Presentation for The World Bank

Economics of "Last Mile" Electrification

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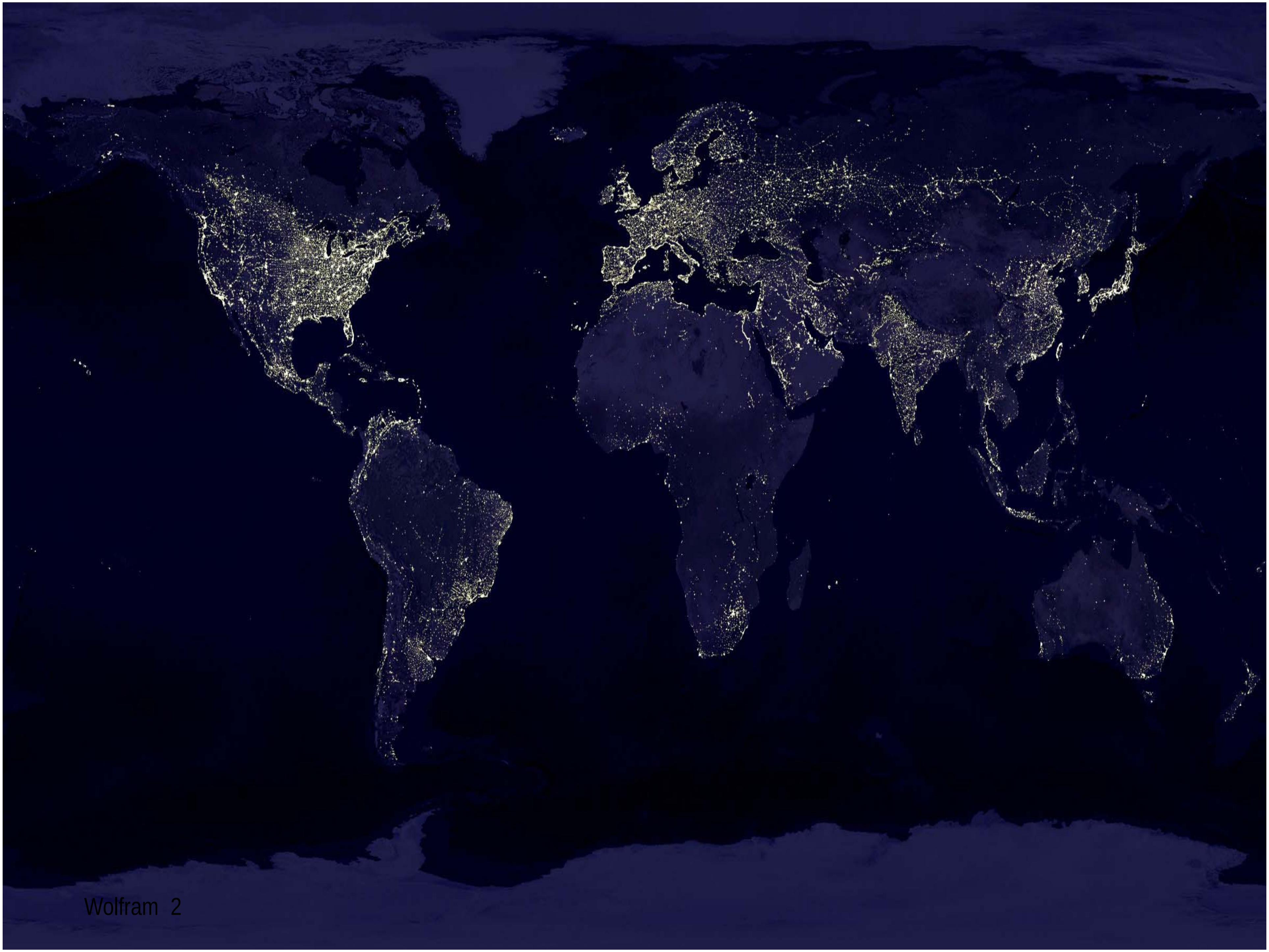
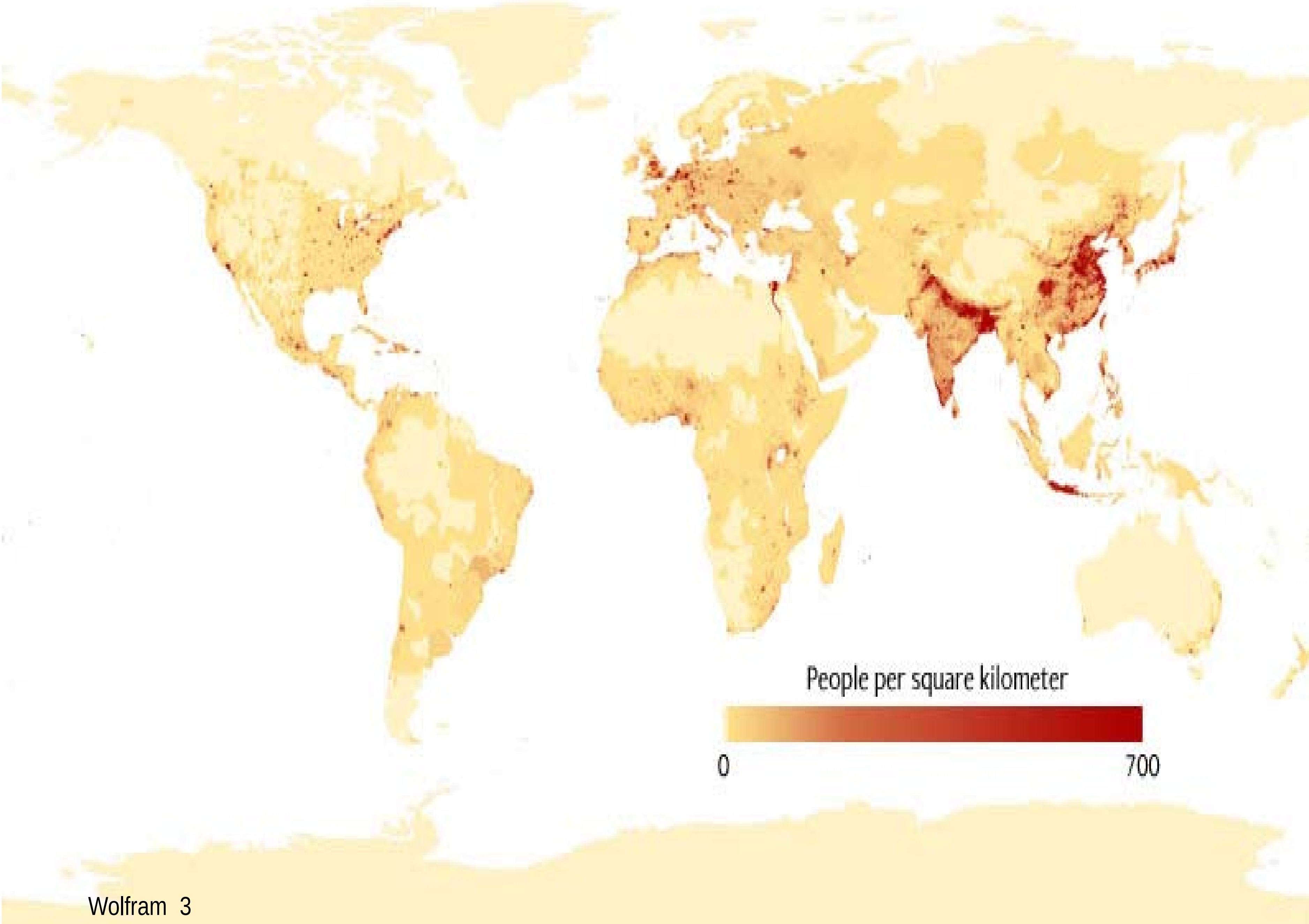
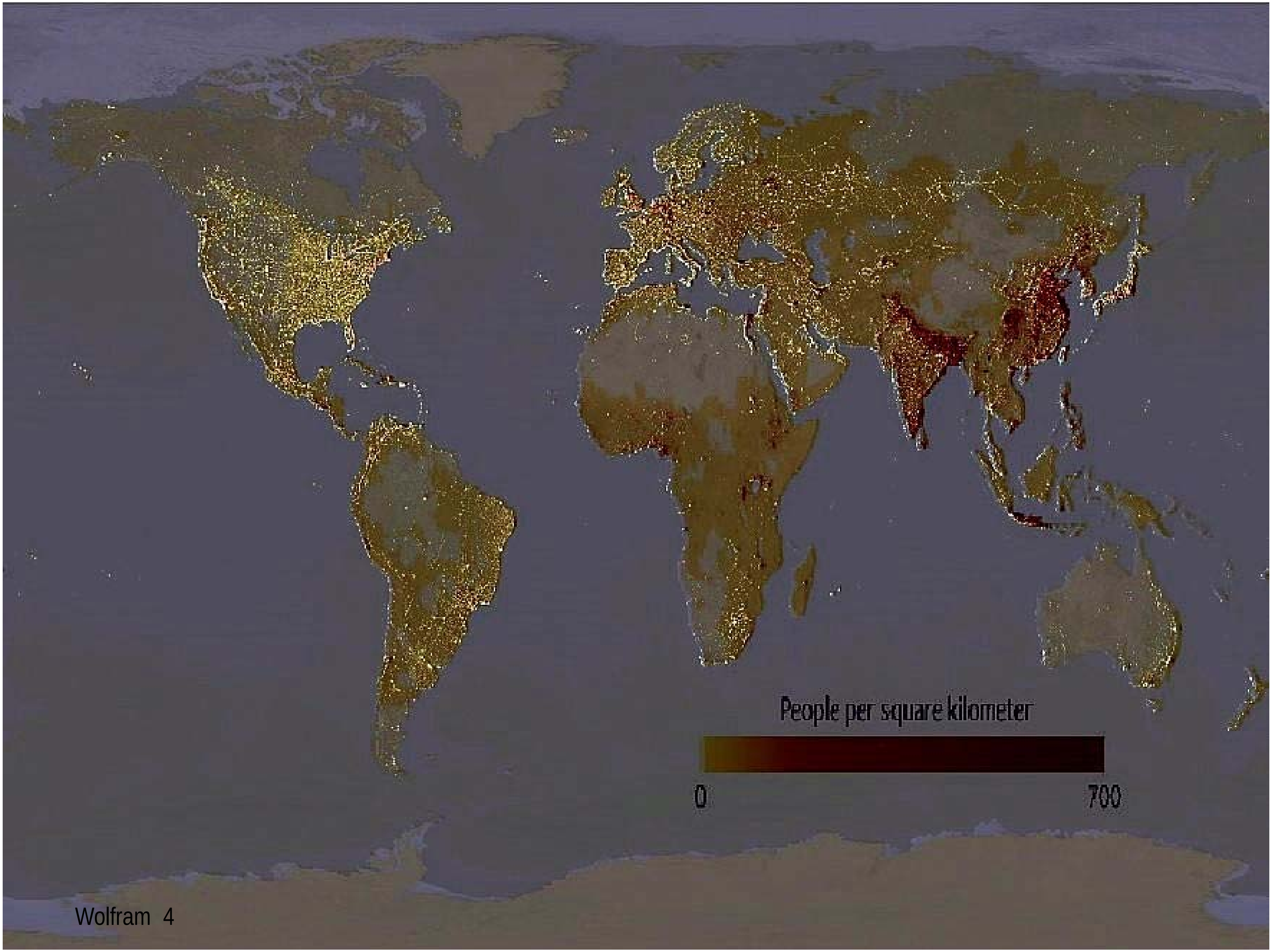

Wolfram 2

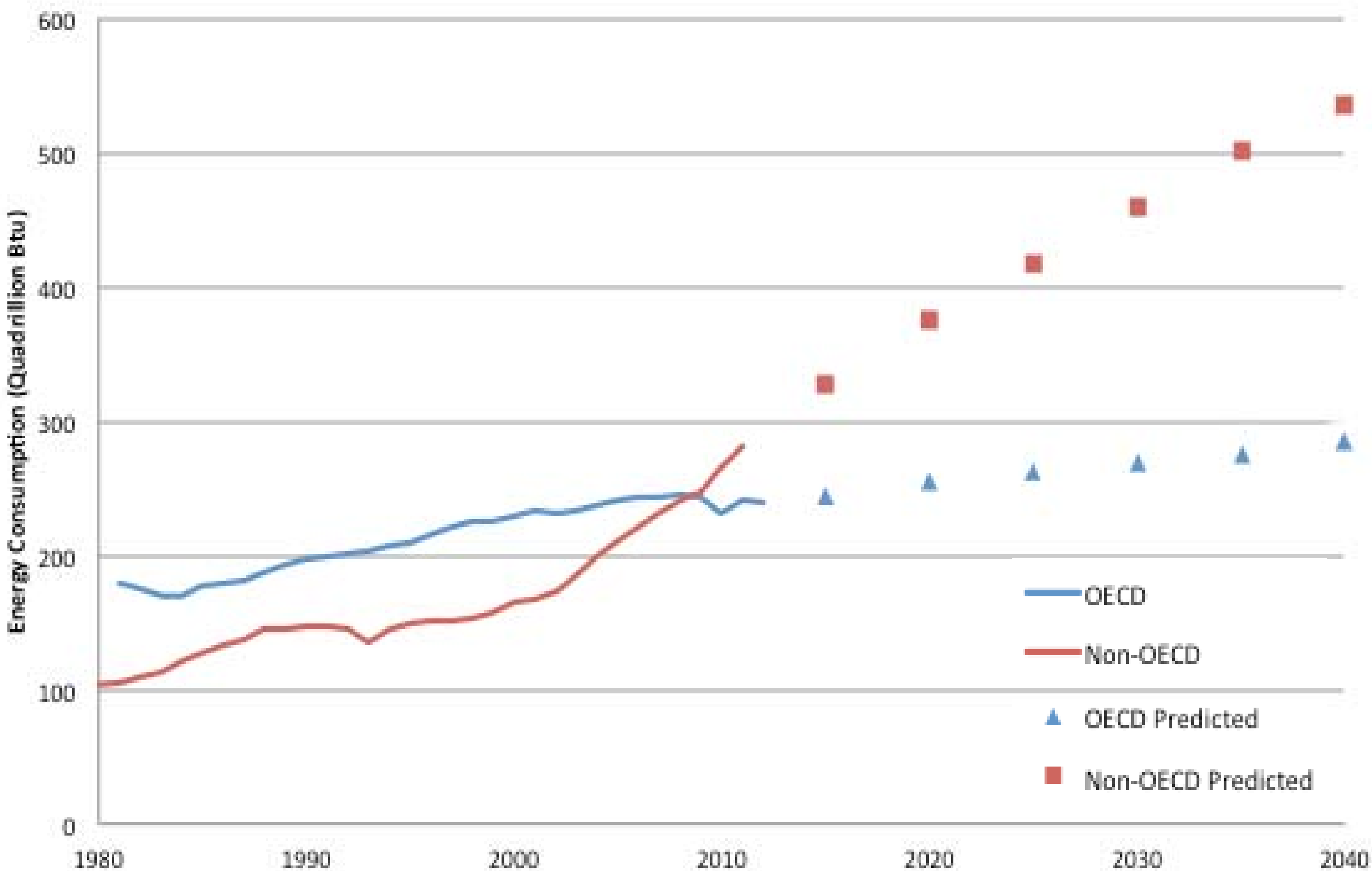


Wolfram 3

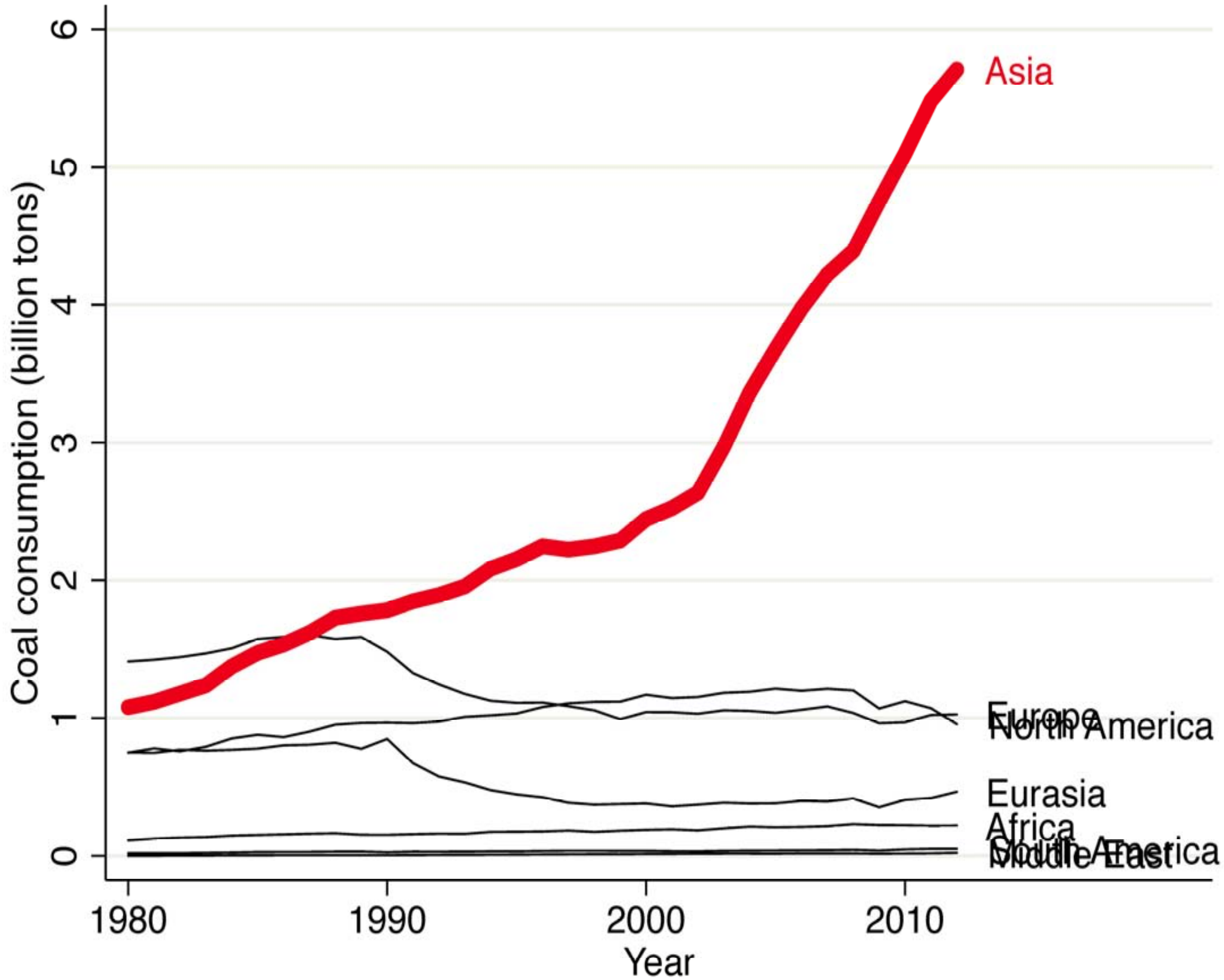

People per square kilometer
0
700
Wolfram 4

Developing countries will drive future energy consumption…

- The EIA projects that virtually all of the growth in energy demand over the coming decades will come from outside of the OECD.



...and have been driving recent growth



Source: Energy Information Administration

Motivation

1. What is the demand for electricity connections in rural areas?

1. What economies of scale in costs can be achieved from a mass connection program?

1. How do newly connected rural households consume energy?

1. What are the social and economic impacts of rural electrification?

Motivation

- We address these questions in an RCT of electricity access in Kenya, launched in 2013 in partnership with the Rural Electrification Authority ("REA").

