Voltage quality and economic activity: On-line Appendix

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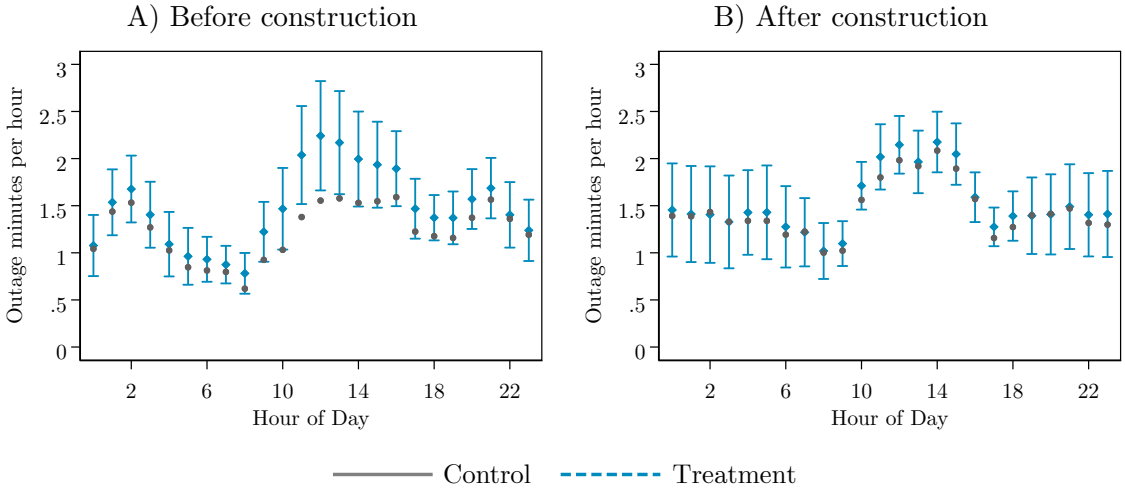
Appendix C: Robustness checks

Figure C1: Impacts of transformer injection on outages by time of day



The figure shows mean minutes of power outages by hour of day separately for treatment and control sites. 95% confidence intervals around treatment means are clustered at the site level. Panel A shows means for the year prior to the start of the transformer construction period, and Panel B shows means for the year after the end of the construction period. **??** shows impacts on average voltage.

Table C1: Balance between panel and attrited respondents

	Matched N	Mean	Attrited N	Difference	p-value
Respondent and Location					
Age (years)	1575	39.23	426	2.73	0.000
Respondent is male	1575	0.35	426	0.02	0.547
Completed secondary education	1575	0.50	426	-0.05	0.050
Owns premises	1575	0.38	426	0.12	0.000
Appliances					
Any television (TV) at location	1575	0.71	426	-0.02	0.419
Any fridge at location	1575	0.62	426	0.01	0.835
Count of mobile phones	1575	2.17	426	0.05	0.605
Any voltage protective devices	1575	0.25	426	0.01	0.571
Count of voltage defensive invest.	1575	0.34	426	0.00	0.978
Electricity and Energy					
Pays someone else for electricity	1575	0.09	426	-0.08	0.000
Count of meter users	1566	1.82	424	-0.38	0.001
Monthly electricity spending	1559	18.37	413	0.50	0.615
Has generator	1575	0.04	426	0.02	0.070
Count of alternative fuels used in past 3 months	1575	0.91	426	-0.07	0.107
Amount spent on all alt. fuels in past month	1575	8.62	426	0.01	0.993
Electricity Reliability and Quality					
Average number of monthly outages - resp.	1575	6.81	426	0.26	0.295
Total outage duration in past 30 days (hrs)	1575	42.05	426	5.19	0.059
Average daily hrs with low voltage - resp.	1566	1.58	422	0.14	0.408
Has apps. burnt/broken due to voltage in past year	1575	0.27	426	0.03	0.141
Amt spent on burnt/broken apps in past year	1562	10.25	426	4.52	0.002
Household Characteristics					
Adult members	746	2.39	251	0.28	0.001
Child members (<18)	746	1.21	251	0.24	0.014
Total household monthly income	714	729.62	234	252.66	0.444
Share of HH adults (18+) with paid jobs in last 7 days	746	0.66	251	-0.04	0.123
Business Characteristics					
Number of workers	829	1.97	175	-0.11	0.579
Total revenue in past month	723	438.67	147	-72.32	0.292
Total measured business costs in past month	1575	173.44	426	14.96	0.390
Total profit in past month	646	108.12	131	-34.17	0.063
Total hours typically open	829	12.07	175	0.20	0.397
Any non-electric business machines at location	829	0.09	175	0.00	0.992
Business engaged in retail activities	829	0.44	175	-0.07	0.085
Business engaged in manufacturing activities	829	0.20	175	0.11	0.000
Business engaged in other service activities	829	0.36	175	-0.03	0.409
Business activity likely using electricity	829	0.22	175	0.09	0.004

