Power Reliability and Grid Connection:
Evidence from Rural Guatemala

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Outline

Motivation: Policy Implications

- In 2019, US$290 Billion dollars spent on the electricity network, almost 190 in distribution (IEA, 2020)
  - Three times Guatemala GDP.
- SDG-7: Affordable, reliable and sustainable access to electricity.
  - Today, 800 million people lack of electricity.
- Urban-Rural Gap
  - In 2018, the worldwide electrification access is 97% for urban population and 15p.p. less to rural (World Bank Data).

Electrification access $\neq$ Electrification rate (grid connect)

  - In 2018, Rural Guatemala: 93.6% versus 77.7%

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How does power reliability affect rural households willingness to grid connect?

- $\Rightarrow$ Power quality as a barrier to electrification
- $\Rightarrow$ Potential heterogeneous effects over municipalities according to past performance.

Methodological approach

Two regression models based on two household database and official quality records at municipality level.

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Why Guatemala is a good country to focus on?

- Finished a civil war in 1996 and experienced a **boost in rural grid expansion** $\Rightarrow$ Electrification access grew from 55% in 2000 to 93% in 2018.
- In 2016, Residential sector energy consumption is based on firewood (90%), and only 5% on electricity (MEM,2019)
- Local urban-rural gap
  - Income and education
  - Poverty
  - electricity reliability: rural area suffered last decade more outages in duration (35%) and frequency (14%).

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Literature review

- Power reliability at industrial sector:
  - Productivity (Alcott et al, 2016; Grainger and Zhang, 2019)
  - Firm Sales (Cole et al., 2018)
  - Average unit costs (Fisher-Vanden et al., 2015)
  - Investment on back up generation (Oseni and Pollit, 2015)

- At **household level**, majority is focus on **electrification benefits**, taking for granted quality. See Bayer et al., 2020 for a systematic review, and Grogan (2018, JED) for the Guatemalan case.

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Literature review

- Interest on reliability in itself:
  - Chakravorty et al. (2014) studies the effect of both grid connection and quality on rural income in India. *High quality service is at least as equally significant and positive on household incomes as electrification*.
  - Dang and La (2019) stresses the positive effect of power quality on rural income in Vietnam.
  - Bajo-Buenestado (2021): blackouts in Kenya discourage electricity connections
- Literature based on WTP:
  - Kennedy et al. (2019): They state that rural households are willing to pay more for better service. More households will connect, if quality is improved.
  - Hashemi (2021): heterogeneity valuation of reliable supply across and within customer categories in India specially for industrial customers.

Literature review

How electricity **quality** supply is measured?

- Mostly come from Surveys.
  - Likert Scale
  - Frequency of outages
  - Duration
  - Reliability Index
- Empirical issues: measurement error, self selection, time frame.

Main contributions

Contribution #1

Study the effects of quality as a barrier to electrification in rural setting.

Contribution #2

Use of an official and objective reliability measure at municipality level.

Contribution #3

Empirical evidence in Latin America in an upper middle income country (World Bank)