- We will cover three topics:

1. "Under grid" households in Kenya [*Working paper - NBER*]
2. The demand for and costs of rural electrification [*Working paper*]
3. Planned IE on social and economic impacts of electrification

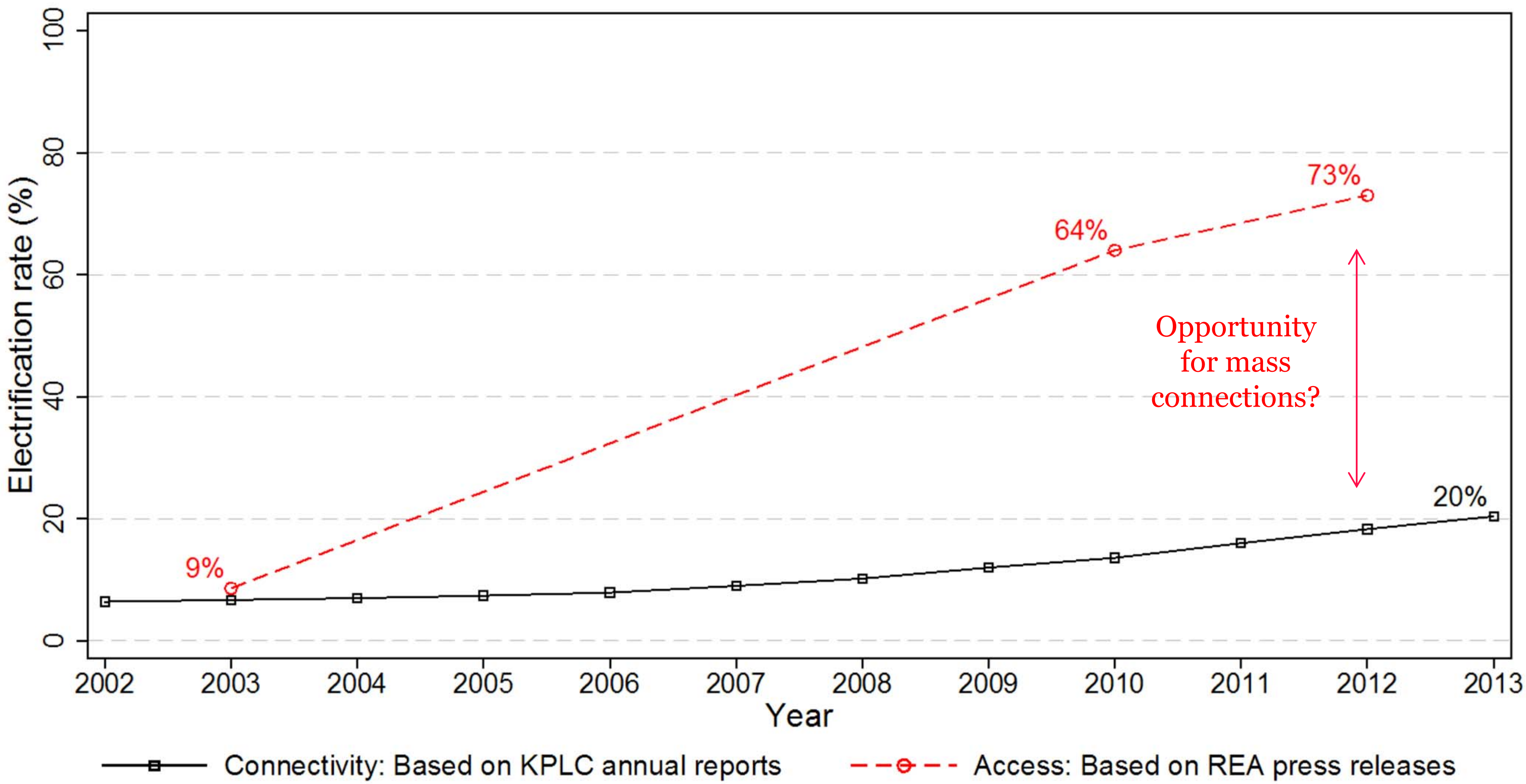
Research paper #1

Barriers to Electrification for "Under Grid" Households in Rural Kenya

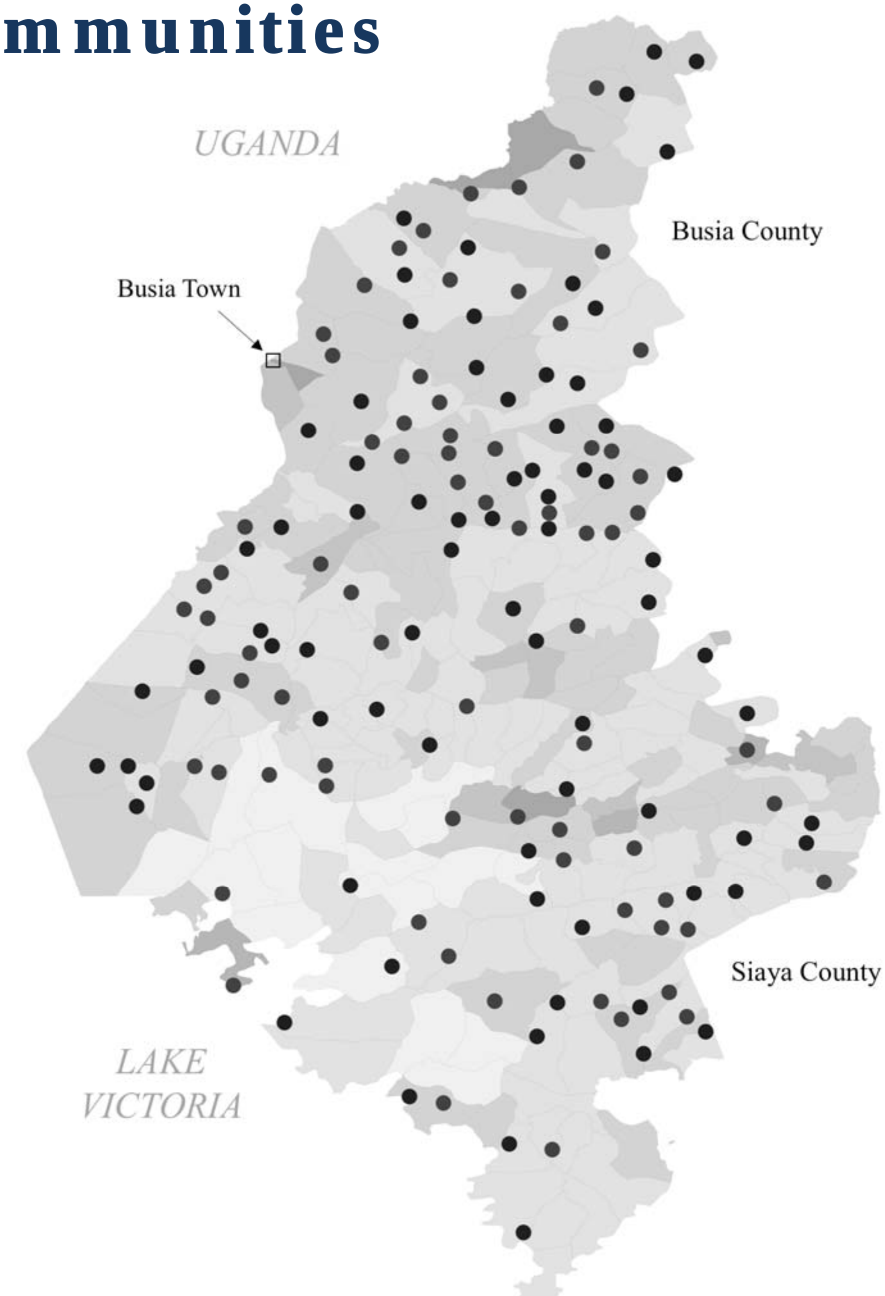
[NBER Working Paper #20327]

“Under grid” households in Kenya

- In May 2012, Kenyan newspapers reported that “73% of the population in the rural areas [now had] access to electricity," with “access” defined as living within 1.2km of a low-voltage line.



Building our sample of communities



In September 2013, we collaborated with REA to identify a representative sample of 150 rural transformers in Busia County and Siaya County in Western Kenya.

Quasi-random selection criteria to ensure that:

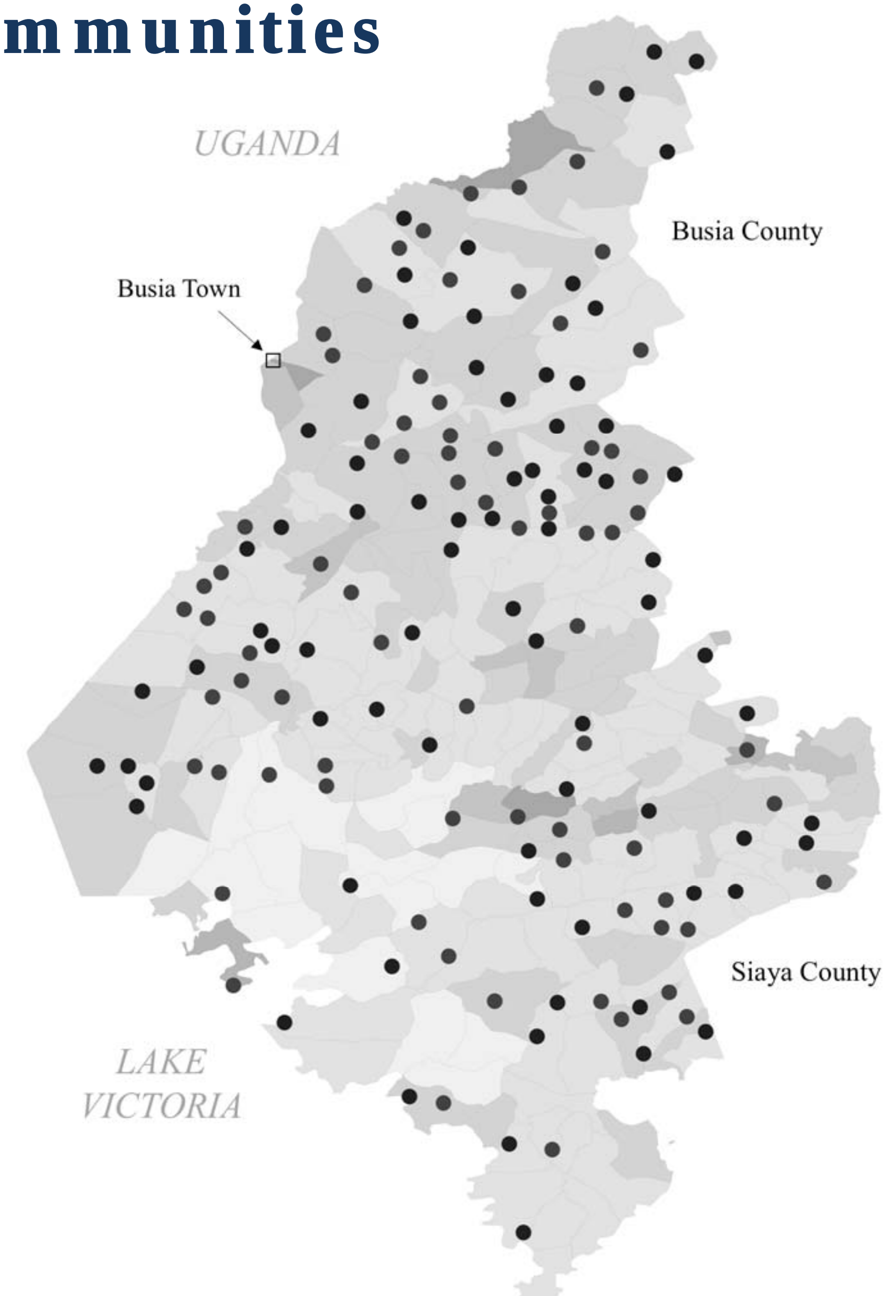
1. Distance between any two transformers was at least 1.6km
2. Each transformer represented a unique REA project
3. Each transformer in service for at least one year

Building our sample of communities

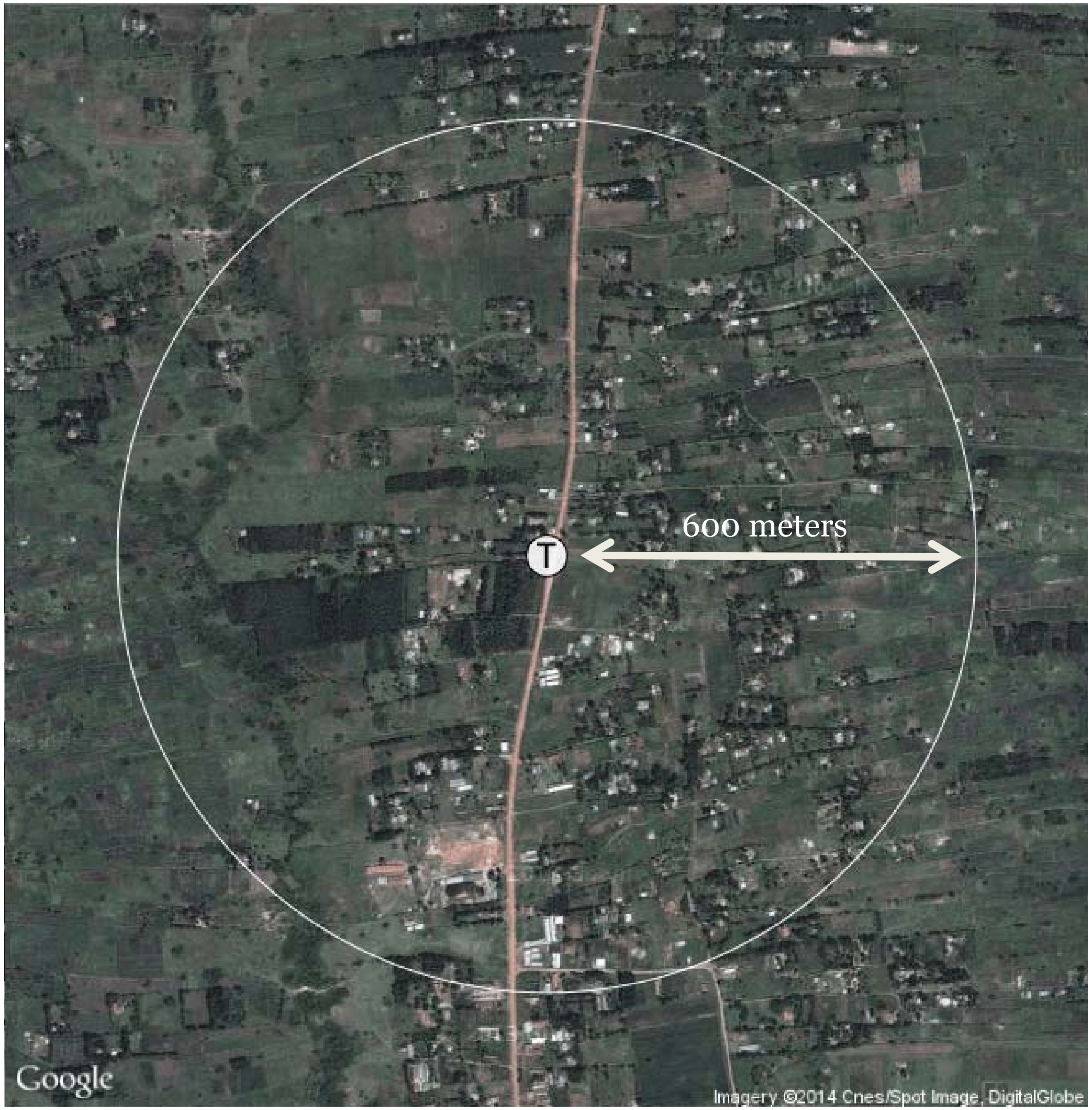
<u>Main objectives:</u>

1. Estimate “local” electrification rates in communities where REA has recently installed transformers.

1. Build a database of unconnected structures to use as a sample for subsequent stage of our overall project.



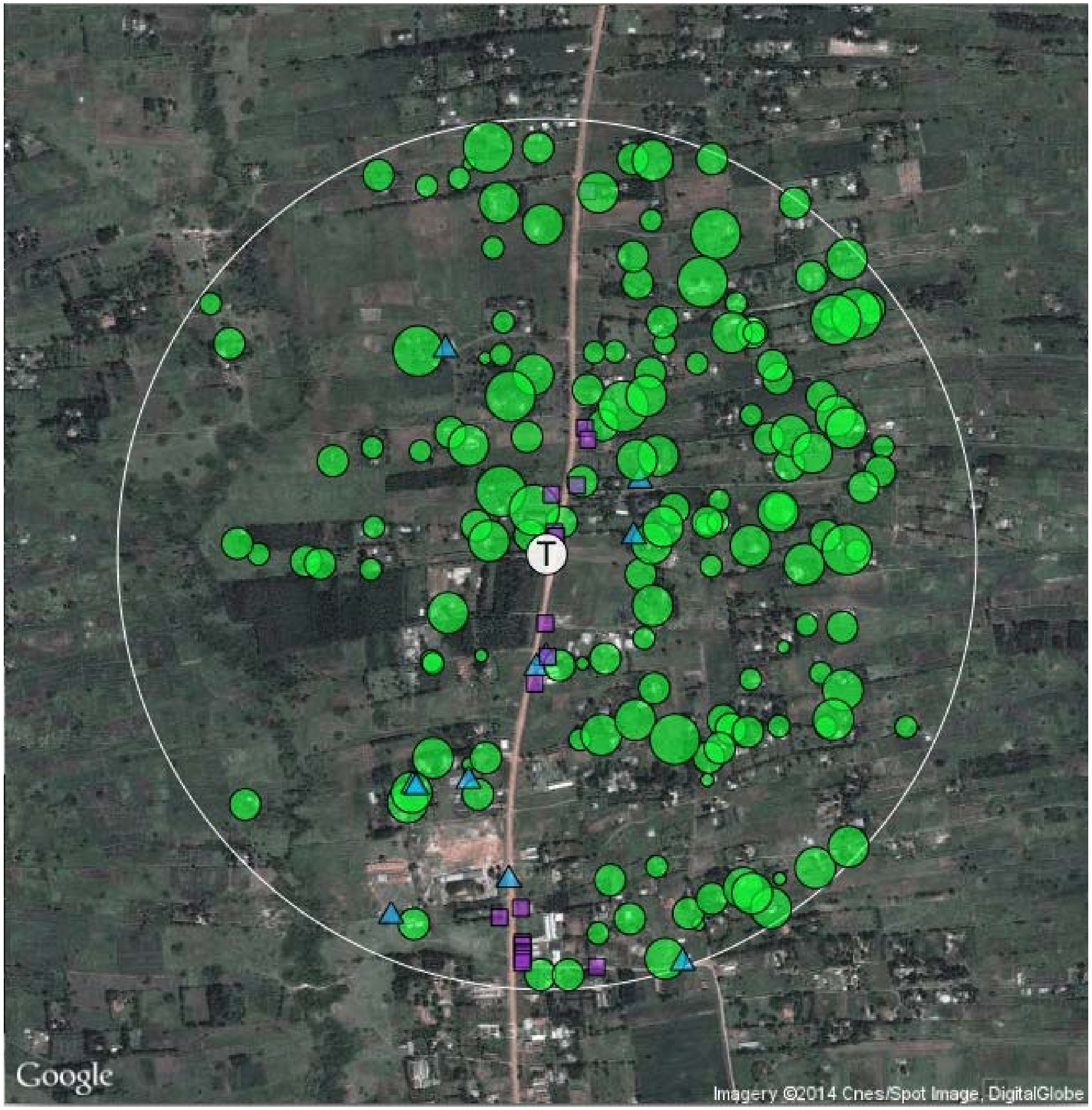
Example #1



Legend

Ⓣ Transformer & 600 meter radius

Example #1



Legend

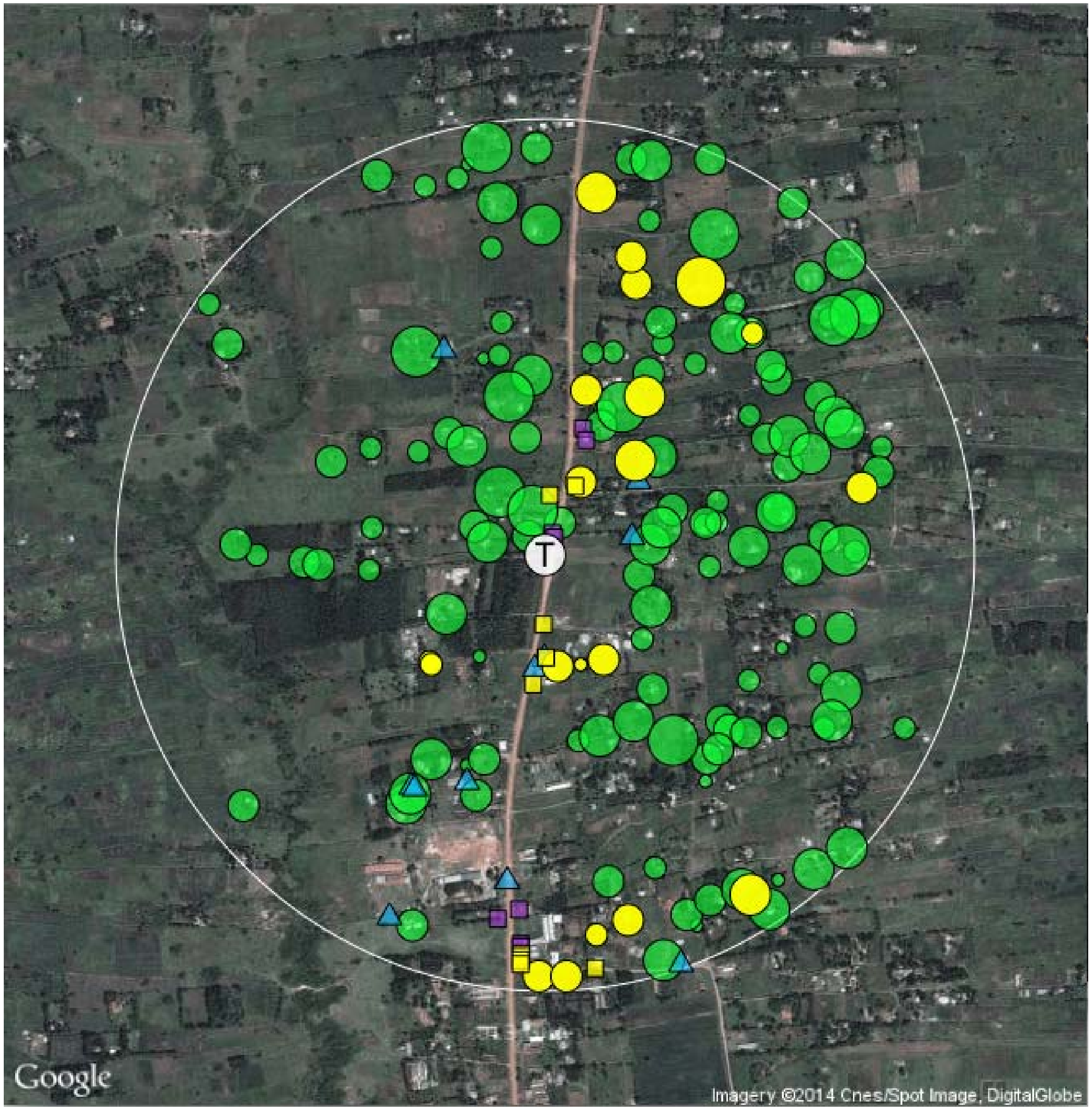
Transformer & 600 meter radius

Households (scaled by household size)

