Energy and Economic Growth
Applied Research Programme

Working Paper - What are the conditions under which electricity access leads to social and economic impacts in lower- and middle-income countries?

A synthesis of EEG funded research

Findings on factors affecting economic and social impact of electricity access from seven research projects commissioned by the Applied Research Programme on Energy and Economic Growth (EEG) across Ethiopia, India, Nepal, and Sierra Leone.

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September 2022

Oxford Policy Management

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Working Paper - What are the conditions under which electricity access leads to social and economic impacts in lower- and middle-income countries?

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Abstract

Access to clean energy is widely regarded as an essential pre-requisite to achieving the majority of the UN Sustainable Development Goals, as well as being a goal in its own right (SDG 7), but academic research on the impacts of electrification has returned mixed results with regards to social and economic impacts realised. This paper examines what the findings from seven research projects commissioned by the Applied Research Programme on Energy and Economic Growth (EEG) across Ethiopia, India, Nepal, and Sierra Leone add to the wider literature.

As per the literature, these seven studies paint a mixed picture of the impacts of electrification. In the case of the grid-connected communities studied in India and Sierra Leone, the research confirms that, post-electrification, electricity consumption by households and enterprises can remain low, not just in the period immediately after introduction of electricity but in the medium term. But this is not always the case and, by contrast, the consumption of electricity in the grid-connected households studied in Ethiopia was found to be significantly higher and approaching European levels. Meanwhile, mini-grid connected households in Sierra Leone were found to consume less than a tenth of the (already low) kilowatt hours consumed by grid-connected households in the same country.

In the studies that considered impact, low consumption translated to low impact (meaning generally confined to access to clean modern lighting and possibly activity that requires minimal power such as phone charging). In the case of recently connected rural mini-grid consumers in Sierra Leone, for example, electrification was found to result in no significant economic, educational or health benefits. Meanwhile, research looking at the social value of energy access in urban Sierra Leone and focused on consumers connected to the national grid, found the net overall costs of electricity access to exceed the social and economic benefits, potentially acting to deepen poverty.

Constraints on demand for electricity vary from location to location in the studies, but evidence suggests the cost of tariffs can have a major impact on consumption, along with absence of 'complementary inputs' that might support productive use of electricity and, in some cases, constraints on the electricity supply itself.

There is some evidence that where economic impacts do occur, they can take time to materialise, which cautions against trying to measure impacts too quickly after electrification happens.

Acknowledgements

This project was funded with UK Aid from the UK government under the Applied Research Programme on Energy and Economic Growth (EEG), managed by Oxford Policy Management.

Introduction

Access to clean energy through the provision of electricity is widely regarded as an essential pre-requisite to meeting a basic standard of living and achieving the UN Sustainable Development Goals (see for example (Mulugetta, Hagan, & Kammen, 2019; Fusu-Nerini & et_al, 2018; UNESCAP, undated; World Bank, 2016)). In the world of academic research significant resources have been applied to trying to determine whether this axiom is indeed true or not by addressing the question "does electrification lead to improved social and economic outcomes"? This paper briefly reviews the relevant literature before exploring how findings from seven research projects carried out under the Applied Research Programme on Energy and Economic Growth inform responses to this question. One conclusion is that that the key question to answer is not 'does electrification lead to social and economic outcomes', but rather 'under what circumstances does access to electricity lead to positive social and economic outcomes and under what circumstances does access extract rather than add value to households?'.

Context

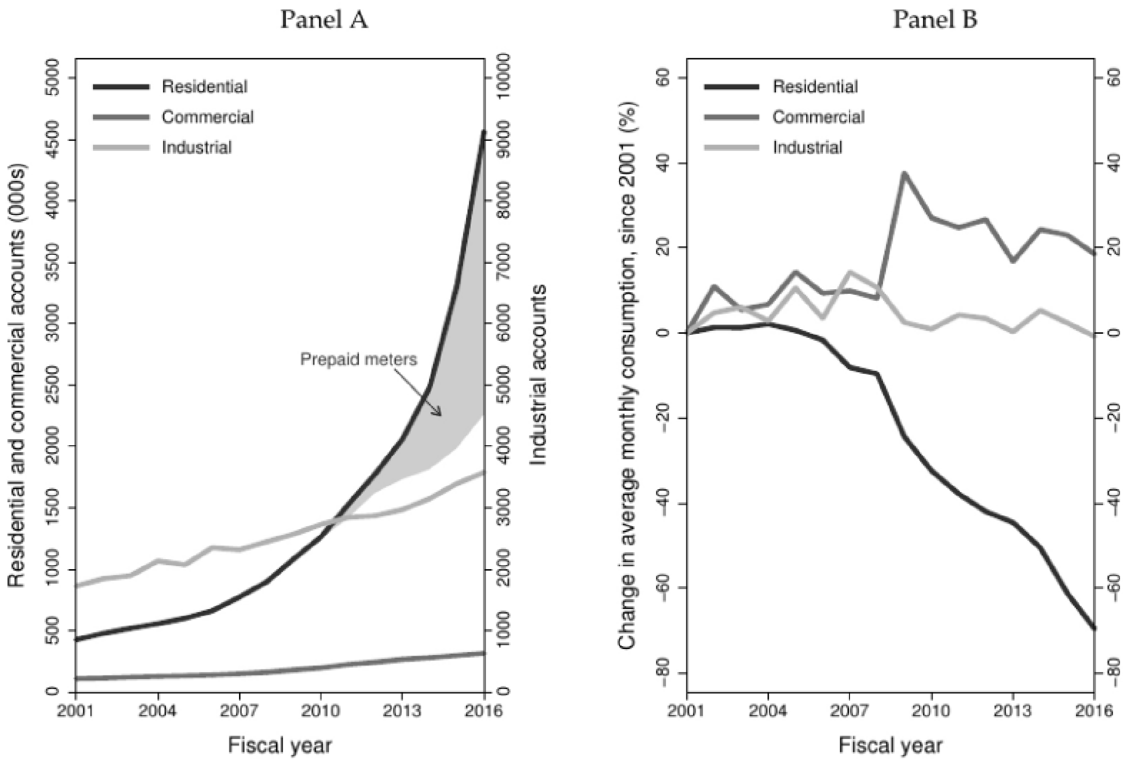
The Applied Research Programme on Energy and Economic Growth (EEG) ran from 2016-2022, funded by the UK Foreign, Commonwealth & Development Office (FCDO). EEG focused on ground-breaking research on sector reforms, innovative technologies, and practicable solutions to some of the most pressing energy-related challenges in Sub-Saharan Africa and South Asia. Priority research areas included energy access, renewable energy, power system reliability and the efficiency and productivity of energy uses.

At the outset of the EEG programme several 'State of Knowledge' papers were commissioned to provide context for the programme and to inform the subsequent calls for research proposals to be launched under it. Amongst these, a 2016 literature review confirmed electricity supply as one of the top constraints to economic growth in developing countries (McCulloch & Zileviciute, 2016). The study reviewed 55 studies on 'binding economic constraints' and found almost all mentioned electricity, around two-thirds discussed electricity access and reliability, while 40% identified electricity as a binding constraint. Particularly low levels of access in Sub-Saharan Africa and South Asia, especially in rural areas, together with poor quality and reliability of supply were frequently cited in these studies. The binding nature of the constraint was shown to be revealed through high shadow prices, the economic costs of outages, and the use of generators to compensate for poor access to reliable power. Data from the World Bank's Enterprise Survey was also found to reflect the importance of energy access to economic growth, suggesting that it is the second most important obstacle for firms in Sub-Saharan Africa and the most important obstacle in South Asia.

