Evaluating Economic Impacts of Electrification in Zambia

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Contents

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Abstract

Energy poverty is prevalent in Zambia. It is one of the world's least electrified nations with 69% of its citizens living in darkness, without access to grid electricity. Zambian government has a goal to achieve universal electricity access in urban areas and increase rural electrification to 51% by 2030. With its main goal to improve the quality of life and wellbeing of Zambians. Electrification is expected to have positive impacts on health, education and employment play an important role to achieve wellbeing, however, previous studies and analysis of renewable energy programs have found different, context-dependent results. To evaluate the impacts of electrification in Zambia I have used the Living Conditions Monitoring Survey (LCMS) of 2015 and applied two different estimation techniques: non-linear regressions and propensity score matching. My study finds that firewood consumption significantly decreases with assess to electricity and education has positive outcomes on grade attainment. I negligible effects on wage earning employment outcomes respiratory health outcomes. Based on these results I conclude that access to grid electrification does have certain positive impacts but empirical evidence is not as strong as the theoretical claims.

JEL classification: C31; C78; O13; Q40

Keywords: Energy Access, Development, Sub-Saharan Africa

I. Introduction

More than 1.3 Billion people in the developing world lack access to electricity and live in darkness. Some 590 million of the energy poor population lives in Sub Saharan Africa alone (IEA, WEO 2018). Through my study I evaluate economic impacts of energy access in one Sub-Saharan country- Zambia.

It is often hypothesized that the lack of access to electricity causes other developmental challenges. Energy Access is a foundation for developmental goals the world is striving to achieve in the 21st century (UN SDG, 2015). Energy is the driver of activity in every economy and, therefore, its importance cannot be overemphasized. A 2014 study from the World Bank found that, in Sub-Saharan Africa, the average household spends around 2 hours per day collecting firewood (Kammila et al. 2014). Globally, these time burdens, like the health effects from indoor air pollution exposure, disproportionately fall on a certain demographic section of society based on age and gender. These include women and children, primarily girls (Adair-Rohani et al. 2016; Köhlin et al. 2011). Various individual level, household level and community level impacts of energy poverty are wide-ranging (Jeuland and Pattanayak 2012). Emissions from polluting fuels have implications for human health, for those who spend time indoors while combustion is happening, again, mostly women and children (Rückerl et al. 2011; Anderson et al. 2012).

Sub-Saharan Africa (SSA) faces general problems of access to modern energy. Most households and industry in SSA use traditional and unclean energy resources for activities such as cooking, lighting and drying of farm produce. Many households in less developed countries have very limited choices with regard to alternatives to traditional energy supplies. The number of rural communities relying on the traditional use of biomass is projected to rise from 2.7 billion today to 2.8 billion in 2030 (Kaygusuz, 2012). Based on the assessments discussed above, energy poverty is overt in many poor countries, electrification is a service which can pave way for progress and growth on issues such as poverty alleviation, gender equity and public health. The energy industry faces a plethora of challenges; these include but are not limited to institutional challenges, business model challenges, industrial challenges and financial challenges (SIPA 2017). Measuring whether someone has energy access or not does not paint a complete picture of the quality of access itself. Universal access to contemporary energy services, in terms of access to electricity and to clean cooking facilities, has been recognized as one of the fundamental challenges for economic development. Despite strong praise for action and the deployment of large-scale electrification programs and improved cookstove (ICS) distribution campaigns, not a lot of studies have focused on the barriers to, the enablers of and the impacts of connection to energy sources on development outcomes, using rigorous methodologies and evaluations. Access to energy impacts socioeconomic development. Energy enables individuals to harness applications across households, productive uses, and community infrastructure. "Universal access to modern energy by 2030" has been proposed as one of the three key pillars of the Sustainable Energy for All (SE4All) program, an initiative co-chaired by the United Nations (UN) Secretary General and the World Bank President. The world is not moving fast enough to reach its universal electricity access goal by 2030 (SEAR 2017). A substantial acceleration of efforts and investments are needed to achieve this objective. In countries with low levels of electricity access, both grid and off-grid solutions are vital for achieving universal access but they must be supported by an enabling environment with the right policies, regulations and incentives. It is very clear in a Shell foundation report (2018) that the present resources are inadequate because with the current pace of financing, SDG7 will be missed by more than 100 million households in sub-Saharan Africa. A study by McKinsey and Company (2014) states that the African Development Bank estimates that the regions needs to invest approximately $42 Billion per year in energy infrastructure over the next decade and a report by the Oxford Business School (2018) estimates that Peru would need an investment of $33 Billion. It is important to study the impacts from energy access to developmental and economic outcomes to attract more funding and break through these investment barriers.

For the scope of my paper I focus on a Sub-Saharan African country because of two primary reasons: (1) The concentration of lack of energy access in the region and (2) The lack of assessment of energy access drivers, indicators and impacts in the region. This past year (2018) the High-level Political Forum, which is the United Nations central platform for follow-up and review of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals focused on concentrating efforts for SDG 7 (Ensure access to affordable, reliable, sustainable and modern energy for all), on Sub Saharan Africa. More specifically I zoom in on Zambia, a nation with a country-wide average of 69% (LCMS, 2015) of its population lacking access to electricity; the number increases to 96% in rural areas. The Government of Zambia has ambitious electrification targets which also highlight the opportunity for improvement and efficient planning using the economic analysis. Zambia has set a target of achieving ambitions goals with a key aim of ‘improving quality of life’ (IEA 2015). These goals are three-fold:

- 100% access to electricity in urban areas
- 51% in rural areas, by 2030 (carried out by the Rural Electrification Authority, REA)
- reducing firewood consumption by 40%

After a visit to Zambia in March 2019, I was able gather a first-hand perspective on the on-ground reality and impacts of electricity on everyday life of Zambians. I took away some observations and insights from time spent in 3 villages: Choma, Monze and Chibombo. Some of the households in these villages were connected to the national grid while the others weren’t. Some observable factors these households differed in were: the construction material used to build them, number of people residing in a household, occupational choices of household members and the fuel they collection and consumption patterns for every day activities like cooking and lighting. I incorporated these factors from the ground to my regression model further explained in a later section of my paper.

II. Background

The case of Zambia

Zambia, a landlocked sub-Saharan country shares its boundaries with Malawi, Mozambique, Zimbabwe, Botswana, Namibia, Angola, Democratic Republic of Congo and Tanzania. The country covers a land area of 752,612 square kilometers. Only half of the 58 percent of Zambia's total potential arable land (an area of 39 million hectares) is cultivated. Its weather patterns depend on its geographical positioning. It lies between 8- and 18-degrees South latitudes and longitudes 22 and 34 degrees East, the country is prone to drought due to erratic rainfall. The Zambian economy depends highly on copper and cobalt deposits, some of the largest in the world (ILO, Overview on Zambia).

According to the Living Conditions Monitoring Survey (LCMS, 2016) Report, Zambia currently has 2,800 MW of installed electricity generation capacity (85% is hydro based). National access to electricity averages at 31%, 67% of the urban population and 4% of the rural population having access to power. Appendix Figure A1 highlights the regional differences in energy access by province, showing the copper belt and the capital to be more electrified and urbanized.

In 1996, the Government of Zambia (GRZ) set a goal for universal electricity access for all Zambians by 2030. Hence, energy has been identified as an important driving force behind economic development in Zambia, and the government has declared its commitment to developing and maintaining energy infrastructure and services. A vast majority of power in Zambia including generation, transmission and distribution is operated by ZESCO, the vertically integrated state-owned utility but Zambia also has a few small private players in the area. Zambia expects to bring online additional MW of solar, hydro, and thermal power through 2020 to add diversity to its portfolio with alternative means of energy sources. Two other players in the utility space include the Copperbelt Energy Corporation (CEC) and the Lusemfwa Electricity Company.

Currently, Zambia’s energy sources include; electricity, petroleum, coal, biomass, and renewable energy. It is only petroleum which is wholly imported in the country, while the country is basically self-sufficient in all the other energy resources and also has substantial untapped reserves of these forms of energy. With an average economic growth of 5 percent per annum over the past 10 years, the demand for energy has been rising. The demand for electricity has been growing at an average of about 3 percent per annum because of the increased economic activity in the country especially in the agriculture, manufacturing and mining sectors (ZDA, Energy Sector Profile). The trend of increase in access to electricity in the country is shown in the Appendix Figure A2.

The USAID, Zambia Power Sector Assessment (2018) is a careful examination of the sector which reveals that Zambia is unlikely to meet its aspirations for 2030 in terms of new megawatts (MW) and connections – reaching 7.2 GW in generation capacity (from 2.8 GW currently) and a 66 percent electrification rate (from 27 percent currently) – unless it can transform ZESCO’s (Zambia’s local electric utility) performance and addresses various gaps in institutional design. Transforming ZESCO’s performance to attain commercial viability is critical to accelerate delivery of electrification, address the potential supply-demand gap, and meet Zambia’s power sector aspirations. Current issues faced by ZESCO include: capacity constraints, insufficient revenue collection, high transmission and distribution losses, the absence of cost-reflective tariffs and balance sheet constraints (Batidzirai et al. 2018). According to the USAID report, Zambia also needs to clarify the contributions it requires from the private sector in terms of, e.g., new capacity investments and off-grid electrification to cater to its increasing energy demand.

Power generation has been declared a priority sector after the amendment to the second schedule of the ZDA Act. This amendment recognizes the need to reduce the cost of developing power plants and attract independent power producers to maximize generation capacity in Zambia. Although Zambia is blessed with renewable resources, its efforts to harness these resources have been minimal. In the

National Energy Policy of 2008, the government stated its intentions for promoting alternative sources of energy such as renewable energy.

In the Rural Electrification in Zambia: A Policy and Institutional Analysis (2008), Charles M. Haanyika finds out that renewable energy electrification has the potential positive impacts on various other sectors. These sectors include agricultural production, tourism and also mining activities. Although the installed electricity generation capacity is almost fully used up, the large undeveloped hydropower potential and energy from other renewable energy resources could be developed and used to meet electricity demand in all rural areas of the country.

III. Literature Review

Impacts of electrification

Electricity may not solely be responsible and able to create all the conditions for economic growth, but energy services like lighting, cooking, cooling, heating, etc. are obviously essential for basic human and economic activity (IEA, 2013). In theory, access to electricity can improve socio-economic conditions in developing countries because of its influence on key components of poverty: health, education, income and environment (Kanagawa and Nakata, 2008). Khandker, Barnes, and Samad (2009) claim that lack of access to electricity is one of the major impediments to economic development in rural parts of the world. Many empirical studies over the years have assessed whether or not these theorized effects of electrification are observed in reality. Three recent reviews of the energy space are presented by Köhlin et al (2015), Bonan, Pareglio, and Tavoni (2016), Peters and Sievert (2016). These review papers identify a total of thirty-three studies on the impacts of electrification. The thirty-three studies focus on countries in three developing continents, namely Asia, Africa and Latin America. The oldest of these studies dates back to 2004 and the most recent one covers studies in 2015. These studies consider a number of electrification outcomes on the household level as well as the individual level. These outcomes can be clubbed into three main categories:

- Employment (productivity),
- Health and
- Education.