Outline

Guatemala

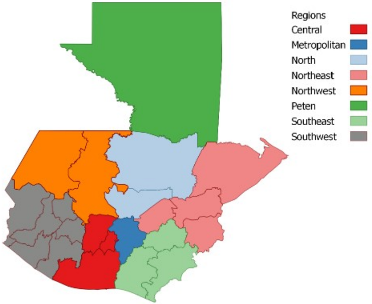


Figure: Regions

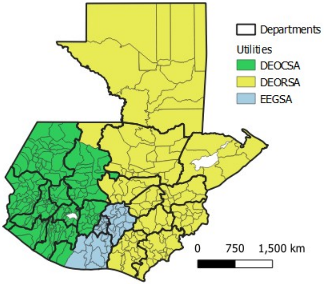


Figure: Firms Zonal distribution

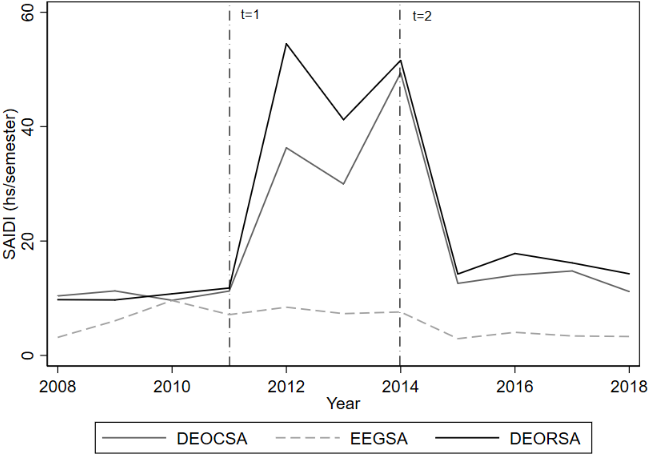
Quality Measure

Definition 1

$$SAIDI_m = (\Sigma_{cm}\Sigma_j(Duration_{cmj}))/\Sigma_{cm} \quad (1)$$

- Being Σ_{cm}=the total number of customers in municipality m ; and j the interruption.
- It is measured by CNEE twice a year and reported at municipality level.
- Unit of measure: hours/semester

Data: Rural Quality



Data

Why this sudden shift in SAIDI?

✓ Evidence of managerial problems.
- DEOCSA and DEORSA sale from Union Fenosa to Actis Group in May 2011 and its later resold in 2016 to ENERGUATE.
- Proximity of Tariff Agreement expiration with CNEE in 2014.
- Anecdotal evidence in local press blaming for lack of investment.

× Generation constraints? There is no load shedding in Guatemala. Outages are more prone to be caused by distribution constraints.

× Reverse causality? ⇒ Unexpected consumer´s growth rate ⇒ Bad quality Go

× High prices ⇒ Unpaid bills, thief ⇒ Bad quality.

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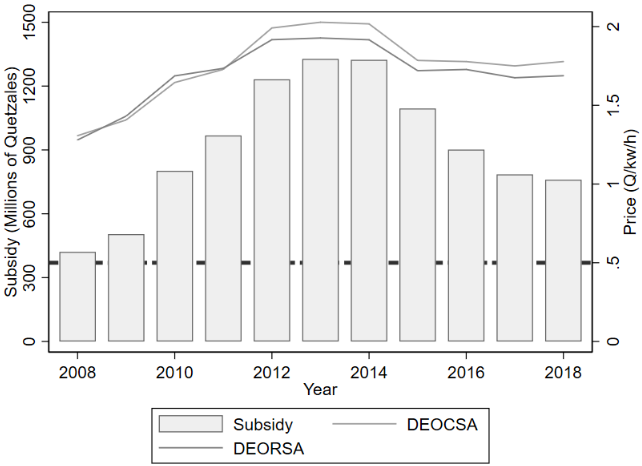
Tariff Scheme



Tariff Scheme

1. **Social Tariff**: those who consume less than 300kw/h per month or 10kw/h per day. $\Rightarrow$ **94% of Guatemalan customers**

$\hookrightarrow$ INDE contribution: additional subsidy scheme for poorest households. It is tiered up subsidy that guarantees a maximum price. For the first 100kw/h consumed:

- 1-60 kw/h: *Q*0.50
- 61-88 kw/h:*Q*0.81
- Then, the Social Tariff is paid.

In December 2018, 70% of DEOCSA and DEORSA customers received the INDE contribution. Since 70% of all DEOCSA customers live in rural zones, and 63% in DEORSA, we can infer that subsidy benefits almost all rural households

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Firms

Table: Utilities main characteristics (2014)

	EEGSA	DEOCSA	DEORSA
Total Consumers	1,108,352	975,717	598,550
Social Tariff Consumers	997,668	952,152	576,215
Per capita consumption (kw/month)	104.66	68.61	79.06
Social Tariff (Quetzal/kwh)	1.63	2.02	1.92
Large Consumers	769	9	49
Compensation (Quetzales)	Q767,967	Q46,211,187	Q54,525,905
Services cut off (%)	6%	17%	22%
KvA installed per user	2.58	0.99	1.44

Notes: Services cut off is a proportion of total consumers. Compensation data is from 2013. Source: CNEE.

