THE COSTS AND BENEFITS OF ELECTRIFYING RURAL GHANA

FRANCIS KEMAUSUOR
Director
The Brew-Hammond Energy Centre, KNUST, Kumasi

KWAKU AMANING ADJEI
Senior Lecturer and Fellow
The Brew-Hammond Energy Centre, KNUST, Kumasi

JOHN BOSCO DRAMANI
Lecturer, Department of Economics, Kwame University of Science and Technology, Ghana, Kumasi

PRINCE BOAKYE FRIMPONG
Lecturer, Department of Economics, Kwame University of Science and Technology, Ghana, Kumasi

NATIONAL DEVELOPMENT PLANNING COMMISSION

COPENHAGEN CONSENSUS CENTER

GHANA PRIORITIES

COPENHAGEN CONSENSUS CENTER

info@copenhagenconsensus.com
www.copenhagenconsensus.com

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The Costs and Benefits of Electrifying Rural Ghana

Ghana Priorities

Francis Kemausuor, Kwaku Amaning Adjei, John Bosco Dramani, Prince Boakye Frimpong, and the Copenhagen Consensus Center

Academic Abstract

This short note brings together information contained in two essays to conduct cost-benefit analyses of interventions to expand electrification in rural Ghana. We estimate the return on investment of three interventions:

- Grid expansion to communities for which the grid is the least-costly solution (less-remote communities)
- Solar and diesel micro-grids to suitable remaining communities
- Grid expansion to remaining communities of more than 200 people

Our results indicate that grid expansion to communities where grid is the least-costly solution, has the highest benefit-cost ratio (BCR) of 4.5. Microgrid expansion for suitable remote communities has a BCR of 1.7-1.8 depending on the technology type and discount rate, while grid expansion to more remote communities has a BCR of 1.1. The results indicate that it is more cost-effective to electrify a subset of rural households, typically those that are less remote, with higher electricity demand and near existing grid infrastructure. For households in more remote communities, providing grid-based electricity just passes a cost-benefit test. If electrification is deemed a must-have by policy-makers, then providing microgrids to remote communities does yield slightly higher BCR than grid electrification to these same communities under current conditions. These results are based on a large jump in consumption due to electrification. More modest assumptions in line with experience in other countries produce lower BCRs but do not change the rank order of interventions.

Policy Abstract

The problem

According to Ghana Energy Commission (2019), the electricity access rate in rural areas was 67.2% in 2018. The recently published Ghana Living Standards Survey (Ghana Statistical Service, 2019), indicates that regions in the northern parts of the country have much lower access to electricity, compared to regions in the southern parts of the country. In all three northern regions, national grid connection is less than 70%. This unfortunate situation emanates from the fact that most communities in the northern parts of the country are mostly of lower population densities and are quite far from major medium voltage lines. Furthermore, many of these communities are difficult to access due to poor road infrastructure and difficult terrain.

The analysis in this report focuses on the Gushiegu Municipality of the Northern Region. It is assumed that this region is representative of other unelectrified rural communities, and the policy implications arising from this analysis are therefore broadly applicable across rural Ghana.

Intervention 1: Expand grid-based electrification to less remote communities

Overview

This intervention extends the national grid to 79 communities with a population of around 40,000. In the first year 4,547 people will be connected corresponding to 743 households. In 2027 no more capital investment is required and 42,000 people (7,005 households) will be connected. Over time as the population expands, the number of households will grow within the community such that by 2040, 55,334 people across 9,222 households are connected to the grid without any additional large-scale capital investment required.

Costs

The intervention will require GHS 59m in investments over 8 years, using an 8% discount rate. Cost of electricity generation is assumed to equal 31 GHp per kWh, and distribution 45.2 GHp per kWh based on tariffs set by the regulatory agency in Ghana. The total discounted costs are

GHS 59m of investment (GHS 6,378 per household) and GHS 42m in ongoing operations and maintenance costs (GHS 4,563 per household) for a total of GHS 101m (10,940) over 20 years.

Benefits

The intervention will lead to several benefits including a 46% increase in household income and improved health services. These benefits are worth GHS 378m (GHS 40,973 per household) and 74m (GHS 7,976 per household), respectively. Total benefits are 4.5 times the cost.

Intervention 2: Microgrids for selected 'more remote communities'

Overview

A micro-grid generates less than 10MW of electricity and distributes to a limited number of customers via a distribution grid that can operate in isolation from national electricity transmission networks. Here we consider both diesel and solar micro-grid options. The modelling suggests diesel micro-grids are suitable for 3 communities with expected higher energy demand (300 households), while solar micro-grids are suitable for 46 communities (1911 households).

Costs

For diesel microgrids, the levelized cost is GHS 4.3 ($0.94) per kWh and includes all investment, maintenance, distribution and fuel costs. For solar microgrids the levelized cost is GHS 5.1. For diesel microgrids there are also a small amount of negative externalities associated with reduced health from exposure to air pollution and carbon emissions.

Benefits

For diesel microgrids, main benefit is an increase in household income equivalent to GHS 39,454 per household over the time period of analysis. There is also an improvement in health associated with electrification equivalent to GHS 5,891 per household. For solar micro-grids the main benefit is an increase in household income equivalen to GHS 28,137 per household.

There is also an improvement in health associated with electrification equivalent to GHS 5,912 per household.

Intervention 3: Expand grid-based electrification to more remote communities

Overview

This intervention models costs and benefits for expanding the grid to more remote communities above a threshold value of 200 people for a total of 2,493 households.

Costs

The costs of the intervention include an investment cost of GHS 58m (GHS 23,224 per household) and ongoing operations and maintenance cost of GHS 25m (GHS 10,026 per household) over 20 years.

Benefits

The main benefit is an expected income increase of GHS 84m (GHS 33,782 per household) over 20 years. Additional health benefits are worth GHS 7m (GHS 2,979 per household)

	Costs (GHS millions)	Benefits (GHS millions)	BCR
Electricity grid for less remote communities	100.9	451.4	4.5
Diesel micro-grid for more remote communities	7.6	13.6	1.8
Solar micro-grid for more remote communities	38.4	65.1	1.7
Electricity grid for more remote communities	82.9	91.6	1.1

	Costs per household (GHS)	Benefits per household (GHS)	BCR
Electricity grid for less remote communities	10,940	48,948	4.5
Diesel micro-grid for more remote communities	25,358	45,344	1.8
Solar micro-grid for more remote communities	20,099	34,048	1.7
Electricity grid for more remote communities	33,250	36,761	1.1

Introduction

According to Ghana Energy Commission (2019), the electricity access rate in rural areas was 67.2% in 2018. The recently published Ghana Living Standards Survey (Ghana Statistical Service, 2019), indicates that regions in the northern parts of the country have much lower access to electricity, compared to regions in the southern parts of the country. In all three northern regions, national grid connection is less than 70%. This unfortunate situation emanates from the fact that most communities in the northern parts of the country are mostly of lower population densities and are quite far from major medium voltage lines. Furthermore, many of these communities are difficult to access due to poor road infrastructure and difficult terrain.

A combination of energy solutions is required in order to bridge the gap in an optimal way. Such combinations could involve the use of both renewable and non-renewable sources of energy through grid extensions and the development of local off-grid solutions.

This short note brings together information contained in two detailed essays to conduct cost-benefit analyses of interventions to expand electrification in rural Ghana. The first essay, Kemausour and Adjei (2020), uses geo-spatial software to model the least-cost technology mix required to electrify a series of unelectrified communities in the Gushiegu Municipality of the Northern Region. Their analysis indicates that for 79 communities with a population of ~42,000, expanding the national grid would be the most cost-effective option, requiring an (undiscounted) investment of GHc 80 million over seven years, while installing a mix of solar and diesel microgrids for 14,000 people in remote communities would require capital investments of GHc 20 million. The second essay, Dramani and Frimpong (2020) uses three waves of Ghana Living Standard Surveys, along with data on electrification to conduct difference-in-difference analyses of the impact of electrification on welfare. The headline figure from their analysis is that connecting to the grid generates a 46% increase in household income. The results of these two papers, one focusing on costs and one focusing on benefits of electrification, are brought together in this note to estimate the return on investment of three interventions:

- Grid expansion to communities for which the grid is the most cost-effective solution
- Solar and diesel micro-grids to suitable remaining communities
- Grid expansion to remaining communities of more than 100 households

For ease of exposition we refer to communities for which grid is most cost-effective as ‘less-remote communities’, while remaning communites are referred to as ‘more remote communities’. Solar and diesel micro-grids are only suitable for some of the more remote communities.

These electrification options were modeled on unelectrified rural communities in the Gushiegu Municipality in the Northern region. The Gushiegu Municipality was selected for the pilot because it has rural communities with a mix of population sizes, ranging between less than 200 to about 1500, presenting a good population mix for studies like this. It is assumed that the results from this municipality are broadly generalizable to other parts of rural Ghana.

Our results indicate that grid expansion to less-remote communities has the highest benefit-cost ratio (BCR) of 4.5. Microgrid expansion for suitable more remote communities has a BCR of 1.7-1.8 depending on the technology type, while grid expansion for more remote communities has a BCR of 1.1. The results indicate that it is most cost-effective to electrify a subset of rural households, typically those that are less remote, with higher electricity demand and near existing grid infrastructure. For households in more remote communities, providing grid-based electricity just passes a benefit-cost test. If electrification is deemed a must-have by policy-makers, then providing microgrids to remote communities does yield slightly higher BCR than grid electrification to these same communities under current conditions. These results are based on a large jump in consumption due to electrification. More modest assumptions in line with experience in other countries produce lower BCRs but do not change the rank order of interventions.

Intervention 1: Expand grid-based electrification to less remote communities

Overview

Software for spatial analysis and planning, load forecasting, optimization of supply options was used to generate a rural electrification blueprint using several technologies namely: expansion of the grid, diesel and solar micro-grids (Kemausuor and Adjei (2020). Out of 159 communities in the Gushiegu Municipality, the model results show that 79 communities are optimal for grid connection.

Traditionally, grid extension in Ghana is undertaken by the distribution utility, with support from the Ministry of Energy. The households are only responsible for wiring their homes to receive the power. The electrification of the 79 communities is expected to be undertaken in 8 years, between 2020 and 2027.

In the first year 4,547 people will be connected corresponding to 743 households. In 2027 42,120 people (7,005 households) will be connected. Over time as the population expands, the number of households will grow within the community such that by 2040, 55,334 people across 9,222 households are connected to the grid without any additional large-scale capital investment required after 2027.

Costs and Benefits

Costs and benefits are measured over 20 years.

Costs

- Cost of connecting the 79 communities with MV lines, transformers, LV lines, and meters estimated at GHS 59 million using an 8% discount rate. This is based on GHS 80 million undiscounted (US$17.8 million) figure documented in Kemausuor and Adjei (2020), but with a discount rate applied.
- Cost of electricity generation is assumed to equal 31 GHp per kWh, and distribution 45.2 GHp per kWh based on tariffs set by the regulatory agency in Ghana (July 2019, Public Utilities Regulatory Commission) matching the forecasted demand. These tariffs are assumed to represent operations and maintenance costs of electricity delivery via the grid. This cost is estimated at GHS 42m over 20 years using an 8% discount rate.

Benefits

- Using the data from the fifth, sixth and seventh waves of the Ghana Living Standards Survey (GLSS) collected respectively in 2005/2006, 2012/2013 and 2017/2018 and a difference-in-differences analysis, there is a statistically significant increase in gross household income of 46% relative the non-electrified households for grid extension (Dramani and Frimpong, 2020). This significant increase would incorporate increased productivity through use of electricity in farm and non-farm-based activities. It is assumed that each household has one primary worker, earning GHS 10,040 per year in the first year rising with projections to GHS 19,760 by 2040 (2018 figures).

- Improved health outcomes from better supporting environment for health services and staff were also included. Some studies have suggested that electrification generates health benefits associated with reduced indoor air pollution due to the switch from wood cooking and kerosene lighting (e.g. Spalding Fecher, 2005; Barron and Torero, 2014). However, discussants at a validation roundtable held at the Ministry of Energy in Ghana in January 2020 indicate that this benefit was unlikely to materialize in the Ghanaian context. This is because Ghanaian households tend not to use electricity for cooking, even when the house is electrified and do not use kerosense for lighting.
- Instead, it was suggested that the presence of electricity would incentivize staff to move to rural communities, thereby increasing availability of health services. This is supported by discrete choice experiments for Ghanaian health workers and final year medical students (Shiratori et al. 2016; Kruk et al. 2010). We focus here on the impacts of electricity on severe health outcomes, proxied by hospitalization rates and associated deaths. A focus on severe health outcomes is motivated by the fact that it likely captures a significant majority of societal health costs, and is not as affected by availability of health infrastructure as with less severe ailments.[1]
- Difference-in-difference analysis indicates that the presence of electricity is associated with a reduction in annual hospitalizations by 35% (Dramani and Frimpong, 2020). Data from the Ghanaian Health Service (2018) suggests 1.6% of the entire population required hospitalization in 2017. Using the effect size from Dramani and Frimpong and assuming that the split of hospitalizations between electrified and non-electrified households follows the national split of electrification (79:21), leads to an estimated reduction in hospitalization of 0.8 pp from electrification.[2] Given a hospitalization fatality rate of 2.8% (Ghana Health Service, 2018), we estimate that electrification would avoid 1 death per ~4,500 individuals connected per year. In the current scenario this means 1 avoided death in the first year, gradually increasing to a long run value of 9 deaths per year for 42,000 connected indivdiuals in 7,844 households. Each life saved

[1] For example, if electricity generates a greater propensity to visit the doctor, it woul be unclear whether that is due to increased availability of local primary health care facilities (positive outcome) or that the population is more sick overall (negative outcome). In the case of severe events requiring hospitalization it is assumed that individuals, with or without electricity, will be more likely to seek medical care due to the seriousness of the ailment, even if hospitals are not close to their residence. Therefore, hospitalization rates are less impacted by the availability of (local) health services, and can be considered a cleaner, albeit still imperfect, indication of overall population health in response to electrification.

[2] To be specific, the estimated annual hospitalization rate for non-electrified households is 2.3%, while for electrified households it is 1.5%.

is assumed to avoid 36 years of life lost (YLL) and each YLL is valued using standard *Ghana Priorities* assumptions of 1.3x GDP per capita.

Summary of Results

Total discounted costs and benefits for 9,222 households over 20 years in million cedi

	5%	8%	14%
Cost: extending grid	65.3	58.8	48.7
Cost: electricity generation and distribution	57.7	42.1	24.2
Cost: TOTAL	123.0	100.9	72.9
Benefit: income increase	521.6	377.9	216.7
Benefit: improved health	103.3	73.6	40.8
Benefit: TOTAL	624.9	451.4	257.5
BCR	5.1	4.5	3.5

Total discounted costs and benefits per household over 20 years in cedi

	5%	8%	14%
Cost: extending grid	7,077	6,378	5,282
Cost: electricity generation and distribution	6,257	4,563	2,626
Cost: TOTAL	13,334	10,940	7,908
Benefit: income increase	56,554	40,973	23,501
Benefit: improved health	11,205	7,976	4,420
Benefit: TOTAL	67,759	48,948	27,920
BCR	5.1	4.5	3.5

Discussion and Sensitivity Analysis

The results indicate that for less remote communities, extending the national grid generates around two times benefits relative to costs. Increased income represents ~80% of the benefit, with improved health the remaining 20%.

The main driver of benefits is the 46% increase in household income, resulting from increased productivity (Dramani and Frimpong, 2020). However, there is little evidence in the literature documenting income and/or productivity benefits of rural electrification at that magnitude in Africa. In a highly-referenced review of the literature, Peters and Sievert (2015) present evidence from the African continent regarding the more popularly-cited benefits: education benefits from increased study time; health benefits from the reduction in kerosene use, and income benefits from increased non-agricultural activities. They find that (1) electrification does not lead to a change in occupation of household members; little effects of electrification on firm creation and firm development; (2) in none of the studies could a shift in time use towards income generation be observed. Changes in the daily routines mostly relate to how people spend their leisure time and to some extent to studying. They conclude that lacking access to markets is much more important for the development of non-agricultural activities than electrification, and it consequently cannot be overcome in the short or mid-term by the provision of electricity.

More recently, a World Bank working paper by Grimm et al (2016) investigated usage behavior and the changes in people's living conditions when households make this first step toward modern energy based on a randomized controlled trial (RCT), implemented in 15 remote villages in rural Rwanda. They find that the reduction of kerosene use improves household air quality. Secondly, children, boys in particular, shift part of their homework into the evening hours and increase their total study time. Furthermore, in both the control and treatment groups, housework is done primarily during the daytime, and the total time dedicated to domestic work per day does not change significantly; neither does the time that household members are awake. Lastly, they do find that both the head of household and the spouse slightly increase the time they dedicate to income generation, but this difference is not statistically significant from the control group. Most recently, similar results are observed in an RCT in 150 rural communities in Kenya by Lee et al (2019). Surveys extending 32 months post-connection show no detectable effects on asset ownership, consumption levels, health outcomes, or student test scores.