I use mirror these categories to evaluate electrification outcomes in my further assessment.

Impact on Productivity (Employment, income and other productivity indicators)

Electrification has positive impacts on productivity but they have been highly varied across contexts and usually smaller than donors expected. Positive impacts tend to occur in better-off areas which shows the exacerbating inequality. Little evidence that it helps the poorest gain higher income or productivity. Electricity is seen as a pre-requisite for productive activities because there is a strong correlation between rural poverty and access to electricity (Chaurey, Ranganathan and Mohanty, 2004). The three reviews of the thirty-three studies mentioned above find evidence of positive impacts on employment, labor supply, income and other productive uses of energy. Electrification can lead to improvements in household economic indicators through adoption of appliances that increase productivity, enabling development of household enterprises, reducing the time needed for household chores (including firewood collection), increasing the time available to engage in income generating activities. Khandker, Barnes, Samad, and Mihn (2009) assess the economic impacts of rural electrification in Vietnam using panel data estimation techniques. They find that electrification leads to a twenty-five percent increase in household income, most of which comes from increases in farm income. A 1986 study of India's renewable energy expansion between 1966 and 1980 found that electrification had positive effects on agricultural productivity, but the magnitude of impacts was less than the planners expected at the onset of the program (Barnes and Binswanger 1986). Similar findings were observed in a state-level assessment of infrastructure spending and rural wages in India between 1970 and 1993. The report finds that expenditure on energy infrastructure did reduce rural poverty, but the magnitude of the reduction was small compared to investments in things like roads and agricultural research and development (Fan et al. 2000). Dinkleman (2011) found positive impacts of electrification on female employment in South Africa. However, they found no increase in wages. This effect was attributed to constant labor demand. Dasso and Fernandez (2015) find that electrification in Peru led to economic improvements for both men and women. After electrification, men work more hours (usually after sunset because of lighting appliances), but are less likely to have a second job. For women the effects are a little different because electrification not only leads to improvements in the opportunities and employment status but also increases their income. It also increases the likelihood that a woman is employed in a sector that is not agriculture. In the Sub-Saharan African context, the study by Peters and

Sievert (2016) finds that electrification does not lead to increase in employment and households rarely use electric appliances for productive uses, like the electric water pumps that led to productivity improvements. They also fail to observe a shift in time use from household tasks to income earning activities in any of the African contexts they studied. They hypothesize this is because of a lack of market connectivity which prevents new firms from emerging as they cannot access markets for their goods. This hypothesis is credible because the few contexts where they do find positive effects on new enterprise (Rwanda and Benin), these effects are observed in business centers with established market connections (Peters and Sievert 2016). A smaller set of studies assesses the impact of electrification on firm-level outcomes. The few reviewed in Bonan et al. (2016) identify positive impacts of electrification on the quantity and diversity of firms and on output levels (Rud 2012; Peters et al. 2011). Some studies point out that employment and productivity effects are harder to capture because they are more prevalent in a long or medium term than in shorter term outcomes.

Impact on Education

Electrification leads to education improvements primarily through increasing the time available for children to go to school, through substitution in time spent on household chores with that spent on studying. This is attributed to the increase in the quality and quantity of household lighting. These outcomes can also be achieved through community-level effects of electrification, e.g. schools getting access to electricity will also lead to access of resources such as internet and computer labs. Community level effects also capture the increases in household-level education expenditure. Education outcomes measured as expenditure, literacy and enrollment, years of completed schooling (also known as grade attainment) and daily study time (Lipscomb et al. 2013; Khandker et al. 2012). In the case of Brazil, Lipscomb et al. (2013) found that electrification at the county level leads to improvements in both enrollment rates and their literacy rates. The effect size is huge as it is equivalent to moving from the fiftieth to the ninetieth percentile, in terms of county-level educational outcomes. In Bangladesh, Khandker et al. (2012). It also found increases in both completed years of schooling and daily study time which were achieved by the household level characteristics. The positive impacts are almost twice as high for boys, when compared to girls, with respect to both years of schooling and study time. In the Sun Saharan African context, studies find an increase in study time after nightfall, which only leads to an increase in total study time if there is no decrease in study time during the sunlight hours. In two contexts, the authors do find a decrease in day-time studying. This could be because of time allocation to leisure activities such as watching television. Senegal was the only country where they were able to identify an increase in total study time combining the day time and night time study hours (Peters and Sievert 2016).

Impact on Health

Health impacts are examined in fewer studies than economic and education outcomes. With regards to health impacts, electrification primarily leads to health improvements through its negative impacts on kerosene and biomass fuel (example: firewood) use and the subsequent reduction in indoor air pollution. In El Salvador (Barron & Torero, 2015) electrification leads to fewer respiratory infections in children under six years of age. This effect comes from reduction in kerosene use and associated particulate matter concentrations in electrified households (Barron and Torero 2015). Solar home systems in Bangladesh are also associated with improved health, particularly for women and girls who spend more time home (Samad et al. 2013). In the African context, electrification has modest effects on health. In the past five or ten years, the use of affordable and accessible LED lights has greatly replaced kerosene and candle use in many rural areas. Since kerosene use is already on the decline, even without access to electricity, electricity access's potential contribution to health outcomes may be low and falling (Peters and Sievert 2016).

Most of the econometric papers that one finds in the literature are actually case studies. The impact of rural electrification is often evaluated for one country or region because electrification is very context and region specific. This is because most energy markets are highly regulated and governments of each country differ from one another in the way they operate and the developmental goals they prioritize.

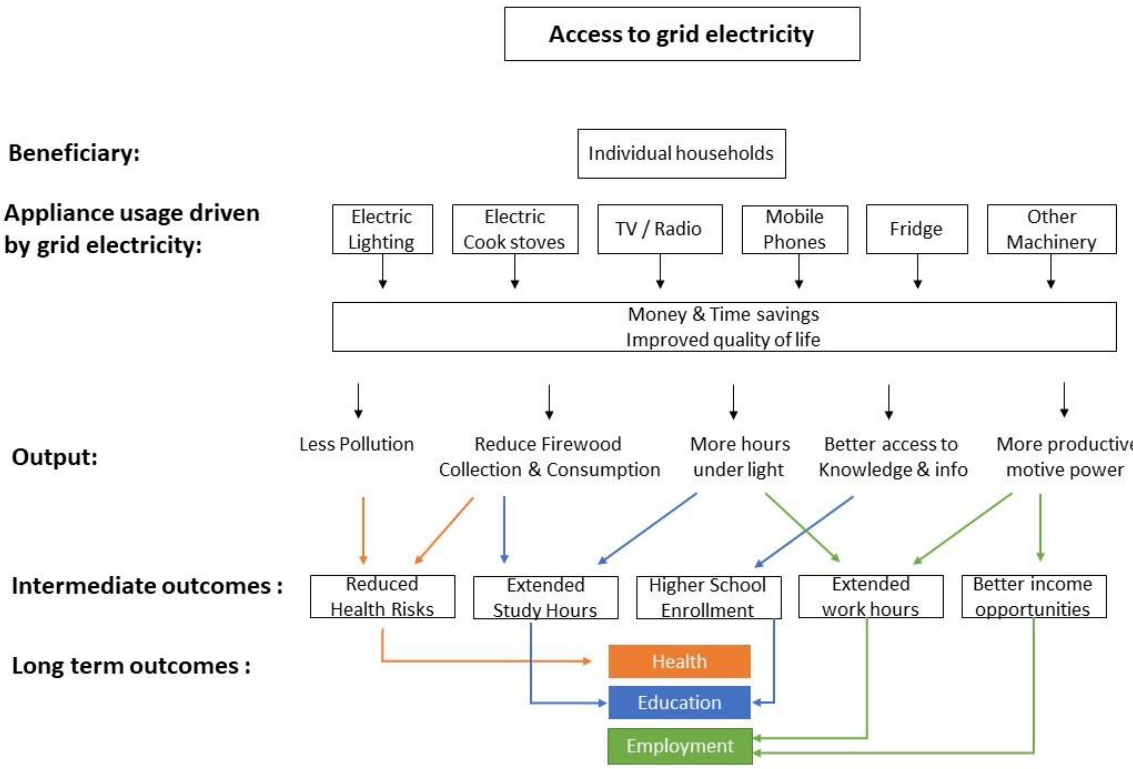
As mentioned in the previous section, one of my main motivations to study Zambia was the lack of research done on the geographical area. Most if not all articles in the African continent focus on electrification in South Africa; for example, Dinkelman (2011) that estimates the impact of rural electrification on employment and Davis (1998) who tries to identify the effects of access to electricity on rural households' choice of fuel. The impact of access to electricity in South Africa is also studied by Spalding-Fecher and Matibe (2003) and Madubansi and Shackleton (2006). The keen interest in this particular country can be explained by the historical perspective of the evolution of electricity access in remote areas of South Africa. In the early 1990s after the democratic transition, the government implemented an electrification program in the country; apartheid policies had created considerable disparities in access to infrastructure (Madubansi and Shackleton, 2006; Bekker et al., 2007). This quite recent roll-out of grid infrastructure in South Africa and the provision of electricity to households provide a very good opportunity to evaluate their impacts (Davis, 1998, Dinkelman, 2011). The findings in most papers also differ depending on the choice of datasets and econometric models.

Until very recently, the possibility of identifying causal relationships between electrification access and its impacts on productivity or rural incomes was limited to macroeconomic studies based upon time series. These studies attempted to identify whether or not these investments preceded the supposed effects that are attributed to such investments. In recent years, however, with the development of evaluation methodologies [Rosenbaum and Rubin (1983) or Heckman, Ichimura and Todd (1998)], advances have been made in establishing causal links from microeconomic evidence, comparing the trajectory of individuals subject to interventions, in relation to the trajectory of other comparable individuals that have not been subject to interventions [for example IEG (2008), van de

Walle (2003), Galiani, Gertler and Schargrodsky (2005) and Escobal and Torero (2005)]. This led me to employ microeconomic factors to my analysis.

IV. Theoretical Framework

Figure 1: Electricity use and outcomes in rural households



For households in rural areas, gaining access to electricity could theoretically lead to improvements in education, health and poverty. The theory of change framework is an adaptation of the schematic diagram presented in Peters & Sievert (2016), Appendix Figure A3. It lays out the many potential pathways through which access to electricity at the individual and household level can lead to adoption of technological appliances which save time, are cost effective and lead to an improved quality of life- the goal of many governments around the world. This change because of the provision of electricity has its associated outputs that lead to intermediate as well as long term positive impacts on health, education and employment (note: these are the same outcomes observed in the 33 studies from 3 reviews mentioned in the literature review section).