Model

Using ENCOVI database

$$Y_{hdrt} = \alpha_0 + \alpha_1 * LnSAIDI_{drt} + H_{hdrt} + D_{drt} + \eta_r + \theta_t + \epsilon_{hdrt} \quad (2)$$

Y: dummy variable equals 1 if the household is connected to the grid; 0 otherwise.

α_1: captures the effect of 1% change in SAIDI at department level, in the probability to get connected.

Using Population Census 2018 database

$$Y_{hmd} = \beta_0 + \beta_1 LnSAIDI_{md} + H_{hmd} + M_{md} + \eta_d + \epsilon_{hmd} \quad (3)$$

β_1: captures the effect of 1% change in SAIDI at municipality level, in the probability to get connected.

Descriptive statistics

Table: Rural Area Descriptive statistics

	ENCOVI				CENSUS	
	2011		2014		2018	
Variable	DEOCSA	DEORSA	DEOCSA	DEORSA	DEOCSA	DEORSA
Rural Household (%)	57.5%	66.0%	54.6%	64.2%	60.4%	61.6%
SAIDI (hours/semester)	10.3	10.3	41.4	45.3	10.3	13.8
Grid Connection (%)	71.9%	52.3%	79.7%	54.8%	84.7%	65.6%
Dwelling characteristics						
Owns the house	85.7%	85.9%	87.0 %	87.6%	88.2%	86.6%
Poor materials	50.1%	57.9%	47.4%	56.9 %	40.3 %	51.0%
Head of Household Variables						
Primary completed	57.1%	58.7%	61.3%	58.3%	63.4 %	62.9%
Farmer (% from workers)	66.8%	71.0%	67.7%	70.8%	60.5%	66.6%
Recent Migrant	1.9%	2.3%	0.8%	0.2%	1.3%	2.1%
Indigenous	61.0%	37.7%	58.3%	38.2%	60.7%	46.1 %
Average monthly TFI	Q 1,433.3	Q 1,368.9	Q 1,682.5	Q 1,844.0	nd	nd
Observations	3,319	3,958	2,695	2,970	671,572	516,747

Notes: 2011 and 2014 data is from ENCOVI, and 2018 from Census. All summary data is from the area supplied by DEOCSA and DEORSA. SAIDI data come from CNEE and is a weighted average by each municipality population. TFI means Total familiar income. From Census data, rural households who have panel solar are not taken into account for dwelling and HH characteristics

Outline

Empirical Results

Table 3: ENCOVI results 2011-2014

	(1) Grid	(2) Grid	(3) Grid	(4) Grid
Ln SAIDI	-0.111**	-0.108**	-0.141**	-0.230**
	(0.041)	(0.039)	(0.061)	(0.084)
Owns the house	0.038**	0.035**	0.042**	0.043**
	(0.019)	(0.017)	(0.017)	(0.017)
Poor Housing materials	-0.269***	-0.199***	-0.196***	-0.197***
	(0.016)	(0.014)	(0.014)	(0.014)
CDD		-0.002	0.000	0.006
		(0.003)	(0.005)	(0.005)
Real Income		0.009***	0.010***	0.010***
		(0.003)	(0.003)	(0.003)
Year FE	Yes	Yes	Yes	Yes
HH controls	No	Yes	Yes	Yes
Department controls	No	No	Yes	Yes
Region FE	No	No	Yes	Yes
Region*Year	No	No	No	Yes
Adjusted R^2	0.226	0.306	0.323	0.324
Observations	12,914	12,825	12,825	12,825

Robust cluster errors at Primary Sample Unit (PSU) level, N=1,138. Department controls are mean characteristics at that level such as: dwelling, water and toilet access; literacy, schooling and employment rate, and proportion of indigenous living in the department, and proportion oh households that have at least one child working. Results remains in model 4 if clustering is at department level, and Wild bootstrap is performed with 400 replications