A 2017 EEG literature review (Lee, Miguel, & Wolfram, 2017) took a microeconomic perspective to the topic of electrification and economic development and noted that, while much of the literature concludes that electrification improves wellbeing, there is a wide range of types of outcomes examined and magnitudes of impacts estimated. Context varies enormously across studies, making it difficult to assess external validity. Also, electricity is an enabling technology and in order for value to be derived from it, complementary inputs are required – for example appliances to convert electricity into useful work, access to credit to finance purchase appliances, access to good roads to provide a route for produce to market and so on. It is possible that some of the studies showing large impacts could therefore be influenced by unobserved complementary inputs.

Lee et al (2017) also noted reporting of very low levels of consumption from poorer households. In Kenya for example, while the electricity utility's residential and commercial accounts grew from just under 500,000 in 2001 to over 4 million by 2016 (Figure 1, panel A), the average monthly consumption per account dropped by almost 70% over the same period (Figure 1, panel B), reflecting the recruitment of large numbers of poorer households with very low electricity demand over the period through rural electrification programmes. As a result, demand can be shown to not always justify, in economic terms, investment costs in rural electrification programmes. A study estimating experimental demand and cost curves for a rural (grid-based) electrification programme in Kenya, for example, demonstrated a total cost of construction nearly five times higher than the consumer surplus derived from the experimental demand curve, even after accounting for economies of scale (Lee, Miguel, & Wolfram, 2016a).

Figure 1: Kenya Power electricity accounts and change in average consumption since 2001 (Lee, Miguel, & Wolfram, 2017)



Indeed the low levels of electricity consumption in poorer households can undermine the potential for significant impacts as the results of a large-scale Randomised Control Trial (RCT) study by the same authors showed. The study, amongst newly connected households in Kenya, demonstrated there were no meaningful medium-term impacts on economic and non-economic outcomes as a result of electricity provision (Lee, Miguel, & Wolfram, 2020).

Three themes emerged from the initial EEG sponsored literature reviews around electricity access and growth which, in turn, provide the research questions that this paper uses to analyse how subsequent research sponsored by the EEG programme sheds further light on this topic. The questions are:

1. Does the consumption of electricity by poorer households always remain low after electrification or are there circumstances where this is not the case and, if so, what influences consumption in such cases?
2. Where consumption remains low what are the impacts of access to electricity on households and are any of these negative?
3. From an economic growth perspective, is there any evidence of a link between electrification, access to "complimentary inputs" and enterprise growth?

Relevant EEG research projects contributing findings to this paper

This paper is largely based on the findings of 7 research projects sponsored by EEG between 2017 and 2022. The projects are summarised in the table 1 below.

Table 1: EEG research projects contributing to this paper

Research location / lead researcher(s) / Institution	Research description
Sierra Leone **Miller, C; Biswas, S et-al, Arizona State University**	**Improving the social and economic impact of energy investments in Sierra Leone through enhance social value creation, capacity building, and decision support.** Exploration of the social value derived from energy access for grid-connected households and enterprises in Freetown, Kenema and Bo and mini-grid connected households and enterprises in Segbwema
Voors, M; Meriggi, N.F.; et-al Sierra Leone Wageningen University	**Electrifying growth: Electricity access for productive use** Estimating the impact of mini-grids on economic, education and health outcomes and the willingness to pay level for energy dependent appliances for households.
Voors, M; Meriggi, N.F.; et-al Sierra Leone Wageningen University	**Can electricity access improve the population of Sierra Leone's resilience to the COVID-19 crisis?** A repeated survey across 4500 respondents in 108 communities and staff in 108 Community Health Centres (CHC), spread across all districts in Sierra Leone looking at whether households and clinics with access to electricity from mini grids were any more resilient to the impacts of COVID-19 than those without
Khanal, G; Pandey C; et-al **Nepal** **Winrock International**	**Electricity and enterprise development in Nepal** A comparative analysis of the economic activities spurred by two different institutional arrangements for electricity distribution in rural market towns and peri urban areas. Based on data collected using a structured questionnaire survey of 770 randomly selected households across 8 sites in 4 different geographic locations.
Fowlie, M; Deshmukh, R; et-al India University of California, Berkeley	**Pairing super-efficient appliances with low-cost battery storage** Research looking at technology configurations, procurement processes, financing terms, subsidy programs, and distribution strategies to support more efficient investments in efficiency among low-income populations.
Ethiopia **Bensch, G; Taneja, J; et-al RWI Leibniz Institute for Economic Research**	**Electricity demand forecasting in agriculture** Work to combine an innovative machine learning prototype simulation model with classical 'on-the-ground' surveys among households, enterprises, and communities. The aim was to develop a scalable, cost-effective approach that uses relatively 'expensive to collect' information by carrying out surveys in a limited number of regions and train machine algorithms to extrapolate this in-depth information to the entire country.
Ethiopia **Beyene, A;** **Policy Studies Institute, Addis Ababa**	**Impacts and drivers of policies for electricity access.** A micro- and macro-level analysis of the electricity tariff reform enacted in Ethiopia, evaluating the impacts of the first phase on the demand for electricity among household and commercial consumers, as well as on the broader economy.

The remainder of this paper considers how the results of these research projects, executed over the period 2017 to 2022, further contribute to providing answers to the three research questions above.

Research Question 1: Does the consumption of electricity by poorer households always remain low after electrification or are there circumstances where this is not the case and, if so, what influences consumption in such cases?

The EEG programme returned mixed results in terms of evidence that poorer households continue to consume low levels of electricity post-electrification.

Low consumption in grid-connected poor households in rural Bihar, India

As part of their research on the potential role for super efficient appliances and battery storage in India, Fowlie (University of California, Berkley) instigated a pilot study of ceiling fan usage by 36 randomly selected poor grid-connected rural households in Gaya district in Bihar state, India. The research team partnered with Gram Power to obtain high resolution data on energy demand and consumption using a state-of-the-art metering infrastructure and, in addition, deployed sensors that could complement consumption data collected by these meters in the sampled households. Although consumption varied by an order of magnitude between the lowest and highest consuming households (see Annex 1, Table 3), the findings of the pilot study confirmed very low electricity usage in the majority of households concerned (Table 2), with median household consumption in October (during the onset of the cold season where ceiling fan usage would be very limited) at just 0.53KWh per day. The research estimated that most household power demands were less than 10W indicating that, outside of ceiling fan use, sampled households utilized loads such as LED bulbs and phone chargers which consume less than 10 W power in majority of the instances. In this context the load from a ceiling fan is relatively high and, during the hottest time of year, the research found that fan usage alone could account for up to 78% of daily household electricity consumption (see Annex 1 Table 9).