A sensitivity analysis was undertaken to determine the impact on the benefit-cost ratio when the income benefits are adjusted/removed. A literature review by the Asian Development Bank on the impact from rural electrification presents the results from different regions of the world, which includes India, Brazil, Vietnam, Rwanda, Bangladesh, and Indonesia. The median income effect from access to electricity is 18%.

The BCR is sensitive to the assumption of a single average rural income of per household (10,040 cedi in 2020) increasing 46% (4,620 cedi increase in 2020). If the income increase due to electrification is assumed to be 18% (1,808 cedi increase in 2020), the BCR is approximately halved to 2.2 at 8% discount rate. If each household is assumed to have two average rural incomes (27,141 cedi in 2020) and it increases 46% thanks to electrification then the BCR increases to 8.2 using 8% discount rate. The results do not include any residual value of infrastructure at the end of the 20-year analysis period, and so may be considered as slightly conservative.

Intervention 2: Microgrids for selected ‘more remote communities’

Overview

A micro-grid generates less than 10MW of electricity and distributes to a limited number of customers via a distribution grid that can operate in isolation from national electricity transmission networks. Here we consider both diesel and solar micro-grid options (though results indicate that the BCR is similar for both technology types and have therefore been included together as a generic micro-grid intervention).

Diesel Micro-grids

Three remote and small communities were considered in this analysis. The first 27 households in each community will be connected in 2020. In 2029 100 households are estimated to be connected, in each of the three communities totalling 300 households.

Costs and Benefits

The usable life of a micro-grid is assumed to be 10 years. However, costs and benefits are modelled over 20 years to ensure the full benefits of the micro-grids are captured.

Costs

- The levelized cost is GHS 4.3 ($0.94) per kWh and includes all investment, maintenance, distribution and fuel costs (Kemausuor and Adjei, 2020)
- Negative health impacts from the diesel emmissions 0.000004 DALY per kWh (enea-quantis life cycle analysis 2013, and A Markandya 2018). Using the value of statistical life year for the project this corresponds to 7.3 GHP (0.073 cedi) per kWh.
- Social cost of carbon emmissions is the value of negative impacts from climate change in the future caused by additional emmissions today. At 5% discount rate the present value of the damage is 1.6 GHP (0.016 cedi) per kWh produced from diesel genset.

Benefits

- The benefit components are the same as for the case of grid electrification: improved welfare in the form of increased gross household income; the health benefits of improved health services. However, the forecasted electricity demand per household from the diesel microgrid is not equivalent to the households with grid electricity, and lower or higher electricity consumption is assumed to generate lower or higher income and health benefits, so the income and health benefits for households are indexed using the average grid electrified household as base. Due to the higher energy demand in these communities, the expected income increase for households is between 46-61%.

Summary of Results

Total discounted costs and benefits for 300 households over 20 years in million cedi

	5%	8%	14%
Cost: electricity	9.4	7.4	4.9
Cost: emmission health impact	0.2	0.2	0.1
Cost: climate change impact	0.0	-	-
Cost: TOTAL	9.6	7.6	5.0
Benefit: income increase	14.7	11.8	8.1
Benefit: improved health	2.2	1.8	1.2
Benefit: TOTAL	17.0	13.6	9.3
BCR	1.8	1.8	1.8

Total discounted costs and benefits per households over 20 years in cedi

	5%	8%	14%
Cost: electricity	31,296	24,824	16,466
Cost: emmission health impact	690	534	338
Cost: climate change impact	144	0	0
Cost: TOTAL	32,131	25,358	16,804
Benefit: income increase	49,127	39,454	27,003
Benefit: improved health	7,385	5,891	3,970
Benefit: TOTAL	56,512	45,344	30,973
BCR	1.8	1.8	1.8

Discussion and Sensitivity Analysis

Results indicate that diesel microgrids have higher benefits than costs with a central BCR of 1.8. The BCR is sensitive to the assumption of a single average rural income of per household (10,040 cedi in 2020) increasing 46%. If the income increase due to electrification is assumed to be 18% the BCR is more than halved to 0.8 (8% discounting). If each household is assumed to have two average rural incomes and it increases 46% due to electrification then the BCR almost doubles to 3.3.

Solar Micro-grids

Solar technology is considered for the 46 of the communities deemed not optimal for grid connection in the analysis.

The first 11-13 households in each community will be connected in 2020 for a total of 580 households. In 2029, 42 households are estimated to be connected, in each of the 46 communities totalling 1,911 households.

Costs and Benefits

As before, solar micro-grids are assumed to last for 10 years, and the analysis is modeled for 20 years to ensure full capture of all benefits.

Costs

- Levelized costs per kWh ranges between US$ 1.07 and US$ 1.28/kWh with an average value of US$ 1.12 (Kemausuor and Adjei, 2020). This includes mostly capital costs such as solar panels, inverters, batteries and LV lines.

Benefits

- The benefit components are the same as for the case of grid electrification: improved welfare in the form increased gross household income and health benefits of improved services. However, the forecasted electricity demand per household from each minigrid is not equivalent to the households with grid electricity, and lower or higher electricity consumption is assumed to generate lower or higher income and health benefits, so the income and health benefits for households are indexed using the average grid electrified household as base. Due to the lower energy demand in these communities, the expected income increase for each household is 37%.

Summary of Results

Total discounted costs and benefits for 1,911 households over 20 years in million cedi

	5%	8%	14%
Cost: electricity	47.1	38.4	26.9
Cost: TOTAL	47.1	38.4	26.9
Benefit: income increase	64.7	53.8	39.3
Benefit: improved health	14.1	11.3	7.7
Benefit: TOTAL	78.8	65.1	47.0
BCR	1.7	1.7	1.7

Total discounted costs and benefits per household over 20 years in cedi

	5%	8%	14%
Cost: electricity	24,650	20,099	14,075
Cost: TOTAL	24,650	20,099	14,075
Benefit: income increase	33,861	28,137	20,551
Benefit: improved health	7,376	5,912	4,021
Benefit: TOTAL	41,238	34,048	24,572
BCR	1.7	1.7	1.7

Discussion and Sensitivity Analysis

Results indicate that solar microgrids have slightly higher benefits relative to costs, with a central BCR of 1.7. The BCR is sensitive to the assumption of a single average rural income of per household (10,040 cedi in 2020) increasing 46%. If the income increase due to electrification is assumed to be 18% the BCR is more than halved, 0.8 (8% discounting). If each household is assumed to have two average rural incomes and it increases 46% thanks to electrification then the BCR almost doubles to 3.1.

Intervention 3: Expand grid-based electrification to more remote communities

Overview

After presenting preliminary results at a validation seminar in January 2020, representatives at the Ministry of Energy requested a cost-benefit analysis of expanding grid-based electrification to more remote communities. This was modelled in the software as forcing grid extension to all communities above a certain (small) threshold value of 100 people.

The costs and benefits of this scenario were estimated and then subtracted from the costs and benefits of Intervention 1 to determine the costs and benefits of grid extension to more remote communities. The results are for 2,493 households in more remote communities. These include both the households that the software determined are suitable for micro-grid, as well as a large number of significantly smaller communities.

Costs

- Cost of connecting households from remote communities is GHS 58m at an 8% discount rate and includes MV lines, transformers, LV lines, and meters. It should be noted that this figure is almost the same for connecting 9,222 households in less remote communities (GHS 59m), demonstrating the vast differences in unit costs between connecting more and less remote communities
- Cost of electricity generation is assumed to equal 31 GHp per kWh, and distribution 45.2 GHp per kWh based on tariffs set by the regulatory agency in Ghana (July 2019, Public Utilities Regulatory Commission) matching the forecasted demand. These tariffs are assumed to incorporate operations and maintenance costs.

Benefits

- The benefit components are the same as for the case of grid electrification: improved welfare in the form increased gross household income and health benefits of improved services. The average electricity demanded per household in this scenario is less than the electricity demanded documented in Intervention 1. As with the micro-grids analysis, lower or higher electricity consumption is assumed to generate lower or higher income and health benefits, so the income and health benefits for households are indexed using the average grid electrified household from Intervention 1 as base.

Summary of Results

Total discounted costs and benefits for 2,493 households over 20 years in million cedi

	5%	8%	14%
Cost: extending grid	69.7	57.9	40.7
Cost: electricity generation and distribution	36.5	25.0	12.4
Cost: TOTAL	106.2	82.9	53.2
Benefit: income increase	120.7	84.2	44.2
Benefit: improved health	11.2	7.4	3.5
Benefit: TOTAL	131.9	91.6	47.7
BCR	1.24	1.11	0.90

Total discounted costs and benefits per household over 20 years in cedi

	5%	8%	14%
Cost: extending grid	27,951	23,224	16,337
Cost: electricity generation and distribution	14,655	10,026	4,986
Cost: TOTAL	42,606	33,250	21,323
Benefit: income increase	48,424	33,782	17,733
Benefit: improved health	4,474	2,979	1,393
Benefit: TOTAL	52,898	36,761	19,125
BCR	1.24	1.11	0.90

Discussion and Sensitivity Analysis

Results indicate that grid extension to more remote communities just passes a benefit cost test. The BCR is sensitive to the assumption of a single average rural income of per household (10,040 cedi in 2020) increasing 46%. If the income increase due to electrification is assumed to be 18%, the BCR is almost halved, 0.5 (8% discounting). If each household is assumed to have two average rural incomes and it increases 46% thanks to electrification then the BCR almost doubles to 2.1.

Conclusion

Our results indicate that grid expansion to less remote communities has the highest benefit-cost ratio (BCR) of 4.5. Microgrid expansion for suitable 'more remote communities' has a BCR of 1.7-1.8 depending on the technology type, while grid expansion to more remote communities has a BCR of 1.1. The results indicate that it is only cost-effective to electrify a subset of rural households, typically those that are less remote, with higher electricity demand and near existing grid infrastructure. For households in more remote communities, grid electricity just passes a cost-benefit test. If electrification is deemed a must-have by policy makers, then providing microgrids is more cost-effective than expanding the grid, under current conditions.

Total discounted costs and benefits over 20 years in million cedi (8% discount rate)

	Costs (GHS millions)	Benefits (GHS millions)	BCR
Electricity grid for less remote communities	100.9	451.4	4.5
Diesel micro-grid for more remote communities	7.6	13.6	1.8
Solar micro-grid for more remote communities	38.4	65.1	1.7
Electricity grid for more remote communities	82.9	91.6	1.1

Total discounted costs and benefits per household over 20 years in cedi (8% discount rate)

	Costs per household (GHS)	Benefits per household (GHS)	BCR
Electricity grid for less remote communities	10,940	48,948	4.5
Diesel micro-grid for more remote communities	25,358	45,344	1.8
Solar micro-grid for more remote communities	20,099	34,048	1.7
Electricity grid for more remote communities	33,250	36,761	1.1

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Cost-benefit Analysis of Interventions to Improve Electricity Access in Ghana

Ghana Priorities

John Bosco Dramani
Lecturer, Department of Economics, Kwame University of Science and Technology, Ghana, Kumasi

Prince Boakye Frimpong
Lecturer, Department of Economics, Kwame University of Science and Technology, Ghana, Kumasi

Academic Abstract

The national electricity coverage in Ghana is currently about 84 percent. The 16 percent of the population who are without electricity comprise of communities that are densely populated and qualify to benefit from the Self-Help Electricity Project (SHEP). In addition, the population without electricity also include the island communities in the middle of Ghana's Lake Volta as well as the Afram Plains. There is a growing demand for electricity for productive use such as irrigation in these communities without electricity and which are usually sparsely populated. Further, some of the communities without electricity are situated far away from the existing grid line and their island nature makes it expensive and uneconomical to extend the national grid to them. The aim of this project is to analyze two interventions addressing rural electrification in the context of Ghana. First, we study the benefits of expanding electrical grid to communities that qualify for SHEP. This intervention envisages connecting all unelectrified households to the electricity grid with a daily continuous 24 hours supply. Second, we study the socio-economic benefits of off-grid connections such as solar stand alone, mini-grids with solar batter or diesel generator back-up and solar home systems extension to island and lakeside communities. Overall, we find that rural electrification intervention led to an increase in gross income of about 46% higher relative to non-electrified households for grid extension. Similarly, we find that being connected to off-grid compared with those without any form of electrification marginally improves welfare through reduction in patient's admission to healthcare facilities.

Keywords: Difference-in-difference, Electricity, Ghana, Mini-Grid, Propensity Score Matching

1.The Problem

By the beginning of 2019, about 84% of the population of Ghana had access to grid-connected electricity – the second highest level in Sub-Saharan Africa (African Energy Reports, 2019). Even though overall access rate in Ghana is high, there exists huge significant differences between the access rates in the urban and rural areas. For instance, in 1993 about 74.6% of urban population had access to electricity. In contrast, 2.8% of rural population had access to electricity in the same year. In 2017, electricity access rate in Ghana for the total, urban and rural population were 78.3%, 90.8 and 65% respectively. Even though the current access rate among the urban population is almost 30% higher than the rural population, the relative trends of the rate indicates a significant improvement in electricity access of rural population (Adu et al., 2018). This major achievement was accomplished in 27 years, up from 1.08% in 1991 with an average annual growth rate of 2.3% (Blimpo & Cosgrove-Davies, 2019). The current rate of growth of electrification appears low and may prevent Ghana from accomplishing her target of universal access by the year 2020. According to Kumi (2017), Ghana can meet her target of universal access in 2020 if the current rate of electrification is raised to about 4.38% per annum.

On the basis of the current national electricity access rate, about 16% of the population constituting about 5 million who are qualified to received grid connection are without electricity. This figure comprises communities that are densely populated, with high demand and qualify to benefit from the Self-Help Electrification Project (SHEP) – a complementary electrification program to support the National Electrification Scheme (NES). Under the SHEP, communities that are within 20km from an existing 33kV or 11kV sub-transmission line can qualify for electrification if they procure all the power poles and have a minimum of 30 percent of the houses within the community wired. Once these conditions are met, the Government provides the conductors, pole-top arrangements, transformers and other installation requirements needed to provide supply to the community. In addition, 2.9 million of the population living in the island communities in the middle of Ghana's Lake Volta as well as the Afram Plains where there is a growing demand for electricity for productive use such as irrigation are without electricity. Communities in these areas are usually less and sparsely populated, situated far away from the existing grid line and their island nature makes it expensive and uneconomical to extend the national grid to them. Thus, alternative technologies such as off-grid solar photovoltaic, biomass gasifier-based power generation and mini-grids are relatively more cost competitive compared to grid extension in the promotion of electrification (Mahapatra & Dasappa, 2012). Based on this, Ghana Energy Development and Access project (GEDAP), through a World Bank facility installed five pilot mini-grids in four island communities in 2016. These mini-grids are hybrid systems with solar battery and diesel generator back-ups and have a generation capacity of 1.5 Megawatts. Since the installation, they have served about 417 households inhabiting 10, 000 people.

The general objective of this project is to undertake analysis of interventions addressing rural electrification in the context of Ghana. First, we study the benefits of expanding electrical grid to communities that qualify for SHEP. This intervention envisages connecting all unelectrified households to the electricity grid with daily continuous 24 hours supply. Second, we study the socio-economic benefits of solar micro-grids backed by diesel generators, solar stand-alone and solar home system extension to island communities. This intervention envisages providing electricity to all unelectrified households by installing solar micro grids distributed across villages as per local capacity requirement. The National Mini Grid Policy has also undertaken an investment plan to scale-up renewable energy aimed at providing off-grid electricity to the island and lakeside population with electricity.

We expect that these interventions will provide more benefits than cost, to justify the need for the government of Ghana to spend an extra cedi in the extension of either the grid or mini-grid to the communities which are currently without electricity. In many cases, decisions concerning the technology to apply to increase access to electricity are being taken without prior adequate empirical evidence (Lee et al., 2016). Many existing studies suggest rural electrification generates important economic benefits which bring significant changes to an economy. These benefits include improvement in employment among female section of the population (Dinkelman, 2011), higher profit margins for firms connected to electricity (Akpan et al., 2013) and time relocation which promote productivity (Bernard & Torero, 2011). Other studies such as Chakravorty et al. (2016) and Lee et al., (2019) compared the benefits and costs of rural electrification and concluded that the benefits outweigh the cost.

However, to effectively make informed decisions on which rural areas to earmark for electrification, which technology should be considered, the amount of finance and incentives required to facilitate utilization, policymakers will need empirical evidence on the benefits and costs of rural electrification. With respect to Ghana, there are limited studies that have simultaneously estimated and compared the benefits and costs of extending electricity to the remaining 16 percent of the population who are without electricity. In fact, all past studies (Adu et al., 2018) estimate only the benefits of rural electrification and neglect the pathways especially the health pathways and cost of extension. Our study relies on microdata on income of households to estimate the effect of rural electrification in Ghana. In addition, we estimate the monetary costs of extension and compare these estimates in benefit-cost ratio framework.