* p<0.10, ** p<0.05, *** p<0.001

Empirical Results

Table 4: 2018 Census estimation

	(1) grid	(2) grid	(3) grid	(4) grid
Ln SAIDI	-0.067***	-0.025**	-0.029***	-0.021*
	(0.023)	(0.012)	(0.011)	(0.011)
CDD		-0.003	-0.003	-0.003
		(0.003)	(0.003)	(0.003)
Public Lightning Tariff		-0.000	-0.001	-0.001
		(0.001)	(0.001)	(0.001)
Poor housing materials		-0.166***	-0.145***	-0.147***
		(0.008)	(0.007)	(0.007)
Owns the house		0.017***	0.026***	0.025***
		(0.005)	(0.005)	(0.004)
Usually receives remittances		0.027***	0.023***	0.022***
		(0.003)	(0.003)	(0.003)
Asset: motorbike		0.061***	0.050***	0.050***
		(0.005)	(0.004)	(0.004)
Household variables	No	Yes	Yes	Yes
Municipality controls	No	No	Yes	Yes
Department Fixed effects	No	No	No	Yes
Adjusted R^2	0.008	0.242	0.255	0.271
Observations	1,178,160	1,161,698	1,161,698	1,161,698

Robust clustered standard errors at municipality level(266)

* p<0.10, ** p<0.05, *** p<0.01

Outline

Potential issues

1. Quality shift in 2012 not full exogenous ⇒ IV strategy
2. Possible measurement error calculating SAIDI at department level in ENCOVI regression. Go To
3. Include households with solar panels, CDD variable and placebo tests. Go To

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IV Strategy

1. Rainfall as the instrumental variable.
2. Two potential sources: INSIVUMEH (local Weather Stations) and NASA satellite images.

IV strategy

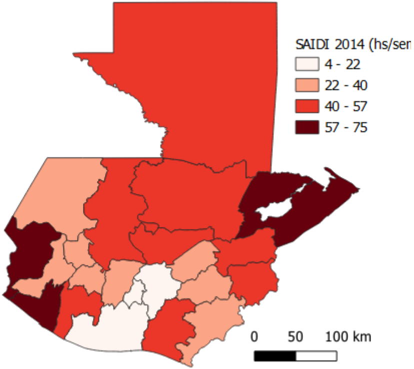


Figure: SAIDI in 2014

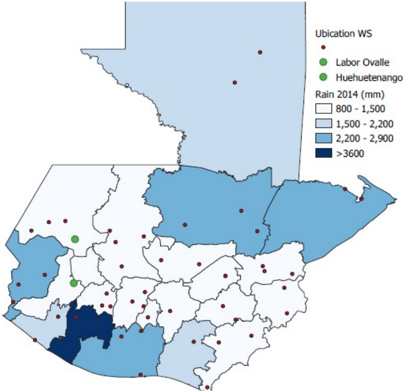
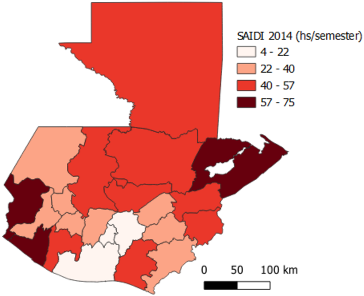


Figure: Weather Stations

IV strategy



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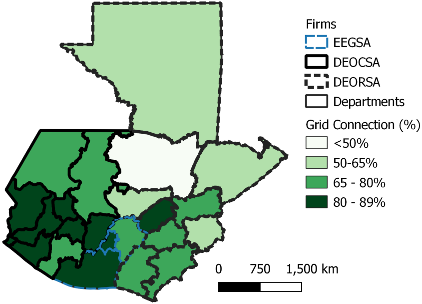


Figure: Grid connection in 2014

IV Strategy

Table 5: IV Regression models-ENCOVI

	(1) M3 $Rain_{WS}$	(2) M4 $Rain_{WS}$	(3) M3 $Rain_{NASA}$	(4) M4 $Rain_{NASA}$
LnSAIDI	-0.388**	-0.396***	-0.854*	-0.771***
	(0.138)	(0.075)	(0.450)	(0.170)
	[0.038]	[0.005]	[0.118]	[0.008]
Household controls	Yes	Yes	Yes	Yes
Department controls	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes
Region Dummies	Yes	Yes	Yes	Yes
Region*Year	No	Yes	No	Yes
Adjusted R^2	0.320	0.324	0.295	0.316
Clusters	19	19	19	19
First stage F-statistic	9.988	23.197	2.750	9.146
Observations	12,825	12,825	12,825	12,825