Table 2: Mean and Median daily household electricity consumption in 36 rural grid connected households in Bihar, India

	Over entire 13 months of study	Highest consumption month (April 2021)	Lowest consumption month (October 2021)
Mean daily household consumption	1.67 KWh	2.35 KWh	0.64 KWh
Median daily household consumption	1.33 KWh	2.30 KWh	0.53 KWh
Lower quartile household consumption	0.87 KWh	1.27 KWh	0.27 KWh

Calculated from data in in Table 8, Annex 1, which was extracted from (Deshmukh, Fowlie, & Venkataswaran, 2022)

Constrained household demand in Sierra Leone

Grid-connected households in urban Sierra Leone

Through a survey of 798 largely grid-connected households across Freetown, Bo, Kenema, and Segbwema[1] in Sierra Leone, the Arizona State University's research took a different approach to investigating consumption, categorising households against three different levels of appliance ownership. The research team then simulated daily demands based on an expected daily level of usage of these appliances and compared it to actual household electricity consumption. The results can be seen in Table 3. There are three important points to note concerning these results. Firstly, this is a survey of households with access to electricity in these locations; 45%[2] of urban Sierra Leone is without electricity and not represented in these figures. Secondly, for the poorer households surveyed (those with the basic appliance set B in Table 3), daily household electricity consumption remains quite low at 3.8KWh, although higher than the 0.53 – 2.18KWh found for poor Indian households above). Thirdly, that actual electricity consumption was found to be significantly lower than would be expected across all three levels of appliance ownership (between 19% and 40% of a simulated demand based on appliance ownership), meaning that even in better-off households' demand is constrained. From the results of interviews, the research ascribed the difference between simulated and actual consumption to a number of areas of constraint: the cost of energy[3], the reliability (and therefore availability) of the electricity supply, the limited availability of appliances, the limited value provided by the use of basic appliance sets, and the cost of maintenance of appliances (which are frequently damaged by voltage fluctuations).

[1] While Freetown, Bo and Kenema households survey were grid connected, the 54 households surveyed in Segbwema included 37 with a mini grid connection, 2 with household solar panels and 17 reliant on battery power alone.

[2] (ESMAP / World Bank, 2022)

[3] The research found that the total energy burden (made up of the cost of the electricity utility bill, back up supply to deal with blackouts, and cooking fuel) was on average 14% of household expenditure in Freetown, 18% in Kenema, 20% in Bo and 40% in Segbwema.

Table 3: Actual daily household electricity consumption against simulated expected demand for three levels of appliance ownership in Sierra Leone

Percentage of households that own different configurations of electrical appliances	Freetown % Households (HH) (Actual vs simulated daily demand)	Bo %HH	Kenema %HH	Segb-wema %HH
Basic appliances (B): Iron, fan, light bulbs, TV, music/entertainment system	14% (3.8kWh vs 4.7KWh)	29%	24%	55%
Basic+ appliances (B+): Basic appliances + refrigerator, home theatre, water heaters	63% (4.8KWh Vs 7.1KWh)	63%	60%	45%
Basic++ appliances (B++): Basic+ appliances + air conditioner, multiple refrigerators & TVs, microwave, rice cooker /electric cooker, blender, water heaters, water filter, washing machine, water pumps	23% (8.8KWh vs 14.7KWh)	8%	16%	0%

(Miller, Biswas, Chhetri, & et-al, Enhancing the social value of energy in Sierra Leone (Workshop presentaton, Freetown, Sierra Leone), 2022)

Mini-grid connected households in rural communities in Sierra Leone

The research project coordinated by Wageningen University on mini-grids in rural towns across Sierra Leone found much lower levels of electricity use (see Table 4) compared to Arizona's figures for grid-connected communities in Table 2 above.

Table 4: Average daily demand from Wageningen mini-grid study sites in Sierra Leone[4]

Consumer segment	Average daily electricity use
Household	0.28 KWh / day
Commercial	1.10 KWh / day
Industrial	2.18 KWh / day

Similar constraints to those found in urban areas (affordability of tariff, availability / reliability of supply and access to appliances) are likely to apply to rural mini-grid sites, although possibly at higher magnitudes, in particular:

1. The residential tariffs for mini-grids in Sierra Leone range between US$0.6 to $0.75 per kwh[5], roughly three to four times the costs of the equivalent tariffs for grid-connected consumers[6]. It is likely that average household incomes in the rural mini-grid locations will be lower than for the grid-connected households in urban centres such as Freetown, Bo and Kenema, meaning the actual difference in affordability between grid and mini-grid tariffs could be a lot more than the apparent difference in tariffs alone.

[4] Average daily electricity consumption through mini-grids of households in rural communities in Sierra Leone based on (Levine & et_al, 2022).

[5] Based on https://www.politicosl.com/articles/edsa-increase-western-area-tariff

[6] During the period of this study the average domestic rate for grid connected customers was $0.14 per kwh, although this was increase to US$0.22 per kwh in June 2022 (see: https://a-zsl.com/edsa-to-increase-tariff-from-14cents-22cents-us/)

2. The peak power capacity of mini-grid sites is significantly more limited that the grid supply in Sierra Leone, despite reliability issues with the latter. In most of the mini-grid sites commercial / industrial loads during the day are only possible because the main domestic loading (lighting) occurs after dark in the evening.

3. The absolute generation capacity of systems (as opposed to ability to meet peak demand) is also likely to be a significant constraint to growth in domestic or commercial demand growth. Many systems are limited to 36-45kWh. Calculations showed that for the average system and average size of community, if every household had just four LED lightbulbs and one efficient ceiling fan, daily total generation capacity would be exceeded by 20% (Levine, et al., 2022). As a result, the ability to carry heavy productive use appliances that could be transformative in agriculture (such as dryers, milling machines, etc, that typical use 2-3kW) is very limited.

Higher domestic consumption in Ethiopia

In contrast to the Sierra Leone and Indian studies mentioned above, an EEG research study conducted by the Policy Studies Institute in Ethiopia , (Beyene, Jeuland, & et-al, 2022) found relatively higher domestic electricity consumption levels averaging 8.6kwh per day[7] across a sample of 2180 households in major cities in Ethiopia (54% from Addis Ababa). Further disaggregation of the data produced Table 5 below. Based on those figures the average lower quartile (poorest households) consumption is 4.6 KWh per day (128 KWh per month), around 20% higher than the poorest group in Sierra Leone (the basic appliances band in Table 3). That said, the overall average Ethiopian consumption across all quartiles (8.6KWh per day) is significantly higher than the average for Freetown in Sierra Leone of 5.6KWh[8] or the 1.81 average consumption for households in Bihar, India (Table 2).

Moreover the average Ethiopian figure of 8.67KWh is comparable with European domestic consumption levels such as Germany at 8.8 KWh per day or the UK at 9.8 KWh per day (Odyssee-Mure, 2019). It should be noted that, even after recent tariff reforms in Ethiopia (Hassen, Beyene, & et-al, 2022), the country continues to have one of the lowest domestic tariffs in sub Saharan Africa at US$0.026 cents (BIRR 1.375) per KWh[9], just 30% of the US$0.088 (Rs7.03) per KWh domestic tariff in Bihar, India[10] or around 18% of the equivalent US$0.14 per KWh tariff for grid-connected consumers in Sierra Leone[11].