2. Intervention 1: Self-Help Electrification Program (SHEP)

2.1 Overview

SHEP was introduced as a complementary electrification program to support the National Electrification Scheme. It aimed at accelerating the process of connecting all communities in Ghana unto the national grid by encouraging communities to undertake self-help developmental initiatives. Communities that initiated the process of getting connected to the national electricity grid received government support to complete the projects at earlier dates than scheduled dates of completion under the National Electrification Master Plan (NEMP).

SHEP was implemented in phases (Ministry of Energy, 2010). The first phase was implemented between 1990 and 1991 and 50 communities were connected to the national grid. The second phase was rolled out between 1992 and 1994 and assisted the connection of 250 communities to the national grid. The third phase identified 1400 communities qualified for connection to the national grid. Due to the large number of communities who had met the requirements for connection, the third phase was subdivided into four phases, of which the first sub-phase commenced in 1996 and ended in 1998, benefiting 170 communities. The second sub-phase started in 1998 and completed in 2000 and provided 480 communities with electricity extension. Sub-phase three started in 2001 and ended in 2010 with electricity extension to 700 communities. The fourth sub-phase commenced in 2011 and it is still ongoing.

2.2 Implementation Considerations

To benefit from SHEP a community must register to join the intervention and must be situated within 20km of the existing 11kv or 33kv network that are appropriate for extension. The nearer the communities are to the 11kv or 33kv the more economical and less cumbersome it is to extend electricity to them. In addition, communities must purchase and erect the required number of low voltage electrical poles that are needed for the local network. The communities must also show evidence that a minimum of one-third of the houses in the communities have been wired and are ready to be connected to the national grid. Communities which meet these conditions are then supported by the government with conductors, pole-top arrangements, transformers and other relevant equipment and resources required to supply the electricity to the communities. Government also encourages the private sector initiatives to obtain electricity connection if they can fund it.

2.3 Related Literature

Electricity is considered an infrastructure that greatly improves the lives of people especially under certain complementary conditions. The benefits of electricity access are realized when it leads to increases in consumer surplus. Consumer surplus is the difference between the price consumers are willing to pay for electricity and what they actually pay. At a given price, the area under the demand curve, represent the stream of benefits attributed to access to electricity. Consumer surplus is high when the benefits are greater than the cost of extending and connecting to grid (Kirubi et al., 2009). The extension of electricity to the island, lake side and Northern sector of Ghana will require households to pay and get connected. Thus, improvements in the welfare of these households through electricity access can be represented by a higher stream of benefits relative to the extension and connection costs. Barido et al. (2017) point out that access to electricity by way of grid extension is relatively cheaper especially for areas with high demand and population densities. According to Bernard & Torero (2011), access to grid electricity allows households to save time which can be channelled into other productive activities. Dinkelman (2011) finds that access to electricity connection in disadvantaged regions in South Africa increased employment opportunities especially for rural women. Women are able to set up enterprises and spend longer hours working. This does not only bring about a positive income shock but also reduces fertility since the opportunity cost of giving birth to many children is now high. Akpan et al. (2013) find that enterprises with access to grid electricity achieve higher profit margins up to 16% more than unconnected ones. Similarly, Bernard & Torero (2009) find that access to grid connection improves the social status of individuals. The authors note that a household’s connection to the grid is related to the behaviour of their neighbours as grid electricity access confers a higher status to them within the community. A study by Chakravorty et al. (2016) follow a three-step approach. The authors first did a projection of grid electricity expansion using a least-cost first principle. The projected expansion then became an instrument used to evaluate the effect of electricity infrastructure on expenditure and income of households in Philippines. Finally, the authors compare these expenditure and income benefits of electricity expansion with cost of extension to the villages. The findings reveal that the monetary cost of electricity expansion is recovered in a year after income improvements of households. Further, the authors find agricultural income as a key transmission channel of electricity expansion on income improvements. This implies rural electrification is channelled for productive use in agriculture which drives income gains. Burlig and Preonas (2016) analysis note that electricity expansion to rural communities may not be a key solution for the reduction in poverty and kick-starting major economic transformation in a country. The authors indicate that short-term and modest economic benefits such as income, labor hours, household wealth, asset ownership and education due to electrification cannot rationalize the huge investment needs of electrifying rural communities. The findings suggest that rural electrification is not very beneficial. Lee et al. (2019) used an experimental design to study the demand and supply of rural electrification in Kenya. Clusters of households were selected randomly with each given the chance to join the grid at subsidized rates. By giving households the opportunity to connect at various subsidized rates and the length of extending the grid, the study produced exogenous differences regarding price and cost of extension. Based on this, the study estimated the demand, average and marginal costs curves associated with both connection to and extension of the grid and compared the demand and costs curves to estimate the welfare issues of rural electricity. The findings show that household demand for grid connection is low even when they are highly subsidized. However, the cost of grid extension is very high and as a result, the estimated consumer surplus is very low relative to overall cost of connection. The findings point to a conclusion that electricity extension to local communities does not promote the enhancements of welfare.

For existing firms, access to electricity increases the productivity of individuals as they make use of electric equipment which would otherwise have been impossible. A fashion designer can now use an electric sowing machine which allows greater production than a manual one. Electricity access also increases the hours individuals can work because they can work during the night as well and this raises their productivity (Bernard & Torero, 2011; Cabraal et al., 2005). Mention can also be made of improvements in the health and educational sectors with access to electricity. Health practitioners get to work with modern equipment and patients receive better ventilation due to electricity access. Students also get the opportunity to study at night with better lighting and can make use of modern computers and equipment to enhance their studies. The end result of this is an improvement in human capital which also raises productivity of individuals (Torero, 2015). Electricity access also enhances the establishment of small and medium scale enterprises (Van de walle et al., 2013). New line non-agriculture enterprises such as cold store, barber shops, café and internet services are made possible due to electricity access in rural areas.

Electricity access enhances a shift from the use of biomass to the use of electric stoves and this has two important implications. First, it allows females to increase the supply of labour as they spend their extra labour time in micro enterprises as well as other self-employment which enhances welfare. The extended working hours further allows males to reduce off-farm hours (leisure) and increases time in other labour activities. Ceteris paribus, an increase in time reallocation to work increases household income. The expected higher income in electrified communities has the potential of increasing consumption expenditure per households which can improve welfare (Khandker et al., 2008; Bensch et al., 2011). Second, a shift from the use of biomass to electricity reduces indoor pollution which can decrease the incidence and percentage of children under 5 years and their mother from getting lower respiratory infections.

2.4 Data and Methods

2.4.1 Data and descriptive statistics

We utilize data from the fifth, sixth and seventh waves of the Ghana Living Standards Survey (GLSS) collected respectively in 2005/2006, 2012/2013 and 2017/2018. For the first part of the analyses, the study combined data from a geo-referenced data on the location electrified in Ghana. We do not use the geo-referenced data on the latest survey because as at the time of the analysis, we had still not obtained the GPS coordinates from the Ministry of Energy and Power Distribution Service. The GLSS are nationally representative cross-sectional survey of households conducted by the Ghana Statistical Service with the support from the World Bank and other agencies. The population living in private households constitute the sampling frame of the survey. This sample frame is then divided into two sampling units (i.e., primary and secondary sampling units). The primary sampling unit is defined as the census enumerated areas that are stratified into ten administrative regions of Ghana based on proportional allocation using the population in each of the regions. In contrast, the secondary sampling unit is defined as the households living in each of the enumeration areas. All data in the three waves are geo-referenced except that in the last wave, where the geo-referenced dataset was not utilized due to the reason given above. The communities within which the households are located have GPS coordinates. That is to say the GPS coordinates are somewhat displaced to locate the exact households. This is done to ensure anonymity of the households being interviewed.

Table 1 presents the sample description of the variables. It must be stressed that the sample includes only households located in the rural parts of Ghana. Pooling the three waves of GLSS together, the total number of households according to the data is 17717 of which 75% are headed by males with an average age of about 47 years. Out of this sample, about 64% had no education with a paltry 3% with higher education. The average household size in the sample is 4.9 members with about 62% of the sample are currently married. The average gross income for a household in the sample is roughly GH¢ 8516.68. Turning to the group analysis, 71% of the households are headed by males in the treated group whereas it is 78% in the control group. Focusing on the main outcome variable, the data presented in Table 2 indicates some marked variation across survey waves and the treatment. For instance, mean gross income shows consistently increase over the survey rounds. Since the estimated effects are usually related to the baseline outcomes, we also present the average gross income across waves and the control group. When we consider only the last wave, the average gross income for the control group, that is, the un-electrified households is GH¢ 9714. Pooling the sample together, the average income for the control group is GH¢ 5642.

Table 1: Sample description of the variables

	(1)		(2)		(3)	
	Overall		**Treated**		**Control**	
	count	mean	count	mean	count	mean
Male	17717	0.75	6857	0.71	10860	0.78
Age	17717	47.31	6857	46.48	10860	47.83
Educational level						
No	17717	0.64	6857	0.50	10860	0.74
Basic	17717	0.27	6857	0.36	10860	0.21
Secondary	17717	0.06	6857	0.09	10860	0.04
Higher	17717	0.03	6857	0.05	10860	0.01
Marital status	17717	0.62	6857	0.58	10860	0.66
Household size	17717	4.87	6857	4.60	10860	5.04
Women with higher edu	17717	0.03	6857	0.05	10860	0.02
Female/male ratio	17717	0.26	6857	0.28	10860	0.24
Gross income	17717	8516.78	6857	13068.85	10860	5642.61

Table 2: Summary Statistics on Gross Income in the Sample

	Observations	Mean (GH¢)
GLSS 5	4,601	1045.891
GLSS 6	6,895	7356.749
GLSS 7	6,221	15327.91
GLSS 7 & Control group	2,651	9714.375
Pooled Sample	17,717	8516.782
Pooled Sample & Control group	10,860	5642.611

2.4.2 Identification and Estimation Methods

We conduct our empirical analysis by appealing two main estimation methods. At the first instance, we rely on estimating the average effect of electrification on outcomes following Adu et al. (2018) and complement the analysis using a seemingly robust estimator. Thus, we seek to compare the outcomes of households who are electrified with those who are not by using data from the 2005/2006, 2012/2013 and 2017/2018 GLSS. Another objective of this project is to estimate the socio-economic benefits of providing micro grids to communities particularly island or lakeside communities. As a consequence, we compare households who have been connected to these mini grids with those without electricity. It is important to note that, information on mini grids is only found in the latest wave of the GLSS. Thus, we are compelled to provide a difference in means estimator when the analysis is focused on the benefits of mini grids.

Regarding the first objective, we seek to identify the average effect of electrification on outcomes (e.g., gross income) in households which are electrified (i.e., the average impact of treatment on the treated). Specifically, we are interested in comparing outcomes when households are electrified to the counterfactual, that is, outcomes when households are not electrified in the treatment areas at the same point in time. The counterfactual is unobservable and ought to be estimated. Conventionally, we would like to assign randomly 'electricity' or 'no electricity' across households and compare the average outcomes of the two groups. We are compelled to use nonexperimental methods in the absence of a controlled randomized experiment under some reasonable assumptions.

One major concern is that households that are electrified could be different from households that are not and that these differences may be correlated with outcomes. For instance, richer households in somewhat influential districts in which gross incomes and expenditures were higher may have been the ones that were electrified. Consequently, the correlation between rural electrification and outcomes would be confounded with the wealth effect. Many of these types of unobservable characteristics that may in principle confound with our identification are those that vary across districts and households that are fixed over time. To control for time-invariant unobserved heterogeneity is to we use panel data (repeated cross section) and estimate difference-in-differences models.

We therefore utilise a difference-in-differences approach which compares the change in outcomes in the treatment group before and after the intervention to the change in outcomes in the control group. By comparing changes, we control for observed and unobserved time-invariant households and community characteristics that might be correlated with electrification as well as with outcomes. The change in outcomes in the treatment households, controls for fixed characteristics while the change in outcomes in the controlled households, controls for time-varying factors that are common to both controlled and treatment households. To put it more tersely, the change in the controlled group is an estimate of the true counterfactual, that is, what would have happened to the treatment group if there had been no intervention.

We formally specify the difference-in-differences model as a two-way fixed-effect linear regression model as:

$$y_{ijdt} = \delta Electric_{ijdt} + \phi Post_{ijdt} + \alpha(Electric \times Post)_{ijdt} + \beta \mathbf{x}_{ijdt} + \lambda_t + \mu_j + \eta_d + \varepsilon_{ijdt} \qquad (1)$$

where y_{ijt} is the outcome variable (e.g., gross income) for household i in community j located in district d in time period $t = [0,1]$, $(Electric \times Post)_{ijdt}$ is an indicator variable which takes on the value one if a household in a community has been electrified in a particular district in year t and zero otherwise, $\mathbf{x}_{ijdt}$ is a vector of control variables that vary across both districts and time, μ_j and η_d are fixed effects unique to community j and district d respectively and λ_t is a time effect common to all districts in period t.

The error ε_{ijdt} is a district time-varying error which is assumed to be distributed independently of all η_d and λ_t. The errors ε_{ijdt} might be correlated across time and space. For instance, the persistence of economic activities intended to reduce poverty could induce time-series correlation at the district level. The errors could also be present in the cross-section dimension in that, economic activities present in one area could affect neighbouring districts. Moreover, various poverty reduction programmes implemented by the government of Ghana would typically apply to all districts in a region at the same time particularly in the era of decentralization. To address these potential biases in the estimation of the standard errors, we first allow for an arbitrary covariance structure within districts over time by computing our standard errors clustered at the district level.

In equation (1), α is the difference-in-differences estimate of the (average) effect of rural electrification on outcomes. Our identifying assumption for this interpretation is that the change in outcomes in the control households is an unbiased estimate of the counterfactual. Another key concern worthy of notice is that the impact of rural electrification may not be homogeneous across households but may vary as a function of the characteristics of the households. For example, the impact of rural electrification may matter more in households in which families are better educated. Thus, estimation using simple difference-in-differences may suffer from two additional sources of bias (Heckman et al., 1997). The first source of bias arises when there are some electrified households but there are no comparable households for there was no electrification. The second source of bias arises when we have different distributions of the vector of observable variables ($\mathbf{x}$) that affect the outcomes within the two groups. Therefore, we implement matching methods to eliminate these two potential sources of biases by pairing electrified households (treatments) with non-electrified households (controls) that have similar observed attributes. To eliminate the first source of potential bias, we use observations in the treatment and controlled groups over the region of common support in the distribution of $\mathbf{x}$. Further, to eliminate the bias due to different distributions of $\mathbf{x}$ between the treated and controlled households within this common support, we reweight the controlled group observations.

Conventionally, matching methods assume that, conditional on the observed variables $\mathbf{x}$, the counterfactual outcome distributed of the treated units is the same as the observed outcome distribution of the units in the controlled group. The assumption is that, there is no selection into treatment based on unobservables. Heckman et al. (1998) propose a generalized difference-in-differences matching estimator as a means of circumventing the assumption of no selection on unobservables. This estimator identifies the parameter of interest without precluding selection into treatment based on time-invariant unobservables. Stated differently, the generalized difference-in-differences estimator conditions on fixed effects to estimate the parameters of interest.

The basic idea is to construct a control group by finding controls with observed $\mathbf{x}$'s similar to those in the treatment. To match treated and untreated individuals on the basis of $\mathbf{x}$ is equivalent to matching them using a balancing score $B(\mathbf{x})$ (Rosenbaum and Rubin, 1983). The coarsest balancing score is the propensity score that gives the conditional probability of receiving treatment given the pre-treatment values of the vector $\mathbf{x}$, that is $P(\mathbf{x}) = Pr(D=1|\mathbf{x})$. The method then assumes that, conditional on $P(\mathbf{x})$, the counterfactual outcome distribution of the treated units is the same as the observed outcome distribution of the controls. We use nearest neighbour with replacement matching procedure to obtain the generalized difference-in-differences matching estimator.

Regarding the analysis on the micro grids as stated before, we conduct a simple difference in means analysis to estimate the effect of being connected to these grids on outcomes. Consequently, we specify the following:

$$y_{ijd} = \alpha Mgrid_{ijd} + \beta \mathbf{x}_{ijd} + \varepsilon_{ijd} \ldots\ldots\ldots 2$$

where all the variables are as previously defined except $Mgrid_{ijd}$ which is an indicator equal to 1 if a household in a community has been connected to the mini grid and 0 if the household has neither been connected to the national grid nor mini grid and does not use any form of power generation[1]. The outcomes in this specification include the log of per capita household expenditure, the probability of consulting a physician due to illness and the probability of being admitted at the hospital or health facility.