Robust Standard errors clustered at department level in parenthesis. Wild Bootstrapped Robust Standard errors clustered at department level (400 replications). Between square brackets it is the p-value. F-statistic is for the heteroskedasticity and cluster robust Kleibergen-Paap weak instrument test. M3 and M4 means models 3 and 4 of Table 3

* p<0.10, ** p<0.05, *** p<0.001

Potential issues

Table 6: Robustness check: weighted measure

	(1)	(2)	(3)	(4)
	Grid	Grid	Grid	Grid
Ln $SAIDI_w$	-0.126***	-0.149***	-0.086	-0.135*
	(0.037)	(0.038)	(0.054)	(0.074)
Year FE	Yes	Yes	Yes	Yes
Household controls	No	Yes	Yes	Yes
Department controls	No	No	Yes	Yes
Region FE	No	No	Yes	Yes
Region*Year	No	No	No	Yes
Adjusted R^2	0.227	0.308	0.323	0.324
Observations	12,914	12,825	12,825	12,825

Robust Standard errors clustered at PMU level. These are the same models as Table 4. Results remains in model 4 if clustering is at department level, and Wild bootstrap is performed with 400 replications

* p<0.10, ** p<0.05, *** p<0.001

Potential Issues

Potential issues

Table 7: Robustness Check Census.

	(1) grid	(2) grid	(3) grid	(4) water	(5) garbage
Ln SAIDI	-0.022**	-0.028**	-0.027**	-0.006	-0.007
	(0.011)	(0.013)	(0.013)	(0.020)	(0.011)
Household controls	Yes	Yes	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes	Yes	Yes
Department Fixed effects	Yes	Yes	Yes	Yes	Yes
adj. R^2	0.270	0.302	0.303	0.182	0.197
Observations	1,161,698	1,243,221	1,243,221	1,161,698	1,161,698

Robust clustered standard errors at municipality level. Model (1) does not include CDD as a control; Model (2) does not includes CDD but includes households with solar panel. Model (3) includes both. Model (4) and (5) are placebo tests. In these models, CDD, DEOCSA dummy variable, and the mean access to water and garbage in each municipality are not included as control variables

* p<0.10, ** p<0.05, *** p<0.01

Heterogeneous effects

- Intensity

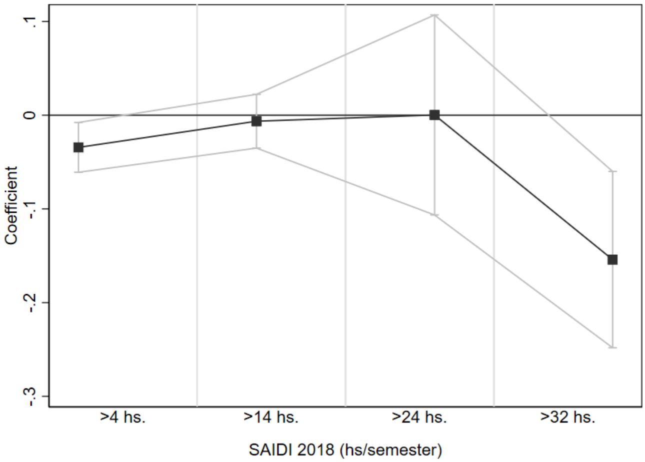
$$Y_{hmd} = \beta_0 + \beta_1 \mathbb{1}(SAIDI_{md} > x) + H_{hmd} + M_{md} + \eta_d + \epsilon_{hmd}$$

- Does past performance matter (2015-2018)?