Notes: This table shows means in the baseline period for survey respondents, pooling businesses and households, and tests for significance of the differences in means by whether the respondent was also surveyed at the endline. The p-value for the joint F-test for household baseline characteristics is 0.001. The p-value for the joint F-test for business baseline characteristics is 0.028. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C2: Correlation between attrited respondents' characteristics and treatment status

	Mean	LB Treat	N
Age (years)	37.11	-1.20	426
	[12.40]	(1.09)	
Respondent is male	0.37	-0.07	426
	[0.48]	(0.05)	
Completed secondary education	0.54	0.04	426
	[0.50]	(0.05)	
Owns premises	0.31	-0.12***	426
	[0.47]	(0.04)	
Any television (TV) at location	0.69	0.08*	426
	[0.47]	(0.04)	
Any fridge at location	0.60	0.02	426
	[0.49]	(0.05)	
Count of mobile phones	2.22	-0.20	426
	[2.00]	(0.18)	
Any voltage protective devices	0.26	-0.03	426
	[0.44]	(0.04)	
Count of voltage defensive invest.	0.35	-0.03	426
	[0.68]	(0.07)	
Amt spent on burnt/broken apps in past year	5.06	1.31	426
	[21.41]	(2.23)	
Pays someone else for electricity	0.17	-0.00	426
	[0.38]	(0.04)	
Count of meter users	2.18	0.02	424
	[2.25]	(0.20)	
Monthly electricity spending	18.86	-1.94	413
	[18.27]	(1.81)	
Has generator	0.02	0.01	426
	[0.14]	(0.02)	
Count of alternative fuels used in past 3 months	0.96	0.05	426
	[0.82]	(0.08)	
Amount spent on all alt. fuels in past month	7.00	3.12	426
	[9.25]	(2.09)	
Average number of monthly outages - resp.	6.76	-0.43	426
	[4.82]	(0.44)	
Total outage duration in past 30 days (hrs)	36.26	1.18	426
	[47.33]	(4.43)	
Average daily hrs with low voltage - resp.	1.42	0.03	422
	[3.41]	(0.31)	
Has apps. burnt/broken due to voltage in past year	0.24	-0.01	426
	[0.43]	(0.04)	

Notes: This table shows the correlation between the attrited respondents' characteristics and treatment status. The sample is restricted to respondents who do not participate in the endline survey. We regress each respondent characteristic at baseline on a dummy variable equals one if the respondent was in a treatment site at baseline. Each row represents an outcome. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C3: Impact of transformer injection intervention on hourly average voltage, robustness to implementation issues

	(1) All sites	(2) Commissioned sites (SMEC)	(3) New tx confirmed sites	(4) All sites, IV new tx with treat	(5) All sites
During construction	0.76	0.79	0.65	0.42	0.79
	(1.09)	(1.09)	(1.18)	(1.22)	(1.55)
Treat X During	2.38	2.55	3.61**		1.95
	(1.60)	(1.63)	(1.70)		(1.93)
New Trafo X During				3.24	
				(2.05)	
Post construction	5.94***	5.95***	5.26***	5.26***	5.95***
	(1.74)	(1.75)	(1.85)	(1.95)	(1.82)
Treat X Post	5.48**	6.07**	8.413***		5.456**
	(2.48)	(2.49)	(2.48)		(2.59)
New Trafo X Post				7.13**	
				(3.13)	
Observations	9866078	9723260	8815828	9866078	9866078
Pre-constr. ctl. mean	219.2	219.2	220.2	219.2	218.0
Hour of day FE	Y	Y	Y	Y	Y
Week of year FE	Y	Y	Y	Y	Y
Site FE	Y	Y	Y	Y	Y
Revised constr. period	N	N	N	N	Y