2.5 Analysis of Benefits

The impacts of electrification are estimated using two distinct approaches: difference-in-difference (DD) and propensity score matching (PSM). We first provide the results at the household level while acknowledging that these households are not the same in the various survey waves. Stated alternately, the GLSS provides repeated cross-section data making it impossible to implement DD design at the household-level since the same households may not have been observed at different point in time. In a standard DD design, we need to observe the progression in a particular outcome for a particular unit (e.g., a household) at different points

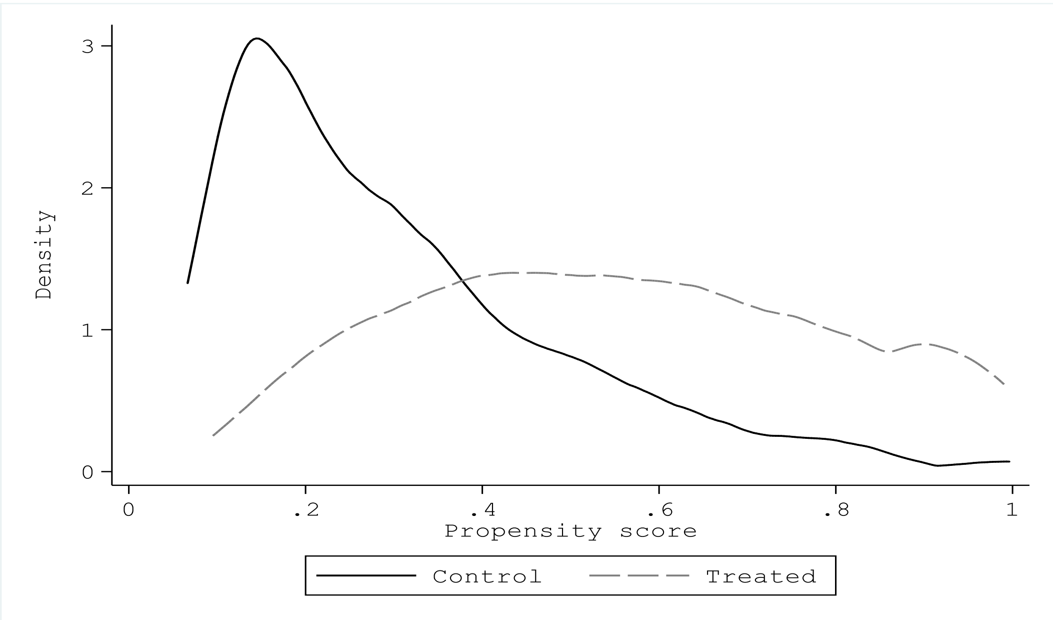
[1] The treatment assignment of the household is done this way because we found that in the data, some households used private generators and solar powered inverters. We believe using households with no electric power generation as control would be ideal for better comparison with the treatment group.

in time. To address the problem, we aggregate the data into district-level averages (thus converting it into panel data), and running the estimation at the district-level. We, however, envisage a similar problem since different districts are selected across different survey waves. As a consequence, we support our baseline results with propensity score matching estimator indicated above.

2.6. Propensity score matching and balancing tests

We further employ the PSM technique, using the baseline data. We aim to determine the region of common support in order to exclude all households outside the common space from the subsequent analyses. Propensity scores were calculated using the baseline values of the main outcome variables as well as other household and community level characteristics. We used age, sex, marital status, education level of household heads, household size and community level covariates such as poverty status, the proportion of women with higher education and female to male ratio. We dropped observations that appeared outside the common support and conducted balancing tests of our main variables at the baseline. Figure 1 presents the plot of the common support region for both the treated and control groups.

Figure 1: Common support for the treated and untreated group



2.7 Economic benefits of electrification

In this section we present the results of the socio-economic benefits of the various interventions to improve access of electricity communities that qualify for SHEP as well as solar micro-grids extension to island communities. We analyse the results by relying on two quasi-experimental methods: diff-in-diff and propensity score matching and report the results in Tables 3 and 4 respectively. Overall, we find that rural electrification intervention led to an increase in gross income of about 46% higher relative to the non-electrified households for grid extension. The coefficient is 0.379 but because the dependent variable is in logarithm, the actually effect is estimated as $(e^{0.379}-1)\times 100\% = 46.1\%$. This compares favourably with the results from the matching estimation which estimates the average treatment effect on the treatment which is around 42.3% (see Table 4). We also find improvement in gross income of about 62% higher for households with grid connection without control. Without control we introduce fixed effects to capture district-level and household-level characteristics that be related to both the decision to connect and to the outcome of electrification.

A key identifying assumptions for the DD design requires that there are no other unobserved, time-varying factors that could be influencing outcomes. To this end, we account for external validility capturing the households connected to the grid who have never moved from their districts and those connected who have moved before. The results show that connected households who have never moved capturing control are most likely to increase their gross income by 69% relative to non-connected households who have never moved and about 86% without controls.

Table 3: Impact of electrification on household economic outcomes: Double Difference

	Full sample		Never movers	
	(1)	(2)	(3)	(4)
	logY	logY	logY	logY
Electric × Post	0.620***	0.379***	0.864**	0.698**
	(0.142)	(0.121)	(0.380)	(0.215)
Controls	No	Yes	No	Yes
District fixed effect	No	Yes	No	Yes
Mean dep variable	7.39	7.39	7.39	7.39
Observations	17,717	17,717	7,869	7,869
R-squared	0.064	0.350	0.051	0.341

Notes: Electric×Post is the difference-in-difference indicator. Robust standard errors clustered at the district level are in parentheses. Y is household gross income. All regressions are weighted by the sample weights in the survey. All regressions include district fixed effects, as well as demographic and community level covariates unless otherwise stated in the table. Demographic covariates include household size, age of the household head, sex and marital status of the head. Community level covariates include fraction of households living below the poverty line, share of female-headed households, and fraction of women with completed higher education. Mean dependent variable is the logarithm of gross income for the control group. *** p<0.01, ** p<0.05, * p<0.1

In Table 4 we present results for PSM estimation as a robust measure for the DD estimations. Basically, we sought to compensate for the non-existence of a selection rule for randomizing the households into treatment and control groups. We apply the nearest neighbour (NN) PSM to ensure that the control observation associated with the evaluated probability value nearest to the treated household is choosen. The findings show that electricity connection to a household improves gross household income. For instance, electricity connection has a high probability of increasing gross income by about 42% respectively relative to comparable households not connected at the district. In doing this we control for demographic covariates such as household size, age of the household head, sex and marital status of the household head. After controlling for district fixed effects, the impact increased slightly particularly for the gross income and welfare. Thus, electrified households are seen to be performing better in terms of the outcomes presented compared with non-electrified households.

Table 4: Average treatment effect on the treated: Matching

	Nearest neighbour		
	nn=1	nn=3	nn=5
	(1)	(2)	(3)
	logY	logY	logY
Electricity (=1)	0.423***	0.423***	0.423***
	(0.068)	(0.124)	(0.069)
Observations	17,717	17,717	17,717

Standard errors are in parentheses. Y is household gross income. All regressions include demographic and community level covariates unless otherwise stated in the table. Demographic covariates include household size, age of the household head, sex and marital status of the head. Community level covariates include fraction of households living below the poverty line, share of female-headed households, and fraction of women with completed higher education. *** p<0.01, ** p<0.05, * p<0.1

Even though the results suggest extension of electricity to rural communities leads to significant welfare benefits, we believe these benefits would have been greater if certain complementarities such as good roads, access to appliances for productive use of electricity, costs of connection and utilization as well as reliability of the grid were provided to the rural communities. There are about 32, 250 km of roads in in Ghana and just about 6,084 km, representing 18 percent of the roads are tarred (Association for Safe International Road Travel [ASIRT], 2014). The huge percentage of untarred roads, particularly in the rural communities inhibits the transportation and marketing of agricultural produce to the consuming centers.

In addition, electricity appliance stock is relevant in determing the utilization of electricity for productive purposes and contribution to improvement in income and welfare of connected villages. Taale and Kyeremeh (2019) reported that on the average households in Ghana owned about 6.69 of appliances. More importantly when disaggregated, entertainment appliances constitute 2.23, laundry appliances 0.75, preservation appliances 0.58 and the remaining 3.13 constitutes other appliances including lighting, heating, cooling. The finding suggests a greater percentage of appliance used by households in Ghana are not meant to draw electricity for productive purposes. This explains why electricity access does not promote agricultural productivity in Ghana.

Expanding electricity access should not only promote the connection of households to the national grid but should also ensure a reliable supply of power to consumers at an affordable tariff. Regrettably, the electricity sector of Ghana sometimes suffers from an unreliable supply of power mostly attributed to a litany of factors such as insufficient rainfall to generate electricity using hydro source, shortfall in natural gas supply from Nigeria and Atuobo plant, frequent breakdown of transmission and distribution equipment and rising world crude oil prices. The unreliable nature of the power system may to a large extent prevent the productive use of electricity by the rural communities to futher raise the benefits of electrification in the remaining un-electrified communities in Ghana.

2.8 Mechanisms

In this section we evaluate possible pathways for which electricity access can impact gross income of households at the district level. To accomplish this, we extracted information on health indicators such as illness within the last two weeks, admission at the hospital within the last two weeks, consulted a medical doctor within the two week and hospitalized within the last twelve months before the survey. The results are presented in Table 5. The finding shows that there is a high likelihood for electrified relative to non-electrified households to reduce admision and being hospitalized at a health facility. This implies households in electrified districts with healthcare spent less on healthcare relative to comparable households in dictricts without electricity. The marginal effects of the probit model are -0.310 and -0.353 for admit and hospitalized repectively and they are statistically significant at 5% level of significance. These marginal effects imply that the likelihood of a household member in a district with electricity connection to be admitted and hospitalized is about 31% and 35.3% lower than comparable households in districts without electricity access.

Table 5: Impact of Rural Electrification – Health Pathways

	(1) Illness	(2) Admit	(3) Consult	(4) Hospitalise
Electric × Post	0.080	-0.310**	0.054	-0.353**
	(0.075)	(0.130)	(0.152)	(0.142)
Mean dep var	0.63	0.01	0.13	0.08
Observations	17756	17756	17756	17756

Notes: Electric×Post is the difference-in-difference indicator. Illness is an indicator which is equal to one if the respondent has been ill or suffered an injury two weeks preceding the survey and zero otherwise; Admit is a dummy variable which is equal to one if the respondent had been admitted at a facility two weeks preceding the survey; Consult is also an indicator if the respondent consulted a doctor two weeks preceding the survey and Hospitalise is an indicator which is equal to one if the respondent has been hospitalised in the last 12 months preceding the survey. Robust standard errors clustered at the district level are in parentheses. All regressions are weighted by the sample weights in the survey. All regressions include district fixed effects, as well as demographic and community level covariates unless otherwise stated in the table. Demographic covariates include household size, age of the household head, sex and marital status of the head. Community level covariates include fraction of households living below the poverty line, share of female-headed households, and fraction of women with completed higher education. Mean dependent variable is the logarithm of gross income for the control group. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

3 Intervention 2: Off-Grid Extension

3.1 Overview

As part of a national strategy to bring electricity to the remote and sparsely dispersed population, off-grid solutions comprising the deployment of Solar Pico Systems (SPS) and Solar Home Systems (SHS), mini mini-grids using solar and wind technologies, with diesel generators back up have been used to supply electricity. These communities comprising lakeside and islands h are beyond the national grid, thus making grid extension uneconomical. Since off-grid solutions such as mini-grids and stand-alone solar provide collective solutions at relatively lower cost to facilitate basic needs and stimulate productive use of electricity. The International Energy Agency (2017) indicated that mini-grid and other off-grid connections will be needed to provide electricity to about 400 million people by 2030 to achieve the Sustainable Energy for All goal of universal energy access.

In the light of the above discussion, off-grid extensions offer another great opportunity to connect a large chunk of the rural population to electricity or to have some form of electricity in their household. While micro grids were the original consideration, the data available on them at the moment is quite scanty. Thus, statistical analysis on it seems to lose power. Consequently, due to the number of observations on the micro grids, we club the other sources of lighting except the main grid (electricity) to constitute off-grid. For instance, in the GLSS 7, 72.14% have been connected to the national grid whereas 24.95% do not have any form of connectivity to electricity. The remaining are split between those who have mini-grids, solar lanterns, solar home systems, private generators, rechargeable batteries and others. We therefore consider these as off-grid extensions and compare the outcomes of these individuals to those without any form of electricity.

3.2 Implementation Considerations

The World Bank-funded Ghana Energy Development and Access Project (GEDAP), has introduced five pilot mini grid projects in 2016 with a total installed capacity of 1.7 MW. These grids provide electricity to four island communities with a population of over 10, 000 people. Besides provision of electricity for residential purposes, the mini-grids and other off-grid solutions stimulated productive use of electricity as they were used for irrigation and other commercial ventures.

While the benefits of the mini grids for these communities are clear, there are still many challenges if these projects are to be scaled up to 200 more island communities without electricity access. The mini grid sector still lacks policy and regulatory clarity, and the pilot projects mainly rely on intermittent funding primarily sourced from development partners and nongovernmental organizations.

3.3 Literature Review

A key challenge of grid-powered electricity is the difficulty in reaching scattered communities with very small population size and which cannot be reached by road. These characteristics increase the cost of grid extension not to mention the additional costs incurred in maintaining them (Torero, 2015). It is in situations like this that off-grid electricity sources such as solar and diesel power becomes very essential. According to Torero (2015), off-grid electricity sources like stand-alone solar, mini-grids with solar battery and diesel back-ups can provide viable means of increasing access for people in remote areas. The difficulty with grid electricity in these scattered settlements makes solar electricity access cost effective in delivering benefits of electricity to such people. Switching to off-grid electricity access will also be a step in the right direction in reducing indoor air pollution and global warming with its attendant negative effects (Rom & Gunther, 2017). Grogan & Sandanand (2012) document how access to off-grid electricity enabled women in Nicaragua to work for more hours in the day using lighting. The authors note that more than 1% of Nicaraguans used off-grid electricity like solar for their lighting in 2005. In Ghana, Gyamfi et al. (2015) examine how the provision of electricity can be improved by exploiting the huge potential in renewable energy sources like wind and solar PV. The authors note one way to expand the generating capacity in the country is to increase the use of these renewable energies which is being under-utilized. Conversely, Kumi (2017) note that solar electricity access is a viable option for areas with hot temperatures like the northern part of Ghana. Solar panels can easily be powered to generate power since they are mostly disadvantaged with regards to access to electricity.

3.4 Economic Benefits of Off-Grids

We analyse the effect of being connected to an off-grid extension in this section as described in the overview. We rely on the latest wave of the GLSS in this analysis since no information on off-grids particularly mini-grids is found in the preceding waves. Though, less than 3 percent of the households are connected to the off-grid, we still present the result, taking into account the possible loss of power of the significant tests due to the small sample. Nonetheless, we do well to provide a first-hand but quite important estimate of the effect of being connected to the mini grid on outcomes. Here, we analyse the effect on outcomes such as household per capita expenditure (as a measure of welfare), the probability of consulting a doctor and the probability of being admitted at the hospital or health facility and on the time an individual spents doing his/her homework while in school. We deem it appropriate to include some health variables since electricity can affect many economic outcomes through its impact on health. The health variables found in the GLSS are quite scanty so we were compelled to use these two proxies for this purpose.

Ideally, it would be appropriate to conduct field experiments to identify the effect of those using off-grid extensions on education and health variables, the present study nonetheless tries to quantify some of these benefits by resorting to the data available. Regarding the education benefits, we argue that if an individual has some source of lighting, it can increase the length of time he/she studies at night and hence would be able to do his/her homework. Thus, we utilise this information in the data in order to estimate the effect of being connected to an off-grid on the time spent doing homework. All analyses done on the off-grid are at the individual levels instead of the household level.

Table 6: Impact of mini grid connection on outcomes: Difference in means estimates

	(1) logW	(2) Consult	(3) Admit	(4) Homework	(5) logW	(6) Consult	(7) Admit	(8) Homework
Off-Grid	0.171	0.043***	0.003	0.095	0.209*	0.045***	0.005*	0.129
	(0.119)	(0.015)	(0.003)	(0.195)	(0.114)	(0.016)	(0.003)	(0.221)
Observations	3,088	15,117	15,117	3,374	3,084	13,049	13,049	3,122
R-squared	0.004	0.002	0.000	0.000	0.072	0.011	0.002	0.037
Controls	No	No	No	No	Yes	Yes	Yes	Yes

Robust standard errors clustered at the cluster level are in parentheses. W is real household per capita expenditure as a measure of welfare. Consult is an indicator variable which is equal to one if the respondent indicated consulting the doctor two weeks preceding the survey and zero otherwise. Admit is an indicator which is equal to one if the respondent indicated admitted to a hospital or health facility and zero otherwise. Homework is the number of hours spent on homework a week preceding the survey. All regressions include demographic characteristics. Demographic covariates include household size, age, sex and marital status. *** p<0.01, ** p<0.05, * p<0.1

We find that being connected to off-grid compared with those without any form of electrification marginally improves welfare. This is evident in column (5). We do not find any effect on education – there is no significant effect of being exposed to off-grid connection on the hours spent doing homework.