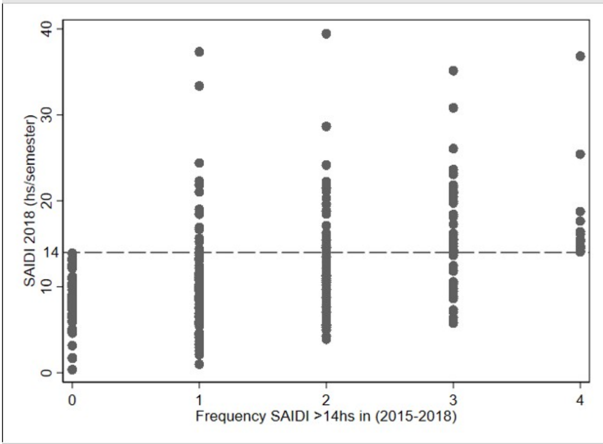
$$Bad \quad reputation = \begin{cases} 1 & \text{if frequency} \geq 3 \\ 0 & \text{if } frequency < 3 \end{cases}$$

Go to

Heterogeneous Effects: Intensity



Heterogeneous Effects: Past Performance



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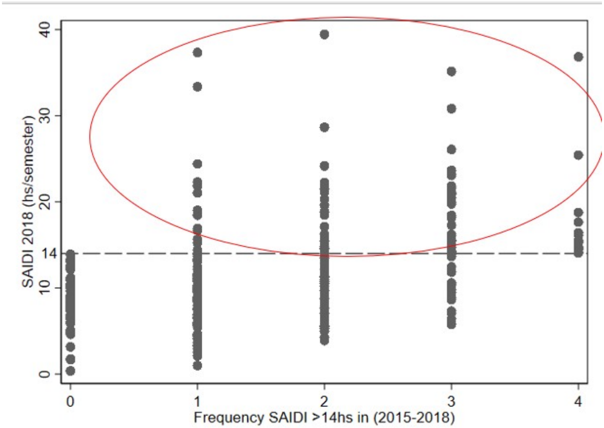


Heterogeneous Effects: Past Performance

Table 8: OLS Census full model specification with different subsamples

	(1) SAIDI<14hs	(2) SAIDI>14hs	(3) SAIDI>14hs
Ln SAIDI	-0.031***	-0.050	-0.186***
	(0.009)	(0.058)	(0.061)
Ln SAIDI* Bad Reputation			0.233**
			(0.115)
Bad Reputation=1			-0.663*
			(0.335)
Household controls	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes
Department Fixed effects	Yes	Yes	Yes
Clusters	184	82	82
Adjusted R^2	0.267	0.298	0.300
Observations	767,308	394,390	394,390

Robust clustered standard errors at municipality level. Model 1 includes the municipalities that had SAIDI levels under 14 hours. Models 2 and 3, upper 14 hours. All models have the same controls as model 4 in Table 4

* p<0.10, ** p<0.05, *** p<0.01

Conclusions

- Results are given a plausible evidence that ***quality matters***:
  - In 2011-2014 period we find that a 1% reduction in outages duration at department level (30 minutes per year), increases probability of grid connection between 23-39 percentage points. This means between 69,000 and 116,000 new connections and 1.6-2.8 US$ Million dollars in annual revenues.
  - In the second regression setup, with a more stable quality level in 2018, a 1% reduction in outages duration (15 minutes per year on average at municipality level) increases probability in 2 percentage points. This means on average an expected increase of 16.3 thousand new customers.
- Results also suggests an **heterogeneous effect** of SAIDI over municipalities. Conditional you are a defaulter, current quality matters unless the municipality has bad reputation.
- **Policy implications**: Efforts to expand the grid line to rural areas should be analyzed in concordance with actual power grid quality levels; better quality will generate more connections, and —as Grogan (2018) studied in Guatemala—, more electrification access will reduce the gender gap.