Table 5: Monthly electricity consumption (self-reported from survey)[12]

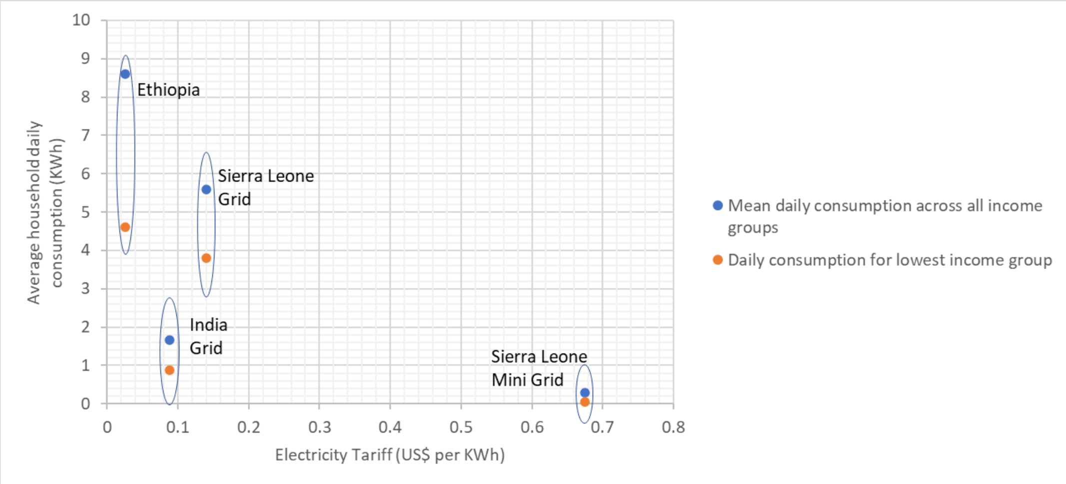
Consumption quartile	Total Sample		Addis Ababa		Regional towns	
	Electricity expenditure (ETB)	Electricity cons. (kWh)	Electricity expenditure (ETB)	Electricity cons. (kWh)	Electricity expenditure (ETB)	Electricity cons. (kWh)
1	163.275	160.663	192.565	184.045	106.872	114.413
2	222.765	215.421	259.855	246.404	179.263	178.889
3	257.55	252.829	273.267	262.891	237.96	239.359
4	320.066	303.074	341.855	320.584	285.391	275.358

While the above quoted three country studies have not been conducted in a way that enables a statistically rigorous comparison

[7] Based on a monthly average household consumption of 258KWh,
[8] Calculated from Freetown figures in Table 3
[9] The weighted average block tariff a household consuming up to 300kwh per month would pay, based on figure 4 4 (Hassen, Beyene, & et-al, 2022)
[10] The weighted average block tariff a household consuming up to 300kwh per month would pay, based on Bihar Electricity Regulatory Commission Rates for 2022-23 (Bihar Electricity Regulatory Commission, 2021)
[11] Based on the average tariff in place during the study (which subsequently rose from $0.14 to $0.22 per kwh in June 2022, meaning the Ethiopian grid tariff would now be just 12% of the equivalent tariff in Sierra Leone)
[12] Based on data collected for (Beyene, Jeuland, & et-al, 2022)

to be made across them, a rough plot of tariff vs domestic consumption levels emerging from these studies (Figure 2) suggests that tariff levels may, unsurprisingly, have a significant impact on consumption.

Figure 2: Average daily electricity consumption vs tariff in sample households in Ethiopia, India and Sierra Leone[13]



Research Question 2: Where consumption remains low what are the impacts of access to electricity on households and are any of these negative?

EEG-funded research found evidence to support arguments made by Lee et al in their original literature review mentioned above (Lee, Miguel, & Wolfram, 2017), that access to electricity for households or enterprises does not automatically lead to social or economic benefits.

Impacts of mini grids in rural Sierra Leone[14]

EEG research in Sierra Leone led by Wageningen University assessed the impact of the UK-AID funded Rural Renewable Energy Project (RREP) on livelihoods, food security, health, and education. Using baseline data collected in 108 communities and follow-up data collected during April – October 2020, the research compared outcomes for respondents from 54 communities where solar mini-grids were constructed (the 'treatment' group) to 54 communities without mini-grids (the 'control' group). It also collected data in health clinics covering the period January 2019 to March 2021 and school attendance for both 2019 and 2020. With the onset of the COVID pandemic the research also looked at whether access to electricity improved communities' resilience against the wider impacts of the virus. The research used a 'difference in difference' approach to compare trends in treatment and control communities over time, making it possible to see if the introduction of mini grids into the 54 treatment communities led to them following a different trajectory with respect to health, education, livelihoods, and economic outcomes compared to the control communities.

In terms of economic outcomes the research showed that respondents living in communities with a mini-grid were more likely to respond to the phone survey, suggesting it is possible electrification drives up mobile ownership and possibly also the ability to keep the phone charged and the powering of signal towers from phone companies. However, the COVID-19 pandemic

[13] Average daily consumption for all income groups shown for grid connected households in Ethiopia, India, and Sierra Leone, plus mini grid connected households in Sierra Leone. Daily consumption figures based on those using basic appliance package for grid connected households in Sierra Leone (table 3) and on lower quartile figure from consumption data for all other cases.
[14] This section is based on (Voors, Meriggi, Langbean, & et-al, 2022)

significantly reduced the average wage income for both communities with and without mini-grids, and there were no significant differences in outcome trends between mini-grid and comparison communities.

With regards to food security outcomes, the COVID-19 pandemic significantly reduced the average weekly food expenditures across both groups. In addition, there was a large increase in the times the household ate less preferred food or household members (adults and children) had reduced portions. There were no significant differences in trends between mini-grid and comparison communities. This general trend also emerges from other LMICs. Egger et al (2021) use a sample of over 30,000 respondents from nine countries in Africa, Asia and Latin America and document a decline in employment and income in all samples.

Knowledge of COVID-19 symptoms was equally distributed between mini-grid communities and comparison communities, suggesting access to electricity had not impacted on access to information in this respect.

In terms of health outcomes, Community Health Centres (CHCs) connected to a functional mini-grid were found to have more hours of electricity each day: almost all mini-grid sites had more than 15 hours of electricity per day while in communities without a mini-grid, more than two-thirds of the clinics had on average zero hours of electricity a day and only 29 percent of clinics had a few hours of electricity per day - mostly through standalone solar panels. CHCs connected to a functional mini-grid had a larger number of working electrified appliances and refrigerated drugs stored compared to those CHCs without a connection (mostly freezers and refrigerators). While the research found utilization rates were significantly higher in CHCs that connected to mini-grids (more patients, a higher number of births, more household visits for ante- and post-natal care visits), this was likely because mini-grid communities are slightly larger in terms of population size and thus have a larger potential patient pool. Overall there was no difference in the trend in utilisation between clinics with and without access to a mini-grid over the period leading up to and including the COVID pandemic.

Finally, in terms of education outcomes there were no significant differences between the type of communities and school attendance or student dropout during the COVID-19 lockdown in Sierra Leone and no impact on trends of pupil attendance and pass rate over time between the two groups.

It should be noted that these mini grids are modular in design and that the condition of low impact encountered is possibly reversible by making complementary investments to stimulate the use of electricity, which would a) drive up demand, b) increase consistency and predictability of consumptions for operators, who would then c) possibly make investments in expanding the infrastructure to supply more electricity and possibly leverage on economies of scale to reduce costs. This has not, however, happened to date in any of the mini-grids reviewed in this study.

Exploring the social value of grid electricity connections in urban areas of Sierra Leone[15]

In its research, Arizona State University (ASU) used the 'social value of energy' as its analytical framework, whereby:

Social value of energy	=	**Economic benefits derived from energy**	+	**Non- economic benefits derived from energy**	-	**Costs of the energy**	-	**Any additional risks or burdens derived from energy**

ASU posits that if the net social value of energy is positive then social and economic development should be expected to occur, whereas if it is negative then the costs of access exceed the value of the benefits and significant social and economic development would not be expected. ASU's study measured the social value of energy and the factors that impacted it for Freetown, Bo, Kenema, and Segbwema. Data was collected in 2020 and 2021 using surveys of households and businesses, together with focus groups on the public use of energy. A total of 619 households, 170 businesses and 53 focus groups in civil facilities were surveyed across the four locations.

