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Rural Electrification with Off Grid Community Microgrids: An Impact Evalution in Uttar Pradesh, India

Final Report

Michaël Aklin* Patrick Bayer† S.P. Harish‡ Johannes Urpelainen§

December 13, 2015

1 Introduction

Electrification remains one of the most formidable obstacles to the social and economic development of rural communities. In India alone, about 400 million individuals suffer from inadequate access to electricity, according to the government's own figures from the 2011 Census (Government of India, 2011*a*). Many rural areas are entirely off the grid; even for those that are connected, electricity is often unreliable and blackouts are a common occurrence. Since we know that access to electricity is a determinant of economic growth (Dinkelman, 2011), finding a solution to these systematic problems offers appealing benefits.

Due to decreasing costs, off-grid options like solar-powered microgrids have become a possible solution to electrification issues in rural areas. The design of these microgrids is simple. A solar photovoltaic panel is installed on a rooftop; neighboring households are then connected through a microgrid to these panels. While the generated electricity varies based on the panels, a typical solar microgrid enables a household to get artificial light and enough power to charge mobile phones.

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The potential benefits of solar microgrids are numerous. Rural households in countries such as India suffer from two problems. First, the lack of electricity is a direct impediment to their economic prospects. When people don't have electricity, they face huge obstacles to start any kind of home-based business. Furthermore, the lack of power makes simple activities such as studying or reading cumbersome, especially when children and adults are in schools and fields during the day. Second, alternatives to electricity are inherently problematic. For instance, kerosene lamps are often used as an alternative lighting source in rural areas, but these are typically of poor quality, require people to spend a substantial part of their meager income on fuel, and their use sometimes results in health problems. It is therefore unsurprising that solar microgrids are seen as a potential silver bullet: they are clean, have a relatively low marginal cost, and they offer better lighting than kerosene lamps.

Despite the appealing characteristics of solar microgrids (and off-grid systems in general), there is little systematic evidence regarding their actual benefits. This project responds to the need for a rigorous assessment of their social and economic effects. In order to provide reliable estimates of these effects, we conducted a field experiment in Barabanki, a rural district in the state of Uttar Pradesh, India. We partnered with Mera Gao Power (MGP), a leading Indian solar power company that currently provides off-grid solar power to more than 100,000 people in this state.

MGP's business model provides households with enough solar electricity to run two bright LED lights and charge their mobile phones for a monthly fee of 100 rupees (∼\$1.6).[1] Households in unelectrified habitations are given the opportunity to subscribe to the service on a monthly basis.[2] Only a modest deposit is required as an upfront commitment, and MGP recovers the capital cost through the monthly payments. Households that fail to pay on time or damage the equipment are disconnected from the service. If there are many households in a habitation that fail to comply with the rules of the service contract, MGP withdraws its service from the habitation in question.

[1] All values in US dollars are based on the prevailing exchange rate on March 24, 2015 (1 Indian Rupee ≅ \$0.015). Most values reported in US dollars are rounded up.

[2] A habitation is roughly the equivalent of a hamlet, i.e. a unit at the sub-village level. The official definition is "a distinct cluster of houses existing in a compact and contiguous manner, with a local name and its population should not be less than 25 in plain area, and not less than 10 in hilly/dessert/sparsely populated areas. In case there exists more than one such cluster of houses in a village, they will not be treated as separate habitations unless the convenient walking distance between them is more than 200 mts." See Open Government Data Platform, Government of India, `https://data.gov.in/keywords/habitation` (accessed on March 20, 2015).

Our aim was to quantify the effects of solar microgrids on rural populations that suffer from acute energy poverty. Our study contains vast amounts of data; here we focus on the effect that these microgrids have on the amount of money spent by these rural households on kerosene. In a sense, this is a lower bound test: for microgrids to have any kind of social effect, it is important to demonstrate that they reduce energy poverty among the most vulnerable segments of the population.