Thank you for your attention

Comments and suggestions: faccursi@alumni.unav.es

Additional material

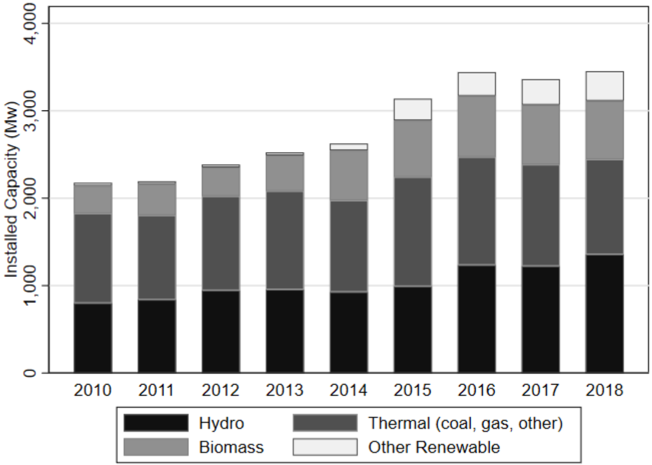


Figure: Capacity

Additional material

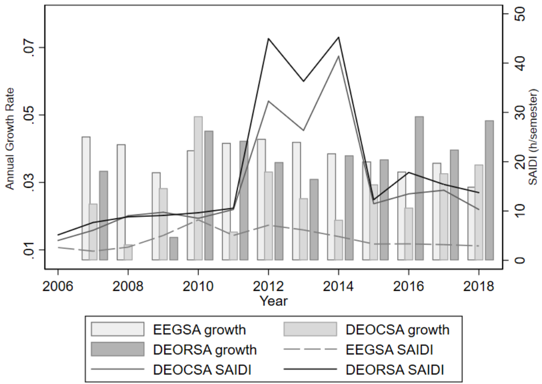


Figure: Growth rate of consumers and quality

Avg Annual Growth rate (2007-2011): EEGSA (3.9%); DEOCSA (2.6%); DEORSA (2.7%) Return

Additional material

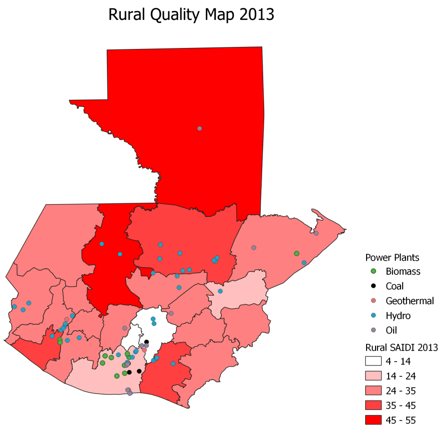
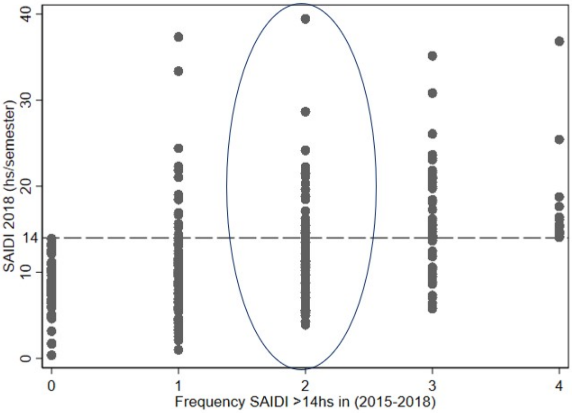


Figure: Power plants location

Additional Material



Additional material

Table 9: OLS Census full model specification and frequency of law compliance

	(1) Frequency=0	(2) Frequency=1	(3) Frequency=2	(4) Frequency>3
Ln SAIDI	-0.010*	-0.036**	0.025	-0.081*
	(0.006)	(0.015)	(0.018)	(0.046)
Household variables	Yes	Yes	Yes	Yes
Municipality controls	Yes	Yes	Yes	Yes
Department Fixed effects	Yes	Yes	Yes	Yes
Clusters	56	78	68	64
Adjusted R^2	0.245	0.305	0.260	0.287
Observations	230,265	305,907	294,171	331,355
$SAIDI_{18}$ mean	8.52	10.32	12.54	16.48
$SAIDI_{18}$ min	0.37	0.99	3.89	5.79
$SAIDI_{18}$ max	13.91	37.35	39.44	36.84
Grid connected (%)	84.5	72.0	75.6	74.6
Solar Panels (%)	3.4	7.6	6.8	7.4

Robust clustered standard errors at municipality level in parenthesis. All models have the same controls as model 4 in Table 4. The information in the last five lines are summary statistics for each frequency group. Data of solar panels is just informative, and it does not mean it was included in the estimations.

* p<0.10, ** p<0.05, *** p<0.01