[15] Based on (Miller, Biswas, Chhetri, & et-al, 2022)

To estimate the social value of electricity, ASU measured two quantities that each assessed how satisfied the household was with its electricity service:

1. In relation to their overall household expenses, households were asked to estimate what level of electricity costs would be affordable for their current electricity service.
2. Separately, households were asked to estimate how much they would conditionally be willing to pay for a reliable electricity service

Together, the two measures were considered to give an indication of how valuable the household considers electricity (both at current service levels and in abstract).

The Realised Social Value of Energy estimates the perceived value that the household derives from energy use by measuring satisfaction with the current cost and reliability of electricity service from EDSA. This is measured using two variables:

1. **Satisfaction with Electricity Cost** – how satisfied is the household with their current electricity costs? This is estimated as the normalized difference between the current household electricity bill (Current Cost) and an affordable electricity budget (Affordable Cost). The latter is estimated by the household based on factors like income and expenses for other essential services.

[(Affordable Cost – Current Cost) / Affordable Cost]

Households with low (negative) cost satisfaction face greater cost burdens and trade-offs between paying electricity bills, paying other essential expenses, and growing savings, thus reducing their overall financial and economic capability.

2. **Satisfaction with Electricity Use** – how satisfied is the household with the reliability of their electricity service? This is estimated as the willingness to pay (WTP) additional Leones in addition to their current electricity bill (Current Cost), reflecting the additional value and well-being of the household that would be obtained from more reliable electricity service. Households with high WTP above current costs show significant unmet demand for reliable electricity and so demonstrate a higher value of electricity service.

[- (WTP / Current Cost)]

An advantage of the approach is that user groups can be disaggregated by social value of energy characteristics and, potentially, policies developed to address the needs of these different groups.

ASU divided respondents into five categories (labelled A – E). Overall sixty-five percent of households surveyed (groups A-C) found the costs of electricity unaffordable.

- Group A (around 20% of sampled households) is excessively cost burdened and vulnerable (costs include electricity bills, costs to buy and repair appliances, and costs to purchase and operate backup power systems). Cost sensitivity of this group means there is no capability to realise additional value from a more reliable electricity service and reducing the cost of electricity is key for this group to realise social value.
- Group B (around 35% of households surveyed) sees current supply as unaffordable but also sees some modest potential increase value creation from higher reliability of services, for which there is a small willingness to pay. For this group a reduction in electricity cost combined with a doubling of hours of service (reliability) would improve social value for this group.
- For Group C (10% of households) electricity is currently seen as unaffordable, but these households see significant value creation opportunity from a more reliable supply. For this group keeping electricity tariffs unchanged but a doubling of hours of service (reliability) would be sufficient to improve social value for this group.
- By contrast groups D and E (35% of the population) do experience an overall positive net social value of energy, with group D prepared to pay significantly more for a better service while group E is content with its existing service.

Essentially, for groups A, B and C (65% of the population interviewed and generally the low-income households, businesses, and communities) the costs, risks, and burdens of electricity access are much higher, which significantly reduces their ability to achieve net positive social value from energy use. As a result the net social value of energy is negative and electricity access is, to an extent undermining household financial security and increasing the effects of poverty.

An insight into why reliability may be so important in this context is that 25% of households interviewed were found to generate primary or supplemental incomes through business activities co-located within the home premises using electricity powered operations. For these households increasing the hours of supply, so reducing the costs of running back-up generators, would be a pathway to enhancing revenue creation.

The high costs of electricity in Sierra Leone mean that households self-curtail electricity usage. The research found that 57% of households surveyed in Bo, Kenema, and Segbwema indicated that they curtailed electricity use in order to reduce costs, while 39% of those households further indicated that they faced circumstances that required them to reduce purchases of other essential services in order to pay their electricity bill. This finding aligns with the finding presented earlier in this paper that average consumption by households in Sierra Leone is well below the simulated demands for the appliance packages owned.

While the high costs of electricity in Sierra Leone, relative to household income and expense levels, do much to explain the overall net negative social value of energy, other factors also contribute to this. The research finds that a relatively poor-functioning electrical appliance market and associated policies also contributes to reducing the potential social value. Few electrical appliances are available, especially outside of the capital. Most of those that are on the market are of low efficiency (thus consuming more energy than necessary and further eroding net social value). Finally few, if any, appliance retailers are found to offer credit to allow householders to enable purchase by instalment. The research concludes that interventions in electrical appliance markets may, therefore, be as important as interventions in energy system design and function in tackling the energy-poverty nexus and in finding ways to transform energy use into a generative source of social and economic value creation and development (Miller, Biswas, Chhetri, & et-al, 2022).

Research Question 3: From an economic growth perspective, is there any evidence of a link between electrification, access to complimentary inputs and enterprise growth?

The Arizona State University research referenced above pointed to the cost of electricity and the cost and availability of appliances as two possible factors affecting the social and economic impact of energy access on households. Other studies under the EEG programme provided additional insights into other potential variables or 'complementary inputs' that may have a bearing on the level of impact provision of access to electricity has in practice.

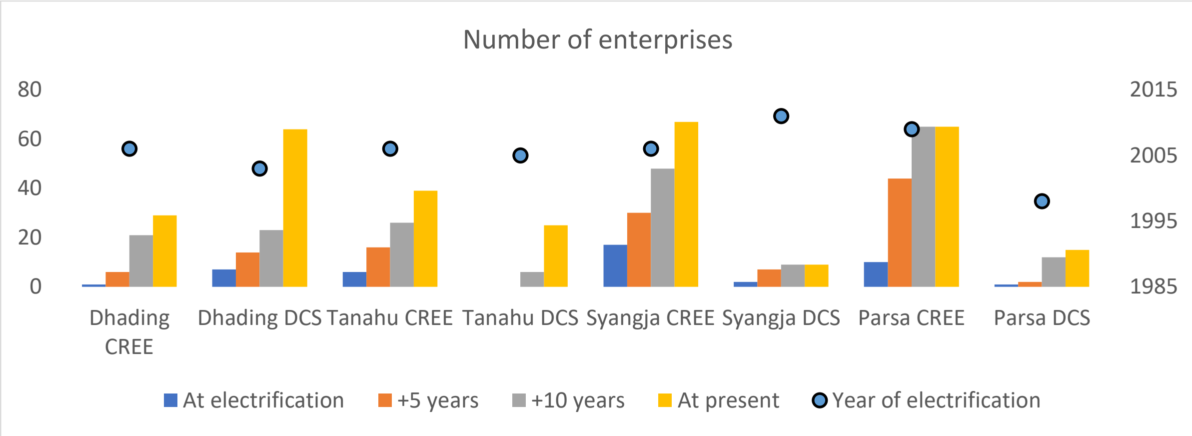
EEG-funded research by Winrock International in Nepal examined the impact of two different systems of electricity distribution on the growth of small enterprises and local employment generation in rural Nepal (Khanal, Upadhyaya,, Pandey, & et-al, 2022). The study adopted a comparative analysis framework. A total of four geographic areas were selected. In each area two study sites were then identified – one involving a traditional utility-managed distribution system under the auspices of the Nepal Electricity Authority's Distribution and Consumer Services business unit (DCS) and one a community-managed system run as a Community Rural Electrification Entity (CREE). In the latter case a community-based institution buys electricity wholesale from the Nepal Electricity Authority and is then responsible for operation and maintenance of the local distribution system and household billing. Each pair of sites were selected to be as similar as possible to each other.