Businesses

Public facilities (e.g. schools, health)

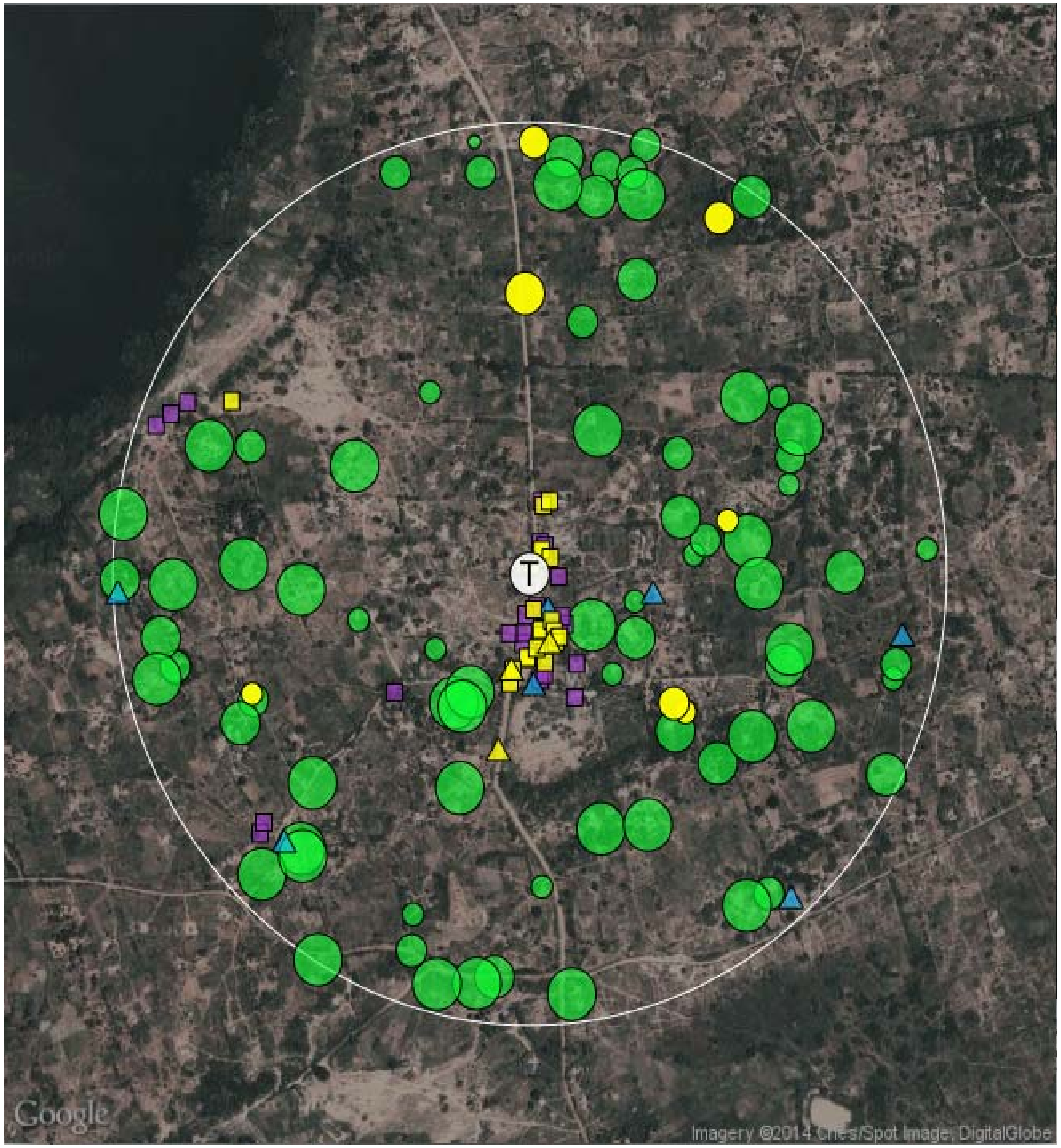
Example #1



Legend

- Transformer & 600 meter radius
- Households (scaled by household size)
- Businesses
- Public facilities (e.g. schools, health)
- Electrified households
- Electrified businesses
- Electrified public facilities

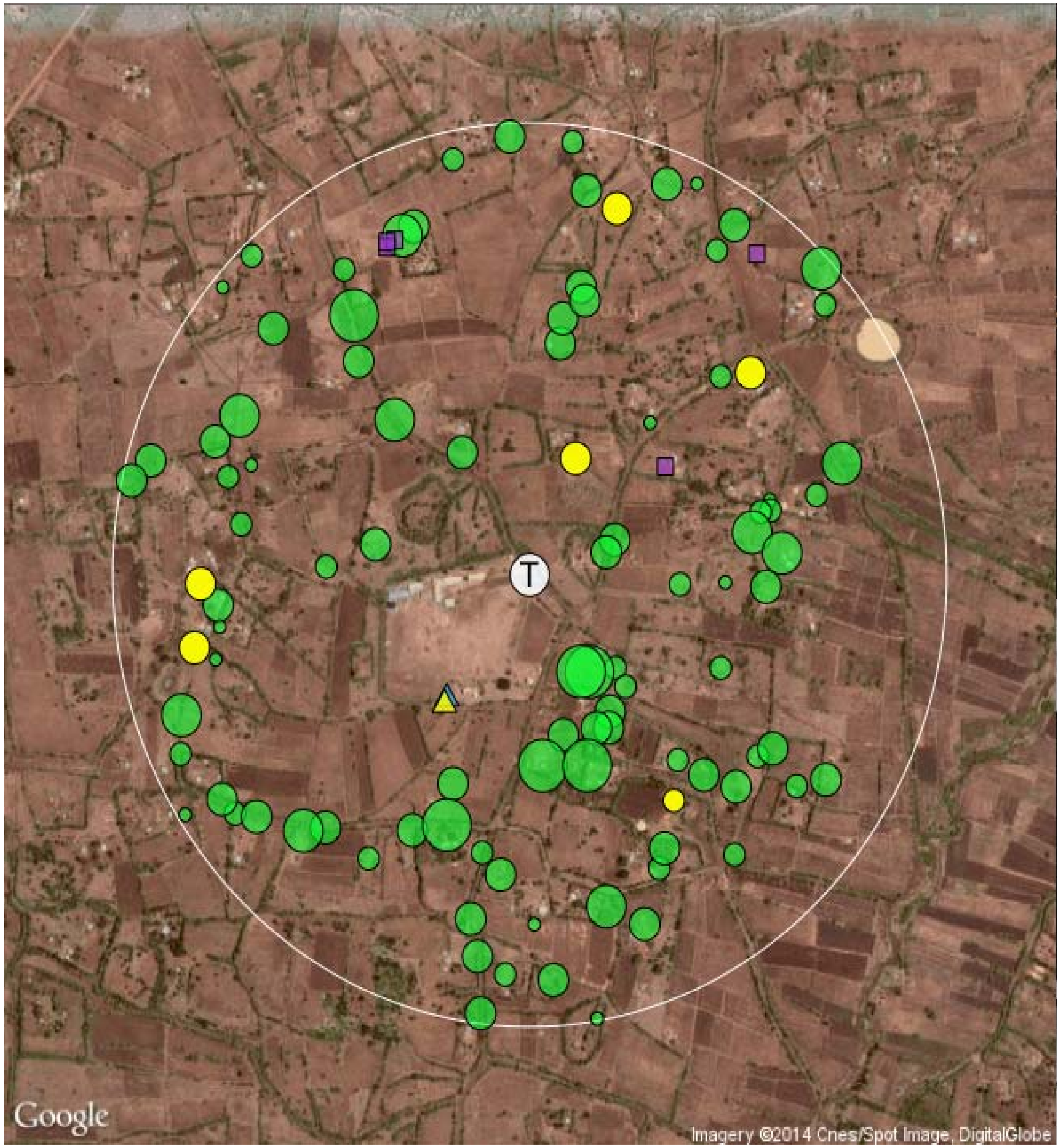
Example #2



Legend

- Transformer & 600 meter radius
- Households (scaled by household size)
- Businesses
- Public facilities (e.g. schools, health clinics)
- Electrified households
- Electrified businesses
- Electrified public facilities

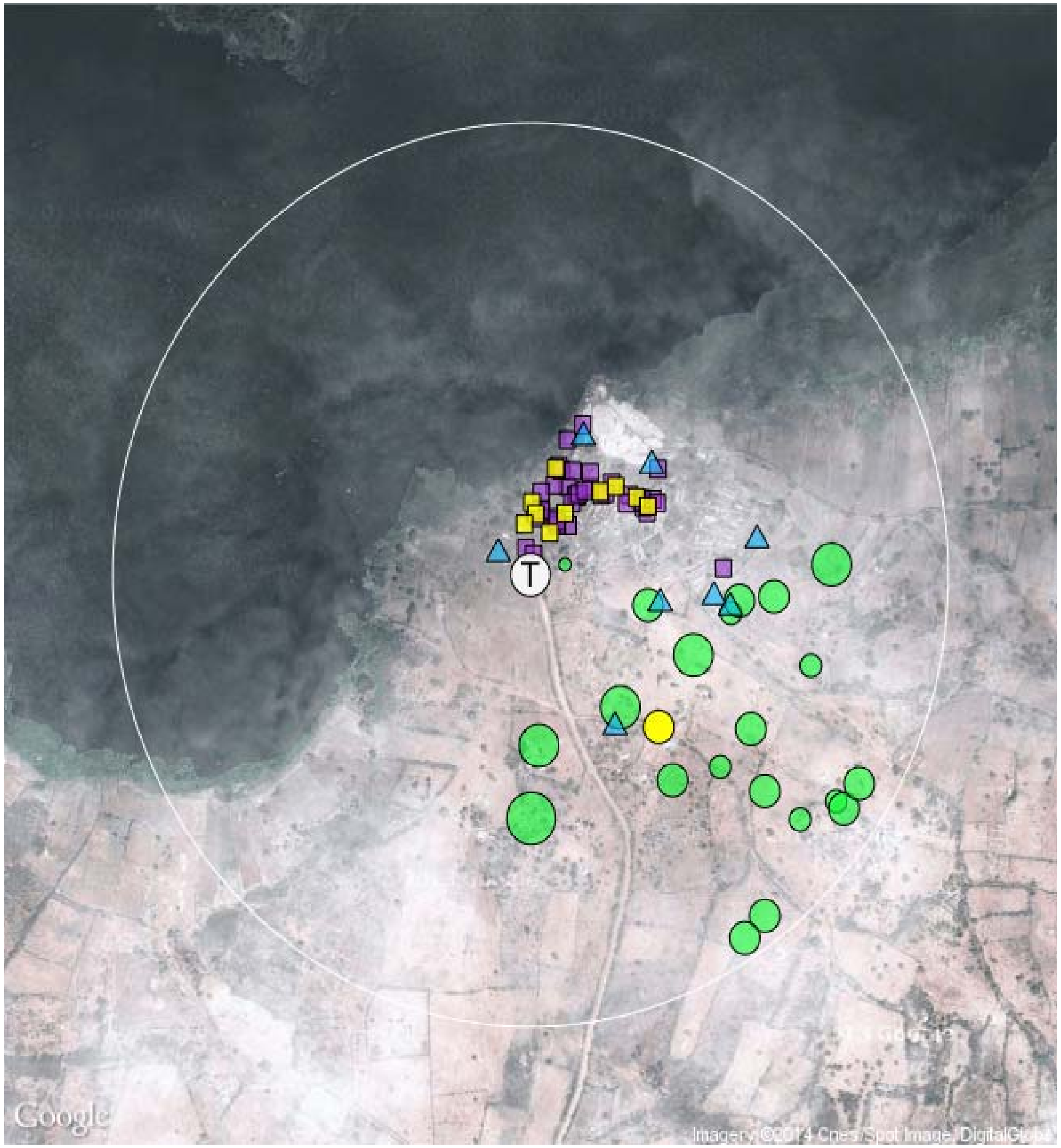
Example #3



Legend

- T Transformer & 600 meter radius
- Households (scaled by household size)
- Businesses
- Public facilities (e.g. schools, health clinics)
- Electrified households
- Electrified businesses
- Electrified public facilities

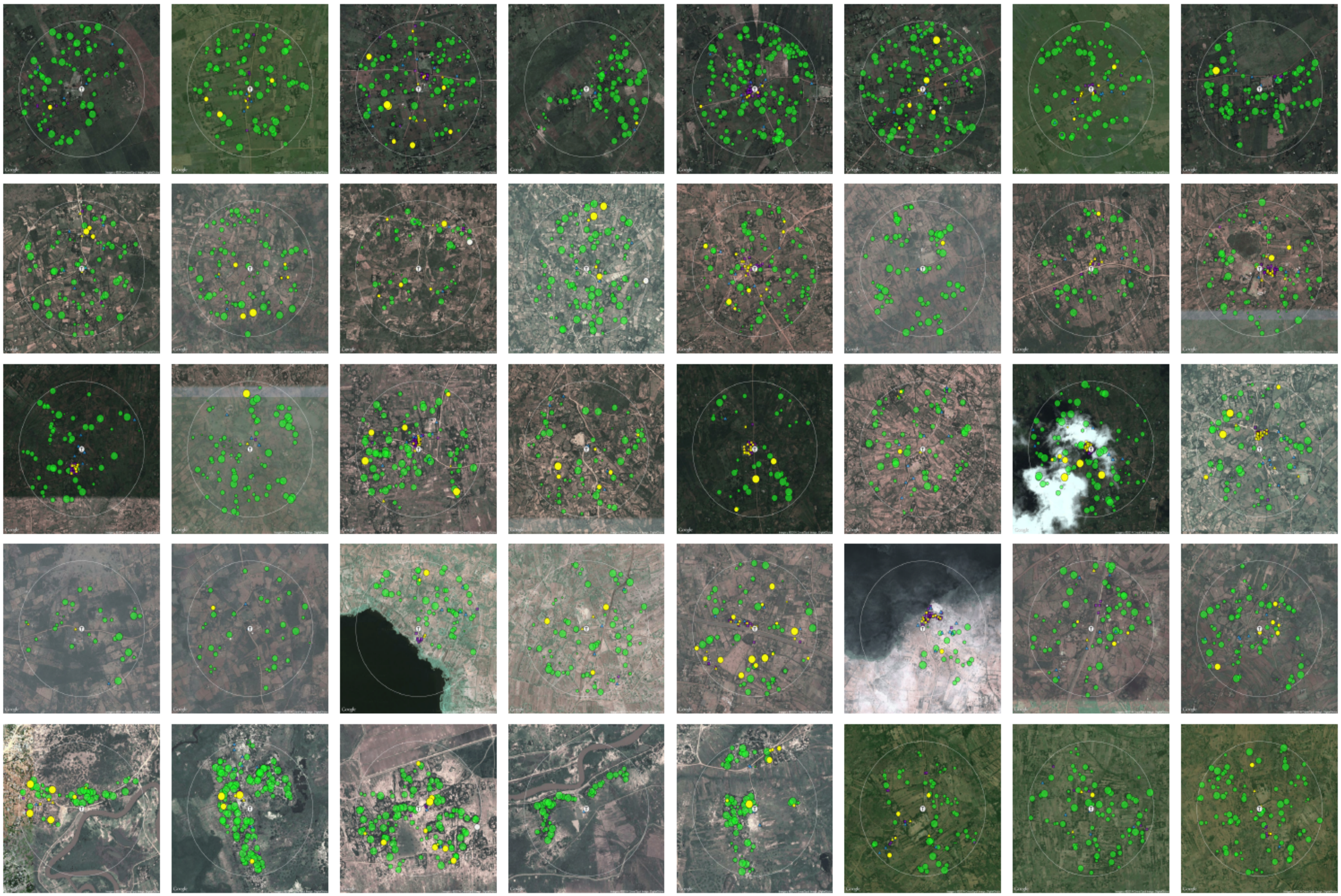
Example #4



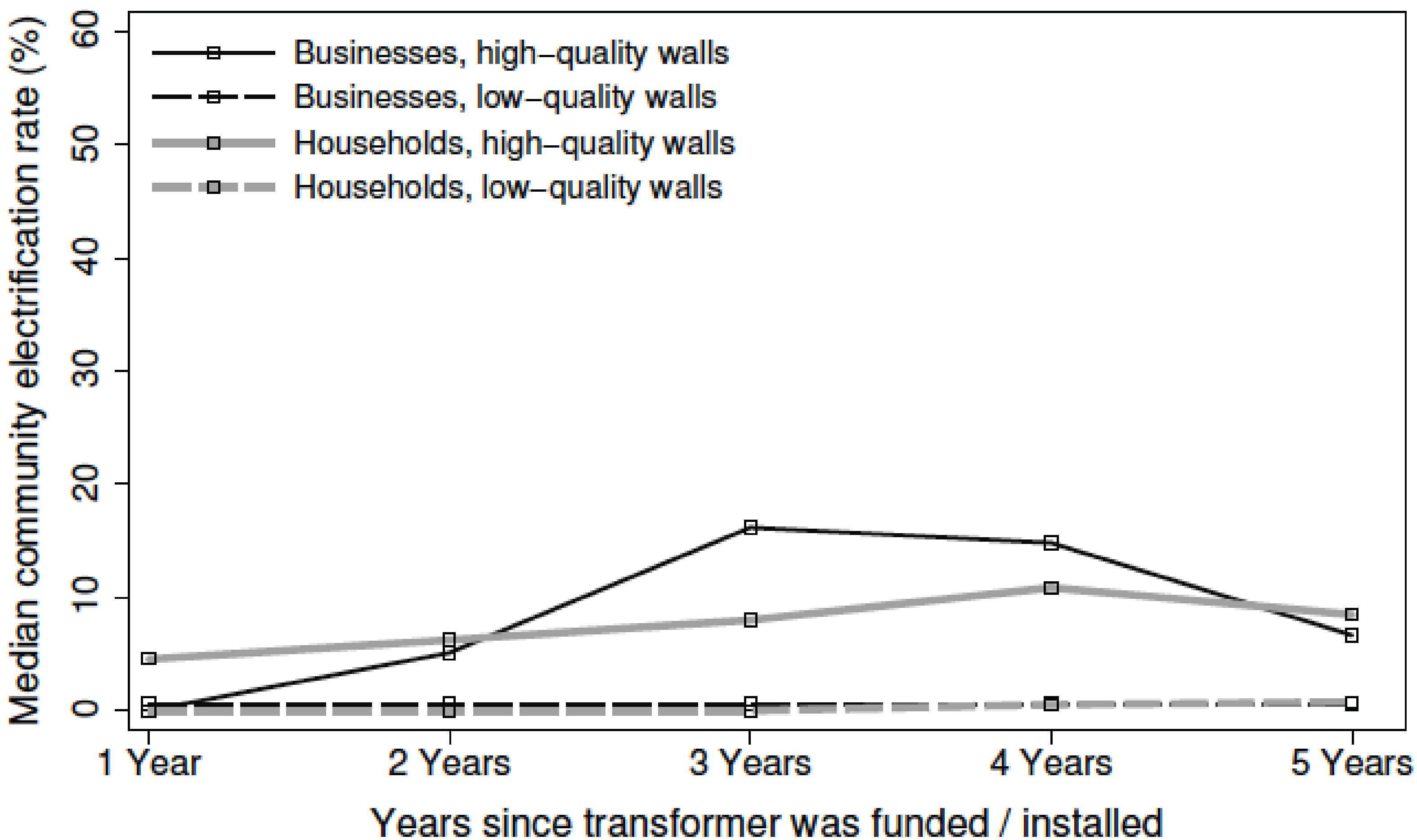
Legend

- Transformer & 600 meter radius
- Households (scaled by household size)
- Businesses
- Public facilities (e.g. schools, health clinics)
- Electrified households
- Electrified businesses
- Electrified public facilities