2 Project Details

The experiment took place in the Suratganj block of Barabanki district located in the state of Uttar Pradesh, India (see Figure 1).[3] Uttar Pradesh is the country's most populated state with about 200 million inhabitants, which means that about 16% of India's population live in this state (Government of India, 2011*d*). At the same time, Uttar Pradesh is one of the country's poorest state. Its GDP per capita is about 38,000 rupees (∼$600) per year; in comparison, the national average income per capita is about 74,000 rupees per year (Government of India, 2014). Unsurprisingly then, Uttar Pradesh ranks at the bottom of most indicators of social and economic well-being. For instance, its literacy rate of 68% places it at the 29th position out of 35 states (Government of India, 2011*c*). Barabanki itself has about 2.6 million inhabitants and a surface area of about 3,900 square kilometers, or 1,500 square miles (Government of India, 2011*b*).

The treatment is the installation of an MGP micro-grid. We first randomly selected 81 unelectrified habitations from the Suratganj block in Barabanki. Of these habitations, 40 were assigned to the initial treatment group. The other 41 habitations were randomly ranked in a waiting list in case not enough habitations that would be electrified for the statistical analysis. Based on the reports we received from the ground operations, we decided that the first nine habitations on the wait list would be moved to the treatment group. This increased the treatment group to 50. MGP then accidentally installed microgrids in four additional habitations; these were random, because MGP did not know about the treatment assignment at the time of these installations. We therefore included these additional habitations in the treatment group. In total, the treatment group

[3] Indian states are first divided into divisions, then districts, followed by blocks.

Figure 1: Maps of the Barabanki district (right) in the state of Uttar Pradesh, India (left). Source: Google Maps.

consisted of 54 habitations. In addition to the 81 habitations, we created an additional control group based on 20 randomly selected unelectrified habitations from the Ramnagar and Fatehpur blocks, both located in Barabanki district. The reason for the second control group was in the event there were any spillover effects between control and treatment habitation in Suratganj. We label this group the "remote" control group (in contrast to the "close" control group from Suratganj). We sampled a total of 1,597 households in 101 habitations (16 households per habitation), and all respondents were above 18 years of age.

The timeline for the project can be summarized as follows. First, we conducted a baseline survey across all habitations in February-March 2014. This enabled us to gather data before MGP's intervention in the field. Technically, this also allowed us to assess the quality of the randomization process by comparing populations in the treatment and the control groups.

In the next part of the project, MGP traveled to the treatment habitations to sell their product to their potential customers. MGP was only allowed to travel to the treatment habitations; access to control habitations (both close and remote) was strictly forbidden. Once there, MGP proceeded as it would typically do in other regions with potential customers. We thereby ensured that the conditions under which these transactions occurred reflected realistic situations. Of course, residents of the treatment habitations were free to decide whether they wished to become MGP customers. The final decision to install a solar microgrid depended on the level of interest within a given habitation.

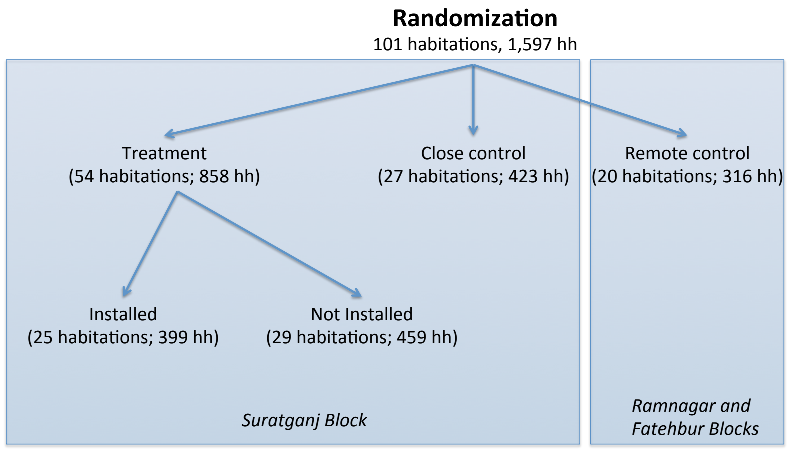

Figure 2: Description of the randomization and success of deployment. 'hh' means households. The number of households is based on the responses to the (pre-treatment) baseline survey. The sample size therefore slightly differs from the midline and the endline surveys.

MGP's operations only made commercial sense if about 10 customers sign up. In practice, MGP microgrids were installed in 25 out of 54 habitations (46%) from the treatment group.[4] This does not mean that all respondents within a given habitation actually became customers. Overall, 140 respondents living in a treatment habitation accepted MGP's offer.[5]

Figure 2 describes the randomization and the microgrid deployment process. The deployment of the microgrids took place between March and July 2014. No microgrids were installed in the habitations afterwards.[6] In turn, Figure 3 shows the locations of the realized treatment outcomes.