This table shows the difference-in-difference results for the impact of the transformer injection treatment on hourly average voltage levels measured by GridWatch devices in each site. Column 2 drops two sites where the construction manager SMEC indicated the new transformer was not commissioned successfully. Column 3 drops sites where our own construction monitoring activities indicated no new transformer was built in a treatment site or a new transformer was built in a control site. Column 4 instruments for observing a new transformer during the construction monitoring visits with site treatment assignment. Column 5 defines the construction period as July 1, 2020-December 31, 2020 instead of October 1, 2020-March 31, 2021, based on reported dates of transformer construction activity from the construction manager, SMEC. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C4: Impact of transformer injection intervention on hourly outage minutes, robustness to implementation issues

	(1) All sites	(2) Commissioned sites (SMEC)	(3) New tx confirmed sites	(4) All sites, IV new tx with treat	(5) All sites
During construction	0.21***	0.21***	0.16**	0.22***	0.00
	(0.071	(0.07)	(0.08)	(0.08)	(0.08)
Treat X During	-0.06	-0.07	-0.04		-0.11
	(0.12)	(0.12)	(0.13)		(0.12)
New Trafo X During				-0.09	
				(0.15)	
Post construction	-0.08	-0.08	-0.12	-0.05	-0.04
	(0.08)	(0.08)	(0.08)	(0.09)	(0.08)
Treat X Post	-0.21	-0.23*	-0.23		-0.23*
	(0.13)	(0.13)	(0.14)		(0.14)
New Trafo X Post				-0.28	
				(0.17)	
Observations	10033086	9888612	8962703	10033086	10033086
Pre-constr. ctl. mean	1.39	1.39	1.41	1.39	1.48
Hour of day FE	Y	Y	Y	Y	Y
Week of year FE	Y	Y	Y	Y	Y
Site FE	Y	Y	Y	Y	Y
Revised constr. period		N	N	N	Y

This table shows the difference-in-difference results for the impact of the transformer injection treatment on hourly power outage minutes measured by GridWatch devices in each site. Column 2 drops two sites where the construction manager SMEC indicated the new transformer was not commissioned successfully. Column 3 drops sites where our own construction monitoring activities indicated no new transformer was built in a treatment site or a new transformer was built in a control site. Column 4 instruments for observing a new transformer during the construction monitoring visits with site treatment assignment. Column 5 defines the construction period as July 1, 2020-December 31, 2020 instead of October 1, 2020-March 31, 2021, based on reported dates of transformer construction activity from the construction manager, SMEC. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C5: Impacts of transformer injection intervention on additional voltage quality measures, hourly data

	N	Control Mean (SD)	During Construction (SE)	Post (SE)	Treat × During (SE)	Treat × Post (SE)
Mean voltage during hour	9866078	219.18	0.76	5.94***	2.38	5.48**
		(22.39)	(1.09)	(1.74)	(1.60)	(2.48)
Any voltage >20% below nominal	10033086	0.08	-0.00	-0.03**	-0.03**	-0.04**
		(0.26)	(0.01)	(0.01)	(0.02)	(0.02)
Minutes voltage >20% above nominal	10033086	0.00	-0.00	-0.00	-0.01	-0.00
		(0.31)	(0.00)	(0.00)	(0.01)	(0.01)
Minutes voltage 10-20% below nominal	10033086	9.60	-0.59	-2.96***	-2.08*	-4.21***
		(19.83)	(0.61)	(0.93)	(1.15)	(1.41)
Minutes voltage >20% below nominal	10033086	2.76	0.04	-1.54***	-1.39*	-1.40*
		(11.59)	(0.56)	(0.57)	(0.77)	(0.85)
Minutes with no power (outage)	10033086	1.39	0.21***	-0.08	-0.06	-0.21
		(8.59)	(0.07)	(0.08)	(0.12)	(0.13)

Notes: This table shows the difference-in-differences effects of the transformer injection intervention on measures of voltage quality using hourly data at the GridWatch device level. The minutes variables indicate the number of minutes in each hourly observation that the electricity had a certain status. 'Any voltage >20% below nominal' is a dummy variable for whether voltage fell below this threshold at any point during an hourly observation. All regressions include hour of day, week of year, and site fixed effects. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C6: Impacts of transformer injection intervention on additional voltage quality measures, monthly data