Health and environmental outcomes: The World Health Organization estimates that indoor air pollution causes 4.3 million premature deaths annually, making it the highest environmental risk for deaths (Adair-Rohani et al. 2016). Switching away from traditional biomass fuels, towards cleaner fuels (for lighting and cooking) and more modern appliances, reduces indoor air pollution. Currently households traditionally use polluting fuels like firewood. In addition to environmental impacts, firewood emissions have health implications, especially among women and children, who spend time indoors while combustion is happening (Rückerl et al. 2011; Anderson et al. 2012). Use of polluting fuels also has major time-use implications. A 2014 study from the World Bank found that, in Sub-Saharan Africa, the average household spends around 2 hours per day collecting firewood (Kammila et al. 2014). Globally, these time burdens, like the health effects from indoor air pollution exposure, disproportionately fall on women and children, primarily girls (Adair-Rohani et al. 2016; Köhlin et al. 2011). Emissions from kerosene are almost one hundred percent black carbon, a particulate or aerosol that is second only to carbon dioxide in contributions to current atmospheric warming (Adair-Rohani et al. 2016; Ramanathan and Carmichael 2008).

Education outcome: Time spent collecting and preparing fuel prevents individuals from pursuing more productive activities, in the case of children this includes attending school or studying after school. Improved electric lighting can also extend the time children have to study at home (Khandker et al. 2012).

Employment outcomes: These time savings, in addition to more productive hours in the day because of improved electric lighting, can free up time for household members to increase their incomes through wage-earning or income generating activities. At the community level, lack of access to electricity can hinder the development of energy-intensive enterprises and the associated increases in labor demand and wage-earning opportunities. These opportunities can be created through adoption of technology and the potential of self-started businesses.

V. Data

In order to estimate the impact of electrification, I rely on the Zambia Living Conditions Monitoring Survey (LCMS), obtained from the Zambian government's Central Statistical Office. The Zambia LCMS sampling and data collection methodologies are based on the World Bank's Living Standard Measurement Survey. The survey evolved from the Social Dimensions of Adjustment Priority surveys conducted by the Central Statistical Office of Zambia in 1991 and 1993. LCMS is a seven series dataset collected in 1996, 1998, 2002/2003, 2004, 2006, 2010 and 2015. I use the latest, 2015 data which uses the same sampling frame as the 2010 Census of Population and Housing. I was limited to use just one year because of restriction on the availability of the required dataset from previous years. The survey uses a total of 664 enumeration areas, selected from 25,600 enumeration areas across all 10 provinces in Zambia which speaks to representation from the entire nation. The sample has 12,260 non-institutionalized households from both urban and rural areas. The data is not a panel, but a repeated cross section.

Questions are asked at the household and individual level, and the data collected covers a wide range of topics, including demographics, education, health, employment, housing, income, asset ownership, public facilities, access to services, credit, social capital, poverty, and happiness. The diversity of questions is important because it not only allows for the estimation of the impacts of Rural Electrification on the diverse array of outcomes which the program targeted, but it also allows for the consideration of confounding factors which affect the desired outcomes and differ between households with and without access to electricity.

The LCMS estimated a total population of 15.5 million people with 58.2 percent of the total population living in rural areas. The survey estimated a total of 2,014,965 households in the country and an average household size of 5.1 people in each household. According to the LCMS report published in 2016, 54.4 percent of the population lives below the poverty line; unpaid family workers account for 6.3

percent and unemployed made up 9.2 percent of the working population. Most rural households spend majority of their income on food (56.4 percent) and 43.6 percent on non-food items (which would also include electricity), in urban areas households spend 34.7% of household income on food and the rest on non-food items, including electricity and other energy sources. (LCMS Report, 2016)

Based on Zambian government's energy access goals, literature review and theoretical framework, I constructed 4 outcome variables from the data set that measure impacts on health, education and employment. (Construction of all variables explained in the appendix Table A1) These variables capture the health effects through firewood consumption and respiratory illness; Productivity through employment in a wage-earning business; and education through grade attainment for children between 7 and 18. Table 1 represents the summary statistics of dependent and independent variables used. After cleaning the dataset, I studied 62,854 individuals which belonged to 12,246 households. With the household characteristics I capture the number of individuals in each household and also demographic information about the household head who mostly has the decision-making authority in the household. The individual characterizes measure demographic information about each individual and their relationship to the household head. After constructing correlation matrices among the variables (Appendix Table A2), I observed multicollinearity between one par of variables: Gender of the head of household (hoh_gender) and the Marital status of the head of household (hoh_maritalstatus). I added an interaction variable to account for this multicollinearity by multiplying the two variables.

Table 1: Summary Statistics of variables included in the study

Variable	N	Mean	Standard Deviation
Outcomes			
Grid Access (1=yes)	62,854	0.3461196	0.4757357
Monthly firewood consumption (1=yes)	62,854	0.4751965	0.4993884
Employed in Own Business or Wage-Earning Activity (1=yes)	62,854	0.2803958	0.4491962
Sick with a respiratory illness in the last 2 weeks (1=yes)	62,854	0.0311675	0.1737715
Years of completed school for children between 7 and 18	19,230	8.37377	0.1907421
Household Characteristics			
Household size	12,246	6.46927	2.904015
Gender of household head (0= female, 1=male)	12,246	.8008878	0.3993358
Age of household head	12,246	0.0178509	0.1324104
Marital status of household head (1= married)	12,246	0.7933147	0.404931
Brick is main household construction material (1= yes)	12,246	0.0495275	0.2169683
Individual Characteristics			
Age	62,854	24.34859	16.68972
Gender (0= female,1=male)	62,854	.4858638	0.4998041
Relation to head of household (1=self)	62,854	0.1948325	0.3960748
marital status	62,854	0.2883031	0.4529765

V. Methodology

As mentioned before, in my analysis, I consider four outcomes explicitly mentioned or constructed from the survey data. These outcomes test the theory with empirical evidence for common targets governments want to achieve when talking about electrification. Broadly these outcomes measure quality of life. The outcome variables include 1) firewood consumption, binary variable as a measure of biomass fuel use to study health and environmental aspects at the individual level, 2) years of completed schooling among children ages 7 to 18, as a measure of education outcomes, 3) reported respiratory illness in the two weeks before the survey, as a measure of improved health, and 4) employment status in a personal business or a wage-earning activity.

I use two methods to estimate the impacts on these four outcomes identified above. The first is linear and non-linear regression methodologies, controlling for the household- and individual-level drivers identified. The outcomes of interest are modeled as a function of grid electrification as well as the drivers identified above, district characteristics, and individual characteristics. The following equation is estimated:

$$y_{ih_J} = \beta_0 + \beta_1 E_{ijh} + \beta_2 X_{hj} + \beta_4 V_{ijh} + \gamma + \varepsilon_{ihj} \qquad (1)$$

Where y_{ih_J} is the outcome of interest, E_{ijh} is status of grid electrification, X_{hj} is a set of household characteristics in community j, and V_{ijh} is a set of individual characteristics for individual i in household h in community j. γ is the district fixed effects to account for unobserved characteristics in each district that may be simultaneously driving grid electrification and other household and individual characteristics and ε_{ihj} is the error term. I would estimate this equation using a number of regression models. In the case of firewood consumption, health and employment outcomes, all measured as binary outcomes equal to 1 if an individual reported to be using firewood, ill or employed in a personal business or wage-earning activity, probit estimation is used. In the case of education outcomes, measured as a count variable of years of completed schooling, negative binomial regression be used.

As an additional estimate and robustness check, I apply propensity score matching techniques, which is an increasingly popular approach in practical evaluations of development and environment outcomes (Pattanayak, 2009). In applying this technique, I first calculate a household's probability of treatment, which means if it is connected to the grid or not, conditional on a set of household and individual characteristics. The propensity score for each household is the probability of treatment estimated from this equation, i.e.:

$$p_{hj}(X_{hj}, Z_j) = \Pr(E_{hj} = 1 | X_{hj}, Z_j) = E[E_{hj} | X_{hj}, Z_j] \quad (2)$$

Where p_{h_J} is the propensity score, equal to the expected value of E_{hj} conditional on X_{hj} and Z_j (Rosenbaum and Rubin 1983). Grid connected households are then matched with non-connected households based on this propensity score, using the nearest neighbor matching techniques to reduce the difference in propensity score between matched treatment and control households (Rosenbaum and Rubin 1985). In applying nearest neighbor matching, I match each treated house to the nearest control house; I match on only one unit to minimize bias. This matched subsample generates a treatment and control group that are similar on characteristics known to be driving grid electrification. Propensity score matching techniques are beneficial in that they do not restrict the relationship between outcomes and covariates to a pre-defined functional form.

There exist some limitations to the method because while this methodology satisfies the assumption that all potentially confounding variables can be observed, it does not account for unobserved characteristics that may bias the impact estimates. The additional assumption required then is that unobserved characteristics are sufficiently correlated with observables so that, after conditioning on observable characteristics, treatment assignment is random. When the majority of households in a community connect to the grid, bias from household-level unobserved characteristics may be reduced. The rapid increase in electrification rates can also reduce endogeneity bias, given that other factors that may be driving outcomes had less time to change over the restricted time period of this study. All of these factors combined reduces the bias from household- and community-level unobserved characteristics.

VI. Results

The methodology discussed prior to this section is applied to the sample of individuals. Table 2 provides a snapshot of differences between the outcomes, household characteristics and individual characteristics in households which are not connected to the grid and those that are connected to the grid. A total of 7,967 households and 41,099 individuals live in darkness as they are not connected to the grid and 4,279 households and 21,755 individuals have access to grid electricity. About 70% of the individuals with no access use firewood whereas only 3% of individuals connected to the grid used firewood as a fuel in 2015. About 28% of both the connected and non-connected population had their own businesses or were involved in a wage-earning activity. More individuals exposed to indoor air pollution suffered from respiratory illness in the recent two weeks. Children who lived in households without electricity studied up to grade 5 on an average, whereas the children who lived in households with electricity access studied 3 more years (grade 8) on average. The difference in the means are highly significant for all outcomes except from employment. Graphical representations of these differences are shown in Figure 2. The grid connected and non-grid connected households have significant differences in most other categories at the household as well as the individual level. The wealth variable, (captured if the building material of the house is bricks). Non-connected households are larger, more likely headed by an older male.