3.5 Grid versus micro-grid technologies in Ghana

Many factors influence the choice of connecting to the national grid or a mini grid in the rural or an isolated area in Ghana. These facors comprise of economic, financial, social, environmental, and technical parameters (Energy Management Assistance Program [EMAP], 2017). Grid connection has become the preferable method of electricfication globally, because it generates high economies of scale which reduces the cost of supply. Customers connected to the grid will thus have a lower cost and will be generally provided with electricity on a more reliable and stable basis than customers connected to mini grid. In addition, grid provides a much wider end-user usage of electricity relative to mini grid. PwC and KITE (2012) in a survey revealed that more than 90% of households interviewed lamented the limited capability of mini grid and solar energy by indicating that apart from charging of phone battery and lighting these sources of electricity cannot be used for any other activity. However, despite its merits, grid technology is incapable of reaching many isolated areas such as islands, lakeside and sparsely populated communities due to high extension costs. The only cost-effective means of getting electricity to these communities is through mini grids or solar PVs. Mini grids have thus, become important in the provision of electricity to communities with lower demand for electricity and at a cost lower than the fixed capital cost of grid extension.

Installed capacity for the provision of grid connection has increased significantly leading a high level of reliability of the national grid. For instance, in Table 6, the total installed capacity of on-grid electricity supply is 35,130 kw representing about 82% of total installed capacity from 2013 to 2017 while off-grid and mini- grid contributed only 7614 kw denoting 8%. In addition, in 2019, the dependable capacity of grid connected electricity was about 90% of total installed capacity while mini-grid and off-grid recorded a dependable capacity of 0% (Republic of Ghana, 2019).

Table 6: Installed renewable electricity generation capacity, 2013 – 2017, kw

Year	Off-grid		On-grid				Mini-Grid		Installed (kW)
	Solar	Wind	Dist.SPV	Utility Solar	W2E	Hydro	Solar	Wind	
2013	-	-	495	2,500	-	-	-	-	2,995
2014	1,350	-	443	-	-	-	-	-	1,793
2015	4,003	20	700	20,000	100	4,000	256	11	29,090
2016	1,238	-	2,626	-	-	-	-	-	3,865
2017	678	-	4,266	-	-	-	58		5,002
TOTAL	**7,269**	**20**	**8,530**	**22,500**	**100**	**4,000**	**314**	**11**	**42,774**

Source: Energy Commission (2018)

With respect to tariffs, there exist two major schemes; deregulated cost- reflective tariffs and uniform utility tariffs (Reber et al., 2018). Deregulated tariffs ensure that mini-grid developers are allowed to generate electricity and set their own rates to cover both capital and operational costs. Even though deregulated tariffs are subjected to regulatory approval, the tariffs charge though even higher than those charged by the national grid operator, they will still be lower than cost of using kerosene and other forms of energy. Unfortunately, deregulated tariffs schemes are rarely practiced in Ghana. On the other hand, national utility tariffs scheme ensures consumers of electricity are charged a uniform rate regardless of connection to national grid or mini-grid. The principal intention is to provide fairness and equality among consumers. Tariffs are based on the utility grid rates or are tied to the utility's cost-of-service. In most cases the tariffs are either cross-subsidized or the government provides the subsidy by making the cost of electricity affordable. The intention of government to make electricity affordable compels micro-grid developers to compete with tariffs that are below cost-recovery rates. In 2019, electricity tariffs in Ghana range from a lifeline rate of Ghp35.36 per kWh (USD 0.077) to Ghp97.09 per kWh (USD 0.233) for residential customers. The highest tariff for commercial consumers was Ghp162 per kWh (Reber et al., 2018). The tariffs rise with increases in consumption of electricity. The highest commercial rate is a huge challenge to min-grid developers as they are unable to build financially viable system. Ghana Energy Development and Access Project (GEDAP) has developed 5 micro-grid projects. However, the tariffs charged are inadequate to cover the variable cost. As a result, subsidies needed to cover the operational cost ranges from GHS 5.82 and GHS 55.73 (USD 0.01 and 0.13) per kWh per month conditional on the category of tariff (Reber et al., 2018).

4. Conclusion

By the beginning of 2019, about 84% of the population of Ghana had access to electricity – the second highest level in Sub-Saharan Africa. This significant achievement was accomplished in 27 years, up from 1.08% in 1991 with an average annual growth rate of 2.3% (Blimpo & Cosgrove-Davies, 2019) through the National Electrification Scheme. The current rate of growth of electrification appears low and may prevent Ghana from accomplishing her target of universal access by the year 2020. Experts have indicated that Ghana can meet her target of universal access in 2020 if the current rate of electrification is raised to about 4.38% per annum. To increase the rate of electrification and to speed the universal coverage dream, the government of Ghana introduced the SHEP and off-grid electricity connections technologies to supply electricity to island and lakeside communities who do not have access. The general objective of this project is to undertake cost-benefit analyses of two interventions addressing rural electrification in the context of Ghana. First, we study the benefits of expanding electrical grid to communities that qualify for SHEP. This intervention envisages connecting all unelectrified households to the electricity grid with daily continuous 24 hours supply. Second, we study the socio-economic benefits of solar micro-grids back by dieseal generators, solar stand-alone and solar home system extension to island communities. Overall, we find that rural electrification intervention led to an increase in gross income of about 46% higher relative the non-electrified households for grid extension. Similarly, we find that being connected to off-grid compared with those without any form of electrification marginally improves welfare.

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Modeling Electrification Costs in Rural Ghana

Ghana Priorities

Francis Kemausuor
Director
The Brew-Hammond Energy Centre, KNUST, Kumasi

Kwaku Amaning Adjei
Senior Lecturer and Fellow
The Brew-Hammond Energy Centre, KNUST, Kumasi

Academic Abstract

Ensuring affordable, reliable, sustainable and modern energy for all by 2030 remains possible but will require more sustained efforts, particularly to reach some of the world's poorest populations and to improve energy sustainability. A combination of energy solutions is required in order to bridge the gap in an optimal way. Such combinations could involve the use of large hydro, thermal and adoption of renewable energy technologies where applicable. An appropriate electrification plan is a key element for policy-makers to set policy direction and develop programme-roadmaps on energy access. Such programmes can utilize both renewable and non-renewable sources of energy through grid extensions and the development of local off-grid solutions. This study modelled electrification options for unelectrified rural communities in a Ghanaian district to show which of the options present least cost for electrification of the communities.

Key Words: Grid extension, mini-grids, rural communities, least cost

1. Introduction and Literature Review

1.1 Background

One of the significant drivers of socio-economic development of a country is access to electricity (Duer and Christensen, 2010; Kanagawa and Nakata, 2007). Access to electricity contributes to improvements in health delivery, education, environmental sustainability and agricultural development including crop irrigation, agro-processing, and preservation of farm produce (Haanyika, 2008; Sokona et al., 2012).

Reports from the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), and the United Nations Statistics Division (UNSD) in 2019 suggests that despite significant progress in recent years, the world is falling short of meeting the global energy targets set in the United Nations Sustainable Development Goals (SDG) for 2030. Ensuring affordable, reliable, sustainable and modern energy for all by 2030 remains possible but will require more sustained efforts, particularly to reach some of the world's poorest populations and to improve energy sustainability.

Notable progress has been made on energy access in recent years, with the number of people living without electricity dropping to roughly 840 million from 1 billion in 2016 and 1.2 billion in 2010 (World Bank, 2019). India, Bangladesh, Kenya and Myanmar are among countries that made the most progress since 2010 according to data from the International Energy Agency. However, without more sustained and stepped-up actions, 650 million people will still be left without access to electricity in 2030. Nine out of 10 of them will be living in sub-Saharan Africa (United Nations Statistics Division, 2019).

Insufficient financial resources, lack of effective planning, fast population growth and a high population density with widely dispersed rural inhabitants are just some of the many challenges in Africa's bid to attaining energy access (Nerini *et al.*, 2016). African governments struggle to find solutions that can provide an acceptable level of energy access to the larger segment of their population without exceeding the limited budgets that they have to work with. A combination of energy solutions is required in order to bridge the gap in an optimal way. Such combinations could involve the use of large hydro, thermal and adoption of renewable energy technologies where applicable. An appropriate electrification plan is a key element for policy-makers to set policy direction and develop programme-roadmaps on energy access (Szabó *et* *al*, 2011). Such programmes can utilize both renewable and non-renewable sources of energy through grid extensions and the development of local off-grid solutions.

In view of this, the aim of this research paper is to model electrification options for unelectrified rural communities in Ghana. This is expected to be achieved using grid and mini-grid interventions as follows:

i. Expansion of Electrical Grid

This intervention envisages connecting un-electrified households to the electricity grid with daily continuous 24 hours supply.

ii. Solar Micro-grids

This intervention envisages providing electricity to un-electrified households by installing solar micro grids distributed across villages as per local capacity requirement.

iii. Diesel Micro-grids

This intervention envisages developing diesel generator based micro grids distributed across villages as per local capacity required to provide electricity to all un-electrified households.

1.2 Brief Review of Literature

Despite the poor state of electrification access in Africa, Ghana has an enviable position on the African continent, with regards to access to electricity. The 2019 Energy Ststaistics Publication from the Energy Commission (Energy Commission, 2019) reveals that total grid electricity generation in the country was 16,246 Gigawatt-hours (GWh) in 2018, comprising 62.8% thermal generation, 37% from large hydro and 0.2% from other renewable energy sources (solar and biogas).

By the beginning of 2019, over 84% of the population of Ghana had access to electricity, with urban access rate at about 93% and rural at around 71%. The recently published Ghana Living Standards Survey (Ghana Statistical Service, 2019), indicates that regions in the northern parts of the country have much lower access to electricity, compared to regions in the southern parts of the country (See Table 1). In all three northern regions highlighted in Table 1, national grid connection is less than 70%. This unfortunate situation emanates from the fact that most communities in the northern parts of the country are mostly of lower population densities and are quite far from major medium voltage lines. Furthermore, many of these communities are difficult to access due to poor road infrastructure and difficult terrain (Palit and Bandyopadhyay, 2016). The situation is worse in rural communities.

Table 1: Source of electricity supply to households by Region

Region	National Grid Connection	Local Mini Grid	Private Generator	Solar Home System	Solar Lantern/ Lighting System	Other	No Electric Power
Western	82.9	0.0	0.1	0.1	0.6	0.8	15.0
Central	84.4	0.0	0.1	0.2	0.9		13.8
Greater Accra	93.7	0.0		0.0	0.1	0.0	5.8
Volta	75.3	0.0	0.0	0.1	0.7	0.3	23.7
Eastern	73.8	0.6	0.2	0.2	0.6	0.2	24.0
Ashanti	89.2	0.0	0.0	0.0	0.2	0.6	9.5
Brong Ahafo	72.5	0.8	0.1	0.1	0.1	0.2	25.9
Northern	66.1	0.0	0.0	0.4	0.3	0.2	32.1
Upper East	47.7	0.0	0.2	0.7	5.3	0.6	38.8
Upper West	57.8	0.9	0.0	0.4	0.2	0.0	40.5

Northern Ghana (as used in Table 1, before its split in early 2019) has the largest land area and contributes to about 10% of the total population of the country. The population portfolio has created more rural communities than urban areas with a low population density. Agriculture, hunting, and forestry are the main economic activities which altogether account for the employment of 71.2% of the economically active population. The prevailing economic and demographic characteristics present accessibility challenges as most of these communities are dispersed and far from the existing grid. Weather conditions average 32 ℃ in the north which could be favourable for the use of Solar PV systems and other forms of renewables. These conditions make interesting case for research to explore possibilities for using different electrification approaches for the remaining unelectrified communities.

Studies exploring least cost electrification options for settlements have been conducted using a number of planning tools. Kemausuor *et al* (2014) used the Network Planner to explore costs of different electrification technology options in un-electrified communities in Ghana. The aim of the study was to recommend electrification technology options for 2600 unelectrified communities in Ghana and determine the estimated cost of electrification and other inputs (such as length of medium and low voltage lines), for these communities at different penetration rates. The study found that by the end of a 10-year period, the cost optimized option for the majority of the un-electrified communities in each of the regions in the country will be grid electrification, accounting for more than 85% of the total un-electrified communities in each region. The high rate of grid extension was attributed to the extensive pre-existing grid network coverage over the country, which reduces the distances and thus the costs, to connect remaining communities. Mini-grids accounted for 8% and standalone systems accounted for 7%.

Using Geographical theory and Graphical Information Systems, Mentis *et al.* (2015) applied geographical tools to explore all electrification options for rural communities in Ethiopia. The integration of energy system models and Geographic Information Systems (GIS) and the development of combined tools were deemed fundamental for a better understanding of the spatio-temporal dynamics of energy planning. The research applied such a methodology drawing on GIS tools and remote sensing data to fill data gaps in national databases, such as renewable energy resources, actual costs of diesel at the point of consumption, population density linked to energy demand and transmission infrastructure. The paper illustrated two major aspects of energy planning; 1) how the optimal electrification mix is influenced by a range of parameters including population density, existing and planned transmission networks and power plants, economic activities, tariffs for grid-based electricity, technology costs for mini-grid and off-grid systems, and fuel costs for consumers and 2) how the electrification mix differs from location to location. Using 2030 as the time horizon for this planning, the study concluded that grid connections were optimal for the majority of the rural communities that were targeted for the exercise; grid extension constituted the lowest cost option for approximately 93% of the newly electrified population. The geographical tool also found some remote areas with low population density where a mini-grid or a stand-alone solution were the recommended economic solution.

In another study, the techno-economic analysis of stand-alone wind micro-grids, compared with PV and diesel in Africa was investigated by Gabra *et al* (2019). The study analyzed the economic feasibility of small-scale wind systems for rural electrification in Africa. A spatial mapping model was used to enable the visualization of the electrification costs of wind systems across the African continent. The results of the analysis were integrated with previous work performed for photovoltaic (PV) and diesel systems. This integration produced a map indicating whether PV, diesel or wind systems are the least cost off-grid electrification option across the continent. The results show that PV and diesel systems are the most economically viable method of rural electrification in Africa, while wind systems are economically advantageous only within the horn of Africa and across few dispersed areas.

In order to argue for the adoption of decentralized renewable energy in South Asia's Lao PDR, Martin and Susanto (2014) developed decision aid modules that undertook a cost-benefit analysis of the existing grid expansion module to alternative decentralized renewable energy (DRE) options. The tool was developed to compare the financial limitations, flexibility and decentralized operational capabilities of DREs. The study showed that DREs possessed flexibility that suits the fluctuating nature of demand in rural communities. However, grid-extension was a cheaper and consequently possessed more subsidy for the consumers.

Additionally, Zeyringer *et al.* (2015) used micro-data from a national household survey to estimate electricity demand for households that are within reach of electricity infrastructure to predict latent demand in unconnected households. They used this to analyse the cost-effective electrification solution for Kenya comparing grid extension with stand-alone PV systems. Results suggested that decentralized PV systems could make an important contribution in areas with low demand and high connection costs. The findings showed that up to 17% of the population can be reached cost-effectively by off-grid PV systems for up to five years.

The challenges of access to electricity was also studied across five federal states in Nigeria to ascertain the required combination of energy systems it might take to provide 100% electrification. The modelling process looked at grid extension, hybrid minigrids, and solar home systems in a technically and economically sound way for different implementation phases. The study showed that investments of approximately $1600 million for medium-voltage (MV) and low-voltage distribution infrastructure, minigrids, and smallscale systems were required to achieve a 100% electrification rate. An overall load of about 1804 MW characterized the simulated electricity system of the five states.

The studies cited above are few indications of how decision aid tools and modules influence energy supply and access to electricity across the African continent. The outputs from these tools influence energy policies and investment decisions in order to make efficient utilization of the rarely available financial resources in the energy sector.