Immediately following the deployment, we conducted a second survey in Barabanki (September-October 2014). We were particularly interested in the reasons that encouraged people to accept (or not) MGP's offer. Except for a handful of households, we were able to interview the same ones as in our baseline survey. All households that subscribed to MGP reported doing so because of the improved lighting it was expected to provide. About 42% also indicated that they wanted to use electricity for mobile charging. Finally, about 24% mentioned that they hoped to save money by buying less fuel (such as kerosene). The most widespread reason to refuse MGP's product was its cost (28%). Only 10% reported that they were already satisfied the way things were, pointing at

[4] Of the non-installations, four were due to heavy flooding during the treatment assignment period.
[5] Other households outside our sample have also accepted the offer, so the total number of subscribers is larger.
[6] In one remote control habitation, MGP accidentally installed a microgrid at the end of the project.

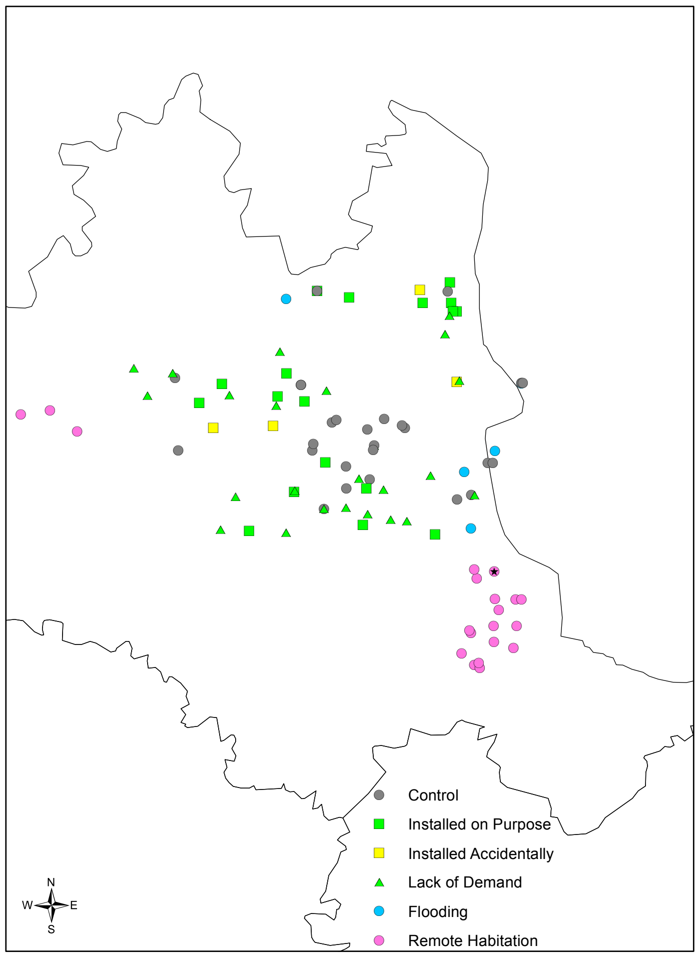

Figure 3: Geographic illustration of the realized treatment assignment. The asterisk illustrates a remote control habitation that later accidentally received a micro-grid during the endline survey.

the general dissatisfaction with the state of affairs.

Finally, around a year after the deployment, we returned to our original households to conduct a third survey between May and June 2015 and asked the same questions as we did in the baseline survey.

3 Outcomes

In our proposal, we identified four sets of important outcomes that could be affected by the provision of electricity through microgrids:

1. Small business activities
2. Human capital
3. Energy spending
4. Social capital

First, productive activities can be expanded by expanding the time in which business can be conducted (Cabraal, Barnes, and Agarwal, 2005). For instance, people who benefit from artificial lighting can work at night on sari decoration. To assess this hypothesis, we asked respondents in each wave of the survey whether they possessed a business and whether they planned to open a business in the future.