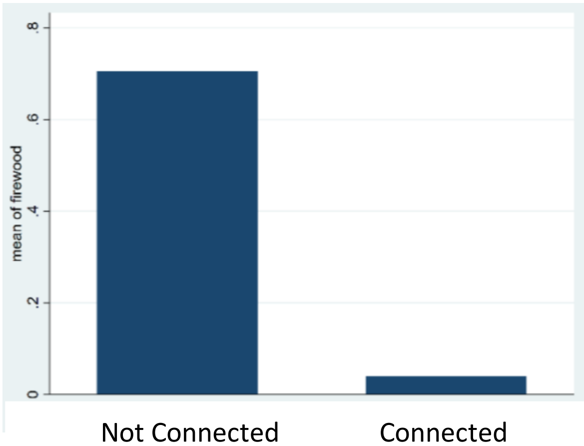
Table2: Key Variables and Comparison of Connected & not connected households

Variable	Not connected to the grid		Connected to the grid		
	N	Mean	N	Mean	Diff in Mean
Outcomes					
Monthly firewood consumption (1=yes)	41,099	0.705	21,755	0.039	0.666***
Employed in Own Business or Wage-Earning Activity (1=yes)	41,099	0.2802258	21,755	0.2807171	-0.0004913
Sick with a respiratory illness in the last 2 weeks (1=yes)	41,099	0.03654	21,755	0.021006	0.015534***
Years of completed school for children between 7 and 18	13,087	5.14	6,143	8.37	-3.23***
Household Characteristics					
Household size	7967	6.53	4279	6.35	0.18***
Gender of household head (1=male, 0= female)	7967	.7920387	4279	.8176051	0.02***
Age of household head	7967	44.51	4279	44.02	0.49***
Marital status of household head (1= married)	7967	0.79	4279	0.78	0.01***
Brick is main household construction material (1= yes)	7967	0.117	4279	0.013	0.104***
Individual Characteristics					
Age	41,099	24.08	21,755	24.85	-0.77***
Gender (1=male, 0= female)	41,099	.4856441	21,755	.486279	0.001
Relation to household head (1=self)	41,099	0.193849	21,755	0.19669	-0.002841
marital status	41,099	0.29081	21,755	0.283567	0.007243**

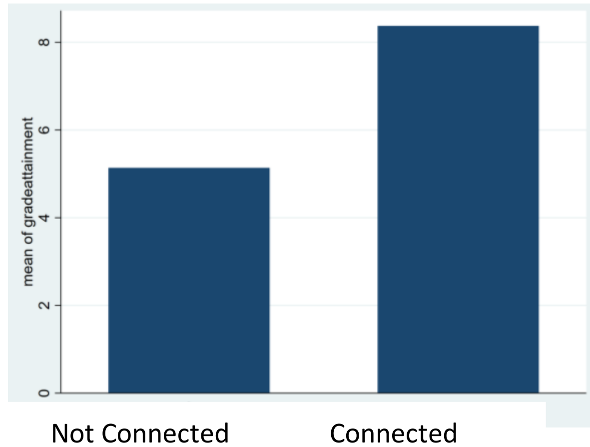
Stars indicate significance level of t-test of difference in means; *** p<0.01, ** p<0.05, * p<0.1

Figure2: Comparison of Means of key outcomes, not connected v. connected to the grid

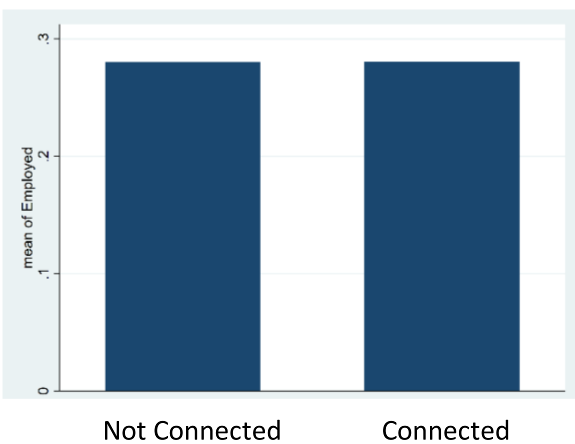
Firewood Consumption



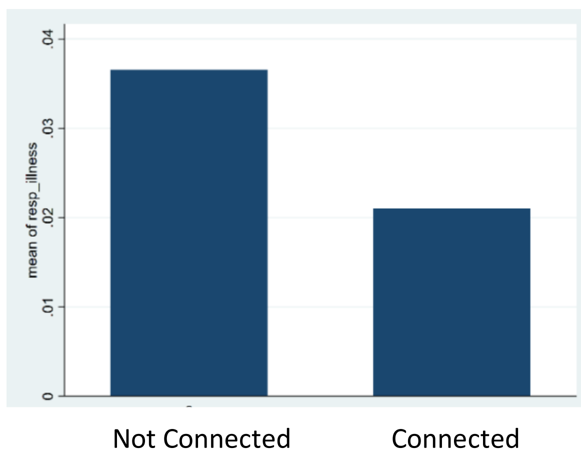
Grade Attainment



Labor Supply



Respiratory Illness



Determinants of grid Electrification

Regression analysis mentioned in the methodology section confirms what is illustrated in Table2. The results from estimating equation (1) is presented in Table3. All variables are very significant and hence many of the variables identified in Table 1 and 2 are drivers of grid electrification. The results show is wealth is an important aspect which is captured by the building material used for house construction. Houses whose dwellings are constructed from brick represent more wealthy households. The gender of household head also plays an important role on the household level decision making. Table A3 in the appendix presents the predicted effects of outcomes and drivers. Most of them have predicted relationships except the ones with a bold box in the table. The findings are similar to other studies in the field. A systematic review on cookstoves adoption (Lewis and Pattanayak, 2012) reports that adoption of new technology is positively related to income and education. Another study of electrification in Bangladesh speaks to the correlation between households made of brick and access to electrification (Khandker et al.,2012).

Table 3: Drivers of Grid Connection

Variable	Grid connection (1=yes)	
Household Characteristics	(1)	(2)
Household size	.0056783*** (.0006533)	.0056783* (.0039965)
Gender of household head (1=male, 0= female)	.1297293*** (.0078634)	.1297293*** (.0169686)
Age of household head	.0983571*** (.0136963)	.0983571*** (.0210308)
Marital status of household head (1= married)	-.092518*** (.0082817)	-.092518*** (.0212981)
Brick is main household construction material (1= yes)	.4982673*** (.007116)	.4982673*** (.0316314)
Individual Characteristics		
Age	.0010254*** (.0001419)	.0010254*** (.0002426)
Gender (1=male, 0= female)	-.003314 (.0039545)	-.003314 (.0038595)
Relation to household head (1=self)	.0133439*** (.0063189)	.0133439** (.0064572)
marital status	.0253389*** (.0055369)	.0253389*** (.0047274)

Values reported are coefficients of linear regression
Robust Standard Errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1
Standard errors in column 2 clustered at a district level

Impact Analysis

The results from estimating equation (1) and (2) are presented in Panels A and B respectively in Table 4. In panel A, column 1 presents the results of a bivariate regression of the outcome of interest on the status of grid electrification. Column 2, 3 and 4 test the robustness of this estimate by including household level and individual level covariates and district fixed effects. Column 4 also includes the clustering of standard errors at a district level. The last two columns divide the population by gender to see impacts on men/boys and women/girls differently.

The regressions show that electrification and having access to the grid led to a decrease in firewood fuel consumption (by 53 percentage points). Table 5 helps interpret the Probit regression by reporting the predicted probability. Houses with no access to grid electrification are much more likely to use firewood as compared to households with access to grid electricity. Similar results are seen in the education outcome.

Children in houses connected to the grid are more likely to attain higher levels of education than children who live without the access to electricity this is because they will be spending more time collecting fuel, have lesser access to resources and do not have lighting to do productive activities such as studying after sunset. These children with access to lighting get about 3-4 years of additional schooling. It is seen that boys get one additional year of schooling than girls with access to electricity. This may be because of females bear heavier time burdens with regards to fuel collection and preparation. Electricity grid connections reduce a portion of this time burden, allowing girls to spend more time studying or in school.

With respect to employment, there is evidence that grid electrification leads almost no change in the likelihood of working age adults being employed, either in a personal business or through wage-earning activities. This may be because of two reasons. (1) There are limitations within the dataset because of omitted variable bias. The data does not account for the level of wage earnings and if the electricity increases income but simply only measures if the person is engaged in any productive wage-earning activity. It is not the most ideal variable to measure productivity but was the best possible indicator available through the survey. (2) Employment outcomes have more long term impacts and my study of cross sectional data only captures very short term impacts.

The small difference in instance of respiratory illness (1.2 percentage points) among individuals between nonconnected and connected households that was observed. People without access to electricity have a higher probability of getting sick from breathing in the particulate matter. It is important to note that electrification leads to a reduction in firewood consumption at the household, it does not eliminate firewood consumption. Biomass is still being used for fuel at grid-connected households, which leads to the same negative health effects from indoor air pollution discussed in the first section of this study. It is also hard to observe improvements in health outcomes as indoor air pollutant concentrations need to be reduced to very low levels.

The robustness of these findings is further tested using propensity score matching techniques. The results are reported in Panel B of Table 4. The propensity score was calculated based on the Probit model estimated in the first stage of this analysis for firewood consumption, respiratory health and employment and the initial negative binomial regression for education variable. Household-level observations were then matched using nearest neighbor matching (n=1). The results of the matching method are presented. The Propensity Score Matching estimates are consistent with those presented in Panel A, though the point estimates are slightly larger. All estimates of outcome are significant in this estimation. However, the impact on respiratory illness and employment are very small and negligible. These findings match with the findings of Peters and Sievert's review from 2016 which claim that the impacts in the African context are not large in magnitude. The respiratory health and employment impacts in their studies were also not substantial in relation to studies in other continents.

Taken together, these estimation methods provide evidence that, with regards to education and reduced biomass consumption, electricity access in Zambia has had some economic effects on the wellbeing of citizens. The estimates of health impacts are small. Employment impact estimates are negligible, and not robust to sub-sample estimation. There are limitations with the cross-sectional dataset and restrictions of data availability through the survey that feed into the omitted variable bias. I tried to eliminate measurement error by taking mostly binary variables.