The aim of the study was to examine the impact (if any) of two different systems of electricity distribution on the growth of small enterprises and local employment generation in rural Nepal. The study identified and interviewed all enterprises in the study areas using a structured questionnaire. Household level information was collected using a structured questionnaire survey of 770 randomly selected households in the study areas (385 households each in CREE and DCS areas). Focus group discussions, key informant interviews, and field observations were used to validate data collected through enterprise and household surveys and also to collect additional information. Overall the study found that CREE-managed systems provided a better service to household consumers than DCS ones, most likely because of a more localised management and operation structure, a better ratio of maintenance staff per head of population and reduced paperwork required to obtain a connection. In three of the four locations reviewed, using two different metrics[16], the CREE-managed systems also appeared to be more effective in supporting

[16] The study compared sites using two metrics – the current number of enterprises divided by the number of households in a community (to account for the fact that larger communities are likely to have more businesses) and the average number of new enterprises created per year since electrification (to take account of the time electricity has been available).

the establishment of new enterprises. In making these comparisons between CREE and DCS-managed systems the research uncovered a number of possible 'complimentary inputs' that were more common in sites that were more successful in supporting new enterprises in each pair of locations compared[17]. Time since electrification, perhaps unsurprisingly, was found to be an important factor in the growth of enterprises (see Figure 3). In most locations studied growth in number of enterprises in the first five years after electrification was quite modest. This is an important consideration that may account for why studies looking for economic impacts soon after electrification occurs fail to find substantial changes.

Figure 3: Growth of enterprises in Nepal comparison sites over time



From the interviews conducted, the study elicited several potential comparative advantages that might influence whether a particular site was more successful at nurturing new enterprises post-electrification. Based on the data collected Table 6 below summarizes the frequency with which these comparative advantages actually occurred for the most 'successful' system (CREE or DCS managed) at each of the four study locations, to provide an analysis of the factors that seem to most commonly be associated with a high performing site, in terms of enterprise creation.

The comparative advantages most commonly associated with the 'best' sites in terms of enterprise connection (those factors that occurred in at least 75% of the locations listed in Table 6) were found to be: better road access, fewer power interruptions per week, fewer voltage issues, higher numbers of technicians per thousand households, fewer days to resolve minor issues, lower distance to travel to pay bills and easier ability to upgrade power connection to 15 Amps. It is interesting to note that, except for 'better road access' the most common comparative advantages listed above related to the management and operation of the electricity supply rather than external 'complimentary inputs' such as access to finance[18].

[17] The scale of this research was modest, with only 4 pairs of communities compared, and should be treated as a case study. A larger sample of sites would be required to conduct any statistical regression to confirm correlation between variables.

[18] The sample in this study is too sample to determine real correlation between such factors, net alone causation. If a study of a larger sample of communities found a similar result however it would in itself potentially raise further interesting questions about whether factors of good utility management are contributing to a generally good environment for business, or whether there are other not-measured variables (e.g. good governance more broadly in those communities) that are contributing to both good management and a good business environment.

Table 6: Summary analysis of most common comparative advantages of most 'successful sites'

Study Sites	For each pair of CREE and DCS sites, what were the comparative advantages of the site with the highest number of enterprises created per year since electrification (i.e., the 'most successful' site)?												Who managed the 'most successful' site?	
	Better road connection	More development agency initiatives	Better financial access	More enterprise oriented ethnic group	Fewer power interruptions per week	Fewer voltage issues	Higher number of technicians per	Fewer days required to resolve minor issues	Less paperwork required to establish a	Lower distance to travel to pay electricity bill	Electrified earlier	Easy power upgradation to 15A connections	CREE managed	DCS managed
Parsa				X	X	X	X	X	X	X		X	X	
Syangja	X	X	X		X		X	X	X	X	X	X	X	
Dhading	X					X		X			X			X
Tanahu	X				X	X	X	X	X	X		X	X	

Another difference noted between the more successful CREE-managed and DCS-managed systems was the nature of the enterprises created under both management approaches. When enterprises were categorised as to how dependent they were on electricity it could be seen that CREE-managed systems were not only more successful overall in supporting the creation of new enterprises, but also that CREE systems attracted enterprises that were more dependent on electricity, and thus less likely to have been created had electricity not been provided (see Table 7).

Table 7: Relative performance of CREE and DCS management systems in stimulating enterprises that use electricity

Level of dependence of enterprises on electricity	Proportion of enterprises in each dependency category across all sites	
	CREE Managed systems	DCS Managed Systems
High electricity dependence	30%	18%
Medium electricity dependence	29%	22%
Low electricity dependence	41%	60%

The relationship between access to transport links and the productive use of electricity emerged in at least one other EEG-funded research project entitled: Improving productive uses of electricity in Ethiopia's agriculture. The research was based on data from a cross-sectional survey of 464 irrigation beneficiary farm households and their 1,037 plots in four regions of Ethiopia (Tigray, Amhara, Oromia, and Southern Nations, Nationalities, and Peoples (SNNPR)) that was conducted in 2016/17 to analyse the economics of irrigation systems from technological and management perspectives by the International Food Policy Research Institute (IFPRI), Addis Ababa. One of the findings of the research was that access to transportation increases the probability of adopting any form of mechanical pumping for irrigation (manual, diesel, or electric) compared to gravity-based irrigation. Similarly, distance to a *woreda* (administrative headquarters) market and adoption of electric pumps correlate negatively, providing, in the researchers' view "further evidence for the importance of market access for adoption of modern energy inputs in irrigated agriculture" (Bekele, Mekonnen, & Arega, 2022).

Not all EEG-funded research that collected data concerning 'complementary inputs' found strong relationships between electrification, the presence of these additional inputs and enterprise creation, however. Another EEG-funded research project in Ethiopia with the RWI Leibniz Institute for Economic Research[19] collected data for 36 rural communities (50% of which were connected to the national electricity grid). For the 18 communities with a grid supply, based on the data set provided by RWI, EEG was able to review the number and type of enterprises present at each location along with information on the quality of phone reception, distance to a tar road, distance to nearest main market, access to various financial services and number of years since electrification. Although the data set is too small to perform a regression analysis, plots of the different variables against the number of enterprises per household[20] at each location suggests there is no strong relationship between any of these variables and post-electrification enterprise creation in these cases (see Annex 2 for further details).

Discussion

EEG research looking at mini-grids in Sierra Leone finds a large impact on access to clean modern energy for lighting which, although not measured in this research, may have important social benefits in terms of enabling greater social interaction after dark, the ability to charge phones and have better access to information and improved perceptions of security, for example[21]. The research however found very little indication of significant health, education or economic impact on beneficiary communities compared to similar communities without electricity connections. This finding aligns with the extremely low levels of domestic electricity consumption found at the mini-grid sites investigated, indicating current household electricity use is indeed, most likely to be mainly just for lighting. Given tariffs for mini-grids are two to three times those for grid-connected households in urban Sierra Leone, while rural mini-grid consumers' average household income is likely to be less that their grid-connected urban counterparts', affordability of electricity is likely to be a key constraint at these mini-grid sites. It may not be the only constraint however, as the overall generating capacity of these systems is likely to be a significant constraint on demand growth or productive use.

EEG research on (mostly) grid-connected households in Sierra Leone finds 65% of that population struggling with affordability of tariffs and suggests that the cost of electricity, together with the affordability and limited availability of appliances, is significantly constraining demand, especially among poorer households. This research goes further however and, using the concept of the "social value of energy", suggests that the total cost of grid access for many households in Sierra Leone exceeds the social and economic benefits derived and may, as a result, actually deepen poverty.