Second, we explored the relations between the microgrids and the accumulation of human capital. More artificial lighting means that children in particular have more time to read and study. Lighting from kerosene (the prevalent source of artificial lighting in areas without electricity) is of poorer quality and has a higher marginal cost. We asked respondents whether they used lighting for studying. In addition, we asked whether their children use lighting for studying. We combined these variables in a single dummy variable that takes value 1 if somebody in the household uses lighting to study.

Third, we examined whether the microgrids reduced spending on kerosene. As we indicated above, kerosene is the main source of lighting for households that do not have access to electricity.

Kerosene is a fuel that pollutes and has a non-trivial marginal cost. In India, people can buy it on through the public distribution system (PDS), a subsidized market. Since supply is limited, many households buy additional reserves on the black market (or private market). In turn, this may allow households to save money. Notice however that the microgrids may not increase savings if households' consumption is constraint by lack of cash. In such a situation, the savings from the microgrids would simply be used for other kinds of expenditures. We asked respondents to indicate how much rupees they spend per month through the PDS and on the private market. Because it is subsidized, kerosene from the PDS is less expensive than kerosene from the private market (Rao, 2012). Our prediction therefore is that microgrids should reduce spending on the black market first. We anticipate that there could be residual demand for kerosene even after a household gets access to a microgrid; in that case, the effect of microgrids on PDS spending is expected to be closer to zero than for private market spending.

Finally, microgrids may increase social capital by providing more time for households to socialize at night. Artificial lighting makes it easier to host guests. To the extent that these interactions generate higher levels of trust, we would expect that microgrids may increase the accumulation of social capital in the habitation. To test this conjecture, we asked respondents about how often they meet with friends and family (per week). In addition, since social capital is also related to trust, we asked people how much they trusted individuals from their habitation.

The summary statistics for these variables is provided in Table 1. The data come from our first (pre-treatment) survey; we divide the sample based on whether a respondent lived in a habitation that became part of the treatment group. As we can see, the differences across the two groups are very small. Indeed, they are not statistically significant, as we would expect following a successful randomization.

4 Data

Both the baseline and the post-treatment surveys were conducted with a sample of 1,597 households. We asked about 200 questions covering basic socio-economic factors as well as people's views on their energy situation. Drawing on the baseline survey data, we begin by providing a brief overview

Summary Statistics

Treatment Group	Mean	S.d.	Min.	Max.	Obs
Business Ownership (=1)	0.08	0.27	0	1	794
Lighting Used for Studying	0.63	0.48	0	1	794
Kerosene Spending (Private Market) (INR/Month)	72.94	64.41	0	440	794
Kerosene Spending (PDS) (INR/Month)	37.15	29.49	0	400	794
Time Spent with Family/Friends (Times per Week)	7.00	3.52	0	18	694
Trust people in hamlet	3.84	1.29	1	5	794

Control Group	Mean	S.d.	Min.	Max.	Obs.
Business Ownership (=1)	0.05	0.22	0	1	803
Lighting Used for Studying	0.61	0.49	0	1	803
Kerosene Spending (Private Market) (INR/Month)	73.73	66.87	0	350	803
Kerosene Spending (PDS) (INR/Month)	36.85	24.43	0	216	803
Time Spent with Family/Friends (Times per Week)	6.91	3.48	0	19	729
Trust people in hamlet	3.88	1.32	1	5	803

Table 1: Summary statistics for the main dependent variables. Data based on the baseline survey.

of the profile of our respondents.

Our average respondent was almost 40 years old. He (very few household heads were women) spent almost three years in school. Only about 35% could read. Respondents were predominantly Hindu (86%) with a sizable Muslim minority (14%). They mostly belonged to a backward caste (64%); 25% belonged to a scheduled caste.

The households were also very poor. It is difficult to obtain reliable data on income. Therefore, we asked respondents about their monthly spending and savings. On average, they reported spending about 4,400 rupees per month (about $70). Recall that Uttar Pradesh's average GDP per capita is about 38,000 rupees. Respondents at the 5th percentile situated their spending at 1,500 rupees per month ($24); households at the 95th percentile reported spending about 10,000 rupees per month ($160). Savings were low. The median respondent saved about 500 rupees per month ($8), while the average was about 861 rupees ($14). But for many households, saving money seems to be out of reach: 38% of all respondents in the baseline survey reported not being able to save at all. Unsurprisingly, about half of all households were in debt. The interest rates that they had to pay typically ranged between 7 and 13.5%, with a mean of 9.8%.