	N	Control Mean (SD)	During Construction (SE)	Post (SE)	Treat × During (SE)	Treat × Post (SE)
Hours with no power (outages)	19079	11.15	2.78***	1.12*	-0.04	-1.34
		(10.96)	(0.59)	(0.65)	(0.92)	(1.09)
Number of spells with voltage <207	19079	185.36	-2.58	-31.75*	-13.83	-45.75**
		(265.45)	(12.77)	(16.29)	(18.90)	(23.26)
Number of spells with min voltage >200	19079	156.14	-4.24	-29.05**	-10.34	-33.66*
		(225.77)	(10.74)	(13.54)	(15.45)	(19.49)
Number of spells with min voltage btwn 184-200	19079	22.15	0.20	-2.30	-1.74	-8.59**
		(39.60)	(1.87)	(2.80)	(2.96)	(3.70)
Number of spells with min voltage <184	19079	7.07	1.46**	-0.40	-1.75	-3.50***
		(12.78)	(0.71)	(0.83)	(1.35)	(1.27)
Total hours of spells with voltage <207	19079	91.87	7.27	-22.57**	-21.63	-37.22**
		(157.81)	(8.77)	(11.11)	(13.52)	(15.40)
Total hours of spells with min voltage >200	19079	11.68	0.64	-1.42	-0.17	-2.72*
		(16.83)	(0.85)	(1.05)	(1.18)	(1.47)
Total hours of spells with min voltage btwn 184-200	19079	24.08	1.59	-3.36	-0.55	-5.88*
		(39.92)	(2.04)	(2.44)	(2.86)	(3.22)
Total hours of spells with min voltage <184	19079	56.12	5.05	-17.79**	-20.92*	-28.62**
		(131.51)	(7.42)	(8.70)	(11.45)	(12.26)
Share of low-voltage time in spells with min voltage <184	14776	0.37	-0.02	0.03	-0.11***	0.01
		(0.38)	(0.02)	(0.02)	(0.04)	(0.04)
Mean spell length (hours)	14776	0.75	-0.10	-0.31**	-0.04	-0.08
		(2.14)	(0.12)	(0.14)	(0.16)	(0.19)
Median spell length (hours)	14776	0.15	-0.05	-0.07**	0.01	0.05
		(0.69)	(0.04)	(0.03)	(0.05)	(0.05)
Maximum spell length (hours)	14776	10.92	-0.79	-2.95**	-2.86	-4.46**
		(20.49)	(1.27)	(1.48)	(1.75)	(2.15)
Mean of mean voltage during a spell	14776	189.73	1.35	-8.82***	1.18	-14.22***
		(35.25)	(2.28)	(2.34)	(2.84)	(3.85)
Median of mean voltage during a spell	14776	191.86	1.65	-8.39***	1.89	-14.22***
		(36.15)	(2.32)	(2.37)	(2.86)	(3.86)
Mean of minimum voltage during a spell	14776	187.18	1.23	-8.86***	2.22	-13.70***
		(36.73)	(2.31)	(2.46)	(2.97)	(4.05)

Notes: This table shows the difference-in-differences effects of the transformer injection intervention on measures of voltage quality using monthly data at the GridWatch device level. Outcomes in the first 4 rows measure the total hours in each monthly observation that the electricity had a certain status. Outcomes in all other rows are measured based on identifying individual low-voltage 'spells' during which voltage fell below 207V (10% below nominal) in any 2-minute interval. Individual spells with different characteristics are then aggregated to the month-device level. Months where there were no low voltage spells for particular devices are assigned a 0 for outcomes that are not conditional on experiencing at least one such spell. Number of spells refers to the number of individual low voltage spells in a device-month. Total hours of spells take the sum of the duration of individual spells in a device-month. Mean, median, and maximum spell length are statistics calculated over all individual spells in a device-month. Mean and median of mean spell voltage are statistics calculated over the mean voltage level within a spell for all individual spells in a device-month. Mean minimum voltage is calculated similarly. These statistics are conditional on any low-voltage spell being observed in a device-month. All regressions include month and site fixed effects. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C7: Impact of transformer injection intervention on primary outcomes for businesses