Table 4: Estimated Impacts of Rural Electrification

Outcome and Estimation method	(1)	(2)	(3)	(4)	(5)	(6)
A. Regression	Bivariate	Controls	Full Controls With fixed effects	Clustered Standard Errors	Boys / Males	Girls/ Females
Monthly firewood consumption (1=yes): **Probit**	2.299773*** (.0168188)	-2.270281*** (.01706)	-2.096985*** (.0205741)	-2.096985*** (.0875262)	-2.071017*** (.088933)	-2.125899*** (.0895714)
Employed in Own Business or Wage-Earning Activity (1=yes): **Probit**	.0014583*** (.0111795)	-.0145831 (.0161643)	-.0030209 (.0188408)	-.0030209 (.0253776)	-.0817448** (.0353581)	.0591628** (.0302784)
Sick with a respiratory illness in the last 2 weeks (1=yes): **Probit**	-.241131*** (.0224659)	-.243243 *** (.0232476)	-.1895824 *** (.0260469)	-.1895824*** (.0403253)	-.2158518*** (.0397161)	-.168153*** (.0569643)
Years of completed school for children between 7 and 18: **Negative Binomial**	.4886279*** (.0291601)	.417706*** (.0261724)	.3961944*** (.0306479)	.3961944*** (.0398476)	.4424459 *** (.0535611)	.3534087*** (.0383535)

	(1)
B. Propensity Score Matching	Nearest Neighbor
Monthly firewood consumption (1=yes)	.6431042*** (.0030193)
Employed in Own Business or Wage-Earning Activity (1=yes)	.0199375*** (.0026594)
Sick with a respiratory illness in the last 2 weeks (1=yes)	.0136442*** (.001555)
Years of completed school for children between 7 and 18	2.769675*** (.2223893)

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Panel A column 3 is estimated with district fixed effects. Panel A column 4 is estimated with full covariates and clustering standard errors at the district level.
Panel A Columns 5 and 6 are estimated for gender-based subsamples. Panel B Column 1 is estimated using the nearest neighbor (n=1) matched sample.

Table 5: Predicted Probability of variables using Probit estimation

	Firewood _consumption	**Resp_illness**	**Employment**
0- Not connected to the grid	0.6206	0.03507	0.2777
1- Connected to the grid	0.0907	0.02302	0.2772

VII. Conclusions

By studying the impacts of electrification in Zambia through robust estimations I conclude that electrified households have a better quality of life and standard of living because of the positive impacts on health and education outcomes. Reduction of firewood consumption not only prevents indoor air pollution which has health benefits but also has environmental impacts including reduction of deforestation and social impacts because of the time saved from collecting the firewood which can be used in other productive activities and/ or leisure. There are little but significant benefits shown on respiratory illnesses. Schooling increases in both boys and girls indicating higher grade attainment in children who live in households with access to electricity. Employment does not have any visible effects in my analysis. The long-term impacts of electrification may be much more than this study presents. The 2015 data limits us to a cross-sectional analysis of the impact and drivers of grid electrification. With a goal of urban universal access and 40% reduction of firewood by 2013 approaching, Zambia is on the right trajectory for development through grid electrification. There is potential for further study with the upcoming National Census Survey in 2020 with more up to date data reflecting the true impact of energy access. When compared to existing literature in the field the results found are comparable those findings that high theorized impacts of electrification are not found in practice.

There are lessons to learn from the current way of measuring grid access which does not capture all kinds of energy used by a household. It is important to note that electricity in itself is not the final product but the services it provides lead to developmental outcomes. These services are supported through different appliances and are on a multi-tier level. This World Bank framework (WB, ESMAP) provides a more zoomed in look on the energy services. Zambian government has the opportunity to create a brighter Zambia through continuing their efforts and realizing their goals by 2030.

VIII. References

Adair-Rohani, Heather, Jessica Lewis, Johnathan Mingle, Sophie Gumy, Maria Neira, Carlos Dora, Vera Brinkman et al. Burning Opportunity: Clean Household Energy for Health, Sustainable Development, and Wellbeing of Women and Children. Geneva: World Health Organization, 2016. Accessed April 23, 2017. http://who.int/indoorair/publications/burning-opportunities/en/

Allcott, Hunt, Allan Collard-Wexler, and Stephen D. O'Connell. "How do electricity shortages affect industry? Evidence from India." The American Economic Review 106, no. 3 (2016): 587-624.

Anderson, Jonathan O., Josef G. Thundiyil, and Andrew Stolbach. "Clearing the air: a review of the effects of particulate matter air pollution on human health." Journal of Medical Toxicology 8, no. 2 (2012): 166-175.

Rückerl, Regina, Alexandra Schneider, Susanne Breitner, Josef Cyrys, and Annette Peters. "Health effects of particulate air pollution: a review of epidemiological evidence." Inhalation toxicology 23, no. 10 (2011): 555-592.

Barnes, Douglas F. The challenge of rural electrification: strategies for developing countries. Washingotn, DC: Resources for the Future, 2007.

Barnes, Douglas F., and Hans P. Binswanger. "Impact of Rural Electrification and Infrastructure on Agricultural Changes, 1966-1980." Economic and Political Weekly (1986): 26-34.

Barron, Manuel, and Maximo Torero. "Household Electrification and Indoor Air Pollution." Munich Personal RePEc Archive Paper No. 61424. Munich: Munich University

Batidzirai et al. “Willingness to pay for improved electricity supply reliability in Zambia.”International Growth Center (2018)

Bensch, Gunther; Grimm, Michael; Langbein, Jörg; Peters, Jörg (2015) : Impacts of access to solar energy on rural households: An evaluation of a Netherlands supported programme in Burkina Faso, RWI Materialien, No. 95, ISBN 978-3-86788-672-7, Rheinisch-Westfälisches Institut für Wirtschaftsforschung (RWI), Essen, http://nbn-resolving.de/urn:nbn:de:hbz:061:3-49773

Bensch, G., J. Peters, and M. Sievert (2013), Fear of the Dark? How access to electric lighting changes attitude and behavior in rural Senegal. Journal of Rural and Community Development, 8(1), 1-19

Bensch, G., J. Peters, and M. Sievert (2011), Report on ERSEN Baseline Study. Baseline report on behalf of the German Technical Cooperation (GTZ). Report and data are available from the authors upon request.

Bonan, Jacopo, Stefano Pareglio, and Massimo Tavoni. "Access to Modern Energy: a Review of Barriers, Drivers and Impacts." FEEM Working Paper No. 68.2016. Milan: Fondazione Eni Enrico Mattei, 2016. Accessed November 20, 2018.

Central Statistical Office. 2015 Living Conditions and Monitoring Survey (LCMS) Report. Lusaka, Zambia, 2016. Accessed November 20, 2018. https://www.zamstats.gov.zm/phocadownload/Living_Conditions/2015%20Living%20Conditions%20Monitoring%20Survey%20Report.pdf

Dasso, Rosamaría, and Fernando Fernandez. "The effects of electrification on employment in rural Peru." IZA Journal of Labor & Development 4, no. 1 (2015): 6. 41 Dinkelman, Taryn. "The effects of rural electrification on employment: New evidence from South Africa." The American Economic Review 101, no. 7 (2011): 3078-3108.

Farooquee A. “Revisiting the Rural Energy Challenge in Developing Countries.” SIPA Columbia University (2017). Accessed on April 5, 2019 https://jia.sipa.columbia.edu/online-articles/revisiting-rural-energy-challenge-developing-countries

Ferraro, Paul J., Kathleen Lawlor, Katrina L. Mullan, and Subhrendu K. Pattanayak. "Forest figures: Ecosystem services valuation and policy evaluation in developing countries." Review of Environmental Economics and Policy (2011): rer019.

Fisher-Vanden, Karen, Erin T. Mansur, and Qiong Juliana Wang. Costly Blackouts? Measuring Productivity and Environmental Effects of Electricity Shortages. No. w17741. National Bureau of Economic Research, 2012

Grimm, Michael; Munyehirwe, Anicet; Peters, Jorg; Sievert, Maximiliane. 2016. A first step up the energy ladder ? low cost solar kits and household's welfare in Rural Rwanda (English). Policy Research working paper; no. WPS 7859. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/966011476292381076/A-first-step-up-the-energy-ladder-low-cost-solar-kits-and-households-welfare-in-Rural-Rwanda.

Grimm, M., Peters, J., & Sievert, M. "Impacts of Pico-PV Systems Usage using a Randomized Controlled Trial and Qualitative Methods." International Institute of Social Studies (2013)

International Energy Agency. World Energy Outlook 2011: Energy for All. Paris: OECD/IEA, 2011. Accessed December 23, 2018. https://www.iea.org/weo2018/http://www.worldenergyoutlook.org/media/weowebsite/2011/weo2011_energy_for_al l.pdf.

International Energy Agency. World Energy Outlook 2016: Executive Summary. Paris: OECD/IEA, 2016. Accessed December 23, 2018. http://www.iea.org/Textbase/npsum/WEO2016SUM.pdf.

International Energy Agency. World Energy Outlook 2018: Executive Summary. Paris: OECD/IEA, 2016. Accessed March 25, 2019 https://www.iea.org/weo2018/.

International Labor Organization. "Living Conditions Monitoring Survey Report: Overview on Zambia" www.ilo.org/surveydata/index.php/catalog/1516/download/11780

Kaygusuz, K. (2012). Energy for sustainable development: A case of developing countries. Renewable and Sustainable Energy Reviews, *16*, 1116–1126.10.1016/j.rser.2011.11.013

Khandker, Shahidur R., Douglas F. Barnes, and Hussain A. Samad. "The welfare impacts of rural electrification in Bangladesh." The Energy Journal 33, no. 1 (2012): 187.

Khandker, Shahidur R., Douglas F. Barnes, and Hussain A. Samad. "Welfare impacts of rural electrification: A case study from Bangladesh." World Bank Policy Research Working Paper No. 4859. Washington, DC: World Bank, Development Research Group, Sustainable Rural and Urban Development Team, 2009. Accessed December 23, 2018. https://openknowledge.worldbank.org/handle/10986/4055.

Khandker, Shahidur R., Douglas F. Barnes, Hussain A. Samad, and Nguyen Huu Minh. "Welfare impacts of rural electrification: evidence from Vietnam." World Bank Policy Research Working Paper No. 5057, Impact Evaluation Series No. 38. Washington, DC: World Bank, Development Research Group, Sustainable Rural and Urban Development Team, 2009. Accessed April 23, 2017. https://openknowledge.worldbank.org/handle/10986/4248.

Litzow (2017), "The Impacts of Rural Electrification in the Kingdom of Bhutan". Duke University

McKinsey and Company. "Energy Infrastructure Seizing the Opportunity on Growth Markets."(2014) Accessed on October 25, 2018. https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/energy-infrastructure-seizing-the-opportunity-in-growth-markets

Neelsen, S., J. Peters (2011), Electricity Usage in Micro-Enterprises – Evidence from Lake Victoria, Uganda. Energy for Sustainable Development 15 (1): 21-31.

Neelsen, S., J. Peters (2013), Micro-Enterprise Electricity Usage in Two Export-Oriented Fishing Communities at Lake Victoria, Uganda. Energy Sector Management Assistance Program (ESMAP), the Africa Electrification Initiative (AEI), and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ).

Neelsen, S., J. Peters, and G. Bensch (2011), Renewable Energy Based Electricity Generation for Isolated Mini-Grids, Zambia. Baseline Report on the GEF project on behalf of the United Nations Industrial Development Organization (UNIDO).

Oxford Business Group. "The Report: Peru 2018." (2018) Accessed on March 20, 2019. https://oxfordbusinessgroup.com/peru-2018

Peters, Jörg, and Maximiliane Sievert. "Impacts of rural electrification revisited–the African context." Journal of Development Effectiveness 8, no. 3 (2016): 327-345.