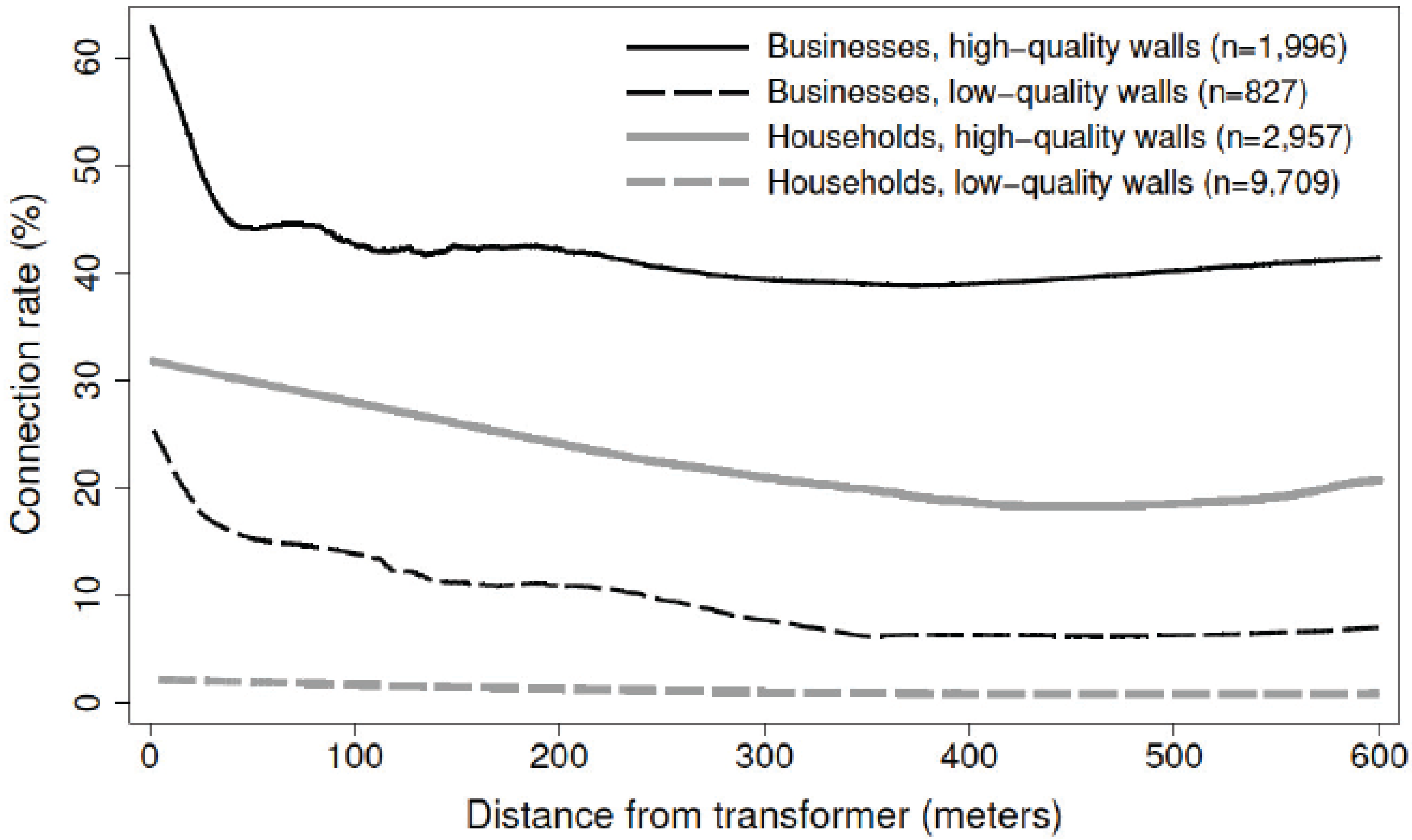
What did we learn from this activity?



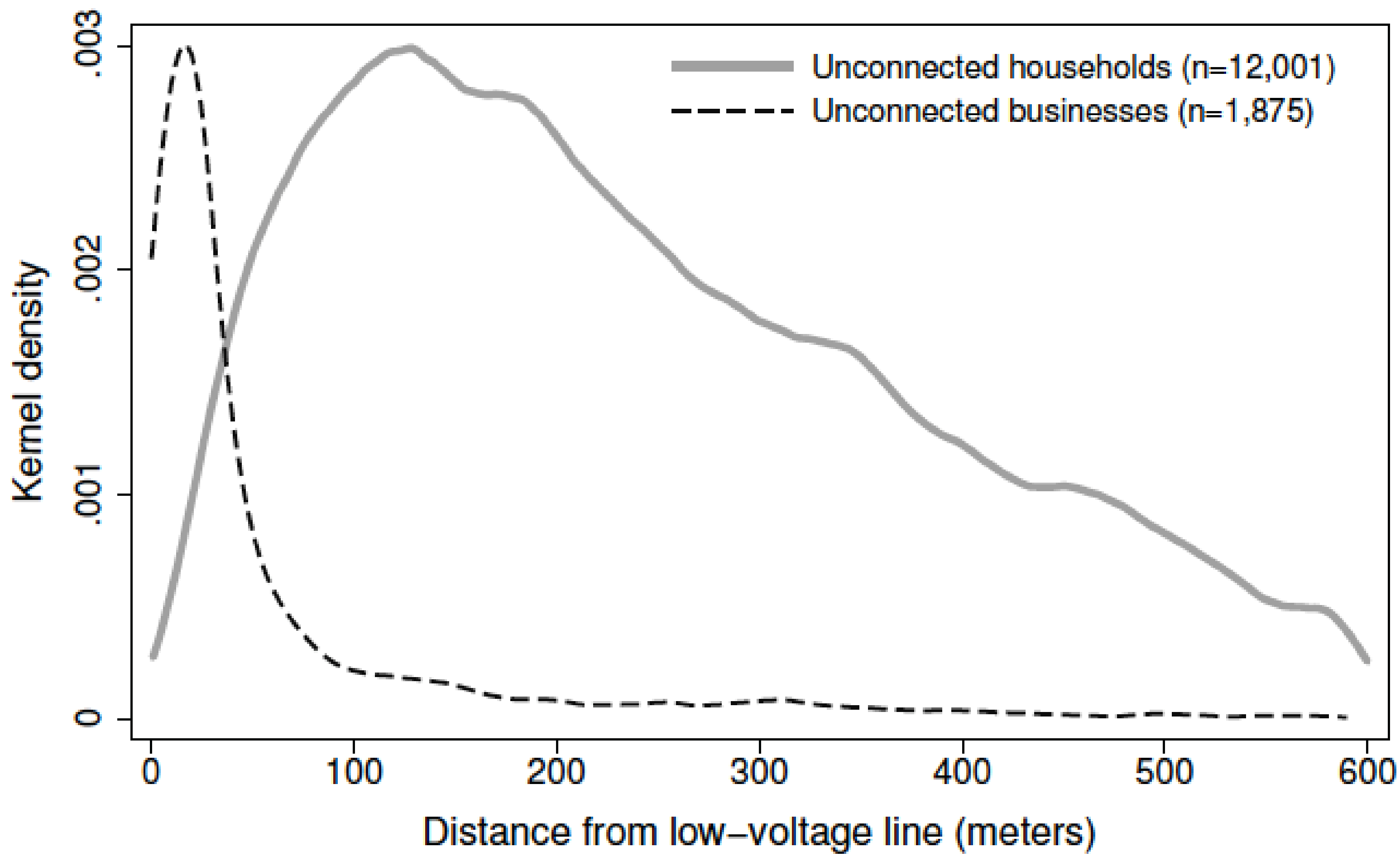
Pattern #1: Despite large investments in grid infrastructure, electrification rates remain low.



Pattern #2: Connectivity is low even for relatively well-off households and businesses.



Pattern #3: Half of the unconnected households in the study are "under grid."



Policy conclusions from Paper #1 (2014)

1. Despite large investments in national grid infrastructure, rural electrification rates remain low, even up to five years after transformers have been built.

1. Half of the unconnected households in our sample are “under grid,” or clustered within 200 meters of a low-voltage line, and could be connected at a relatively low-cost.

1. Prioritizing the connections of these “under grid” households could rapidly increase electrification rates.

1. Given the large economies of scale associated with network infrastructure, connecting groups of neighboring households through a mass connection program could potentially lower per connection costs.

Research paper #2

Experimental Evidence on the Demand for and Costs of Electricity in Kenya

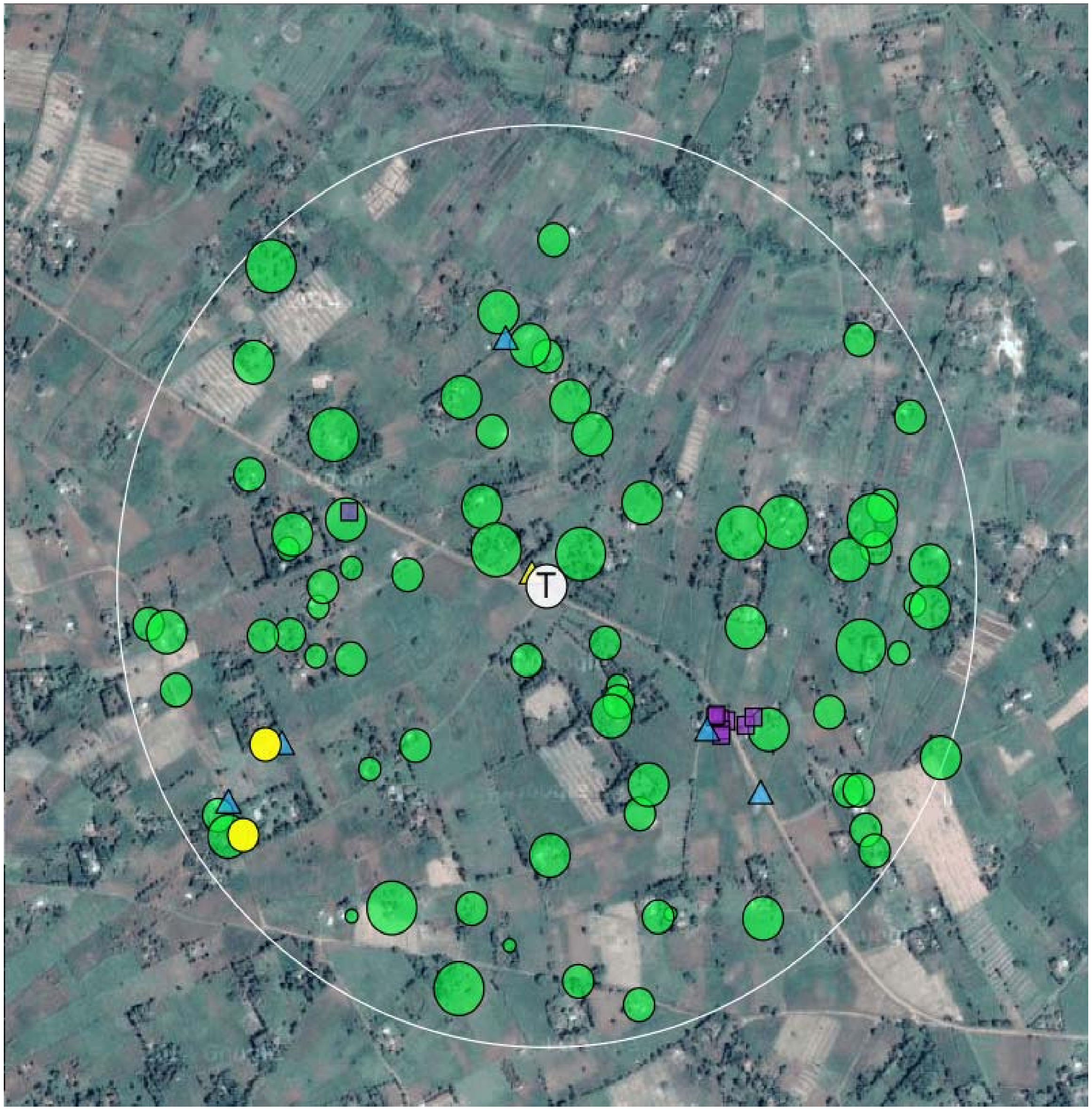
[In Progress – Preliminary Draft]

“Last-mile” connectivity in Kenya

- National electrification rate is estimated to be roughly 32%.
- Over 80% of the population is now believed to be “under grid.”
- The high cost of “last-mile” connectivity has emerged as a major policy issue—until last month, the price was 35,000 KSh (≈ $398).
  - Government subsidizes difference between actual cost and price
- Our goal is to answer two questions:

1. What is the demand for electricity connections in rural areas?
2. What economies of scale in costs can be achieved from a mass connection program?

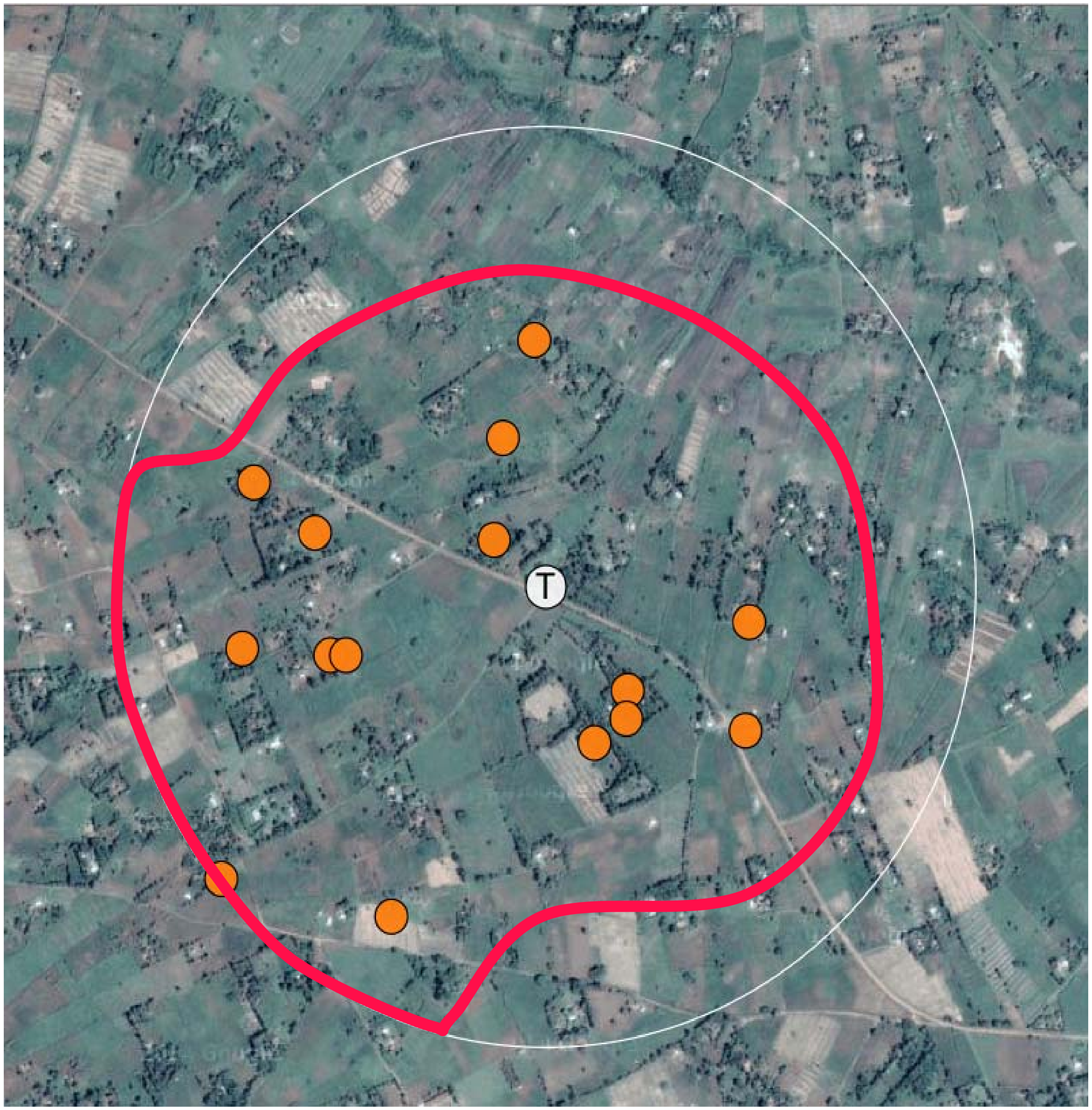
Using our maps of all households...



Legend

- Transformer & 600 meter radius
- Households (scaled by household size)
- Businesses
- Public facilities (e.g. schools, health)
- Electrified households
- Electrified businesses
- Electrified public facilities

...and sampled 15 households per community



Legend

Transformer & 600 meter radius

Randomly selected REPP households

Random sampling:

Distance to LV line is approximated by the distance of the unconnected household to either: (1) a transformer, or (2) a connected household, public facility or business.

This sampling procedure was determined in collaboration with REA, in order to reduce the average costs of connections.

Final sample of 2,504 households

Between January and May, 2014, we enrolled 2,504 rural households across the 150 transformer communities into our research program.