The findings in Sierra Leone and India align with narratives in the literature such as Lee et al (Lee, Miguel, & Wolfram, 2017): that existing electricity consumption levels are low in many lower and middle income country contexts and that access to additional 'complementary inputs' may be required in order to help poorer households convert access to electricity in to social and economic benefits. The findings from the EEG studies in Ethiopia however contradicted this narrative, with household consumption levels approaching European levels. A key factor here appears to be the cost of access. The difference between relatively high levels of consumption and very low tariffs in Ethiopia compared to relatively high tariffs and low expressed demand in India (see Figure 2), as well as evidence of self-curtailment of demand because of cost in Sierra Leone, suggests that the cost of electricity itself plays a major role in determining whether poorer households can realise the full potential value from an electricity connection.

EEG research in Nepal suggests that likely candidates for 'complementary inputs' to support enterprise creation post-electrification include access to transport links, but also factors around how electricity systems are operated and maintained, such as: fewer power interruptions per week, fewer voltage issues, higher numbers of technicians per thousand households, fewer days to resolve minor issues, lower distance to travel to pay bills and easier ability to upgrade power connection to 15 Amps (for heavier-duty productive use appliances). The research also suggests that enterprise creation does not necessarily happen quickly after electrification and may, in fact, take some years, suggesting studies that attempt to measure economic impact too soon after construction works are complete may under-estimate the effect of access to electricity. While access to transportation is also supported as an important 'complementary input' by one EEG research project in Ethiopia, another finds a lack of strong evidence of any connection between enterprise creation post-electrification and a range of factors such as quality of phone

[19] Electricity demand forecasting in agriculture: Harvesting the synergies of machine learning and survey data for electrification planning in Ethiopia

[20] The ratio of number of enterprises divided by number of households in a community is used to account for the fact that larger communities are more likely to have a greater number of enterprises present.

[21] Similar for example to the benefits documented from solar home systems in Kenya on (Wagner, Reiger, Bedi, Vermeulen, & Demena, 2021)

reception, distance to a tar road, distance to nearest main market, access to various financial services or even number of years since electrification. The absence of clear evidence of the role of "complementary inputs" from EEG-funded research in Ethiopia maybe because their effect is masked by the effects of very low tariffs.

A final lesson from the findings of this research is that it cannot be assumed that access to appliances or changes in tariffs would always be the answer to increasing electricity consumption and the associated benefits. "Complementary inputs" and affordable tariffs will not, alone, make a significant difference to impact when other constraints (for example generation capacity in the case of mini grids in Sierra Leone) may themselves be binding constraints.

Further research

For a long time the research question in the literature has been "does electrification lead to better social and economic outcomes?" The above findings would suggest that the key question to answer is rather "under what circumstances does access to electricity lead to positive social and economic outcomes and under what circumstances does access extract rather than add value to households?"

The above research was limited in extent and in some cases (notably the Nepal work) based on case study and observational research rather than statistically significant samples. There is room for further research therefore to test potential hypotheses arising from this work further. These could include:

- Larger-scale research that will bear more rigorous statistical analysis to better identify common binding constraints that restrict the potential impacts of provision of electricity services being realised, and which assess in more depth the effects of 'complimentary inputs' to electricity supplies and their effects on the levels of social and economic impacts achieved.
- Longer term impact evaluations of energy programmes to better understand how social and economic impacts change over time.
- Action research to understand how the concept of 'social value of energy' can be effectively used in planning to improve the social and economic impacts of electricity service provision
- Longer term trials to understand the social and economic return on the provision of access to appliances at the domestic and enterprise level and the most appropriate means of financing such access.
- A review of the impacts of other co-investments in infrastructure or agreements to coordinate the consumption of electricity and reduce ambiguity for utility companies (e.g. instances where there has been an attempt to secure anchor loads by building mini grids near to small factories or processing plants or other enterprises that would guarantee a minimum level of electricity demand during daytime).
- Research to develop planning tools to assist governments and planners to factor in the presence or absence of complementary inputs, affordability of proposed tariffs and reliability and load carrying capacity of electricity systems, to better predict what realistic impacts are likely from the provision of particular levels of electricity services in specific local circumstances.

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Annex 1 – Domestic electricity consumption figures from Bihar

Table 8: Monthly electricity consumption from 36 rural households in Bihar, India (Deshmukh, Fowlie, & Venkataswaran, 2022).

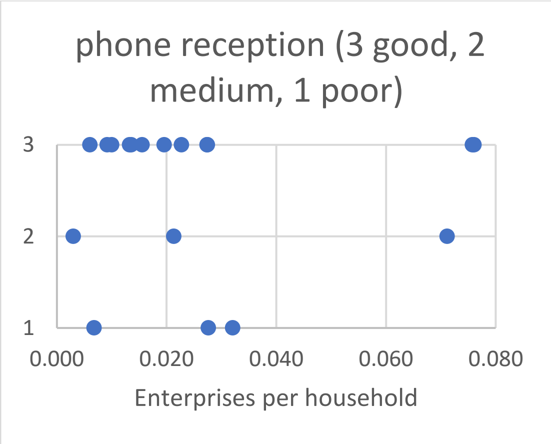
HHid	Monthly Energy Consumption (kWh)													Total Consumption (Oct 2020 - Oct 2021)
	2020	2020	2020	2021	2021	2021	2021	2021	2021	2021	2021	2021	2021	
	10	11	12	1	2	3	4	5	6	7	8	9	10	
7005	109	89	85	127	142	179	234	396	387	270	215	144	42	2419
7010	59	88	65	74	68	123	121	167	184	189	190	145	54	1528
7007	71	128	104	95	89	125	170	188	157	144	95	85	0	1451
7003	48	69	116	112	103	127	86	79	75	97	112	99	26	1148
7004	36	95	122	108	59	113	99	71	61	17	103	91	36	1008
6006	34	73	78	86	67	80	69	76	91	95	89	86	39	962
1102	44	26	25	25	24	76	112	121	122	114	117	76	30	911
9002	32	77	69	59	60	105	94	70	74	68	83	80	32	903
5005	33	34	31	28	28	65	72	69	87	130	136	109	58	882
5003	30	37	33	53	34	61	71	86	79	113	92	93	29	813
5001	29	38	39	47	39	42	86	84	113	79	62	111	42	810
1103	30	26	25	25	22	37	65	118	87	95	121	113	30	792
1101	37	45	42	47	47	96	128	99	88	100	5	0		733
1104	31	27	32	29	27	64	124	57	83	61	68	71	15	689
7002	30	23	23	29	22	53	75	87	89	76	66	74	29	676
6003	34	29	20	21	24	75	83	86	79	60	55	43	10	620
7001	26	26	19	17	19	51	62	82	74	58	72	58	20	584
9005	43	69	71	82	60	46	60	37	32	38	0	0	0	538
7012	115	54	21	16	13	26	38	42	58	59	25	31	14	512
9001	51	49	31	30	26	40	78	93	91	14				503
5004	23	25	23	23	19	40	40	50	55	58	38	25	0	417
9006	37	29	19	19	15	27	45	55	53	8	53	43	13	415
5002	24	23	29	27	20	48	81	87	52					390
5006	15	12	11	125	6	70	22	15	17	43	27	26	0	389
6005	29	28	23	24	22	33	41	35	41	40	41	29		387
7009	54	74	57	58	49	84	0	0	0	0	0	0	0	376
9004	27	32	29	35	32	54	44	60	34	0				347
1106	22	12	8	11	10	18	34	50	50	40	63	16	6	342
7008	16	53	26	13	51	33	24	35	34	32	2	0	0	319
6002	10	7	7	7	6	14	21	29	53	58	56	36	13	317
9003	24	33	21	26	32	41	61	46	15					297
1105		10	16	13	11	18	32	32	48	47	33	32		291
7006		0	0	0	0	42	72	66	21	34	0	22	18	280
6001	11	13	5	7	5	28	23	27	39	52	29	23	9	271
7011	16	15	13	12	19	34	38	59	50	14				270
6004	12	18	11	10	14	26	27	26	23	18	26	18	9	238