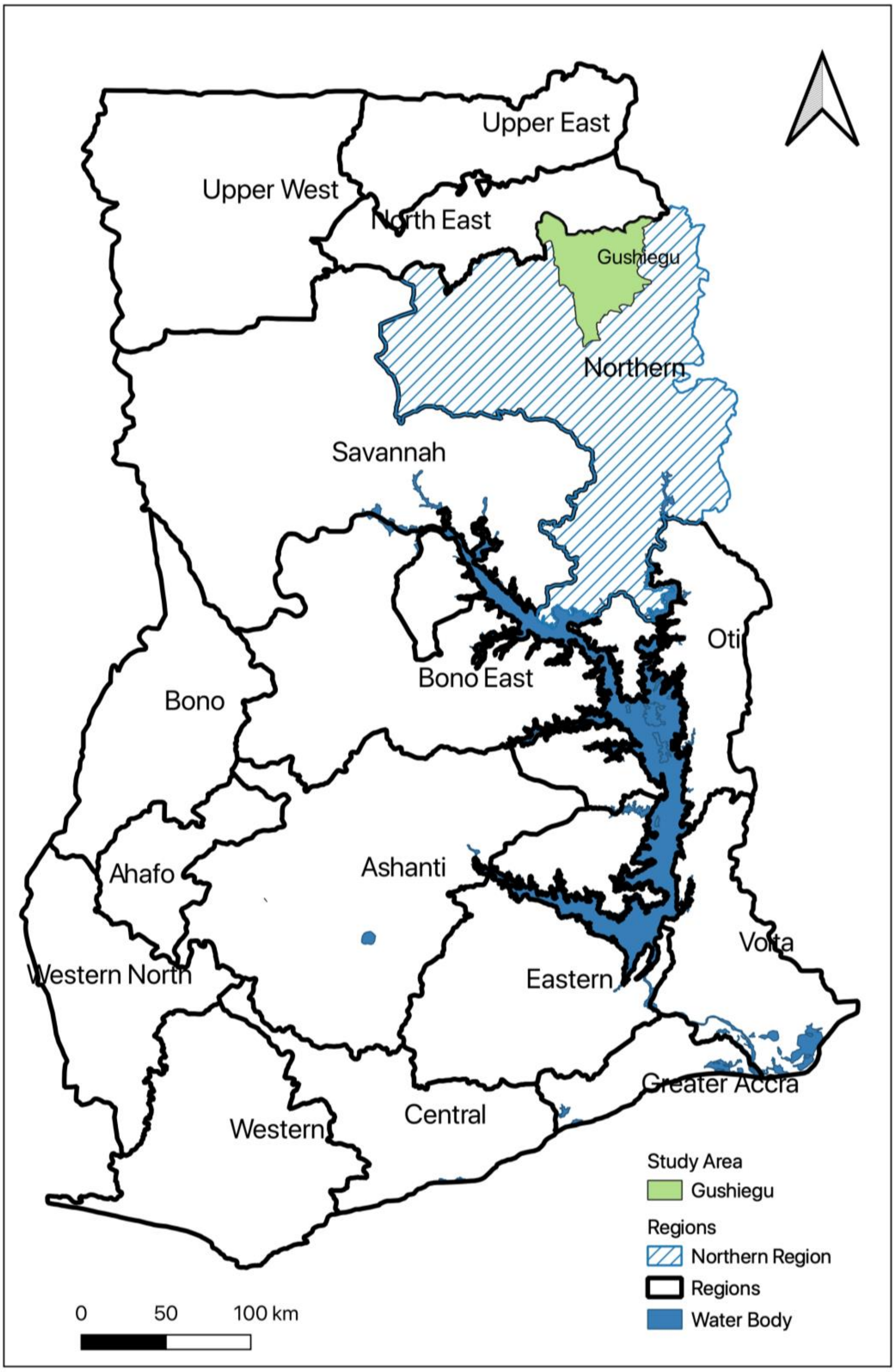
2. Methodology

2.1 Pilot Study District

This pilot study was conducted in the Northern Electricity Distribution Company (NEDCo) operational area, which consist of the seven regions in the northern parts of the country (until 2019, there were only four regions, which have since been split into seven regions). The northern part of the country was chosen for this study because of the lower access to electricity in the region and the dispersed nature of communities, making it ideal for this pilot study. Even though there are several island communities in the Southern parts of the country, government already has a major mini-grid electrification plan for the island communities. Research into electrification options for mainland rural communities could assist in the prioirtisation of resources for electrification of those remaining rural communities, using appropriate technologies.

The Gushiegu Municipality in the Northern Region was selected for the pilot because if it has rural communities with a mix of population sizes, ranging between less than 100 to about 3000, presenting a good population mix for studies like this. The Gushegu Municipality is one of the sixteen Metropolitan, Municipal and District Assemblies (MMDAs) in the new Northern Region. It is located on the north-eastern corridor of the country (see Figure 1). The Administrative capital of the Municipality is Gushiegu and is about 105 kilometers north-east of Tamale, the regional capital. The total land area of the Municipality is approximately 2,674.1 square kilometers. The Municipality shares boundaries to the east with Saboba and Chereponi Districts, Karaga District to the west, East Mamprusi Municipal to the north and Yendi Municipality and Mion District to the south. As of the 2010 population and housing census, the population of the Municipality was 111,259 with 54,186 males and 57,073 females.

Figure 1: Map showing position of Gushiegu in Ghana



2.2 Application of GeoSim Decision Planning Tool

The study used a decision support tool focused on rural electrification planning designed by Innovation Energie Developpement (IED) based in France. The software, GEOSIM, is based on a Geographical Information System (GIS) technology and operates in the MANIFOLD environment. GEOSIM can be used to identify key development centers, grid extension and least cost decentralized projects using renewable energy resources. The available energy supply options together with the spatial, economic and existing energy demand data are also used to recommend an optimum electrification plan and to determine the estimated cost of electrification and other inputs (such as length of the medium and low voltage lines), for these communities.

GEOSIM consists of four interdependent modules: Spatial Analyst, Demand Analyst, Network options, and Distributed Energy. The sequence of operation is as demonstrated in Figure 2. The interface of the model is shown in Figure 3.

Figure 2: GEOSIM planning process

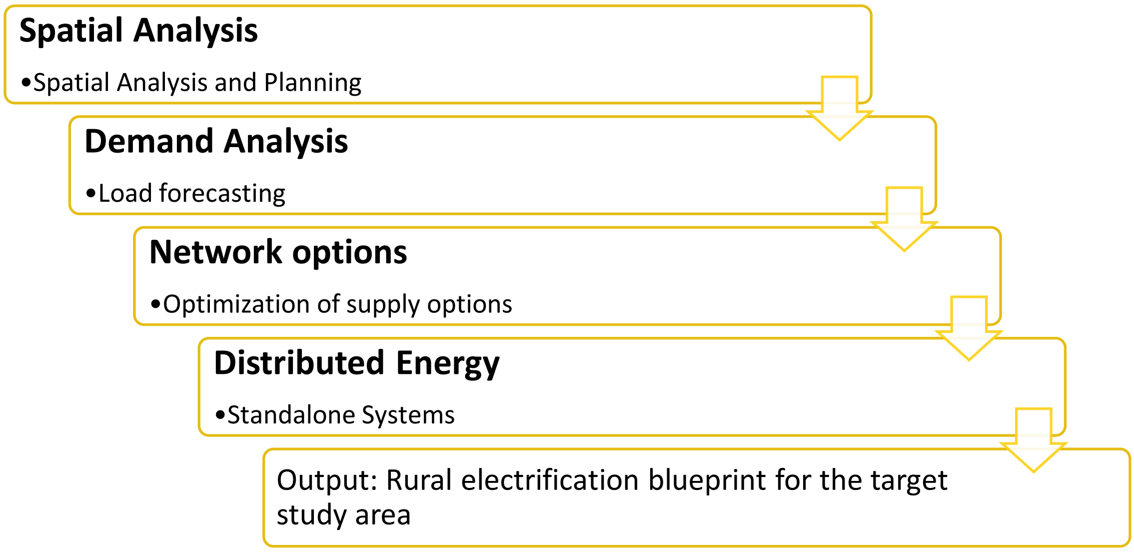


Figure 3: Interface of GeoSim Tool

2.2.1 Spatial Analyst

The main feature of this module is the Spatial Analysis and multisectoral planning aid. Through the concepts of development poles and hinterlands, the tool identified and analyzed settlements with high potential for social and economic development as priority, in order to maximize the impact of rural electrification. Given that the major limitation to achieving higher electrification is often financial, the spatial analysis tool optimizes the planning system by prioritizing projects that will benefit the largest number of people through access to improved social services (health, education, portable water) and local opportunities like businesses and employment.

The spatial analysis module initiated the planning process by completing the following tasks:

i. Calculation of the Indicator of Potential Development (IPD) for each settlement. The IPD is a measure of the quality of socio-economic services provided by a given settlement. Its structure is inspired from the Human Development Index (HDI), and as such comprises three main themes: health, education and local economy;
ii. Selection of the development poles (areas with high priority) according to this indicator;
iii. Calculation of the population covered by each development pole;
iv. Ranking of the development poles;
v. Mapping of hinterlands or areas of attractions; and

vi. Identification of isolated areas – settlements with low accessibility to social and economic services provided by the development poles.

2.2.2 Demand Analyst

Demand Analyst is a specialized tool for forecasting village or cluster of village demand. By its 'bottom-up' approach the model predicts reliable demand in the medium and long term. The bottom-up approach requires data gathering from the demand of end-users or small administrative units moving up to the larger scales.

The Demand Analyst tool was used to model and forecast the demand for electricity at the village level using average consumption patterns of different types of end-users (poor, medium, rich households, schools, shops, other productive activities, etc.). The tool calculated the following load characteristics for each village of the study area and supply scenario:

i. Number of clients (both low and middle voltage);
ii. Peak demand (kW);
iii. Yearly consumption (kWh); and
iv. Load duration curves.

The tool also considered outliers classified as special demand in the data driven process. This special demand tag was assigned to end-users whose power consumption significantly outweighs the consumption of a single settlement and can be of the same order of magnitude than a small cluster of settlements. These large specific demands are typical of large agribusinesses or factories.

Load Forecast

The demand calculation was preceded by the provision of key parameters which includes definition of planning period, study area, scenario type and other miscellaneous parameters. Planning period definition requires the use of population data, existing household connection rates (if available), infrastructure and services connection rate and the corresponding growth rates for households and services in the mid-term and final year of the planning period.

In the study area data, the population growth rate and the number of people per household were provided based on latest census data gathered in the targeted rural communities. A 'scenario type' defines the number of hours of productive power consumption. For this pilot study, it was assumed that power is available 24 hours a day, though not necesairly translating to 24 hours of usage of every appliance. Miscellaneous parameters provided for overall estimated technical losses and the proximity of households to the grid. These parameters were used for forecasting the expansion of the electrical grid to possible non-electrified areas.

2.2.3 Network Options

Prior to undertaking the least-cost sizing of decentralized supply options, the Network Options module first defines the areas unlikely to be connected to the grid in the near future. This forecast of the national grid network is done by simulating the extension of the national grid, taking into account several possible constraints (distance to substations, investment budgets, available energy on the grid, etc.). The module was used to find the best decentralized option to supply electricity to previously identified development poles and their surrounding settlements, using selected projects with the lowest actualized cost of electricity.

The network module is designed with sophisticated least-cost path algorithm that draws medium voltage lines according to natural and infrastructure constraints such as forests, lakes, protected areas, etc. The network module is run from the GIS database using the following layers; settlements, existing grid network lines, hydro potential, wind turbines and biomass potentials of the target communities. For this pilot case, GIS data for hydro, wind and biomass potential is not available and was not considered. Mini-grids for this pilot were therefore assessed using diesel gensets and solar systems.

While we understand that consumer preference is often for grid connected power, it is also important to stress that policy makers would consider what is best within the overall energy policy framework of the country. The results from this analysis is based purely on least cost options and does not factor consumer preferences. Indeed, Ghana Government's mini-grid interventions on the island and lakeside communities are based purely on costs, otherwise, the grid is the most preferred electrification technology in Ghana,

2.2.4 Distributed Energy

The final module is used to assess the feasibility of pre-electrification programmes for communities that are far from the development poles and not electrified in the planning horizon. The tool was not used in this analysis, as it falls outside the scope of the objectives of this study.

2.3 Data Requirements

Data requirements to run the model were obtained from various sources. A summary of data obtained to run the model are as follows.

2.3.1 Grid Extension

- Cost of extending medium voltage lines;
- Cost of extending low voltage lines;
- Cost of transformers; and
- Cost of other accessories

2.3.2 Mini-grid systems

- Cost of solar panels;
- Cost of wind turbines;
- Cost of diesel gensets;
- Cost of storage systems;
- Cost of fuel; and
- Cost of other accessories

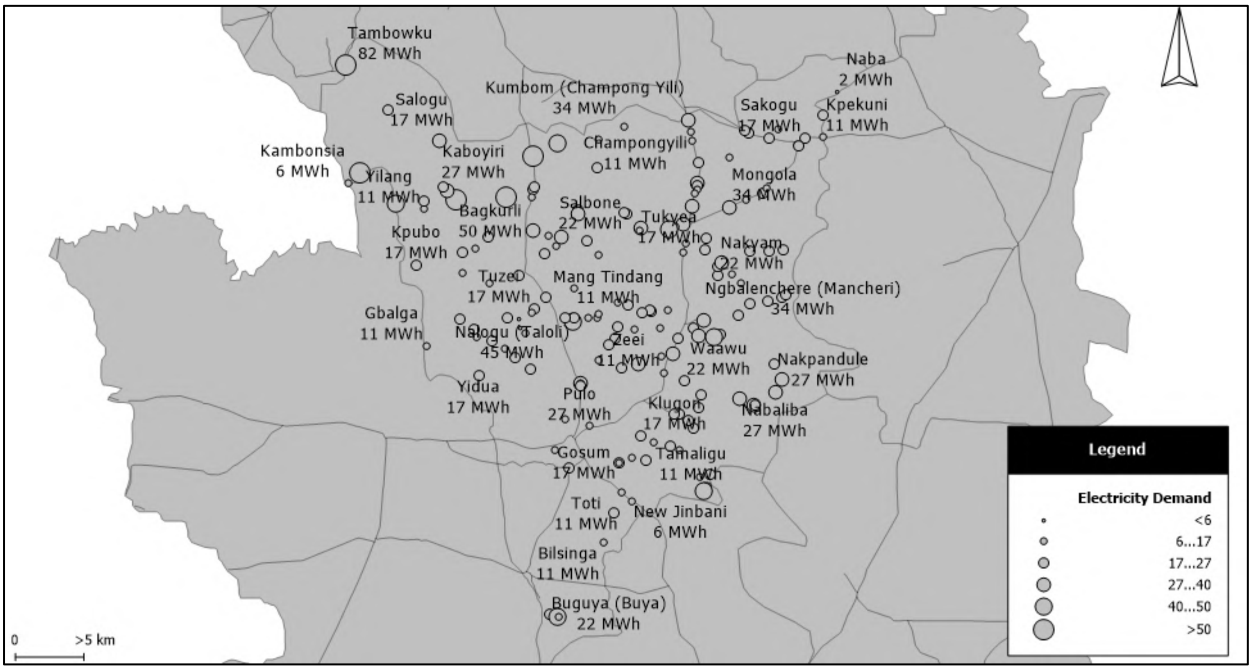
Data on unelectrified communities and their population and GIS information was obtained from NEDCo. NEDCo also provided data on cost of medium voltage lines, low voltage lines, transformers, and other accessories. Data on renewable energy systems were obtained from the Ministry of Energy pilot mini-grids on the islands. Data on diesel gensets were obtained from Mantrac Ghana. Other data sources include the National Petroleum Authority for diesel costs. See Appendix 1 for details of the dataset used for the analysis.

3. Cost of Electrification Interventions – Preliminary Results

3.1 Load Forecast

A total of 175 unelectrified rural communities in the Gushiegu Municipality were modeled to assess which electrification technologies are best suited for which communities for electricity access. The year 2010 population estimate for these 175 unelectrified communities, based on data provided by the utility, NEDCo, is 46,160 (see Appendix 2). Load forecasts were done from 2020, chosen as the first year for electrification projects, to 2030, the last year. Population forecast for the year 2020 was done using the Ghana Statistical Service growth rate of 2.9% for the region. The first year assumes a conservative demand level, with 30% connection rate and predominantly low-income households, resulting in a low demand per household and community.

Figure 4: Map showing estimated community demand in 2020



In subsequent years, availability of electricity is expected to increase income levels of households, and lead to an increased connection rate, as well as increased demand for households, translating to multiple increases for the comunities. It is assumed that 90% of households would have been connected by 2030, and a higher percentage of these households would have increased income by the end date. This will result in an overall increased demand for communities, and hence the district. Total electricity demand and peak demand maps for the municipality for the year 2020 are shown in Figures 4 and 5 respectively. Map showing 2030 projected demand for communities is shown in Figure 6.