Conducted a detailed 1.5 hour interview to collect baseline information on social and economic living standards, including:

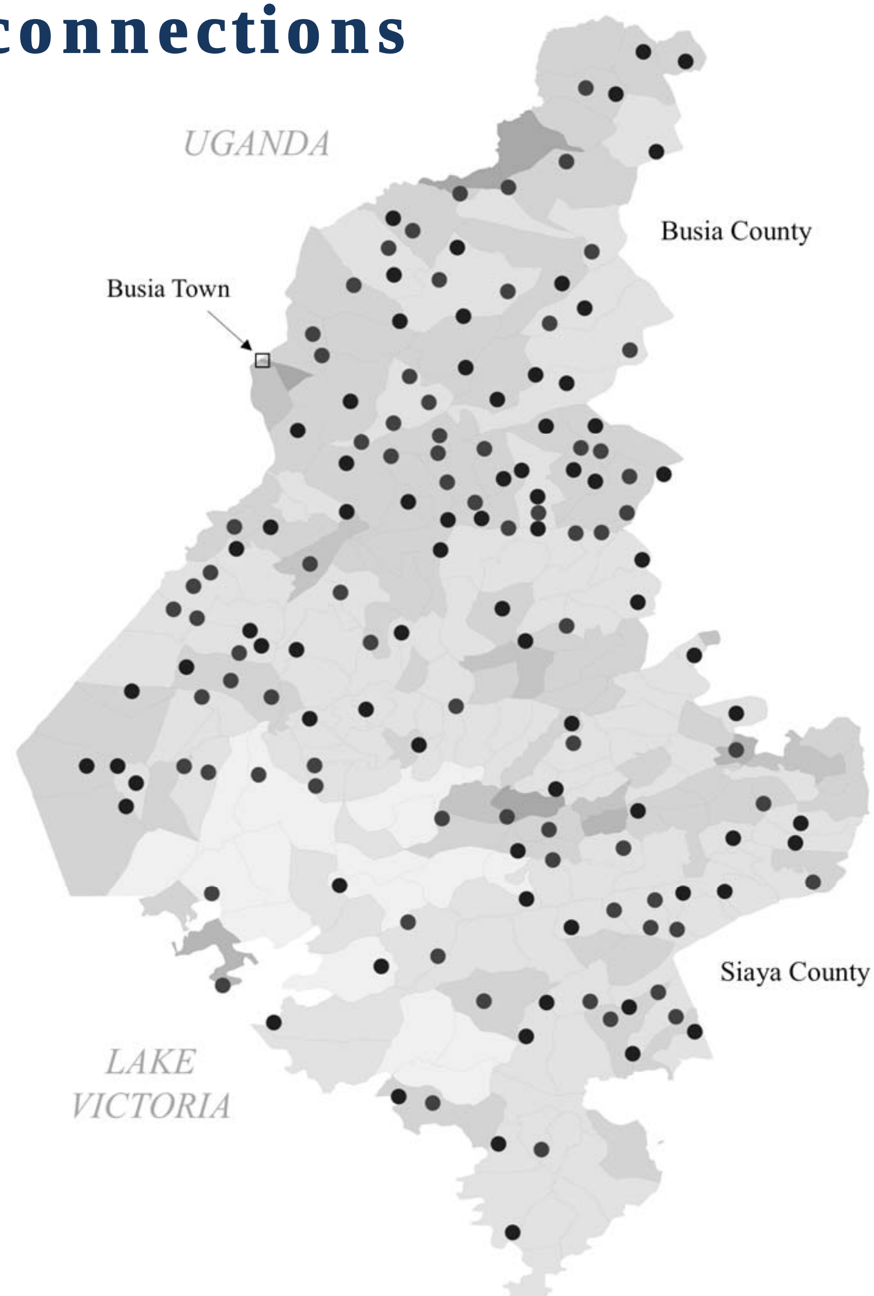
- Household quality and assets
- Employment
- Education
- Energy consumption
- Time use
- Other modules

Intervention: Subsidized connections

In our experiment, we provided households in randomly selected transformer communities with an opportunity to connect to the national grid at a subsidized price.

The experiment generated random variation in:

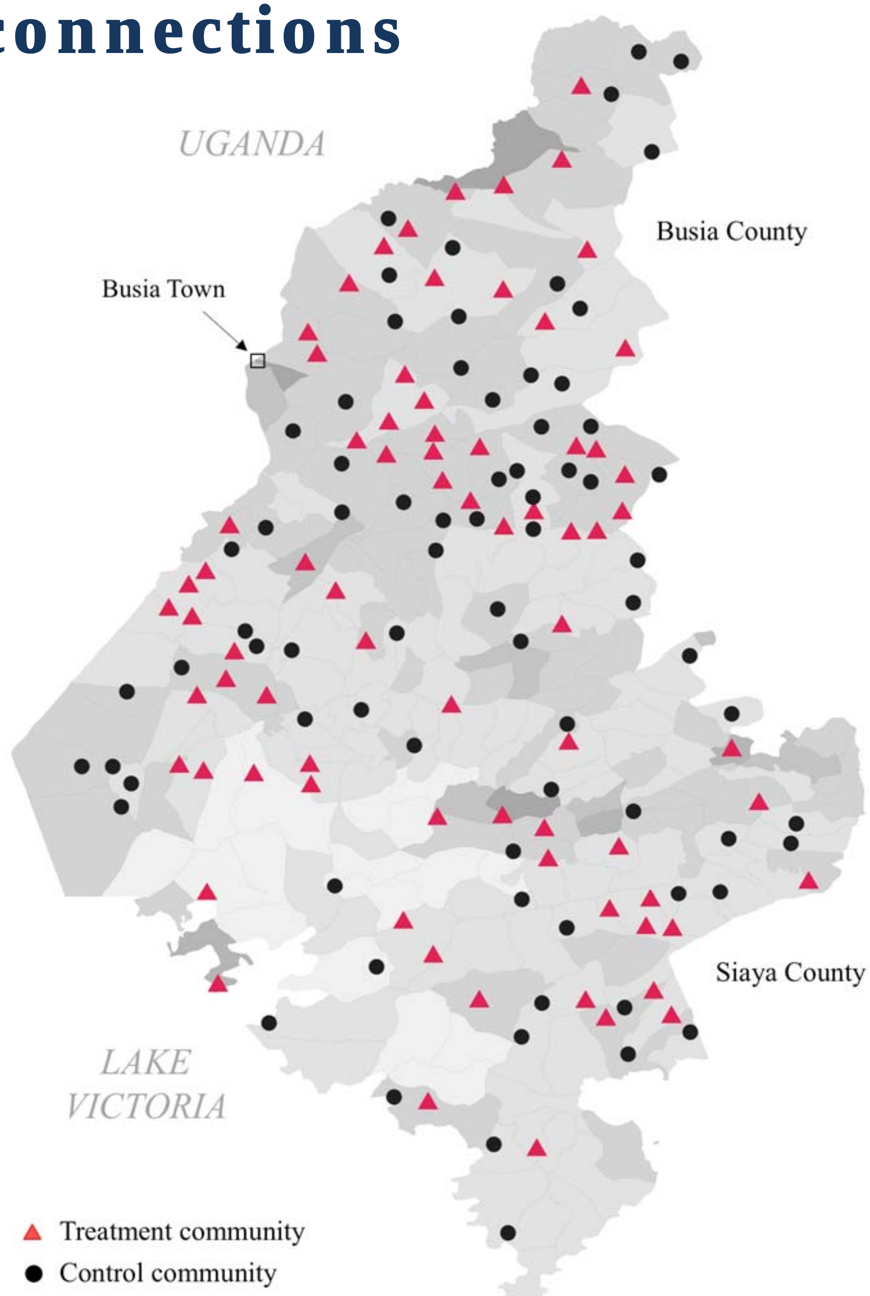
1. Effective connection price (at the community-level)
2. Number of households connecting to the grid at the same time from each community



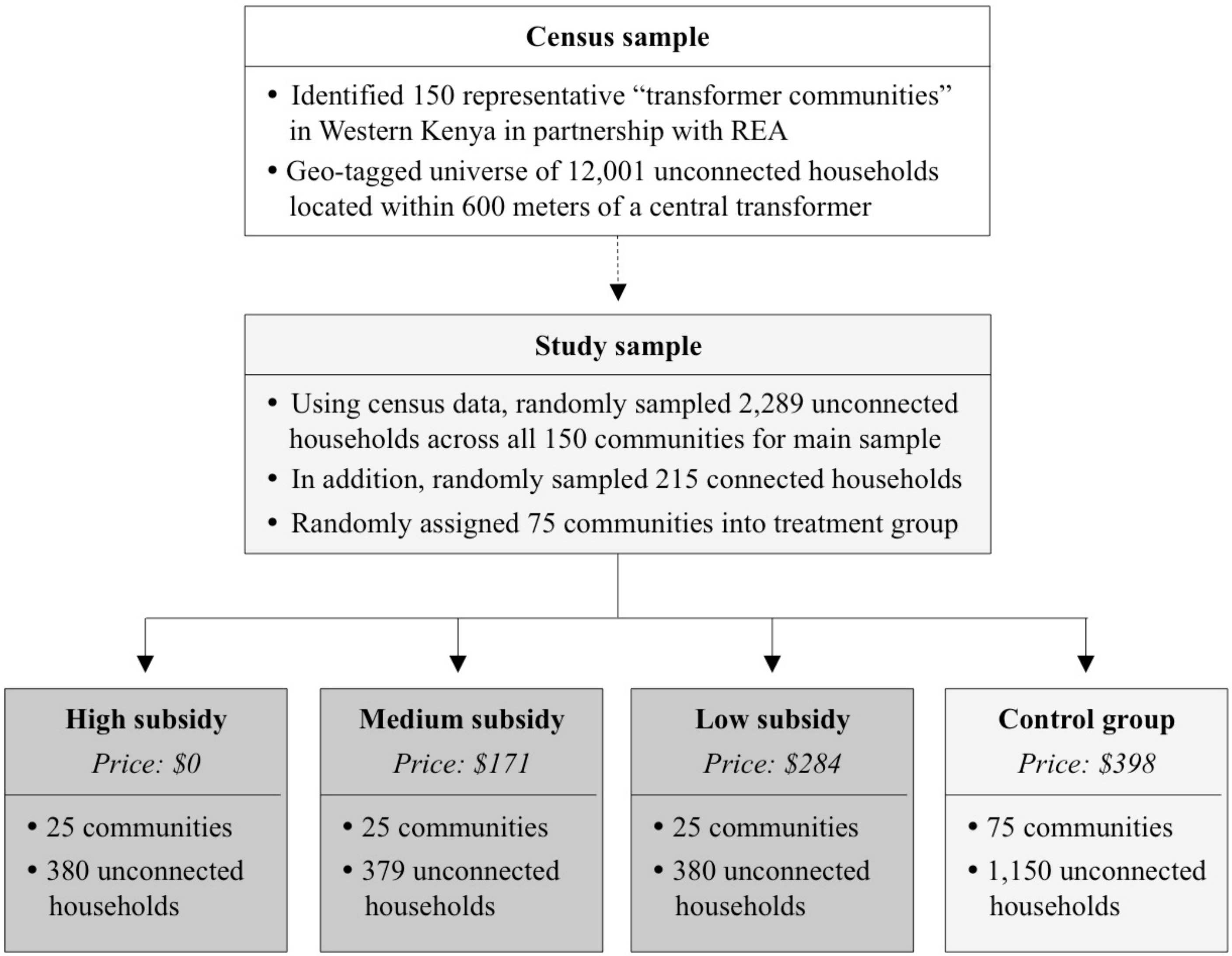
Intervention: Subsidized connections

The design allowed us to trace out:

1. Experimental demand curve
2. Experimental average total cost (ATC) curve associated with connecting groups of households at the same time



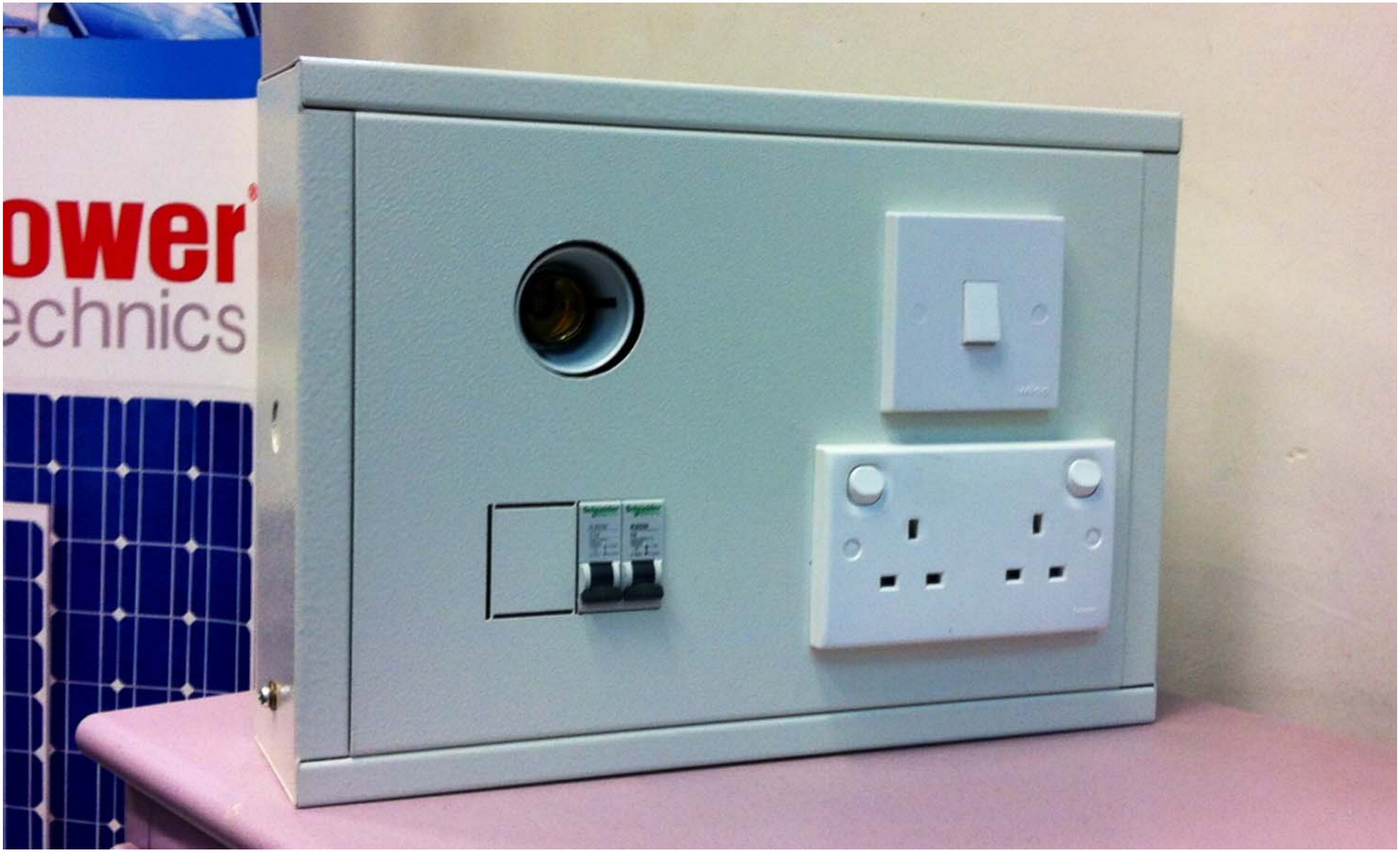
Experimental research design



Step 1: IPA distributes “subsidies” to households

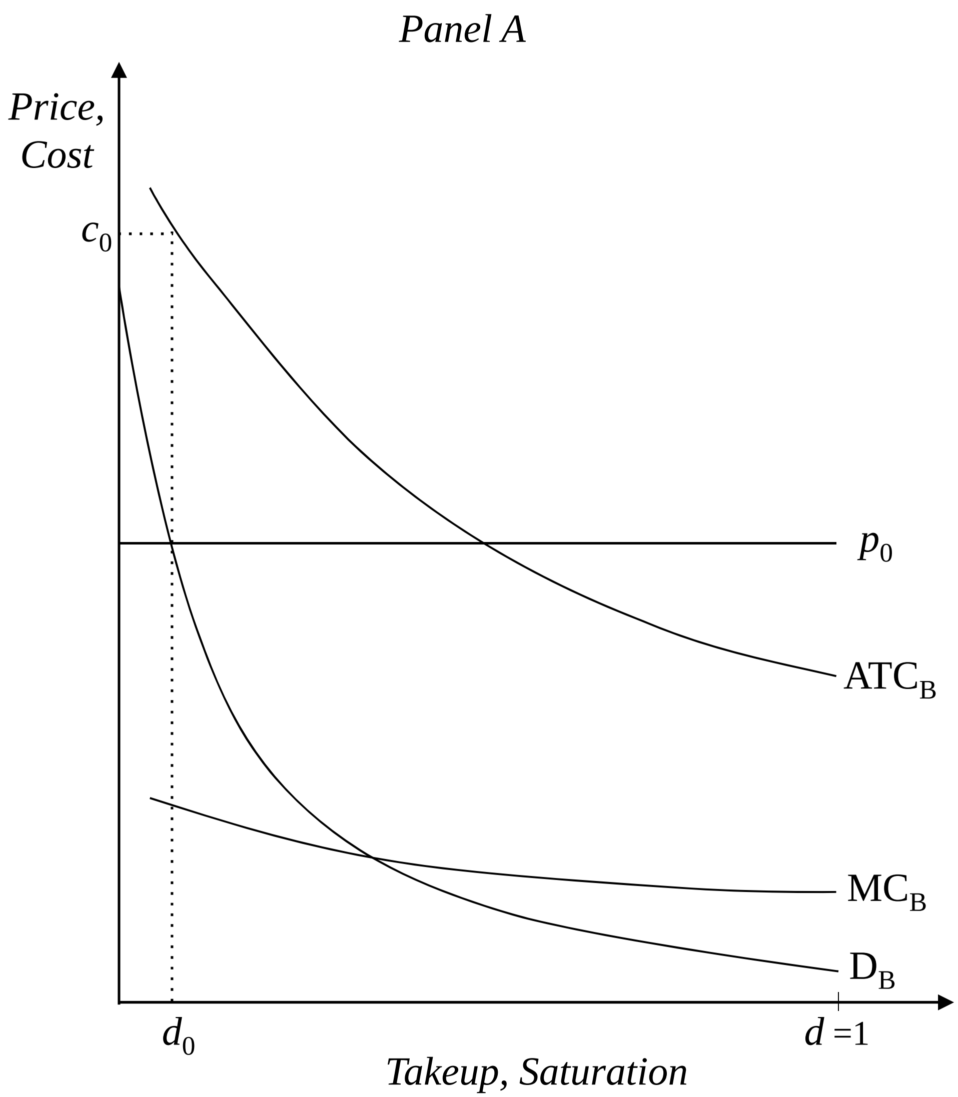
Step 2: REA extends national grid to households

Step 3: IPA provides "ready boards"