Peters, Jörg, Colin Vance, and Marek Harsdorff. "Grid extension in rural Benin: Micromanufacturers and the electrification trap." World Development 39, no. 5 (2011): 773- 783.

Rosenbaum, Paul R., and Donald B. Rubin. "Constructing a control group using multivariate matched sampling methods that incorporate the propensity score." The American Statistician 39, no. 1 (1985): 33-38.

Rosenbaum, Paul R., and Donald B. Rubin. "The central role of the propensity score in observational studies for causal effects." Biometrika (1983): 41-55.

Rubin, Donald B. "Using propensity scores to help design observational studies: application to the tobacco litigation." Health Services and Outcomes Research Methodology 2, no. 3 (2001): 169-188.

Rubin, Donald B., and Neal Thomas. "Combining propensity score matching with additional adjustments for prognostic covariates." Journal of the American Statistical Association 95, no. 450 (2000): 573-585.

Rud, Juan Pablo. "Electricity provision and industrial development: Evidence from India." Journal of development Economics 97, no. 2 (2012): 352-367.

Shell Foundation. “Off-grid Finance Gap in Africa” Accessed on September 15, 2018. http://www.shellfoundation.org/ShellFoundation.org_new/media/Shell-Foundation-Reports/Catalyst-Report.pdf

Sustainable Energy for All. “Progress Toward Sustainable Energy: Global Tracking Framework Report.” (2015) Accessed on April 5, 2019. https://www.seforall.org/sites/default/files/l/2013/09/GTF-2105-Full-Report.pdf

Torero, M. "The Impact of Rural Electrification Challenges and Ways Forward." International Food Policy Research Institute (2014).

United Nations. “2012 International Year of Sustainable Energy for All.” United Nations, 2011. Accessed April 23, 2017. http://www.un.org/en/events/sustainableenergyforall/.

United Nations. “Sustainable Development Goals: Goal 7.” United Nations. http://www.un.org/sustainabledevelopment/energy/.

United Nations Development Programme. “Bhutan sustainable rural biomass energy project.” New York, NY: UNDP, 2012. Accessed December 23, 2018. http://www.undp.org/content/bhutan/en/home/operations/projects/environment_and _energy/Bhutan-SRBE.html.

United Nations Development Programme. Human Development Report 2016: Briefing Note, Bhutan. New York, NY: UNDP, 2015. Accessed December 23, 2018. http://hdr.undp.org/sites/all/themes/hdr_theme/country-notes/BTN.pdf.

US Agency for International Development. “Zambia Country Fact Sheet.” Accessed November 20, 2018 https://www.usaid.gov/sites/default/files/documents/1860/Zambia-November_2018_Country_Fact_Sheet.pdf

World Bank. "State of Electricity Access Report (SEAR)." (2017) Accessed on April 5, 2019. http://www.worldbank.org/en/topic/energy/publication/sear

Zambia Development Agency. "Energy Sector Profile." Lusaka, Zambia. Accessed January 25, 2018. http://www.zda.org.zm/?q=content/energy

IX. Appendix

Figure A1: State of Electrification in Zambia (2015)

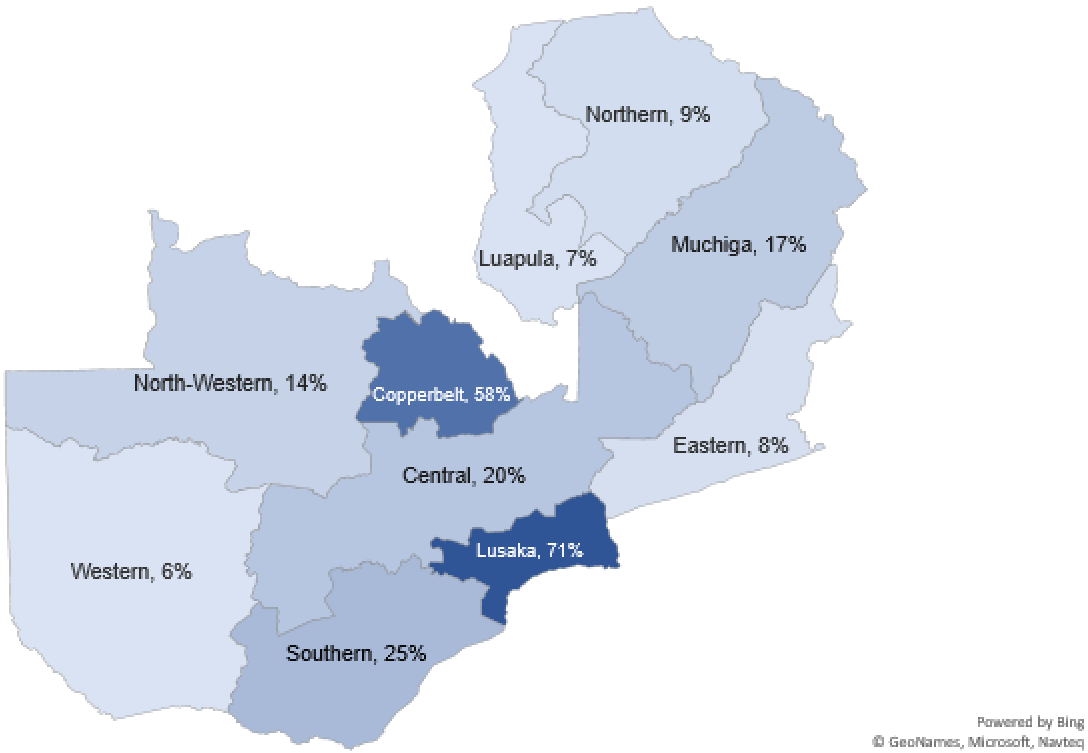
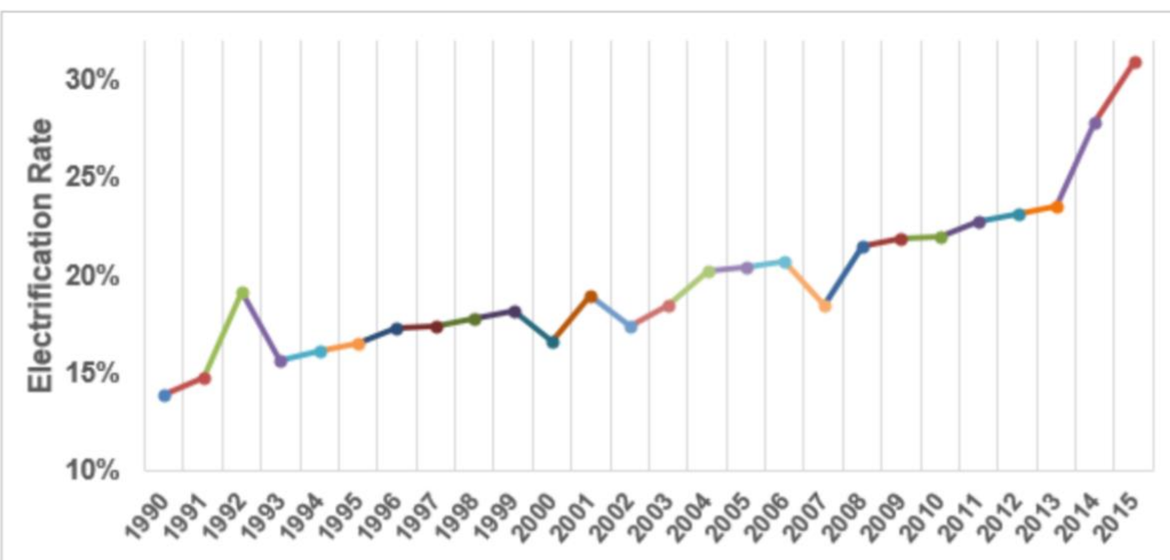


Figure A2: Trend of Electrification in Zambia (1990-2015)



Zambia electrification rate trend (Source – World Bank and Government of Zambia)

Figure A3: Electricity use and outcomes in rural households (Peters & Sievert 2016)