The initial electricity conditions were not favorable. Based on the baseline data, only 1.5% of all households had access to the grid (as expected, given that we targeted non-electrified habitations).

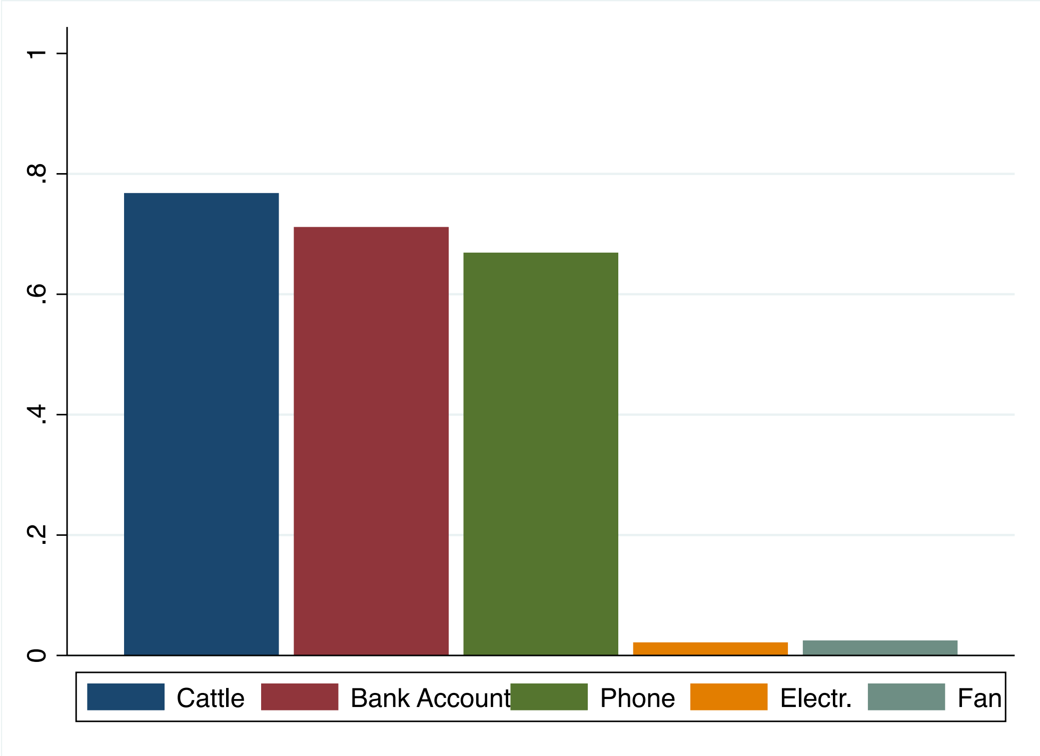

Figure 4: Proportion of respondents that possess the selected items.

In other words, only 24 households out of 1,597 were connected.[7] And even these few households could only rely on intermittent power; on average, they had between 7 and 8 hours of electricity per day. Unsurprisingly then, few households reported having electronic devices such as fans (Figure 4).

In the absence of reliable electricity, households had to turn to other sources of energy for lighting and cooking. The average household spent about 126 rupees per month ($2) on any kind of fuel. Kerosene, which is often used to provide fuel to lamps, represented costs of about 110 rupees per month ($1.75). Kerosene represents therefore on average of about 3% of monthly household spending.

[7]Ten more households had a battery.

5 Estimation Strategy

We measure the effects of MGP's microgrids on a range of outcomes summarized above. We report two kinds of estimates: intent-to-treat (ITT) and local average treatment effects (LATE). The ITT measures the effectiveness of the treatment overall. This accounts for the fact that some habitations declined MGP's offer. The second estimates are LATE. These measure the effect of the treatment on households that live in habitations that were provided service by MGP. ITT estimates are obtained from a least square regression of the following equation:

$$Y_{i,h,t} = \alpha_i + \omega_t + \tau^{ITT}\text{Treatment}_{h,t} + \varepsilon_{i,h,t}, \tag{1}$$

where subscript i denotes the household, h the habitation, and t the survey wave. LATE estimates are derived from a two-stage least square estimation of the two equations:

$$\text{Installed}_{h,t} = \beta_i + \theta_t + \delta\text{Treatment}_{h,t} + \mu_{i,h,t}, \tag{2}$$

and

$$Y_{i,h,t} = \alpha_i + \omega_t + \tau^{LATE}\widehat{\text{Installed}}_{h,t} + \varepsilon_{i,h,t}. \tag{3}$$

Installed is a dichotomous variable that denotes that MGP was installed in the habitation. *Treatment* indicates whether the habitation was in the treatment group or not.