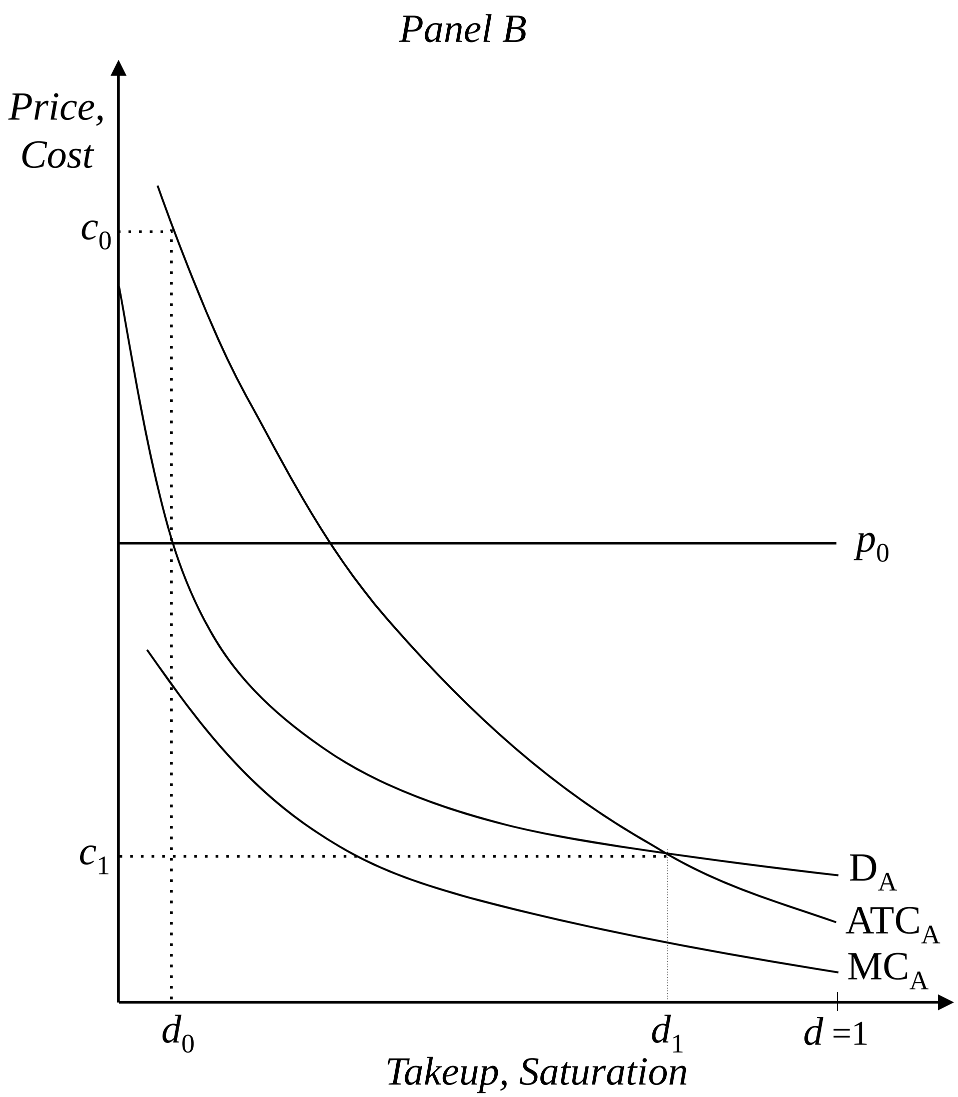


Step 4: Kenya Power installs prepaid meters

Example of natural monopoly #1



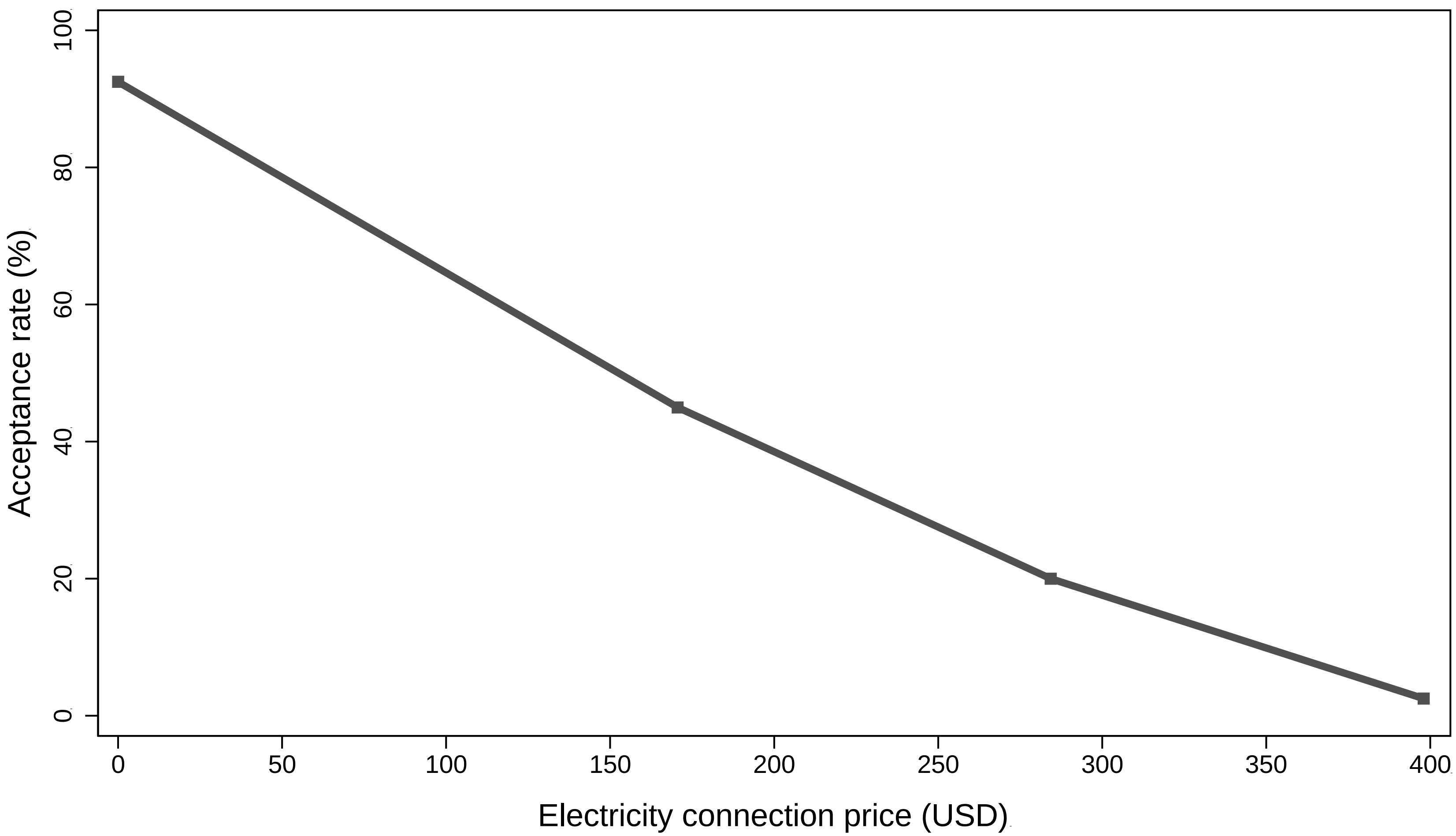
Example of natural monopoly #2



Preliminary Experimental Results

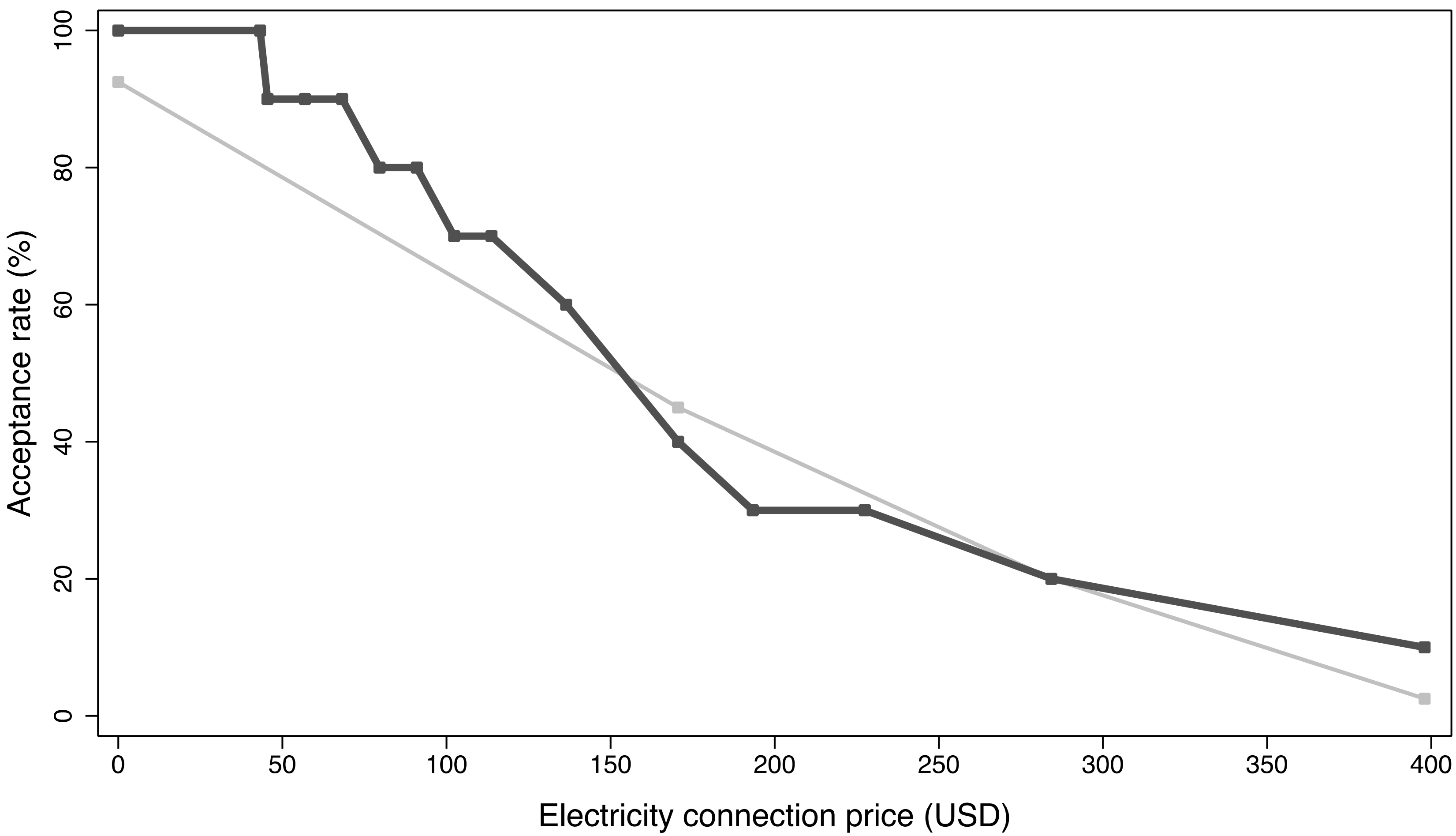
a. Pre-analysis plan assumptions

In 2014, we made assumptions about take-up, mostly for budgeting purposes, and recorded these assumptions in our pre-analysis plan.



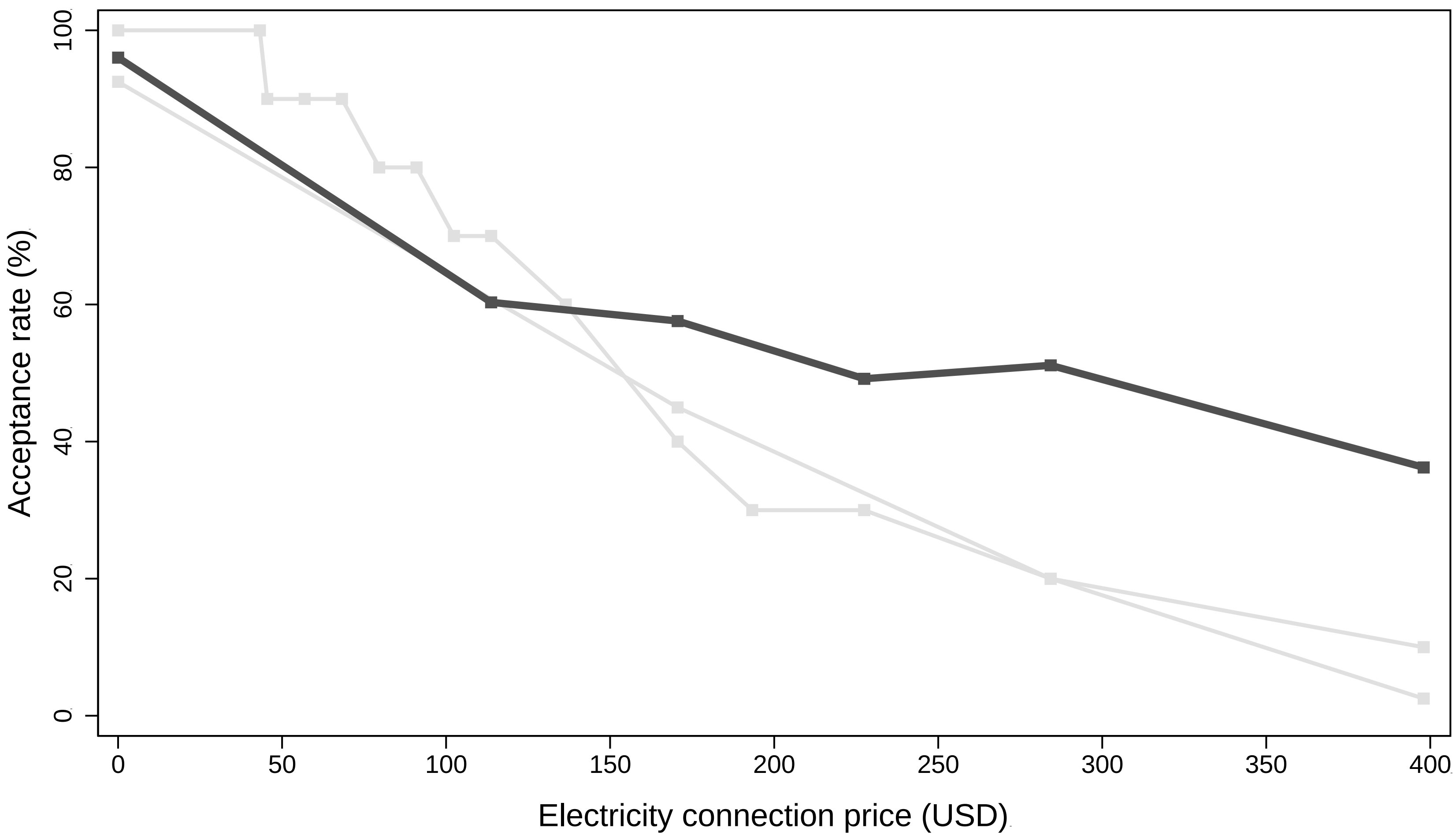
b. Kenya Ministry of Energy assumptions

In 2014, the Ministry of Energy shared a draft of its *National Electrification Strategy* (NES) *Policy* document which included a set of assumptions on demand.



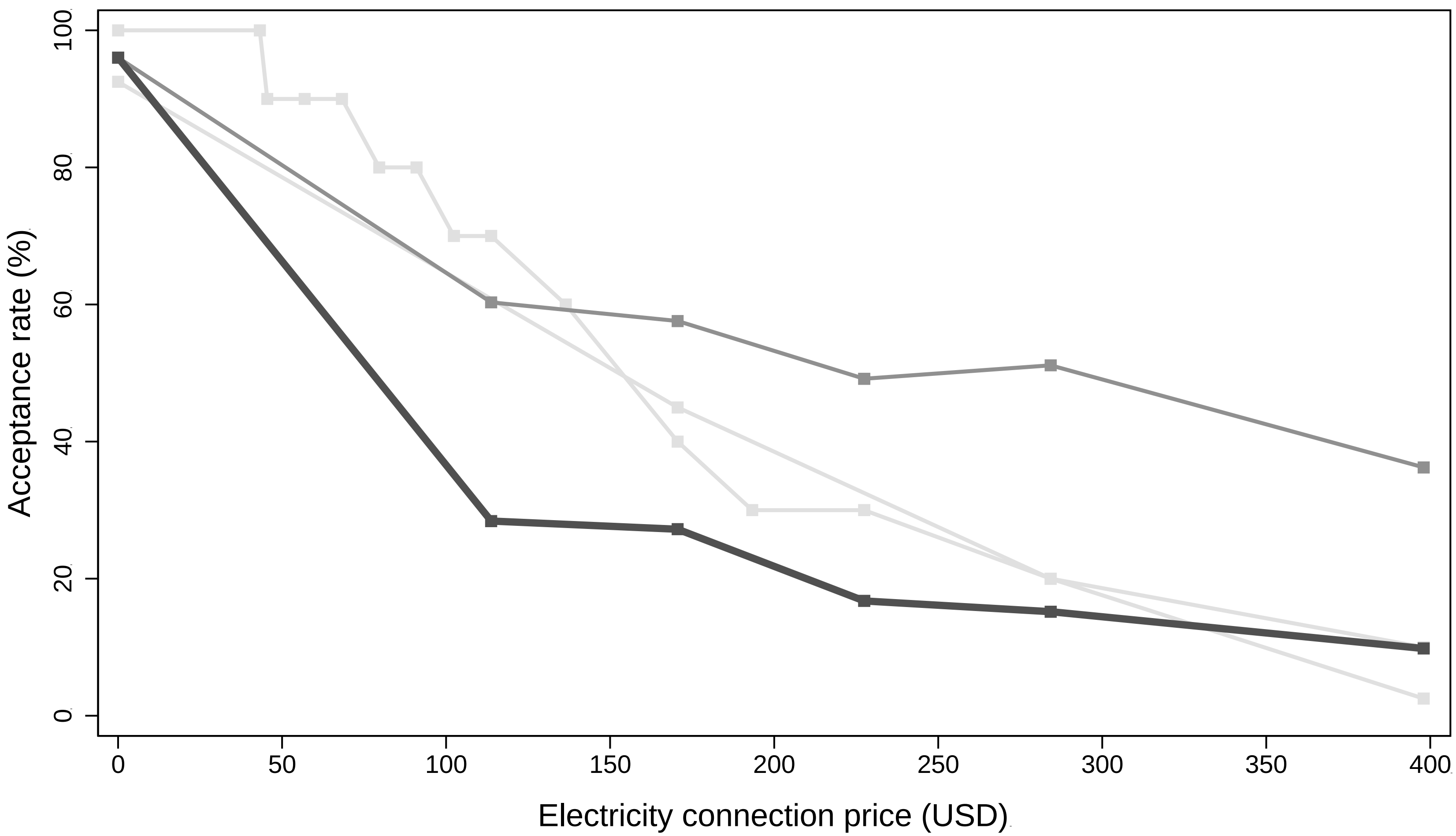
c. Experimental WTP #1

During the baseline survey, 2,094 households were asked whether they would be willing to pay a randomly selected price for an electricity connection.



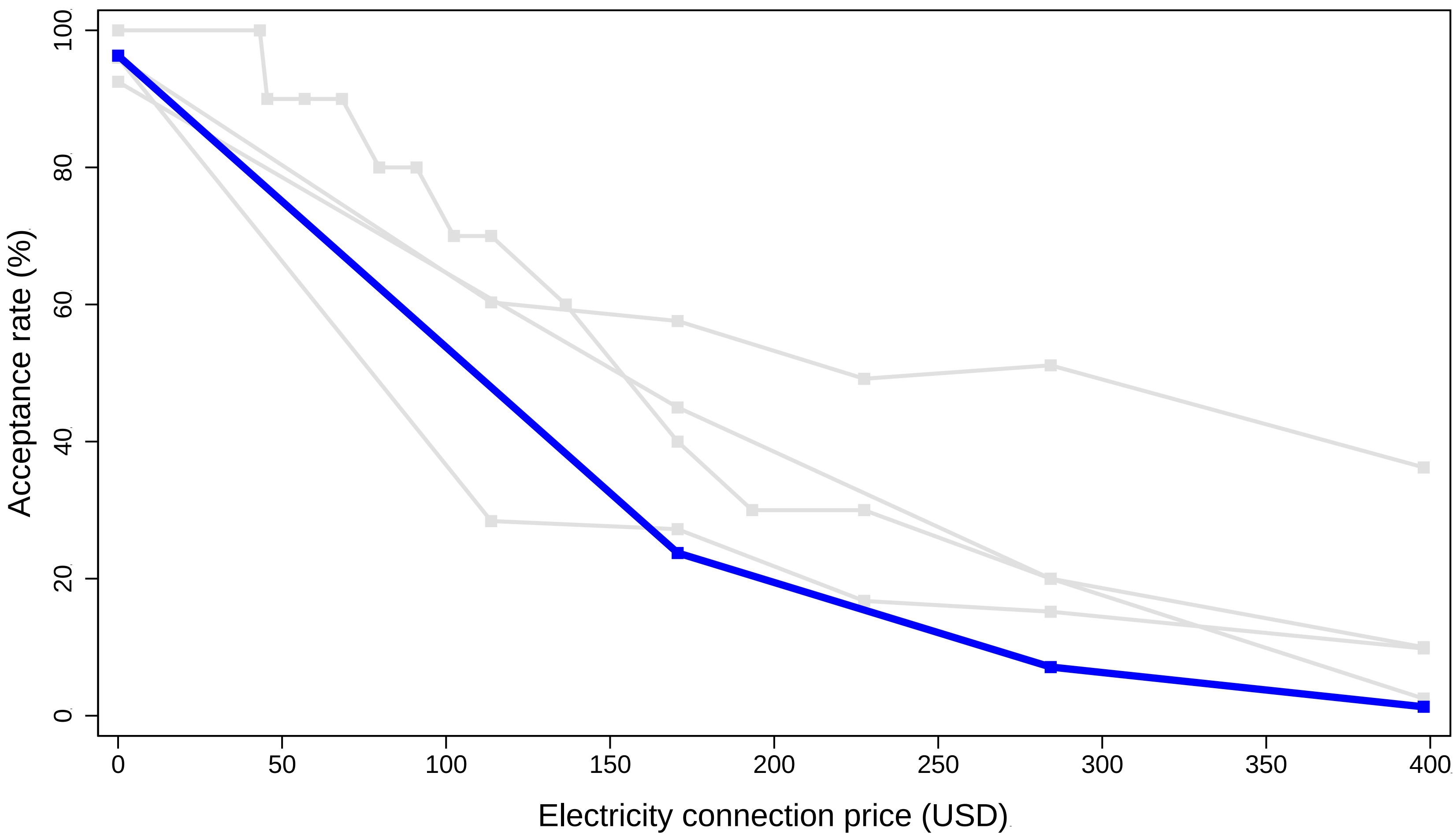
d. Experimental WTP #2

Survey respondents were then asked whether they would be willing to pay the price if they were given six weeks to complete the payment.



