	0.418***
	(5.43)	(4.16)
Age of head of household	0.0553	-0.528***
	(1.49)	(-8.46)
Female head of household	0.203***	-0.111
	(5.57)	(-1.87)
Marital status	0.092*	0.043
	(2.48)	(0.71)
Household size	0.012*	-0.013
	(2.45)	(-1.65)
No. of females>18		-0.037
		(-1.20)
Employed members		0.003
		(0.56)
Enterprise ownership	0.0847***	0.0538*
	(6.20)	(2.51)
Infrastructure index	0.515***	0.002
	(17.12)	(0.08)
Asset index	0.008	0.067**
	(0.67)	(2.87)
Housing index	-0.008	0.164***
	(-0.67)	(7.49)
Constant	-0.121	5.145***
	(-0.82)	(21.07)
Observations	7,928	6,889

5 Conclusion

This project used five waves of Ugandan household-level panel data to analyse the socioeconomic impact of grid connectivity in a developing country. While household income increased, household electricity connectivity to the grid did not increase by the same magnitude over the study period; this suggests that inequality in energy access and use may be greater than that of income, suggesting that household income poverty may not always be a good indicator of energy poverty. Even with a rapid expansion of the grid, households may not take full advantage of the available clean energy infrastructure (Table 2).

This investigation indicates the need to address the constraints to improving energy access and energy usage, even when electricity grids are expanded. The primary motivation to increase access to clean energy is that it improves in-house lighting and facilitates home production activities. These aims are consistent with the targets of Sustainable Development Goal 7. Policies that improve income levels can make it easier for households to connect to the grid, which in turn could open opportunities for yet more economic activity. However, the findings show that interventions such as the government of Uganda’s ‘last mile’ connectivity program may not be sufficient to induce households to connect to the grid, since electricity use has associated recurrent costs. The costly nature of grid expansion and maintenance suggest that the supply driven model may not be optimal. Whilst a connection subsidy can relax the constraints facing households wanting access to the grid, it offers them only temporary relief. In contrast, policy measures that support access to off-grid renewable energy forms, such as solar power, can provide some of the socioeconomic impacts of clean energy. Given that the main objective of increasing people's access to grid connectivity is to provide equal opportunities for growth and development, more interventions are needed to improve the incomes of households at the bottom of the economic pyramid – who constitute the majority. Clean energy, whether on- or off-grid, is one key trigger that generates initial capacity for such households to use energy for more socioeconomic activities, which in turn improve their capacity to use the expanded grid infrastructure.

6 Policy implications

In this project, we investigated the effects of grid connectivity in Uganda on selected key socioeconomic outcomes. The findings show that grid connectivity has largely positive and significant impacts on a range of development outcomes. These results were found to be robust to the different dimensions of the analysis. Specifically, similar effects were found whether the analysis was based on a difference-in-difference estimation, on OLS with fixed effects estimation, or when different measures of grid connectivity were used. This suggests that the findings do not depend on the estimation method used or the measure of grid connectivity.

The project makes the following contributions: First, it highlights how the impacts of grid connectivity can depend on local socioeconomic conditions. For instance, electricity from the grid may enhance local economic activity with respect to the production of certain goods. Importantly, however, all the empirical results show that infrastructure has positive and significant effects on the selected socioeconomic outcomes, i.e., achieving the benefits of electrification may require complementary factors to be in place. Such factors might include demand for these locally produced goods, through the availability of markets and roads, and other supportive services, such as schools to train the labour force, health services to guarantee a healthy labour force, or financial services to provide credit.

Second, certain context-specific factors have been neglected in studies based on establishing the "average treatment effect" of grid expansion as part of national rural electrification programs. Uganda has experienced improvements in other socioeconomic infrastructure. This study shows that grid electricity provides more opportunities in combination with other infrastructure than either approach provides alone. The findings are expected to inform policy on the complementary role of infrastructure in electrification. This is expected to help guide policymakers in determining how to sequence development interventions.

An important direction for future research should be to understand when, where, and after how long, electricity access has the greatest economic impact. For example, electrification may result in substantial gains in economic productivity in urban settings, or in regions with some industries. Finally, quantifying the non-market benefits from electrification is another interesting dimension for future research.

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