6 Results

The main results are reported in Table 2. For each outcome, we alternative the ITT and the LATE estimates.

To investigate further whether the results on kerosene spending are robust or spurious, we followed two approaches. First, we report a fuller range of models to examine how sensitive the models are to the behavior of our 'remote' controls. The results are reported in Table 3. Panel A reports the analysis of kerosene spending on the private market, and Panel B does the same for spending on the public system. The first five models are the ITT estimates, followed by five LATE

Impact of Solar Microgrids

	Business		Study		Keros. Private		Keros. PDS		Socialize		Trust	
	(1) ITT	(2) LATE	(3) ITT	(4) LATE	(5) ITT	(6) LATE	(7) ITT	(8) LATE	(9) ITT	(10) LATE	(11) ITT	(12) LATE
Treatment	-0.02	-0.03	-0.01	-0.02	-17.45**	-37.58**	2.91	6.26	0.81	1.75	0.08	0.17
	(0.02)	(0.04)	(0.03)	(0.07)	(7.29)	(15.77)	(2.65)	(5.71)	(0.71)	(1.57)	(0.11)	(0.23)
Constant	0.06***	0.07***	0.58***	0.52***	62.58***	48.75***	30.03***	38.79***	7.44***	7.44***	3.77***	3.69***
	(0.01)	(0.01)	(0.02)	(0.02)	(5.33)	(5.03)	(1.92)	(1.66)	(0.62)	(0.62)	(0.09)	(0.07)
Household FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Wave FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Remote Controls	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Observations	4761	4761	4761	4761	4761	4761	4761	4761	4413	4413	4761	4761
R^2	0.00		0.02		0.10		0.03		0.02		0.00	
$\hat{\sigma}$	0.15		0.30		45.93		17.52		4.97		0.98	
# Households	1597	1597	1597	1597	1597	1597	1597	1597	1574	1574	1597	1597

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Effect of decentralized solar systems on a range of outcomes. Standard errors clustered by habitation.

estimates. Models 5 and 10 are the same as the ones discussed above. The specifications differ in terms of their inclusion (or not) of specific trends for remote controls, household fixed effects, and survey wave fixed effects.

We can see that the results are remarkably robust: spending on the private market goes down in all models and the effect is almost always significantly different from zero. The ITT estimates range between a decrease of 6 to 32 rupees per month. The LATE are quite larger, ranging from 14 to 72 rupees per month.

Second, we examine how households responded to two additional questions. The results are reported in Table 4. The first question asked whether households had electricity (Panel A); the second question asked how many hours of electricity households have per day (Panel B).

We find that access to electricity significantly increases both for the ITT and the LATE estimates. The effect of the intervention, captured by the ITT models, suggest that electrification increase by 11 to 36 percentage points. The magnitude of these effects is remarkable. A fairly simple decentralized system is therefore able to significantly indent electrification issues in rural settings. This also points at the existence of latent demand that is not being responded to. This is in contrast to beliefs that lack of electrification is largely due to cash-strapped poor households. Instead, the problem might come from the supply side as well.

Finally, Panel B shows that not only do households report higher electricity access, but they also suggest that duration of access to electricity is significantly increasing. On average, the intervention increased electricity duration by 30 minutes to almost two hours (ITT). For households that did adopt MGP, the effect is obviously larger, with estimates ranging from 1 to 4 hours. This suggests that the quality of the electric system provided by MGP is good enough to make a significant contribution to these households' energy access.