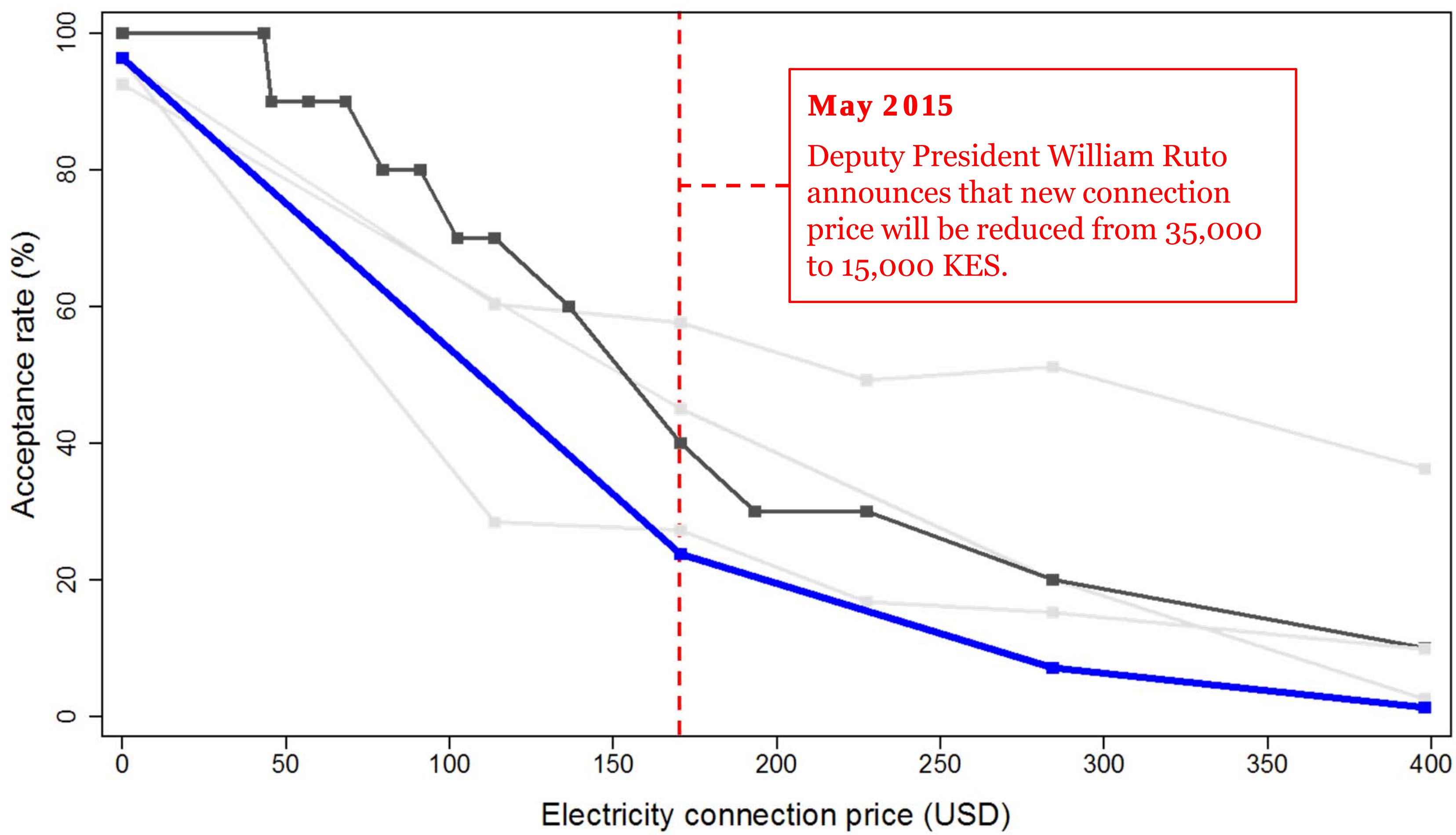
e. Experimental demand curve

In our experiment, we trace out the actual demand curve for electricity connections at four different price levels: 0 KES, 15,000 KES, 25,000 KES, and 35,000 KES.



f. New connection policy

In May 2015, Kenyan newspapers reported that the connection price will be reduced from 35,000 KSh ($398) to 15,000 KSh ($171).

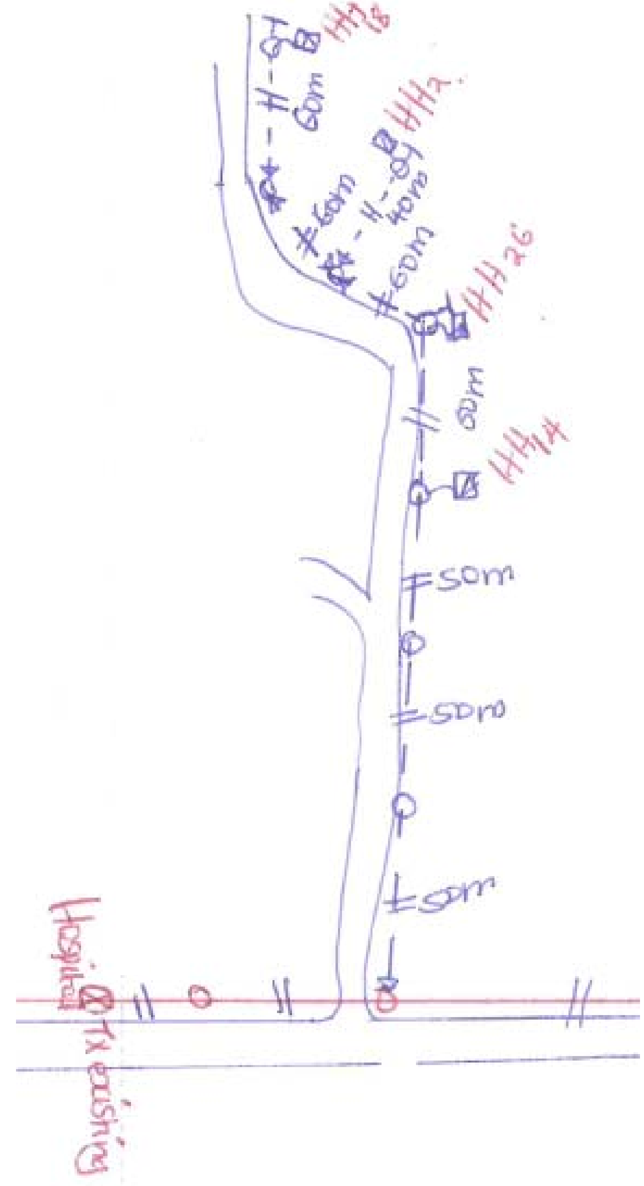


Economies of scale in mass connections

Electricity network has important economies of scale in terms of costs—when one household connects, it becomes far cheaper for neighboring households to connect.

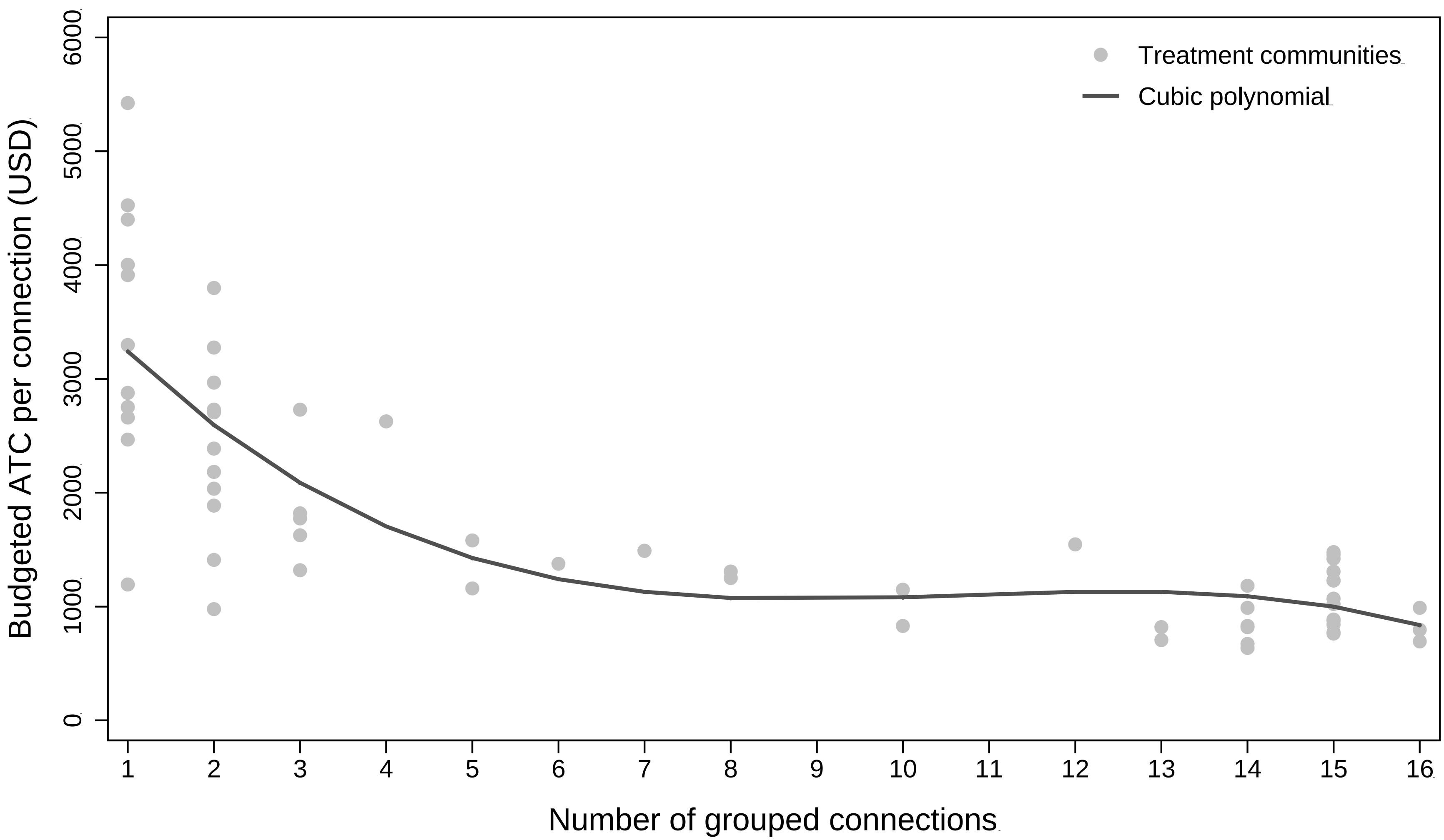
Substantial economies of scale could be achieved by connecting clusters of households along at the same time.

Our experiment generated random variation in the number of households connected at the same time, allowing us to trace out an average total cost (ATC) curve.



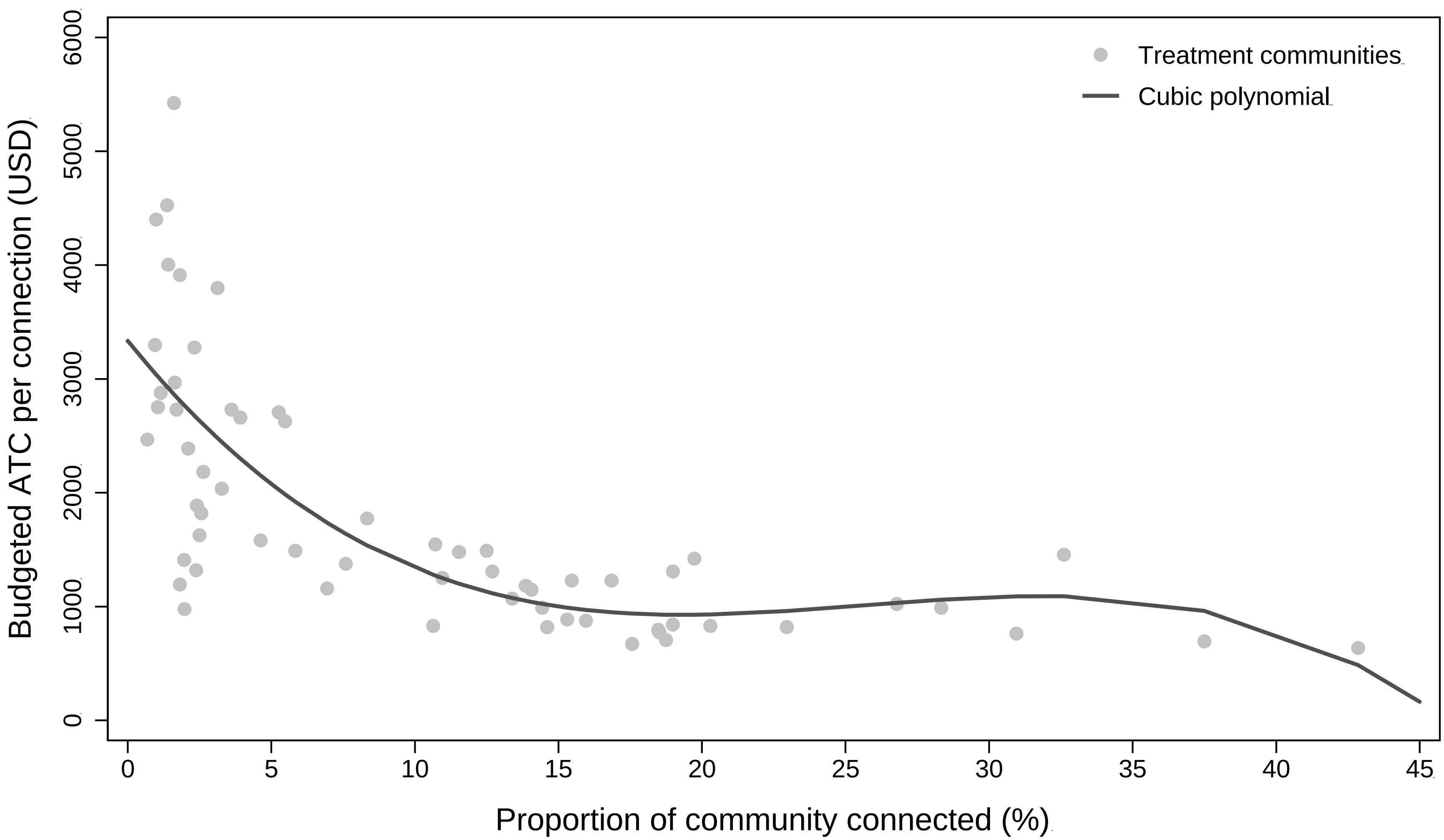
Experimental ATC curve

Using our experimental variation in scale, we trace out the average total cost (ATC) curve based on the number of households connected.



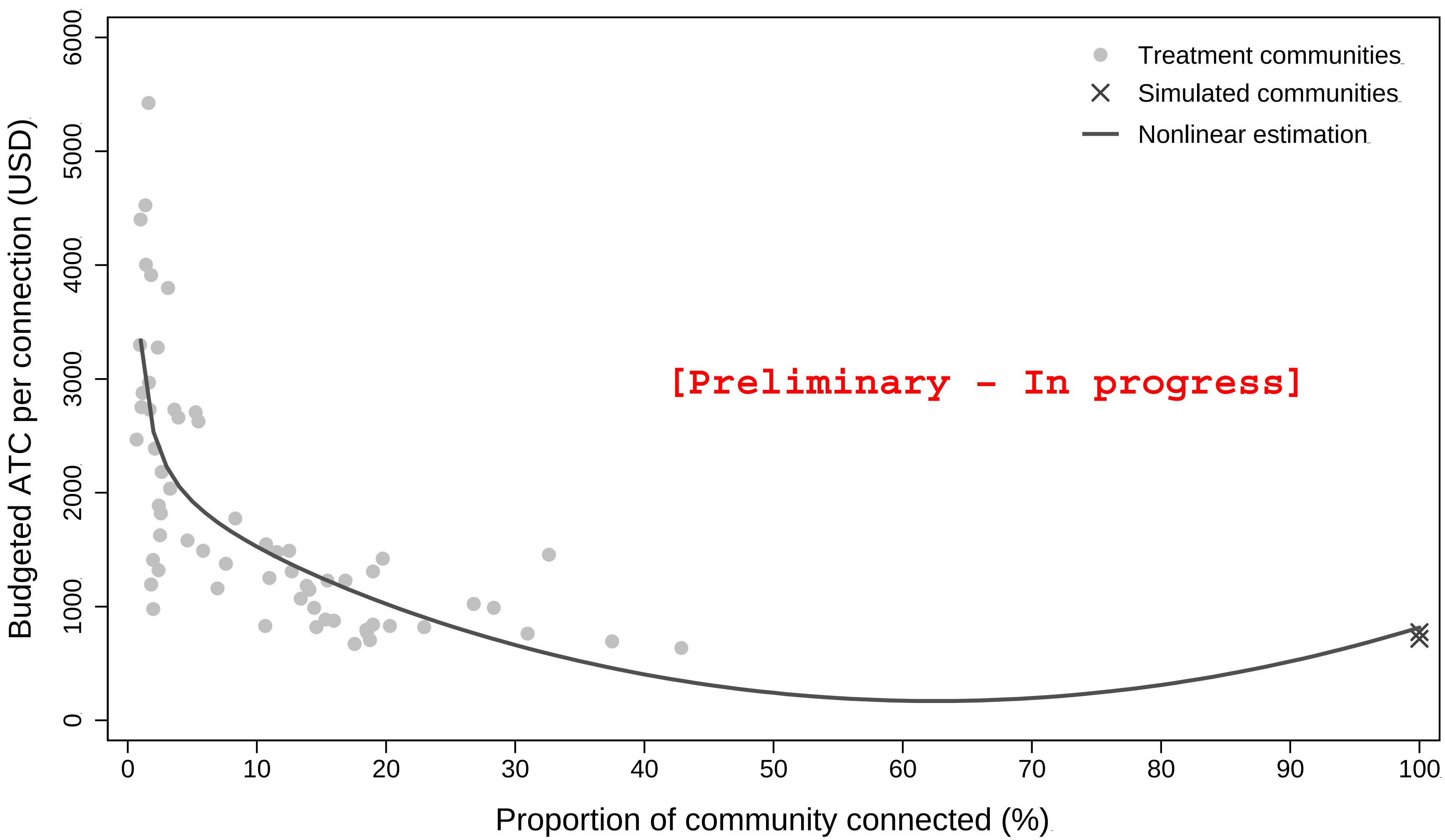
Experimental ATC curve (cont'd)

We also plot an experimental ATC curve based on the proportion of each community connected.