Figure 5: Map showing projected Community peak in 2020

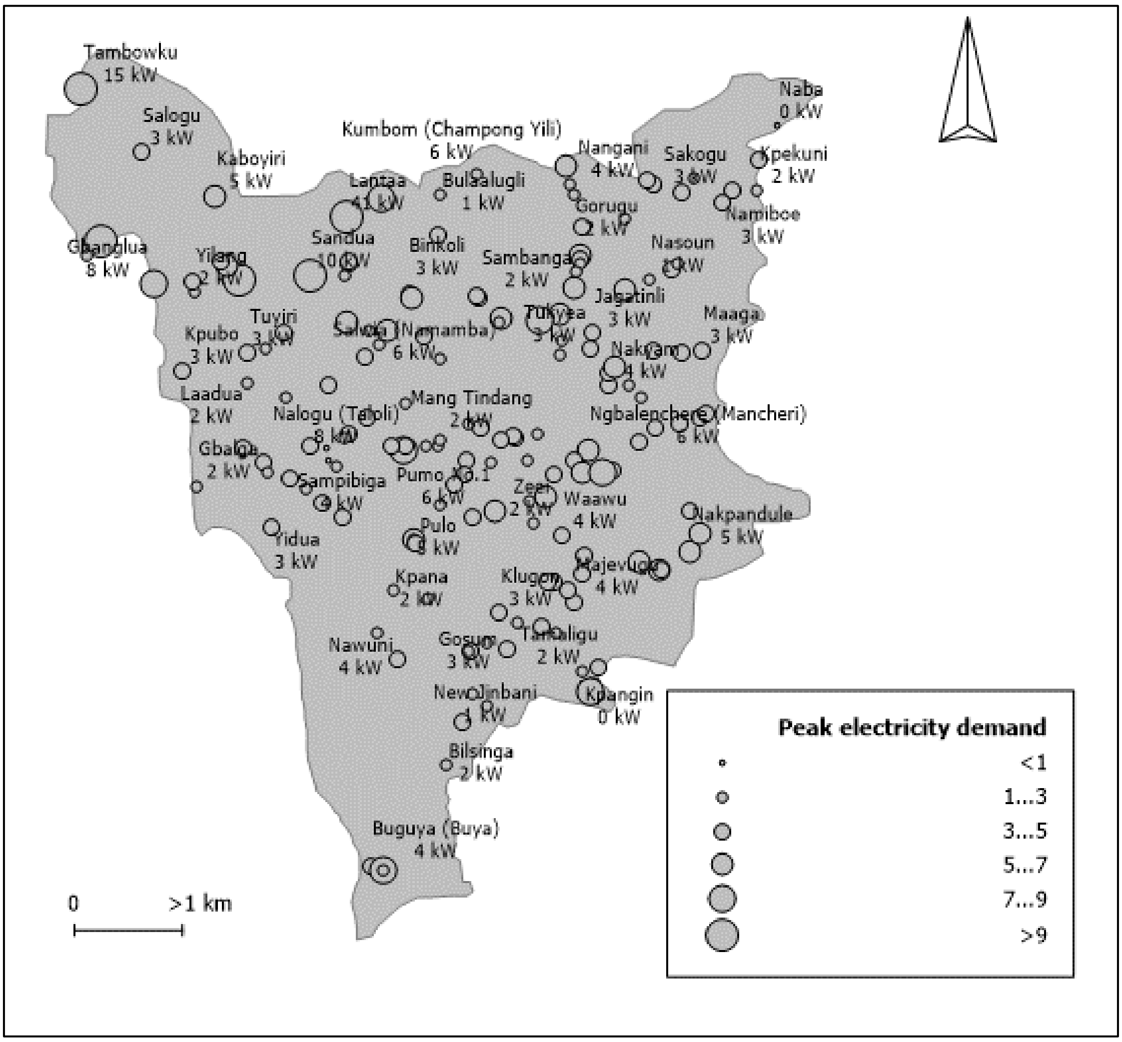
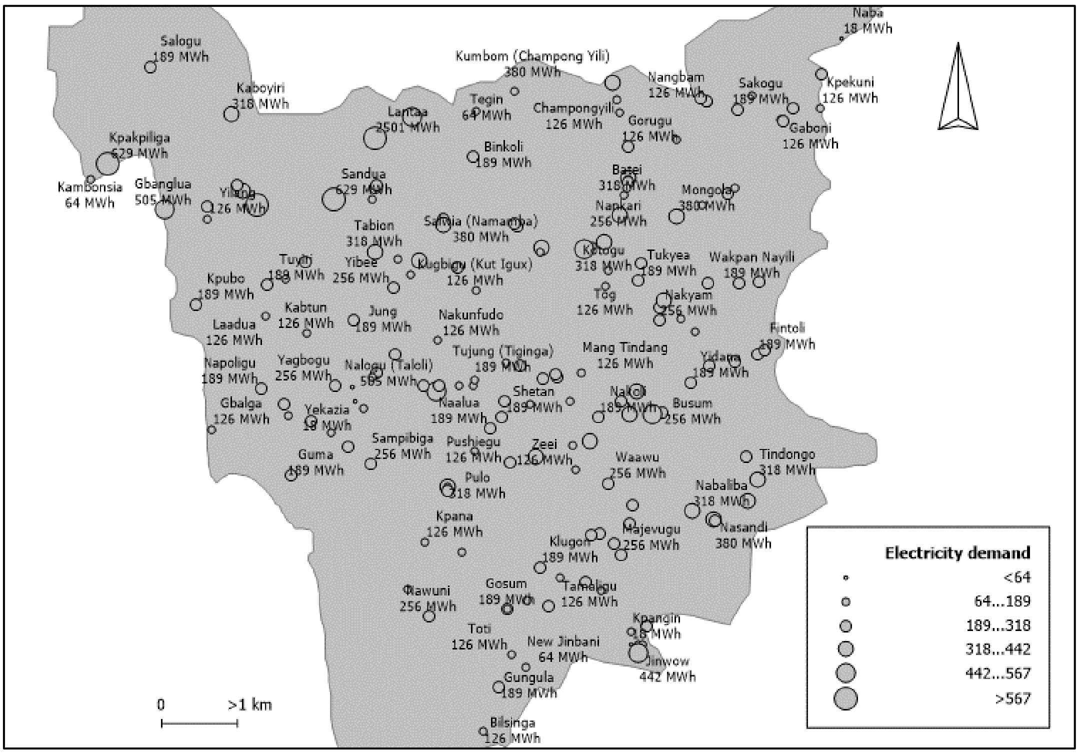


Figure 6: Projected 2030 demand by community



3.2 Intervention 1: Grid Connection

3.2.1 Overview and Implementation

Grid connection is the most common and preferred electricity access option in Ghana today, accounting for more than 95% of all connections in the country. In this first intervention, grid connection is retricted to communities where grid extension is the most cost optimized electrification solution. In this approach, a community that is deemed 'isolated' based on its location, may not be recommended for grid connection because it may require longer medium voltage (MV) lines, making grid connection more expensive than a mini-grid. Based on the stepwise modeling approach used in this pilot, 79 communities are viable for grid electrification in the district. This accounts for about 45% of the currently unelectrified communities in the district. The electrification of the 79 communities is expected to be undertaken in 8 years, between 2020 and 2027. Traditionally, grid exention in Ghana is understaken by the distribution utility, with support from the Ministry of Energy. Depending on the model adopted, the community may contribute some items, either from their own resources, or through philanthropic or local government assistance. Recent rural electrification is often entirely covered by the Ministry of Energy and the utility. The households are only responsible for wiring their homes to receive the power. This is the model that is likely to be implemented for rural electrification, going forward.

3.2.2 Costs and Benefits

Costs

Details of medium voltage line extension expected, as well as investment costs for other major components are provided in Table 2. The population expected to be electrified per year is shown in Figure 7. Electrification cost indicators are summarized in Table 3. Costs are inclusive of connection costs. Total investment per inhabitant for grid electrification is US$ 411.

Table 2: Grid Extension Results

Year	No. of communities	MV line length (m)	Investment (US$)			
			MV Lines	LV Lines	Other costs	Total
2020	10	15,600	702,000	521,664	60,746	1,284,410
2021	10	25,794	1,160,730	608,608	62,919	1,832,257
2022	10	28,437	1,279,665	560,560	62,961	1,903,186
2023	10	27,642	1,243,890	570,856	63,294	1,878,040
2024	10	39,909	1,795,905	565,136	63,221	2,424,262
2025	10	37,754	1,698,930	539,968	60,486	2,299,384
2026	10	44,827	2,017,215	663,520	69,929	2,750,664
2027	9	34,869	1,569,105	1,257,256	87,858	2,914,219
Total	**79**	**254,832**	**11,467,440**	**5,287,568**	**531,414**	**17,286,422**

Figure 7: Population Electrified per year

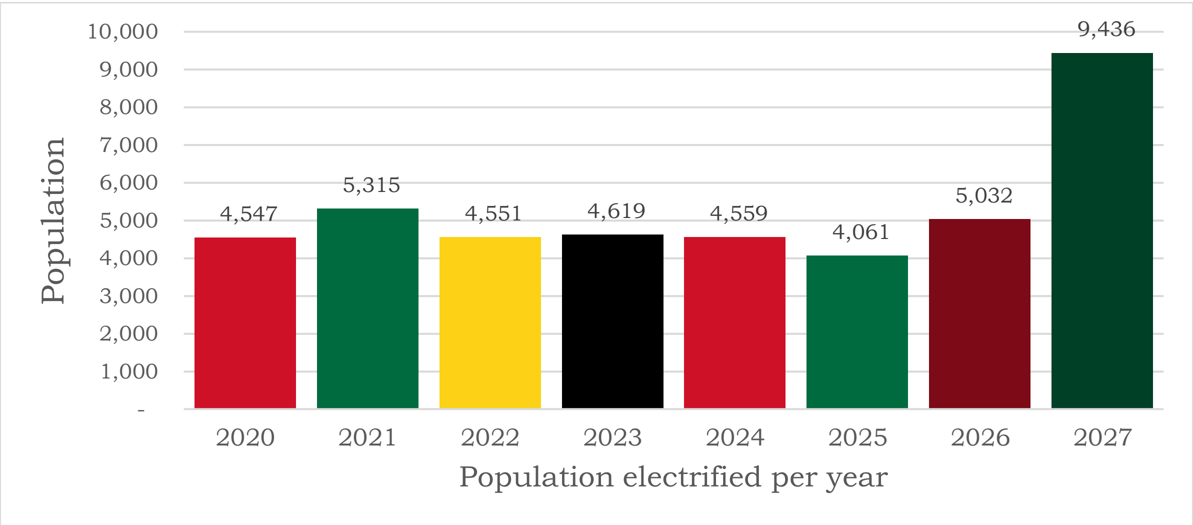


Table 3: Electrification cost indicators

Indicator	Cost	Unit
Distribution / locality	73,658	US$
Connection / locality	145,157	US$
Total Investment / locality	218,815	US$
Total Investment / inhabitant	411	US$

3.3 Intervention 2: Mini-grids

3.3.1 Overview and Implementation

Franz *et al*. (2014) define mini-grids as involving 'small-scale electricity generation, and the distribution of electricity to a limited number of customers via a distribution grid that can operate in isolation from national electricity transmission networks and supply relatively concentrated settlements with electricity at grid quality level'. They go on to define micro-grids as similar to mini-grids but operating at a smaller size and generation capacity of 1-10 kW. USAID (2011) also defines mini-grid as a 'set of electricity generators and possibly energy storage systems interconnected to a distribution network that supplies electricity to a localized group of customers via a distribution grid that can operate in isolation from national electricity transmission networks'. The definitions point out three main issues: (1) mini-grids are small scale, often less than 10 MW; (2) mini-grids serve limited customers, compared to the national grid; and (3) mini-grids are isolated from the national transmissions network. While mini-grids are by their design made to operate independent of the central grid, they may be designed with the option to connect to the central grid when the grid reaches a community where a mini-grid operates (Verma and Singh, 2013).

Ghana's current mini-grid policy places the burden of mini-grid development and operation on the government, through the energy sector utilities. According to the policy, every aspect of mini-grid development from design to operation will be public sector led, with private sector participating only through contracts for services, such as construction, for example. The policy requires that mini-grids only charge electricity tariffs approved by the Public Utility Regulatory Commission for grid customers, limiting investment opportunities for the private sector. It is a matter of fact that mini-grid tariffs are always higher than grid tariffs in almost every country where mini-grids are operated. The government is not willing to pay any subisdies to private sector investors, nor allow for the charging of ‘cost-recovery’ tariffs required to make private investment profitable. In view of this public sector approach, the Energy Commission is yet to develop a regulation to guide mini-grid development in Ghana.

3.3.2 Costs and Benefits

Costs

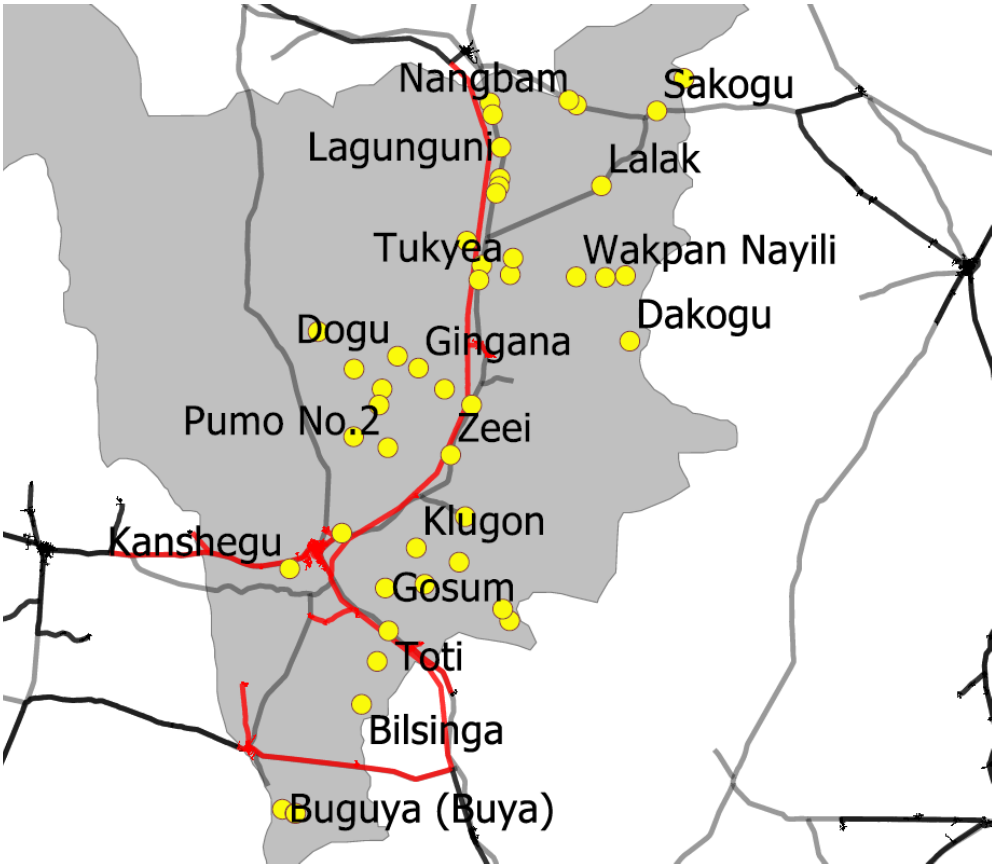
Communities that were not connected to the grid within the planning period were analysed for diesel and solar mini-grids. In all, 46 communities were modelled for diesel and solar mini-grids. Typical of mini-grids, levelized costs are much higher than current electricity cost of electricity from the grid. Levelised costs are extremely higher in this analysis because the planning period only covers the period between 2020 and 2030. Typically, some mini-grid assests could last for up to 25 and 30 years, hence levelized costs would be lower if analysed over a longer lifespan. Other indicators such as investment cost, cost per customer and energy demand for the first and last years are provided in Table 4. Figure 8 shows a map of solar projects. Costs are inclusive of connection costs. The levelized costs for mini-grids is computed using the life cycle costs, which factors operation and maintenance costs for the duration of the projects. Mini-grid investments in Ghana are strictly public sector driven, and cost recovery is not currently an objective in their development. Rather, economic and social benefits are the overarching aim for government’s investment into mini-grids. The Public Utilities Regularoty Commission, the institution that sets tariffs in Ghana, has been tasked to include the costs of mini-grid investments in the computation of electricity tariffs, so that there is cross subsidy across board. In view of this, mini-grid customers in Ghana do not pay a premium tariff. They are charged uniform tariffs that are same as customers on the grid. Mini-grids are sized to provide same power that the grid would provide, including power for productive purposes. However, government only targets communities where the grid is not expected to reach for many years, or where the cost of grid extension is prohibitive, such as small island communities that require underwater cables for grid extension. Where a community is located along the route of the national grid’s extension, government often priortises grid connection over mini-grid options, irrespective of the size of the community.