7 Conclusion

This study is the first systematic analysis of the socio-economic effects of decentralized renewable energy systems. These systems are often heralded as key contributors in the struggle against energy poverty. For instance, SE4ALL, a United Nations initiative to reduce energy poverty, claims that

Explaining Monthly Kerosene Expenditure

	Panel A: Kerosene Spending on Private Market									
	Intent to Treat					Local Average Treatment Effect				
	(1) OLS	(2) FE	(3) FE	(4) FE	(5) FE	(6) IV	(7) IV	(8) IV	(9) IV	(10) IV
Treatment	-22.24***	-33.22***	-18.60***	-6.57	-17.45**	-47.91***	-71.55***	-19.51**	-14.15	-37.58**
	(3.22)	(3.29)	(5.32)	(5.71)	(7.29)	(8.74)	(10.33)	(9.54)	(12.03)	(15.77)
Constant	61.32***	65.25***	52.80***	52.70***	62.58***	61.32***	65.24***	42.32***	40.93***	48.75***
	(2.24)	(1.18)	(5.36)	(3.29)	(5.33)	(2.23)	(1.71)	(4.17)	(3.99)	(5.03)
Household FE		✓		✓	✓		✓		✓	✓
Wave FE			✓	✓	✓			✓	✓	✓
Remote Controls			✓		✓					✓
Observations	4761	4761	4761	4761	4761	4761	4761	4761	4761	4761
R^2	0.03	0.06	0.07	0.10	0.10	.		0.06		

	Panel B: Kerosene Spending on Public Distribution System									
	Intent to Treat					Local Average Treatment Effect				
	(1) OLS	(2) FE	(3) FE	(4) FE	(5) FE	(6) IV	(7) IV	(8) IV	(9) IV	(10) IV
Treatment	0.42	-0.20	4.72*	1.33	2.91	0.91	-0.44	2.51	2.88	6.26
	(1.66)	(1.58)	(2.78)	(2.16)	(2.65)	(3.57)	(3.41)	(4.87)	(4.64)	(5.71)
Constant	36.29***	36.51***	35.78***	31.98***	30.03***	36.29***	36.51***	38.95***	38.87***	38.79***
	(1.11)	(0.57)	(2.40)	(1.23)	(1.92)	(1.10)	(0.57)	(1.72)	(1.34)	(1.66)
Household FE		✓		✓	✓		✓		✓	✓
Wave FE			✓	✓	✓			✓	✓	✓
Remote Controls			✓		✓					✓
Observations	4761	4761	4761	4761	4761	4761	4761	4761	4761	4761
R^2	0.00	0.00	0.02	0.03	0.03	.		0.01		

Standard errors in parentheses (clustered by habitations).
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3: Effect of decentralized solar systems on household spending on kerosene in the private market (Panel A) and on kerosene through the public distribution system (Panel B). The standard errors are clustered by habitation. Both dependent variables are measured in rupees per month.

Explaining Electrification and Hours of Electricity

	Panel A: Access to Electricity									
	Intent to Treat					Local Average Treatment Effect				
	(1) Logit	(2) FE	(3) FE	(4) FE	(5) FE	(6) OLS	(7) FE	(8) FE	(9) FE	(10) FE
Treatment	1.40^{***}	0.36^{***}	0.13^{***}	0.11^{***}	0.12^{***}	0.55^{***}	0.78^{***}	0.27^{***}	0.23^{***}	0.26^{***}
	(0.15)	(0.03)	(0.04)	(0.04)	(0.04)	(0.08)	(0.11)	(0.08)	(0.07)	(0.09)
Constant	-1.82^{***}	0.10^{***}	0.28^{***}	0.26^{***}	0.25^{***}	0.14^{***}	0.10^{***}	0.29^{***}	0.30^{***}	0.29^{***}
	(0.11)	(0.01)	(0.03)	(0.02)	(0.03)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
Household FE		✓		✓	✓		✓		✓	✓
Wave FE			✓	✓	✓			✓	✓	✓
Remote Controls			✓		✓					✓
Observations	4761	4761	4761	4761	4761	4761	4761	4761	4761	4761
R^2		0.16	0.14	0.23	0.23	0.02		0.15		