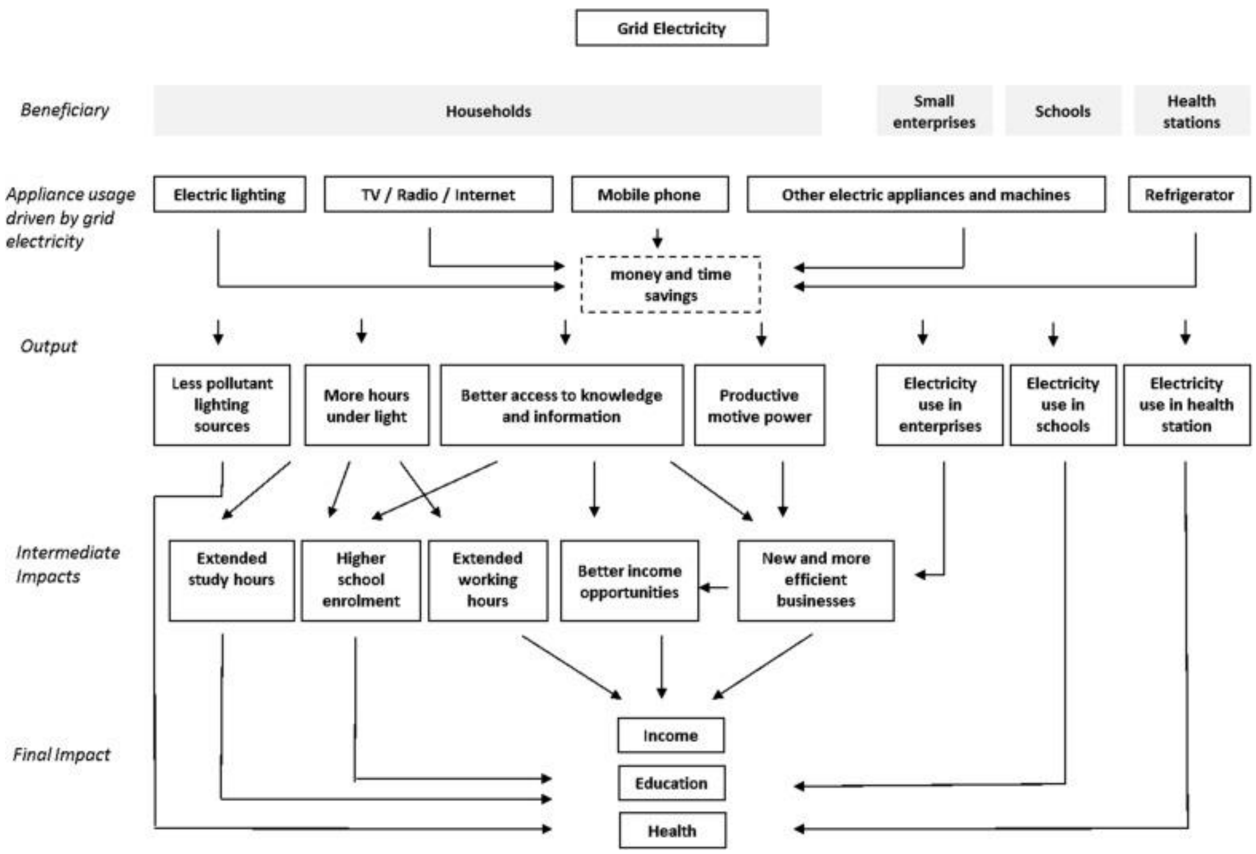


Table A1: Construction of Key Variables from the Zambia LCMS (2015) Data

Variable Name	Description	Explanation of variable construction
firewood_consumption	Firewood consumption (1=yes)	if households reported firewood as the fuel used for lighting and cooking.
employed	Working Age Adult Employed in Own Business or Wage-Earning Activity (1=yes)	if an individual reported to have worked for money or have had a profitable business
resp_illness	Incidence of respiratory illness (1=yes)	if the individual was reported to have suffered from a raspatory illness (cough/ cold/ tuberculosis/ asthma/ bronchitis) in the two-week preceding the survey
grade_attainment	Years of completed school for children between 7 and 18 (0-12)	calculated as the highest year of schooling completed by an individual of school going age
grid_acess	Household grid connection status (1=yes)	if household reports to have access to electricity from the grid at the household
hoh_relation	Relation to household head (1=self)	if the individual responding to the survey is the head of the household
hoh_age	Household head age	age of the head of household
hoh_gender	Household head gender (1=male)	if the head of household is male
hoh_maritalstatus	Household head marital status (1= married)	if the head of household is married
hh_size	House hold size	number of people living in the household
Build_material	Brick is main household construction material (1= yes)	if household reports that main building material of house is mud-bonded bricks/stones or cement-bonded bricks/stones
age	Age	age of respondent
gender	Gender (1=male)	if the respondent is male
maritalstatus	marital status	if the respondent is married
Hohgender_hohmaritalstatus	interaction variable	interaction variable between gender and marital status of the head of household constructed by multiplying the two

Table A2: Correlation Matrices of variables by output

	Firewood_Consumption	Grid_access	Hh_size	hoh_gender	hoh_age	hoh_maritalstatus	build_material	age	gender	Hoh_relation	Marital Status
firewood_consumption	1										
grid_access	-0.635	1									
hh_size	0.0786	-0.0297	1								
hoh_gender	0.0047	0.0305	0.1457	1							
hoh_age	0.0028	-0.0198	-0.2077	0.0594	1						
hoh_maritalstatus	0.0425	-0.0105	0.2087	**0.8172**	0.0688	1					
build_material	-0.1858	0.2287	-0.0062	-0.0031	0.0058	-0.016	1				
Age	-0.0068	0.0219	-0.1276	-0.0162	0.1226	-0.043	0.0099	1			
gender	-0.0049	0.0006	0.0097	0.1175	0.0105	0.0557	-0.002	0.0009	1		
Hoh_relation	-0.0148	0.0034	-0.2264	-0.0467	0.1115	-0.091	0.0003	0.5505	0.2727	1	
MaritalStatus	0.0043	-0.0076	-0.1389	0.2575	0.2118	0.3015	-0.0035	0.5339	0.0105	0.4671	1

	Resp illness	Grid_access	Hh_size	hoh_gender	hoh_age	hoh_maritalstatus	build_material	age	gender	Hoh_relation	Marital Status
Resp_illness	1.0000										
Grid_access	-0.0425	1.0000									
Hh_size	-0.0254	-0.0297	1.0000								
hoh_gender	-0.0108	0.0305	0.1457	1.0000							
hoh_age	0.0097	-0.0198	-0.2077	0.0594	1.0000						
hoh_maritalstatus	-0.0045	-0.0105	0.2087	**0.8172**	0.0688	1.0000					
build_material	-0.0093	0.2287	-0.0062	-0.0031	0.0058	-0.0160	1.0000				
age	0.0349	0.0219	-0.1276	-0.0162	0.1226	-0.0430	0.0099	1.0000			
gender	0.0011	0.0006	0.0097	0.1175	0.0105	0.0557	-0.0020	0.0009	1.0000		
Hoh_relation	0.0181	0.0034	-0.2264	-0.0467	0.1115	-0.0910	0.0003	0.5505	0.2727	1.0000	
Marital Status	-0.0030	-0.0076	-0.1389	0.2575	0.2118	0.3015	-0.0035	0.5339	0.0105	0.4671	1.0000

Table A2 cont.: Correlation Matrices of variables by output

	Employed	Grid_access	Hh_size	hoh_gender	hoh_age	hoh_maritalstatus	build_material	age	gender	Hoh_relation	Marital Status
Employed	1.0000										
Grid_access	0.0005	1.0000									
Hh_size	-0.1843	-0.0297	1.0000								
hoh_gender	0.0017	0.0305	0.1457	1.0000							
hoh_age	0.1111	-0.0198	-0.2077	0.0594	1.0000						
hoh_maritalstatus	-0.0391	-0.0105	0.2087	**0.8172**	0.0688	1.0000					
build_material	-0.0010	0.2287	-0.0062	-0.0031	0.0058	-0.0160	1.0000				
age	0.5434	0.0219	-0.1276	-0.0162	0.1226	-0.0430	0.0099	1.0000			
gender	0.1205	0.0006	0.0097	0.1175	0.0105	0.0557	-0.0020	0.0009	1.0000		
Hoh_relation	0.7011	0.0034	-0.2264	-0.0467	0.1115	-0.0910	0.0003	0.5505	0.2727	1.0000	
Marital Status	0.5787	-0.0076	-0.1389	0.2575	0.2118	0.3015	-0.0035	0.5339	0.0105	0.4671	1.0000

	Education	Grid_access	Hh_size	hoh_gender	hoh_age	hoh_maritalstatus	build_material	age	gender	Hoh_relation	Marital Status
Education	1.0000										
Grid_access	0.4325	1.0000									
Hh_size	0.0364	-0.0297	1.0000								
hoh_gender	-0.0180	0.0305	0.1457	1.0000							
hoh_age	0.0030	-0.0198	-0.2077	0.0594	1.0000						
hoh_maritalstatus	0.0024	-0.0105	0.2087	**0.8172**	0.0688	1.0000					
build_material	0.0825	0.2287	-0.0062	-0.0031	0.0058	-0.0160	1.0000				
age	0.4946	0.0219	-0.1276	-0.0162	0.1226	-0.0430	0.0099	1.0000			
gender	0.0916	0.0006	0.0097	0.1175	0.0105	0.0557	-0.0020	0.0009	1.0000		
Hoh_relation	0.0373	0.0034	-0.2264	-0.0467	0.1115	-0.0910	0.0003	0.5505	0.2727	1.0000	
Marital Status	0.0473	-0.0076	-0.1389	0.2575	0.2118	0.3015	-0.0035	0.5339	0.0105	0.4671	1.0000

Table A3: Predicted relationship between variables

	Firewood Consumption	Employment	Respiratory illness	Education
Household grid connection status (1= connected)	- Shift away from polluting fuels	+ More opportunity and productive time	- Less exposure to pollutants and indoor pollution	+ More access to resources and time to study
Household size	+ More need	+/- Depends on employable people in household	+/- Doesn't affect the exposure to illness	+/- Depends on share of school going people in household
Gender of household head (1=male, 0= female)	- Females would spend more time indoors and cooking	+ More men are employed than women	- Women staying at home would be exposed to more pollutants	+/- Depends if they have a say in education of respondent
Age of household head	+/- Depends on household head's preferences	+/- Depends if they are in working population	+/- Depends if they stay at home more or work elsewhere	+/- Depends if they have a say in education of respondent
Marital status of household head (1= married)	+/- Depends on personal preferences	+/- Depends if they have a say in respondent's employment	+/- Depends if they stay at home more or work elsewhere	+ /- Depends if they have a say in education of respondent
Brick is main household construction material (1= yes)	- Wealthier & may use more efficient fuel	+ Wealthier and in better jobs	- Wealthier and access to better facilities	+ Wealthier and access to better facilities
Age	+/- Depends on preference and availability of fuel	+/- Depends if they are in working population	+ More prone to sickness	+ More years of schooling
Gender (1=male, 0= female)	- Females would spend more time indoors and cooking	+ More men are employed than women	- Women staying at home would be exposed to more pollutants	+ Men are more likely to be enrolled in school than women
Relation to head of household (1=self)	+/- Depends on preference and availability of fuel	+ Has more financial responsibility	+/- Depends if they stay at home more or work elsewhere	If self, not a part of the age cohort studied
Marital Status	+/- Depends on preference and availability of fuel	+ Has more financial responsibility	+/- Depends if they stay at home more or work elsewhere	Married, not a part of the age cohort studied

Table A4: Impact Estimates of electrification, firewood consumption

Firewood Consumption	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Bivariate	Added Controls	Full Controls with fixed effects	Clustered Standard Errors	Boys / Males	Girls/ Females	Nearest-Neighbor Matching
Household grid connection status (1= connected)	-2.299773*** (.0168188)	-2.270281*** (.01706)	-2.096985*** (.0205741)	-2.096985*** (.0875262)	-2.071017 *** (.0889331)	-2.125899*** (.0895714)	-.6431042*** (.0030193)
Household size		.0376645*** (.0022796)	.0225355*** (.0026009)	.0225355* (.0102344)	.0213742 * (.0111979)	.0244096** (.0099908)	-.0167084*** (.0019948)
Gender of household head (0=female, 1= male)		-.2198092*** (.0387631)	-.2371884 *** (.0432965)	-.2371884** (.0959497)	.2809642** (.1229702)	.1355818 (.1262593)	-.3588525*** (.031083)
Age of household head		.0229908 (.0465903)	-.0640698 (.0517843)	-.0640698 (.0696472)	-.0904921 (.0781578)	-.0339924 (.0677579)	-.2932174*** (.042806)
Marital status of household head (1= married)		.3214539*** (.0386532)	.2680614*** (.0405451)	.2680614*** (.1009531)	.4765049* (.2436886)	.2224984 (.2492612)	-.2188286*** (.0701972)
Brick is main household construction material (1= yes)		-.7944303*** (.0553758)	-.8880568*** (.0596365)	-.8880568*** .1705366	-.8811028 *** (.171456)	-.8964145*** (.1879573)	1.388357*** (.0269382)
Age		.0032198 *** (.0004663)	.0043581*** (.0005211)	.0043581*** (.0007675)	.0033644*** (.0009602)	.0048263*** (.0008805)	.0029522*** (.0004155)
Gender		.0356875 *** (.0130398)	.0535769*** (.0142591)	.0535769*** (.0116539)	-	-	.0101959 (.0113537)
Relation to household head		-.0486505 ** (.020795)	-.0842389*** (.0229716)	-.0842389*** (.0159484)	-.0420113 (.0715956)	-.0527543 (.0335426)	-.0385708** (.0179971)
Marital Status		-.0466666 ** (.0181821)	-.0598761*** (.0200934)	-.0598761 *** (.0161047)	-.0904667 (.0705233)	-.0521179** (.0205572)	-.0724383*** (.015934)
Hohmaritalstatus*hohgender		-.0050721 (.053143)	.0681827*** (.0574542)	.0681827 *** (.1222513)	-.087737 (.1487599)	.0159717*** (.1496877)	-.0317031 (.0476073)
Constant	.5414615*** (.0065231)	.1630108*** (.0221949)	-	-	-	-	.2177596 (.0597858)
Di strict Indicators	No	No	Yes	Yes	Yes	Yes	-
Observations	62,854	62,853	62,530	62,530	30,316	32,152	62,853
Pseudo R squared	.3446	0.3552	0.4677	0.4677	0.4665	0.4690	0.0442