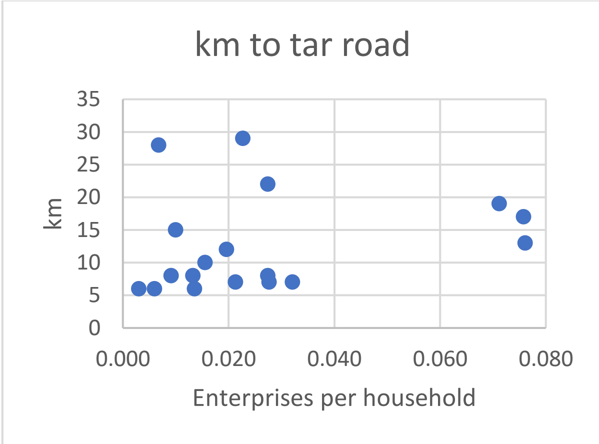
Table 9: Percentage of monthly energy consumption (kWh) by fan for 36 grid-connected rural households in Bihar, India (ibid)

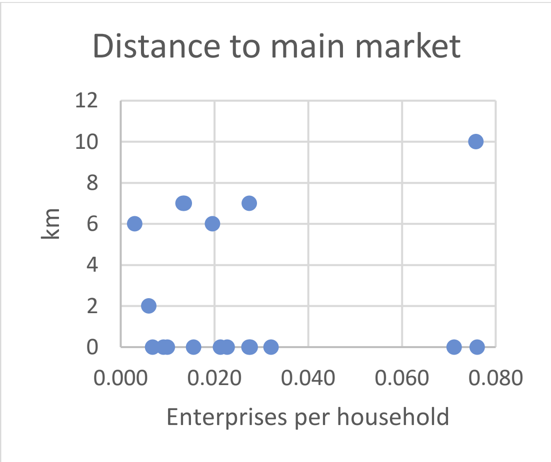
HH iD	2020	2020	2021	2021	2021	2021	2021	2021	2021
	11	12	1	2	3	4	5	6	7
1101	2%	0%	0%	1%	5%	6%	8%	4%	0%
1102	0%	0%	2%	15%	11%	7%	6%	3%	0%
1103	2%	0%	2%	2%					
1104	0%	0%	0%	0%	2%	3%	3%		
1105		0%	0%	0%	14%	24%	26%		
1106									
5001	1%	0%	0%	0%	3%	5%	7%	7%	12%
5002	0%	0%	0%	0%	9%	13%	12%		
5003									
5004	0%	0%	0%	0%	11%	31%	23%	23%	24%
5005	0%	0%	0%	0%	10%				16%
5006	2%	2%	0%	3%	1%	19%	39%	25%	16%
6001	1%	4%	1%	0%	18%	4%			
6002	6%	3%	1%	0%	36%	67%	62%	33%	33%
6003	0%	0%	1%	7%	14%	16%	22%	19%	22%
6004	1%	0%	1%	35%	62%	65%	67%	68%	68%
6005	0%	0%	0%	0%	19%	32%	33%	34%	38%
6006	1%	0%	0%	5%	20%		29%	23%	16%
7001	37%	0%	0%	16%	48%	41%	34%	40%	37%
7002	0%	0%	0%	1%	32%	36%	35%	17%	
7003	3%	0%	0%	0%	8%	35%	44%	36%	45%
7004	0%	0%	2%	16%					
7005	4%	0%	0%	1%	1%	3%	9%	10%	12%
7006					59%	43%	39%	47%	19%
7007	0%	0%	0%	0%	0%	8%	10%	11%	8%
7008	1%	0%	12%	20%	71%	75%	78%	76%	75%
7009	1%	0%	0%	0%	17%				
7010	1%	0%	0%	0%	15%		20%	19%	14%
7011	2%	0%	1%	6%	32%	47%	22%	19%	
7012	0%	0%	0%	2%	18%	24%	31%	35%	27%
9001	0%	0%	0%	1%	8%	11%	9%	11%	
9002	0%	0%	0%	0%	4%	8%	11%		
9003	0%	0%	0%	1%	4%	9%	9%		
9004	0%	0%	0%	0%	1%				
9005	0%	0%	0%	1%	11%	7%	10%	14%	11%
9006	0%	0%	0%	0%	9%	11%	20%	18%	

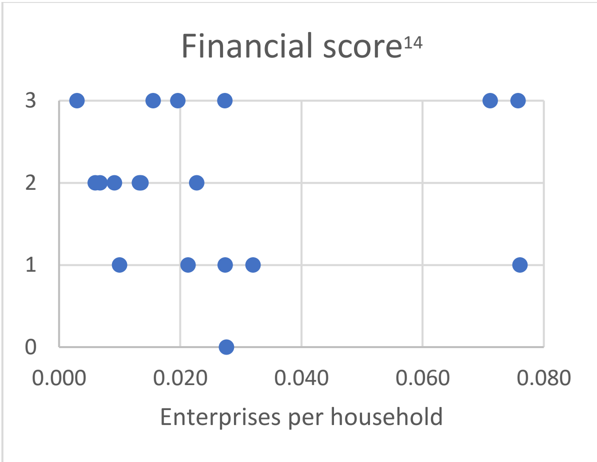
Note: Blank cell represent data unavailability in the data from Gram Power or Data logger

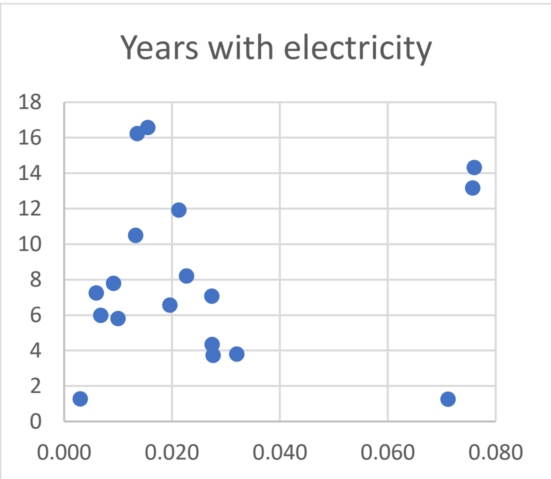
Annex 2 – Ethiopia – relationships between enterprise creation and other factors for 18 grid-connected villages in Ethiopia[22].











[22] Author's own analysis based on data provided by RWI, collected for EEG research project: Electricity demand forecasting in agriculture: Harvesting the synergies of machine learning and survey data for electrification planning in Ethiopia

[23] Financial score based on local access to (a) bank, (b) savings and credit co op, (c) microfinance institution, (d) banking agent, (e) mobile money agent, or (f) money lender, with 1 scored for each type of institution available locally (maximum possible score = 6).

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