	N	Control Mean (SD)	Post (SE)	Treat (SE)	Post x Treat (SE)
Reported hours of bad voltage in past month	1647	40.36 [82.33]	-39.61*** (4.33)	9.54 (8.08)	-10.26 (8.27)
Reported total outage hours in past month	1651	37.48 [45.04]	-34.27*** (3.33)	1.21 (4.49)	-0.35 (4.59)
Max monthly WTP for perfect reliability	1658	3.41 [4.79]	-1.49*** (0.27)	-0.30 (0.33)	0.36 (0.37)
Max monthly WTP for half of curr. outages	1658	1.74 [3.07]	-0.49** (0.19)	-0.29 (0.21)	0.36 (0.26)
Max monthly WTP for half of curr. volt. fluc.	1049	2.07 [3.81]	-0.19 (0.37)	-0.45 (0.46)	0.56 (0.47)
Voltage damage and protection index	1658	-0.15 [0.93]	-0.07 (0.06)	0.14 (0.08)	-0.08 (0.08)
Any appliance damaged by voltage in past year	1658	0.22 [0.41]	-0.01 (0.03)	0.04 (0.04)	-0.05 (0.04)
Amt spent on burnt/broken apps in past year	1628	7.91 [30.66]	-4.74*** (1.75)	0.13 (2.31)	1.56 (2.38)
Any voltage protective device	1658	0.19 [0.39]	-0.03*** (0.01)	0.04 (0.03)	-0.01 (0.02)
Value of voltage protective devices	1426	5.66 [30.79]	-3.78** (1.70)	-0.22 (2.53)	-0.18 (2.44)
Uses an alternative energy source	1658	0.06 [0.24]	-0.01 (0.01)	-0.00 (0.02)	0.00 (0.01)
Total number of appliances	1658	7.07 [5.54]	-0.08 (0.13)	-0.02 (0.36)	0.18 (0.19)
Monthly electricity spending	1594	19.42 [18.71]	-6.41*** (0.81)	-1.74 (1.30)	0.42 (1.05)
Total profit in past month	1104	108.61 [158.44]	-21.45** (10.80)	-11.91 (12.02)	5.21 (14.07)
Total revenue in past month	1280	436.45 [689.48]	18.37 (43.52)	5.87 (55.89)	-87.44 (58.15)
Total monthly reported business spending	1206	304.41 [395.39]	34.28 (35.48)	38.12 (38.04)	-97.95** (49.39)

Notes: This table shows the difference-in-difference results from the **??** for businesses only. Each row represents an outcome. All variables measuring values are in USD; 1 USD≈5.8 GHS during the baseline survey and ≈8.5 GHS during the endline survey. Results are qualitatively unchanged when using logged versions of the outcomes. In all the regressions, we control for respondent age, gender, education, whether the meter is paid directly by the user, number of meter users, whether the respondent is part of the household or business sample, whether the location includes both a household and a business, and district fixed effects. The control mean is the mean for control sites in the baseline period. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Refer to Table D5 for impacts of transformer injection on additional business outcomes.

Table C8: Impact of transformer injection intervention on primary outcomes

	N	Control Mean (SD)	Post (SE)	FDR q-value	Treat (SE)	FDR q-value	Post × Treat (SE)	FDR q-value
Reported hours of bad voltage in past month	3130	43.05 (87.25)	-42.36*** (4.69)	0.001	8.56 (7.47)	0.622	-9.12 (7.64)	0.444
Reported total outage hours in past month	3139	38.61 (47.88)	-35.70*** (2.93)	0.001	1.48 (3.87)	0.881	-0.87 (4.05)	0.933
Max monthly WTP for perfect reliability	3150	3.62 (4.85)	-1.84*** (0.22)	0.001	-0.37 (0.27)	0.622	0.47 (0.30)	0.365
Max monthly WTP for half of curr. outages	3150	1.74 (2.98)	-0.59*** (0.17)	0.002	-0.18 (0.19)	0.622	0.22 (0.22)	0.527
Max monthly WTP for half of curr. volt. fluc.	2000	2.14 (3.68)	-0.42 (0.30)	0.218	-0.42 (0.36)	0.622	0.57 (0.39)	0.365
Voltage damage and protection index	3150	0.00 (1.00)	-0.11** (0.05)	0.040	0.09 (0.06)	0.622	-0.10* (0.06)	0.365
Any appliance damaged by voltage in past year	3150	0.25 (0.43)	-0.05* (0.03)	0.123	0.04 (0.03)	0.622	-0.05 (0.04)	0.417
Amt spent on burnt/broken apps in past year	3080	10.22 (37.23)	-6.90*** (1.47)	0.001	0.25 (1.98)	0.917	1.15 (2.05)	0.755
Any voltage protective device	3150	0.25 (0.44)	-0.02** (0.01)	0.025	0.02 (0.02)	0.831	-0.02 (0.01)	0.365
Value of voltage protective devices	2668	6.05 (25.51)	-3.06*** (1.00)	0.007	0.52 (1.57)	0.881	0.22 (1.70)	0.933
Uses an alternative energy source	3150	0.05 (0.22)	-0.01 (0.01)	0.381	0.00 (0.01)	0.881	-0.00 (0.01)	0.933
Total number of appliances	3150	8.59 (5.98)	0.04 (0.09)	0.691	-0.10 (0.34)	0.881	0.08 (0.13)	0.755
Monthly electricity spending	3050	19.51 (18.67)	-6.41*** (0.67)	0.001	-2.01* (1.12)	0.622	0.77 (0.89)	0.601
Total profit in past month	1104	108.61 (158.44)	-21.45** (10.80)	0.076	-11.91 (12.02)	0.622	5.21 (14.07)	0.865
Total revenue in past month	1280	436.45 (689.48)	18.37 (43.52)	0.691	5.87 (55.89)	0.917	-87.44 (58.15)	0.365
Total monthly reported business spending	1206	304.41 (395.39)	34.28 (35.48)	0.381	38.12 (38.04)	0.622	-97.95** (49.39)	0.365
Total household monthly income	1358	360.69 (491.13)	-76.42** (36.60)	0.066	12.66 (43.51)	0.881	-72.63 (50.21)	0.365