Probit Estimation used in columns 1-6, Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Standard Errors in Columns 4-6 are clustered at the district level. Columns 5 and 6 are estimated by gender
Column 7 is estimated using nearest neighbor (n=1) matched sample

Table A5: Impact Estimates of electrification, incidence of respiratory illness

Health: Respiratory Illness	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Bivariate	Added Controls	Full Controls with fixed effects	Clustered Standard Errors	Boys / Males	Girls/ Females	Nearest-Neighbor Matching
Household grid connection status (1= connected)	-.241131*** (.0224659)	-.243243*** (.0232476)	-.1895824*** (.0712674)	-.1895824 *** (.0403253)	-.2158518*** (.0397161)	-.168153*** (.0569643)	-.0143954*** (.0015374)
Household size		-.0246749*** (.0043308)	-.0290563*** (.0044489)	-.0290563*** (.0064005)	-.0220077*** (.0077113)	-.0359501*** (.0079611)	-.0167084*** (.0019948)
Gender of household head (0=female, 1= male)		-.1811894*** (.0649887)	-.1888977*** (.0657829)	-.1888977*** (.0676998)	.1996914** (.1006668)	.2306384* (.1760443)	-.3588525*** (.031083)
Age of household head		.0361207*** .0706533)	.0231189 (.0712674)	.0231189 (.0881309)	-.1269406 (.1169389)	.154423* (.0941704)	-.2932174*** (.042806)
Marital status of household head (1= married)		.1397886*** (.0624392)	.0828411 (.0638986)	.0828411 (.0623286)	.5296188** (.208214)	.4508438 (.3506105)	-.2188286*** (.0701972)
Brick is main household construction material (1= yes)		.0086251 (.0513188)	-.0088434 (.0525301)	-.0088434 (.0643749)	.0220146 (.0752654)	-.0286072 (.0886143)	1.388357*** (.0269382)
Age		.0066219*** (.0007195)	.0066839*** (.000724)	-.0088434*** (.0643749)	.0057125*** (.0014113)	.0073396*** (.0009257)	.0029522*** (.0004155)
Gender		.0163316*** (.0213548)	.0161931 (.0215897)	.0161931 (.0215793)	-	-	.0101959 (.0113537)
Relation to household head		.0242306 (.0327348)	.0278739 (.0329903)	.0278739 (.0297578)	.0822943 (.1012198)	.0529275 (.0571291)	-.0385708 (.0179971)
Marital Status		-.2081825*** (.0302895)	-.2076997*** (.0304038)	-.2076997*** (.0285429)	-.2355011** (.0999751)	-.2223248*** (.031386)	-.0724383 (.015934)
hohmaritalstatus*hohgender		.112922 (.0873141)	.154103 * (.0888887)	.154103* .0930485	-.3066068** (.1346783)	-.1331269 (.1902191)	-.0724383 (.015934)
Constant	-1.792257*** (.0115618)		-	-	-	-	-.0317031 (.0476073)
Di strict Indicators	No	No	Yes	Yes	Yes	Yes	-
Observations	62,854	62,853	62,853	62,853	30,538	32,315	62,853
Pseudo R squared	0.0069	0.0163	0.0405	0.0405	0.0391	0.0517	0.0442

Probit Estimation used in columns 1-6, Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Standard Errors in Columns 4-6 are clustered at the district level. Columns 5 and 6 are estimated by gender
Column 7 is estimated using nearest neighbor (n=1) matched sample

Table A6: Impact Estimates of electrification, employment

Employment	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Bivariate	Added Controls	Full Controls with fixed effects	Clustered Standard Errors	Boys / Males	Girls/ Females	Nearest-Neighbor Matching
Household grid connection status (1= connected)	.0014583*** (.0111795)	-.0145831 (.0161643)	-.0030209 (.0188408)	-.0030209 (.0253776)	-.0817448* (.0353581)	-.3751683* (.0817022)	.0199375*** (.0026594)
Household size		.006761** (.0028834)	.0066216** (.0029721)	.0066216 (.0044356)	.0021162 (.0058108)	.0155263*** (.00545)	-.0167084*** (.0019948)
Gender of household head (0=female, 1= male)		.3670696*** (.0359583)	.3764441*** (.0364355)	.3764441 *** (.0420381)	-.575568 *** (.049516)	-.1210484* (.0706139)	-.3588525*** (.031083)
Age of household head		-.2335321*** (.0511241)	-.2276504*** (.0514199)	-.2276504 *** (.0516094)	-.1790103 ** (.0878927)	-.2049165*** (.0652681)	-.2932174*** (.042806)
Marital status of household head (1= married)		-.5080922*** (.0638862)	-.5244358*** (.0648073)	-.5244358 *** (.0698499)	-1.870399 *** (.1145348)	-.3366766* (.2073434)	-.2188286 *** (.0701972)
Brick is main household construction material (1= yes)		-.0255745 (.0359566)	-.0326352 (.0369826)	-.0326352 (.0367574)	-.0733596 (.0705391)	-.009787 (.0502745)	1.388357*** (.0269382)
Age		.0126019*** (.0005736)	.0126316 *** (.0005783)	.0126316*** (.0008341)	.008627*** (.0014512)	0132416*** (.0010151)	.0029522*** (.0004155)
Gender		.017604 (.0169212)	.0169984 (.0169851)	.0169984 (.0196031)	-	-	.0101959 (.0113537)
Relation to household head		1.779282*** (.0220456)	1.791917 *** (.0222722)	1.791917 *** (.0436169)	1.750582*** (.0599541)	2.064341*** (.0682657)	-.0385708 (.0179971)
Marital Status		1.409852*** (.0201526)	1.424293*** (.0203324)	1.424293*** (.0411217)	1.411678*** (.0531682)	1.536358 (.0554676)	-.0724383*** (.015934)
Hohmaritalstatus*hohgender		-.3744724*** (.0721838)	-.3751683*** (.0731717)	-.3751683 *** (.0817022)	.8659832*** (.0880408)	-.2842562* (.162829)	-.0317031 (.0476073)
Constant	-.5821708*** (.0065784)	-1.546941*** .0274199	-	-	-	-	.2177596*** (.0597858)
Di strict Indicators	No	No	Yes	Yes	Yes	Yes	-
Observations	62,854	62,853	62,853	62,853	30,538	32,315	62,853
Pseudo R squared	0	0.5253	0.5296	0.5296	0.6516	0.3903	0.0442

Probit Estimation used in columns 1-6, Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Standard Errors in Columns 4-6 are clustered at the district level. Columns 5 and 6 are estimated by gender
Column 7 is estimated using nearest neighbor (n=1) matched sample

Table A7: Impact Estimates of electrification, completed years of schooling

Education: Grade Attainment	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Bivariate	Added Controls	Full Controls with fixed effects	Clustered Standard Errors	Boys / Males	Girls/ Females	Nearest-Neighbor Matching
Household grid connection status (1= connected)	.4886279*** (.0291601)	.417706*** (.0261724)	.3961944*** (.0306479)	.3961944*** (.0398476)	.4424459 *** (.0535611)	.3534087*** (.0383535)	2.769675*** (.2223893)
Household size		.009675** (.0044841)	.0106477 (.004443)	.0106477* (.0049391)	.0217271*** (.0069559)	.0024833 (.0058015)	.0028401 (.0146626)
Gender of household head (0=female, 1= male)		-.084568 (.0799723)	-.1189377* (.0811768)	-.1189377 (.0955166)	-.1967333** (.1043491)	-.0240008 (.1178443)	-.0723039 (.2493993)
Age of household head		.000625 (.0008628)	.0005119 (.0008448)	.0005119 (.0008923)	.0005897 (.001377)	.000526 (.001062)	-.0125701*** (.0032023)
Marital status of household head (1= married)		-.1938355 (.1742121)	-.2808734* (.1785872)	-.2808734 (.2246329)	-.3140044 (.2533339)	-.19946 (.247773)	.5782995 (.5701106)
Brick is main household construction material (1= yes)		-.0154151 (.0626401)	-.0169157 (.0565487)	-.0169157 (.0482113)	.1016156 (.0805097)	-.1042424* (.0725677)	1.492987*** (.2373601)
Age		.1231642*** (.0080807)	.1230436*** (.0079574)	.1230436*** (.0090289)	.107084*** (.0103941)	.1305181*** (.0118801)	.0897237*** (.0180222)
Gender		.0157779 (.0235606)	.0177165 (.0238445)	.0177165 (.0276049)	-	-	.2777178*** (.0815628)
Relation to household head		.2907789 (.3067752)	.2385351 (.3314633)	.2385351 (.4036067)	.198632 (.3752548)	-	.4144283 (.8179844)
Marital Status		.0406851 (.0405102)	.0539626* (.0418697)	.0539626 (.0457455)	.1216216 (.1118319)	.0020901 (.0474197)	-1.180153*** (.1972517)
hohmaritalstatus*hohgender		-.1524982 (.2181529)	.1689734* (.1103788)	.1689734 (.140162)	.1548439 (.1782515)	.1794463 (.1418858)	-.452361 (.3834482)
Constant	1.636477*** (0155429)	-.1524982 (.2181529)	-	-	-	-	-1.964787*** (.5528602)
Di strict Indicators	No	No	Yes	Yes	Yes	Yes	-
Observations	62,854	62,853	62,853	62,853	30,538	32,315	62,853
Pseudo R squared	0.0350	0.1007	0.1219	0.1219	0.1396	0.1291	0.0887

Negative Binomial Estimation used in columns 1-6, Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
Standard Errors in Columns 4-6 are clustered at the district level. Columns 5 and 6 are estimated by gender
Column 7 is estimated using nearest neighbor (n=1) matched sample