	Panel B: Hours of Electricity									
	Intent to Treat					Local Average Treatment Effect				
	(1) OLS	(2) FE	(3) FE	(4) FE	(5) FE	(6) IV	(7) FE	(8) FE	(9) FE	(10) FE
Treatment	1.31^{***}	1.89^{***}	0.59^{**}	0.45^{*}	0.49^{*}	2.82^{***}	4.08^{***}	1.28^{***}	0.96^{*}	1.06^{*}
	(0.18)	(0.18)	(0.26)	(0.23)	(0.27)	(0.53)	(0.67)	(0.48)	(0.49)	(0.58)
Constant	0.80^{***}	0.60^{***}	1.89^{***}	1.30^{***}	1.19^{***}	0.80^{***}	0.60^{***}	1.81^{***}	1.89^{***}	2.00^{***}
	(0.09)	(0.06)	(0.23)	(0.15)	(0.21)	(0.09)	(0.11)	(0.18)	(0.16)	(0.20)
Household FE		✓		✓	✓		✓		✓	✓
Wave FE			✓	✓	✓			✓	✓	✓
Remote Controls			✓		✓					✓
Observations	4760	4760	4760	4760	4760	4760	4760	4760	4760	4760
R^2	0.04	0.07	0.08	0.12	0.12	.		0.07		
$\hat{\sigma}$	3.03	2.31	2.97	2.25	2.25	3.12		2.98		
# Households		1597		1597	1597		1597		1597	1597

Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Effect of decentralized solar systems on household electrification (Panel A) and hours of electricity per day (Panel B). The standard errors are clustered by habitation. The dependent variable in Panel A is a dichotomous variable that takes value 1 if the household reports having electricity, and zero otherwise. The dependent variable in Panel B is the number of hours of electricity available per day.

"clean energy mini-grid sector is crucial in providing clean energy access and alleviating poverty in developing countries."[8] But the effectiveness of these systems had not, until now, been studied in a rigorous way. By implementing a randomized controlled trial, we start tackling this important question.

Our findings are both promising and sobering. Simple solar microgrids can alleviate energy poverty by increasing electrification rates and providing hours of affordable electricity. The simple intervention, which did not require public subsidies, increased access to electricity by about 11 to 36 percentage points. A more comprehensive program could therefore make a major contribution to meet basic power needs. Furthermore, we find that households that adopted microgrids significantly reduced their spending on kerosene. Solar power therefore replaces kerosene, which is a welcome effect given the latter's negative health and environmental effects.

At the same time, we find very little evidence that these small systems have second-order effects. Households that adopted the microgrids were not more likely to create a small business, nor were they more likely to invest in human and social capital. These important development effects therefore remain elusive. Why is this the case? We suggest three possible reasons. First, new energy technologies are on their own not able to affect these outcomes. Perhaps it is only in conjecture to other factors that they have second-order benefits. Second, the microgrids used in this study may not provide enough power to encourage business activities or the accumulation of social and human capital. Perhaps more powerful system would have these side-effects. Finally, our endline survey was perhaps too early to detect systematic changes for these variables. Decisions to study, have more interactions, or open a business are long-term decisions and may take several years. In any case, we encourage future scholarship to improve our knowledge of the conditions under which decentralized technologies have beneficial externalities.

[8] "Clean Energy Mini-grids," SE4ALL, `http://www.se4all.org/hio/clean-energy-mini-grids/` (accessed on December 1, 2015).

References

Cabraal, Anil R., Douglas F. Barnes, and Sachin G. Agarwal. 2005. "Productive Uses of Energy for Rural Development." *Annual Review of Environment and Resources* 30: 117–144.

Dinkelman, Taryn. 2011. "The Effects of Rural Electrification on Employment: New Evidence from South Africa." *American Economic Review* 101 (7): 3078–3108.

Government of India. 2011*a*. "2011 Census Report, Houselisting and Housing Census Data Highlights." `http://www.censusindia.gov.in/2011census/hlo/hlo_highlights.html`.

Government of India. 2011*b*. "Basic Data Sheet: Disitrict Barabanki (46), Uttary Pradesh (09)." `http://censusindia.gov.in/Dist_File/datasheet-0946.pdf`.

Government of India. 2011*c*. "Literacy in India." `http://www.census2011.co.in/literacy.php`.

Government of India. 2011*d*. "States Census 2011." `http://www.census2011.co.in/states.php`.

Government of India. 2014. "State-Wide Per Capita Income and Gross Domestic Product at Current Prices." Annex.

Rao, Narasimha D. 2012. "Kerosene Subsidies in India: When Energy Policy Fails as Social Policy." *Energy for Sustainable Development* 16 (1): 35–43.

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