Table 4: Mini-grid Projects Results

SN		Grid Connected	Levelized Cost (kWh)	Starting Investment (US$)	Investment/ Customer (US$)	Cluster Population (Year 1)	LV Customers		Energy Demand (kWh)	
							First year	Last year	First Year	Last Year
1	**DIESEL CLUSTERS**			**363,918**	**4,493**	**1,816**	**81**	**300**	**114,648**	**1,267,059**
2	Kuduli	No	0.94	121,306	4,493	599	27	100	38,216	422,353
3	Ngbalenchere (Mancheri)	No	0.94	121,306	4,493	603	27	100	38,216	422,353
	Mongola	No	0.94	121,306	4,493	614	27	100	38,216	422,353
	SOLAR PROJECTS			**3,990,754**	**6,881**	**12,353**	**580**	**1,115**	**829,108**	**2,515,581**
1	Klugon	No	1.07	96,216	7,401	270	13	27	20,198	61,495
2	Sambik	No	1.07	96,216	7,401	274	13	27	20,198	61,495
3	Zeei	No	1.28	69,083	6,280	228	11	19	13,800	41,637
4	Pumo No.2	No	1.07	96,216	7,401	294	13	27	20,198	61,495
5	Nakoli	No	1.07	96,216	7,401	276	13	27	20,198	61,495
6	Dakogu	No	1.07	96,216	7,401	287	13	27	20,198	61,495
7	Wakpan Nayili	No	1.07	96,216	7,401	293	13	27	20,198	61,495
8	Nasimbugu	No	1.07	96,216	7,401	279	13	27	20,198	61,495
9	Maaga	No	1.07	96,216	7,401	287	13	27	20,198	61,495
10	Tukyea	No	1.07	96,216	7,401	262	13	27	20,198	61,495
11	Jagatinli	No	1.07	96,216	7,401	254	13	27	20,198	61,495
12	Lalak	No	1.28	69,083	6,280	206	11	19	13,800	41,637
13	Sakogu	No	1.07	96,216	7,401	273	13	27	20,198	61,495
14	Bonbong	No	1.07	96,216	7,401	276	13	27	20,198	61,495
15	Nangbam	No	1.28	69,083	6,280	229	11	19	13,800	41,637
16	Nabuso	No	1.07	96,216	7,401	295	13	27	20,198	61,495
17	Champongyili	No	1.28	69,083	6,280	202	11	19	13,800	41,637
18	Gorugu	No	1.28	69,083	6,280	244	11	19	13,800	41,637
19	Lagunguni	No	1.07	96,216	7,401	268	13	27	20,198	61,495
20	Tamani	No	1.28	69,083	6,280	245	11	19	13,800	41,637
21	Largu	No	1.28	69,083	6,280	244	11	19	13,800	41,637
22	Sambanga	No	1.28	69,083	6,280	222	11	19	13,800	41,637

23	Kpakalga	No	1.28	69,083	6,280	233	11	19	13,800	41,637
24	Lomba	No	1.28	69,083	6,280	228	11	19	13,800	41,637
25	Tog	No	1.28	69,083	6,280	242	11	19	13,800	41,637
26	Gingana	No	1.07	96,216	7,401	254	13	27	20,198	61,495
27	Dogu	No	1.07	96,216	7,401	270	13	27	20,198	61,495
28	Shetan	No	1.07	96,216	7,401	293	13	27	20,198	61,495
29	Bogu-Kambon Nayili	No	1.07	96,216	7,401	262	13	27	20,198	61,495
30	Pushiegu	No	1.28	69,083	6,280	209	11	19	13,800	41,637
31	Tono	No	1.28	69,083	6,280	249	11	19	13,800	41,637
32	Gosum	No	1.07	96,216	7,401	295	13	27	20,198	61,495
33	Kanbonayili No.2	No	1.07	96,216	7,401	294	13	27	20,198	61,495
34	Yapkperiya	No	1.28	69,083	6,280	234	11	19	13,800	41,637
35	Toti	No	1.28	69,083	6,280	220	11	19	13,800	41,637
36	Gungula	No	1.07	96,216	7,401	285	13	27	20,198	61,495
37	Bilsinga	No	1.28	69,083	6,280	248	11	19	13,800	41,637
38	Kanshegu	No	1.28	69,083	6,280	228	11	19	13,800	41,637
39	Buguya (Buya)	No	0.95	123,303	6,850	425	18	35	26,616	81,415
40	Tindapeyili	No	0.78	230,873	6,790	827	34	68	54,536	165,262
41	Tinguli	No	1.28	69,083	6,280	217	11	19	13,800	41,637
42	Nakunfudo	No	1.28	69,083	6,280	226	11	19	13,800	41,637
43	Tindangni	No	1.28	69,083	6,280	217	11	19	13,800	41,637
44	Offin	No	1.28	69,083	6,280	226	11	19	13,800	41,637
45	Zamashegu	No	1.07	96,216	7,401	261	13	27	20,198	61,495
46	Kantanbuguri (Katangbugli)	No	1.28	69,083	6,280	202	11	19	13,800	41,637
Total				**4,354,672**	**6,588**	**14,169**	**661**	**1,415**	**943,756**	**3,782,640**

Figure 8: Solar projects map



3.4 Intervention 3: Grid connection for all communities with population above 200

3.4.1 Overview and Implementation

This intervention was inspired by the Ministry of Energy's policy to continue to increase grid connection in mainland rural areas as much as possible, with productive use and social benefits in mind, rather than cost. To wit, this intervention is similar to Intervention 1, except that the model was 'forced' to extend grid electricity to all communities with population above 200, irrespective of costs. Implementation is therefore the same as that of Intervention 1.

3.4.2 Costs and Benefits

Costs

Results for this intervention is shown in Table 5, with cost indicators presented in Table 6. In this intervention, 85% of the presently unlectrified population will be connected to electricity using grid connection. It can be noted from Table 6 that total investment per inhabitant in Intervention 3 is higher than the case in Intervention 1, US$ 679 compared to US$ 411.

Table 5: Grid Extension Results

Year Electrified	Population	MV line length (m)	Investment (US$)			
			MV lines	LV lines	Other costs	TOTAL
2020	3 764	10 852	324 855	414 128	72 061	811 044
2021	5 589	29 354	878 712	660 088	75 868	1 614 667
2022	6 001	57 712	1 727 607	724 152	76 259	2 528 017
2023	5 622	83 865	2 510 500	690 976	78 343	3 279 819
2024	6 827	97 411	2 916 000	868 296	79 660	3 863 954
2025	5 042	137 225	4 107 829	663 520	77 483	4 848 833
2026	5 890	160 029	4 790 469	766 480	76 524	5 633 474
2027	6 623	187 774	5 621 014	914 056	82 045	6 617 112
2028	7 185	241 698	7 235 230	994 136	88 106	8 317 470
2029	3 989	10 561	316 144	554 840	15 716	886 700
TOTAL	**56 532**	**1 016 481**	**30 428 360**	**7 250 672**	**722 065**	**38 401 090**

Table 6: Electrification cost indicators

Indicator	Cost	Unit
Distribution / locality	58 538	US$
Connection / locality	223 738	US$
Total Investment / locality	282 276	US$
Total Investment / inhabitant	679	US$

5. Conclusion

The aim of this paper research paper was to model electrification options for unelectrified rural communities in Ghana, using the Gushiegu Municipality as a first pilot case. Three electrification technologies were considered. There were: grid extension and mini-grids using either diesel or solar. A total of 175 unelectrified communities were identified from data provided by the utility. An electrification planning model, GEOSIM was used to model the system. The results showed that grid extension will be the most cost-effective technology, recommended for approximately 79 communities, or 68.4% of the population. Options for mini-grids using diesel gensets and solar PV systems have also been provided, accounting for 49 of the communities. The study recommends that planning tools are engaged to plan the last mile electrification system, as they provide decision makers with a shorter planning time in making value-for-money decisions.

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7. APPENDIX 1 – KEY INPUT PARAMETERS FOR MODELLING

General	Unit	Parameter
Year of simulation	Years	2020
Planning horizon	Years	10
Minimum population for grid electrification	Persons	200
Population growth rate	%	2.9
Household connection rates (starting year)	%	30
Household connection rates (mid-year)	%	60
Household connection rates (10^{th} year)	%	90
Household consumption growth rate (first 5 years)	%	10
Household consumption growth rate (6^{th} to 10^{th} year)	%	6
Infrastructure and services connection rate (mid-year)	%	50
Infrastructure and services connection rate (mid-year)	%	70
Infrastructure and services connection rate (10^{th} year)	%	100
Infrastructure and services growth rate (first 5 years)	%	5
Infrastructure and services growth rate (6^{th} to 10^{th} year)	%	3

Economics	Unit	Parameter	Source
Discount rate for financial analysis	%	5, 8, 14	Copenhagen Consensus / Various Sources
Local inflation rate	%	8.5	Ghana Statistical Service for 2019
Power Purchase price from utility in base year /kWh	US $	0.09	PURC (average of lifeline and 51-300 kWh tariff)

Diesel	**Unit**	**Parameter**	**Source**
Hours of service per day	h	24	
Genset safety margin	%	10	
Maintenance down time	%	5	
Diesel Price (including vat/tax etc.)	US$/bbl	159	National Petroleum Authority

Solar	**Unit**	**Parameter**	**Source**
Solar Panel Cost	US$/kWp	800	Estimated from various sources
Inverter cost	US$/kW	300	Estimated from various sources
Battery cost	US$/kWh	200	Estimated from various sources
Battery Round trip Efficiency	%	80	Estimated from various sources
Solar Panel Lifetime	Years	30	Estimated from various sources
Inverter Lifetime	Years	10	Estimated from various sources
Solar Panel O&M Cost ratio	%	2	Estimated from various sources
Depth of Discharge (DoD)	%	50	

Network	**Unit**	**Parameter**	**Source**
Lifetime of LV line	Years	30	
Lifetime of MV line	Years	30	
Lifetime of transformer	Years	10	
LV line km cost	US $	33,000	NEDCo
MV (11 kV) line km cost	US $	29,935	NEDCo
Low capacity meter price	US $	15	ECG (GHC 82.5) http://ecgonline.info/index.php/customer-service/services/getting-electricity
High capacity meter price	US $	32	ECG (GHC 176)
LV line O&M annual cost	%	0.5	Estimated
MV line O&M annual cost	%	0.5	Estimated
Transformer O&M annual cost	%	0.5	Estimated

Project Interconnection	**Unit**	**Parameter**	**Source**
Network Connection Cost	US $	10	Estimated for rural electrification. ECG is GHC 400
Network connection lifetime	Years	30	
Network connection O&M cost ratio	%	2	

8. APPENDIX 2 – UNELECTRIFIED SETTLEMENT INFORMATION, GUSHIEGU MUNICIPALITY

SN	Name	Population (2010)	Population Y1 (2020)	No. of Households Y1 (2020)
1	Zeei	171	228	38
2	Nakoli	207	276	46
3	Champongyili	152	202	34
4	Gorugu	183	244	41
5	Lagunguni	201	268	45
6	Tamani	184	245	41
7	Largu	183	244	41
8	Sambanga	167	222	37
9	Kotogu	351	467	78
10	Kpakalga	175	233	39
11	Lomba	171	228	38
12	Tog	182	242	40
13	Toti	165	220	37
14	Kanshegu	171	228	38
15	Tinguli	163	217	36
16	Kuduli	450	599	100
17	Tukyea	197	262	44
18	Jagatinli	191	254	42
19	Kumbom (Champong Yili)	473	630	105
20	Batei	346	461	77
21	Kpandana	320	426	71
22	Nankari	302	402	67
23	Nanyiri	342	455	76
24	Tujung (Tiginga)	229	305	51
25	Zuoyili	226	301	50
26	Gosum	222	295	49
27	Gungula	214	285	48
28	Nawuni	263	350	58
29	Gbani	272	362	60
30	Kantanbuguri (Katangbugli)	152	202	34
31	Klugon	203	270	45
32	Waawu	301	401	67
33	Pumo No.1	486	647	108
34	Pumo No.2	221	294	49
35	Ngbalenchere (Mancheri)	453	603	100
36	Nakyam	289	385	64
37	Yiyamba	541	720	120
38	Gingana	191	254	42
39	Kanbonayili No.2	221	294	49
40	Bilsinga	186	248	41

41	Buguya (Buya)	319	425	71
42	Tindangni	163	217	36
43	Lunlua	260	346	58
44	Zamashegu	196	261	44
45	Kulikpang	478	636	106
46	Sambik	206	274	46
47	Petuli	237	315	52
48	Patan	231	307	51
49	Yidana	243	323	54
50	Busum	323	430	72
51	Wakpong	285	379	63
52	Dogu	203	270	45
53	Bogu-Kambon Nayili	197	262	44
54	Pushiegu	157	209	35
55	Pulo	411	547	91
56	Lebo	334	445	74
57	Offin	170	226	38
58	Kpakpiliga	762	1014	169
59	Salogu	259	345	57
60	Yidua	207	276	46
61	Majevugu	305	406	68
62	Lunluwa	315	419	70
63	Pabuni	277	369	62
64	Baambuli	475	632	105
65	Mongola	461	614	102
66	Nangbam	172	229	38
67	Nabuso	222	295	49
68	Salwia (Namamba)	484	644	107
69	Salbone	281	374	62
70	Mangbali	294	391	65
71	Shetan	220	293	49
72	Naalua	250	333	56
73	Yapkperiya	176	234	39
74	Tindapeyili	621	827	138
75	Dinyogu	576	767	128
76	Kpekuni	187	249	42
77	Yapala	325	433	72
78	Wakpan Nayili	220	293	49
79	Namongbani	301	401	67
80	Lalak	155	206	34
81	Bonbong	207	276	46
82	Nangani	321	427	71
83	Tono	187	249	42
84	Sampibiga	296	394	66
85	Nabuligu	306	407	68
86	Jinwow	504	671	112

87	Nangbani	163	217	36
88	Kpalubu	203	270	45
89	Guma	210	279	46
90	Binkoli	203	270	45
91	Nabaliba	411	547	91
92	Fintoli	244	325	54
93	Dakogu	216	287	48
94	Nasimbugu	210	279	46
95	Sakogu	205	273	46
96	Nachem	237	315	52
97	Kaboyiri	339	451	75
98	Yilang	186	248	41
99	Suguri	267	355	59
100	Nakpaliga	198	264	44
101	Gbanglua	590	785	131
102	Napoligu	240	319	53
103	Sakulo	283	377	63
104	Piong	544	724	121
105	Natigu	256	341	57
106	Nasandi	427	568	95
107	Adutili	271	361	60
108	Gombeni (Dombini)	270	359	60
109	Maaga	216	287	48
110	Namiboe	247	329	55
111	Tandogu	241	321	54
112	Nakogu	233	310	52
113	Nakunfudo	170	226	38
114	Tambowku	1145	1524	254
115	Yagbogu	281	374	62
116	Pukura	374	498	83
117	Lantani	251	334	56
118	Tintariga	233	310	52
119	Yagbaa	269	358	60
120	Gbenjaga	349	464	77
121	Nakpandule	343	457	76
122	Tindongo	373	496	83
123	Nalogu (Taloli)	625	832	139
124	Tuzei	224	298	50
125	Kpubo	233	310	52
126	Bagkurli	705	938	156
127	Tuyiri	190	253	42
128	Jankpinhi	335	446	74
129	Yibee	263	350	58
130	Tabion	339	451	75
131	Jung	198	264	44
132	Kabtun	180	240	40

133	Sandua	746	993	166
134	Manie	439	584	97
135	Kassale	205	273	46
136	Lantaa	2997	3989	665
137	Tamaligu	127	169	28
138	Tumtuzee	136	181	30
139	Tugbang	98	130	22
140	Nasoun	45	60	10
141	Gaboni	114	152	25
142	Kutigu	92	122	20
143	Mang Tindang	145	193	32
144	Sugubee	148	197	33
145	Kulbila	144	192	32
146	Nworung (Norun)	140	186	31
147	Yizegu	60	80	13
148	Kpana	113	150	25
149	Kanbonayili No.1	140	186	31
150	Goma	148	197	33
151	Kpangin	15	20	3
152	Chabya	100	133	22
153	Gbunduli	37	49	8
154	New Jinbani	94	125	21
155	Kugbigu (Kut Igux)	137	182	30
156	Naba	16	21	4
157	Nakumgbal	47	63	10
158	Nabiegu	95	126	21
159	Gulla	68	91	15
160	Fungaa	95	126	21
161	Sakpali	84	112	19
162	Prungbuna	49	65	11
163	Taloli Akura	14	19	3
164	Yekazia	14	19	3
165	Nabihiya	75	100	17
166	Kambonsia	88	117	20
167	Gbalga	140	186	31
168	Nyinganabu	149	198	33
169	Sogu (Sogunayili)	146	194	32
170	Gbingbon	136	181	30
171	Laadua	136	181	30
172	Bulaalugli	46	61	10
173	Tegin	46	61	10
174	Naadabari	77	102	17
175	Nayobere	133	177	30
TOTAL		46,160	61,436	10,243

GHANA PRIORITIES

The Ghanaian economy has been growing swiftly, with remarkable GDP growth higher than five per cent for two years running. This robust growth means added pressure from special interest groups who demand more public spending on certain projects. But like every country, Ghana lacks the money to do everything that citizens would like. It has to prioritise between many worthy opportunities. What if economic science and data could cut through the noise from interest groups, and help the allocation of additional money, to improve the budgeting process and ensure that each cedi can do even more for Ghana? With limited resources and time, it is crucial that focus is informed by what will do the most good for each cedi spent. The Ghana Priorities project will work with stakeholders across the country to find, analyze, rank and disseminate the best solutions for the country.

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