Notes: This table shows the difference-in-difference results from the **??** pooling businesses and households. Each row represents an outcome. All outcomes pre-specified in the pre-analysis plan (Berkouwer et al., 2019). All variables measuring values are in USD; 1 USD≈5.8 GHS during the baseline survey and ≈8.5 GHS during the endline survey. Results are qualitatively unchanged when using logged versions of continuous outcomes. Sample sizes vary for some questions because of missing data, particularly when respondents were unable to estimate monetary values with a high degree of confidence, or because some questions were only asked to a subset of respondents. In all the regressions, we control for respondent age, gender, education, whether the meter is paid directly by the user, number of meter users, whether the respondent is a household or a business, and district fixed effects. The control mean is the mean for control sites in the baseline period. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Sharpened FDR q-values following Anderson (2008) are also shown.

Table C9: Impact of transformer injection intervention on primary outcomes, accounting for implementation issues and construction timing

	All sites	Commissioned sites (SMEC)	New tx confirmed sites	All sites, IV new tx with treat	All sites, except close sites
Reported hours of bad voltage in past month	-9.12	-10.21	-12.72	-12.04	-4.90
	(7.64)	(7.75)	(7.86)	(10.04)	(8.36)
Reported total outage hours in past month	-0.87	-0.98	-2.33	-1.16	4.09
	(4.05)	(4.09)	(4.41)	(5.33)	(5.10)
Max monthly WTP for perfect reliability	0.47	0.49	0.58*	0.62	0.23
	(0.30)	(0.31)	(0.33)	(0.40)	(0.38)
Max monthly WTP for half of curr. outages	0.22	0.22	0.28	0.30	-0.01
	(0.22)	(0.22)	(0.24)	(0.29)	(0.29)
Max monthly WTP for half of curr. volt. fluc.	0.57	0.62	0.76*	0.75	0.25
	(0.39)	(0.38)	(0.41)	(0.50)	(0.53)
Voltage damage and protection index	-0.10*	-0.11*	-0.13**	-0.14*	-0.16**
	(0.06)	(0.06)	(0.07)	(0.08)	(0.08)
Any appliance damaged by voltage in past year	-0.05	-0.06	-0.07*	-0.06	-0.08*
	(0.04)	(0.04)	(0.04)	(0.05)	(0.05)
Amt spent on burnt/broken apps in past year	1.15	0.97	-0.01	1.52	1.54
	(2.05)	(2.07)	(2.18)	(2.72)	(2.84)
Any voltage protective device	-0.02	-0.01	-0.01	-0.02	-0.02
	(0.01)	(0.01)	(0.01)	(0.02)	(0.02)
Value of voltage protective devices	0.22	0.17	1.03	0.30	-1.11
	(1.70)	(1.73)	(1.91)	(2.26)	(1.72)
Uses an alternative energy source	-0.00	-0.00	0.00	-0.00	0.02
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)
Total number of appliances	0.08	0.08	0.14	0.10	0.12
	(0.13)	(0.14)	(0.14)	(0.18)	(0.16)
Monthly electricity spending	0.77	0.74	0.73	1.02	0.90
	(0.89)	(0.90)	(0.97)	(1.18)	(1.13)
Total profit in past month	5.21	5.61	11.88	7.05	6.39
	(14.07)	(14.22)	(15.19)	(18.82)	(18.81)
Total revenue in past month	-87.44	-87.03	-18.32	-120.09	-104.18
	(58.15)	(59.03)	(58.05)	(83.21)	(71.27)
Total monthly reported business spending	-97.95**	-100.21**	-54.34	-130.42*	-143.81**
	(49.39)	(49.90)	(49.76)	(68.44)	(59.91)
Total household monthly income	-72.63	-79.87	-84.01	-98.25	-51.47
	(50.21)	(50.78)	(54.26)	(67.42)	(58.58)