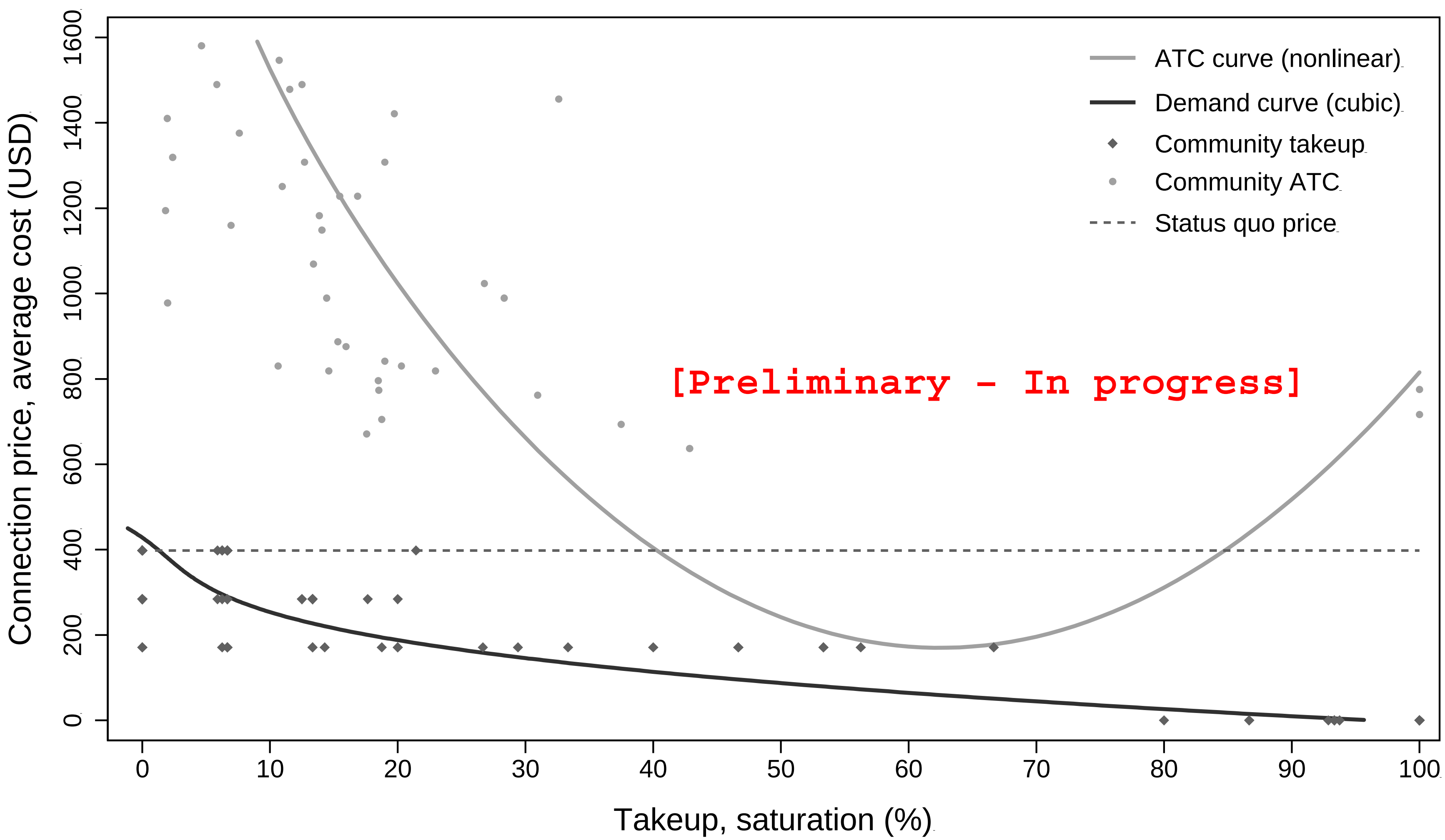
Experimental ATC curve (cont'd)

We also asked REA to design and cost 60%, 80%, and 100% "saturation" projects, using 16 randomly selected "transformer communities."

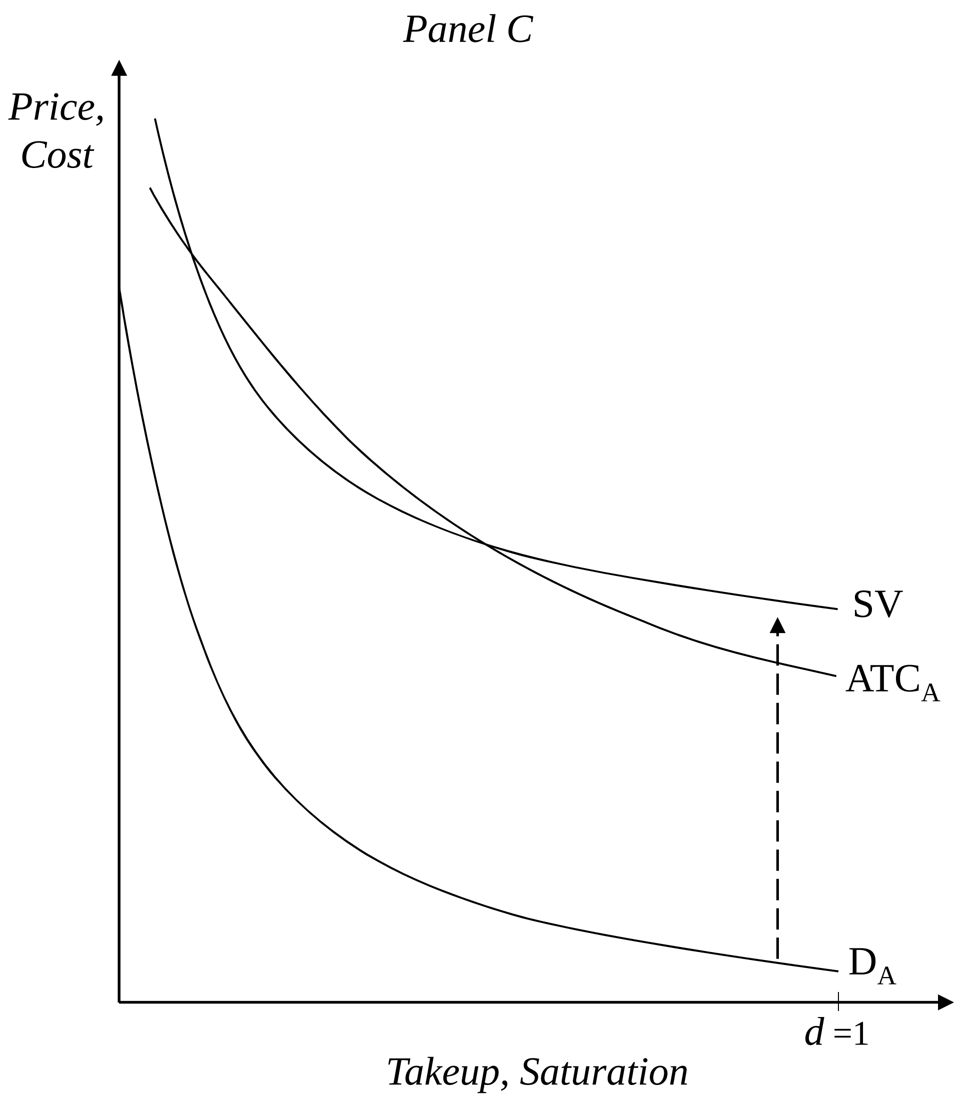


Experimental model of natural monopoly

We overlay both of our experimental curves, revisiting the standard model of the natural monopoly.

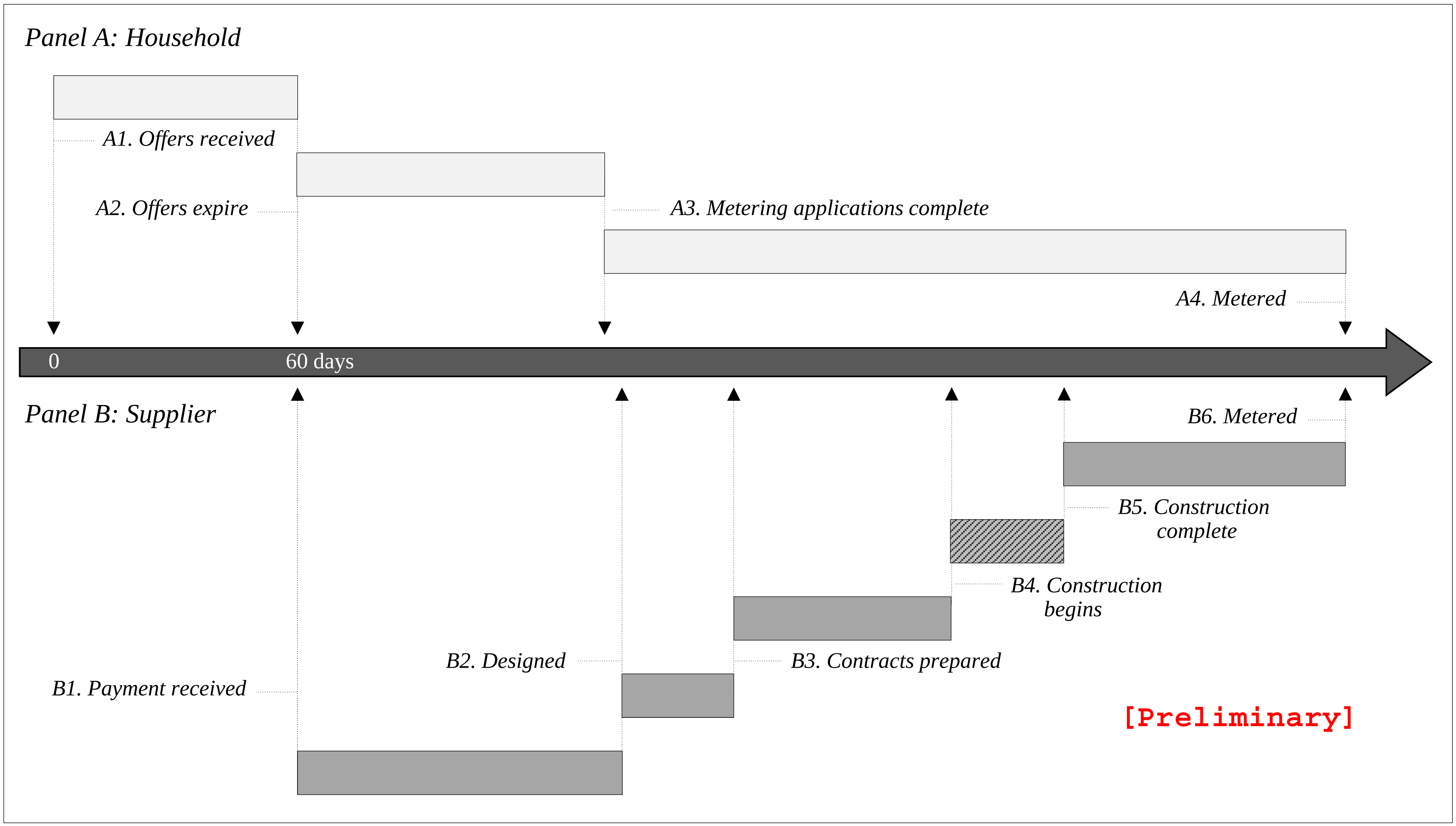


Example of natural monopoly #3



Substantial time costs to complete connections

The World Bank estimates that it takes 163 days to complete a connection. Our findings are in line with this figure, although construction is still in progress.



Preliminary policy conclusions from Paper #2

1. Take-up is low, even when the connection price is 15,000 KSh. Take-up may be higher if credit constraints are removed.

1. ATC curve is substantially [higher] than the demand curve.

1. Substantial economies of scale can be realized when [X%] of the transformer community is connected at the same time.

1. If there are sufficient economic impacts, externalities, or efficiency improvements (e.g. social benefits of electrification or households "sharing" access with neighbors, reduced "leakage" in construction), the gap between the demand and ATC curves may be minimized.

Research paper #3

The Social and Economic Impacts of Rural Electrification

[Ongoing Research: 2015 – 2017]

Impact Evaluation (IE) questions of interest

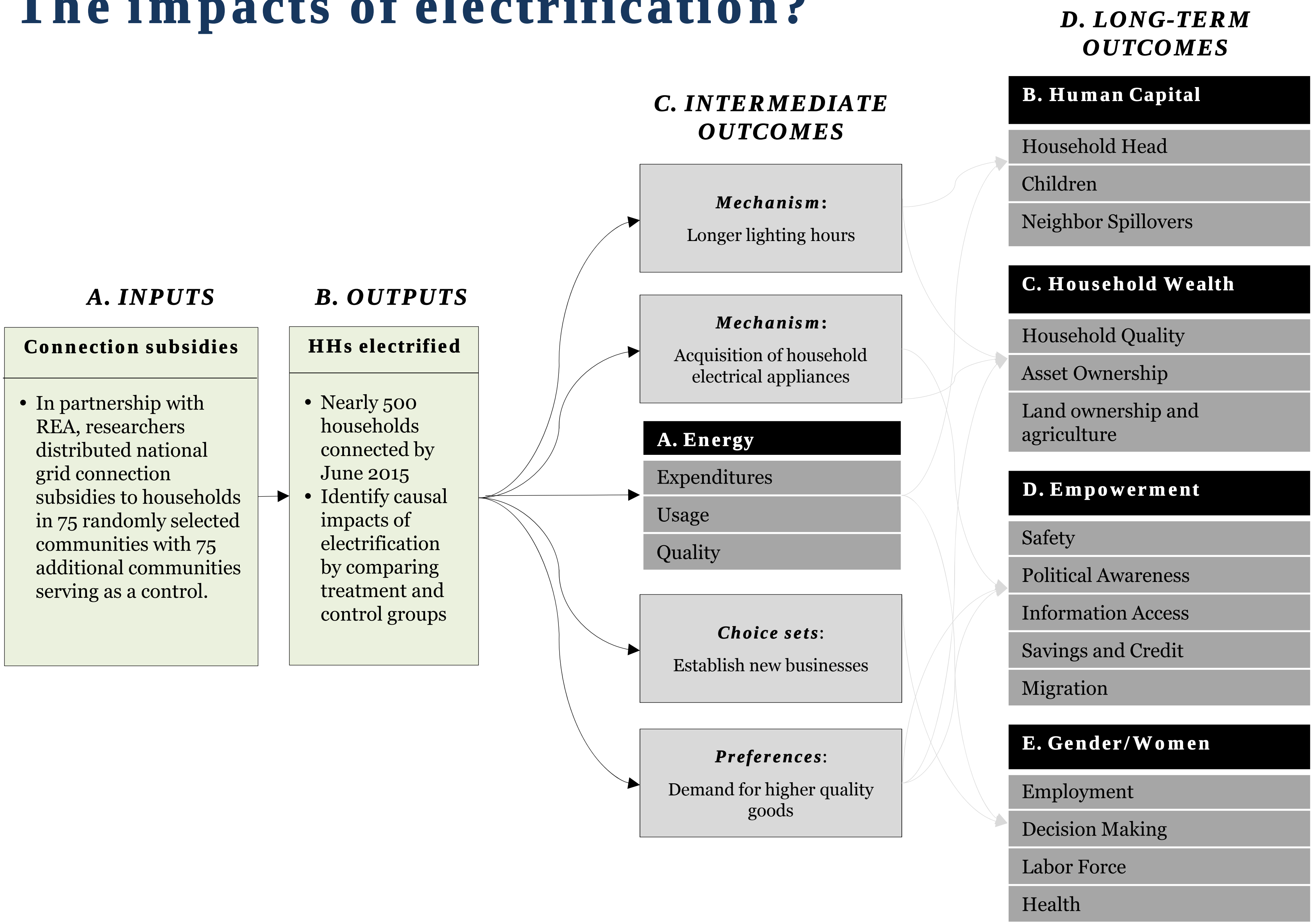
1. What are the impacts of household electrification?
2. How do newly connected households consume power over time?
3. What are the spillovers associated with household electrification (in light of large public subsidies required)?

Identifying impacts w/ baseline data is difficult

Table 1—Baseline differences between unconnected and connected rural households in Western Kenya

	Unconnected (1)	Connected (2)	p-value of diff. (3)
Panel A: Respondent characteristics			
Female (%)	62.87	58.60	0.217
Age (years)	52.30	55.77	0.003
Secondary schooling (%)	13.32	45.12	0.000
Married (%)	65.97	76.74	0.001
Subsistence farmer (%)	77.50	60.47	0.000
Political awareness (%)	11.36	36.74	0.000
Access to bank account (%)	18.25	60.93	0.000
Panel B: Household characteristics			
Number of members	5.23	5.29	0.764
Youth members	2.99	2.56	0.006
High-quality walls	16.03	80.00	0.000
Land (acres)	1.94	3.69	0.000
Distance to transformer (m)	356.50	350.85	0.577
Monthly lighting spend (USD)	5.52	15.38	0.000
Panel C: Household assets			
Bednets	2.28	3.41	0.000
Sofa pieces	5.99	12.46	0.000
Chickens	6.99	14.26	0.000
Radios	0.35	0.62	0.000
Televisions	0.15	0.81	0.000
Sample size	2,289	215	

The impacts of electrification?



***Source*:** Concept Note, World Bank i2i Dime Grant Application

Future research directions

1. Consumption patterns for newly-connected households and businesses
2. Measuring variations in, impacts of and valuations for reliability
3. Improving monopoly service delivery (e.g. governance & accountability in infrastructure delivery)
4. Price elasticity of demand (for connected households)
5. Productive-uses of power
6. Others?

Appendix

Predictors of connectivity

$$y_{ic} = \beta_1 d_{ic} + \beta_2 w_{ic} + \beta_3 d_{ic} \times w_{ic} + \lambda_c + \varepsilon_{ic}$$

Table 3. Predictors of electrification.

	Households			Businesses		
	(1)	(2)	(3)	(4)	(5)	(6)
Distance	-0.69^{***} (0.14)	-0.14 (0.15)	-0.19 (0.16)	-2.71^{***} (0.55)	-2.11^{**} (0.89)	-1.39 (1.06)
Walls		25.33^{***} (1.26)	24.98^{***} (1.26)		29.19^{***} (2.83)	27.69^{***} (3.03)
Walls*Distance		-1.57^{***} (0.31)	-1.54^{***} (0.31)		0.79 (1.11)	0.08 (1.21)
Fixed effects	No	No	Yes	No	No	Yes
Mean of dep. var.	5.47	5.47	5.47	33.58	33.58	33.58
Observations	12,666	12,666	12,666	2,823	2,823	2,823
R-squared	0.00	0.13	0.16	0.01	0.09	0.20

Note: All columns report OLS regressions. The dependent variable is an indicator variable for household connection status. Columns (1) to (3) report results for households; Columns (4) to (6) report results for businesses. Definitions: (a) Distance is the straight line distance to the central transformer (in 100 meter units); (b) Walls is equal to 1 for buildings with high-quality walls (e.g. brick, cement, or stone) and is equal to 0 otherwise; (c) Walls*Distance is the interaction between Distance and Walls. All coefficients are multiplied by 100. Columns (3) and (6) report community fixed effects regressions. Asterisks indicate coefficient significance level (2-tailed): * $P < 0.10$; ** $P < 0.05$; *** $P < 0.01$.

Rich census data on rural businesses

Table 1. Electrification rates for businesses of various types.

	% (1)	N (2)
All businesses	33.6	2,824
Small retail	36.2	1,163
Posho mill	13.3	294
Barber shop / salon	63.2	209
Restaurant	31.3	182
Tailor	26.5	162
Guesthouse	14.2	155
Food stand	5.7	140
Bar / cinema / television hall	62.9	105
Butcher	29.7	91
Welding / carpentry / workshop	39.2	74
Other	42.2	249

Column (1) reports the average electrification rate; (2) reports the total number of observations.

Demand-side regression results

$$y_{ic} = \alpha_0 + \alpha_1 T_c^{low} + \alpha_2 T_c^{mid} + \alpha_3 T_c^{high} + X_c'\gamma + X_{ic}'\lambda + \epsilon_{ic}$$

Table 3—Impact of connection subsidy on take-up of electricity connections

		Including interactions between treatment indicators and					
	Baseline	Busia	Market	Funded	Walls	School	Employed
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Control (intercept)	-6.52	-5.94	-6.88	-6.82	-5.99	-6.20	-5.32
	(4.33)	(4.01)	(4.73)	(4.37)	(4.28)	(4.30)	(4.49)
Low subsidy = 29% (T1)	6.81***	2.52	6.94***	5.83***	4.32***	5.33***	4.74***
	(1.52)	(1.77)	(1.77)	(1.98)	(1.46)	(1.40)	(1.69)
Medium subsidy = 57% (T2)	23.55***	20.66***	23.97***	27.28***	21.90***	20.36***	20.15***
	(4.02)	(5.79)	(4.82)	(6.29)	(4.43)	(3.79)	(4.52)
High subsidy = 100% (T3)	96.39***	96.12***	95.73***	95.75***	97.08***	96.65***	97.28***
	(1.18)	(1.39)	(1.51)	(1.62)	(1.01)	(1.17)	(1.14)
Interacted variable		-1.48*	0.14	-0.26	-0.35	-1.39	-1.51*
		(0.79)	(0.82)	(0.71)	(0.96)	(1.06)	(0.84)
T1 × interacted variable		7.29***	-0.62	2.09	12.87**	10.80	5.53*
		(2.69)	(3.35)	(3.11)	(6.10)	(6.98)	(3.32)
T2 × interacted variable		5.17	-1.78	-7.78	9.22	20.15***	9.47*
		(8.01)	(8.89)	(7.93)	(7.72)	(4.50)	(5.32)
T3 × interacted variable		0.46	2.34	1.41	-5.93*	-4.79	-2.30
		(2.34)	(2.09)	(2.37)	(3.58)	(4.60)	(1.79)
Mean of dep. var.	21.42	21.42	21.42	21.42	21.42	21.42	21.42
Observations	2,176	2,176	2,176	2,176	2,176	2,176	2,176
R-squared	0.71	0.72	0.71	0.72	0.72	0.72	0.72