This table shows the same difference-in-difference analyses presented in **??**. Column 1 replicates the 'Post × Treat' column from **??**. Column 2 drops two sites in Kaneshie where the construction manager SMEC indicated the new transformer was not commissioned successfully. Column 3 drops sites where our own construction monitoring activities indicated no new transformer was built in a treatment site or a new transformer was built in a control site. Column 4 instruments for observing a new transformer during the construction monitoring visits with site treatment assignment. Column 5 shows the difference-in-difference results from the main equation, by dropping geographically close control sites. We define distance by the shortest path to a treatment site, and we drop ant control site that is within 1.3 km from a treatment site, where 1.3 km is the median distance to a treatment site. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C10: Impact of transformer injection intervention on main business outcomes, dropping geographically close control sites

	N	Control Mean (SD)	Post (SE)	Treat (SE)	Post x Treat (SE)
Total profit in past month	1006	100.92	-27.10*	3.90	-7.22
		[151.98]	(16.37)	(15.24)	(22.87)
Total monthly reported business spending	1065	278.23	64.83	80.61**	-130.21**
		[362.22]	(48.82)	(39.01)	(58.39)
Total wages and benefits paid in past month	1118	57.64	16.07	5.85	-16.54
		[142.30]	(15.10)	(13.32)	(17.16)
Total materials cost in past month	1089	179.16	61.45	84.15***	-116.12**
		[283.70]	(37.79)	(29.81)	(46.38)
Monthly electricity spending	1231	18.46	-5.55***	-1.10	-0.34
		[19.40]	(1.03)	(1.62)	(1.21)
Amount spent on all alt. fuels in past month	1256	4.12	0.45	-0.01	-0.86
		[11.98]	(1.12)	(0.86)	(1.34)
Total revenue in past month	1088	394.04	34.99	63.22	-117.17*
		[553.18]	(60.59)	(53.35)	(70.78)
Estimated change in revenue with perfect electricity	985	384.54	-128.46*	67.62	-191.37*
		[757.15]	(71.24)	(70.91)	(99.81)
Number of workers	1256	1.92	0.06	0.06	0.12
		[1.40]	(0.09)	(0.15)	(0.11)
Share of men employees	1252	0.31	-0.00	0.01	-0.01
		[0.42]	(0.02)	(0.02)	(0.02)
Share of full-time employees	1245	0.90	-0.06***	0.01	0.01
		[0.21]	(0.02)	(0.02)	(0.03)
Business open during any 'dark' hours	1256	0.81	-0.11***	-0.05	0.00
		[0.40]	(0.03)	(0.04)	(0.04)
Total hours typically open	1256	12.44	-0.64***	-0.38	-0.10
		[2.60]	(0.16)	(0.23)	(0.24)
Applied for loans in past 12 months	1256	0.14	0.02	0.08***	-0.04
		[0.35]	(0.04)	(0.03)	(0.05)
Total value of outstanding loans	1233	319.92	96.74	143.51	-279.61**
		[1213.41]	(105.84)	(113.73)	(132.18)
Permanently change industry/business (0-1)	1252	0.02	-0.01	-0.01	0.03*
		[0.14]	(0.01)	(0.01)	(0.01)
Permanently substitute to more labor (0-1)	1252	0.00	-0.00	0.01	0.01
		[0.07]	(0.01)	(0.01)	(0.01)
Permanently substitute to non-electric tools or machines (0-1)	1252	0.02	-0.01	-0.02*	0.01
		[0.14]	(0.01)	(0.01)	(0.01)
Business engaged in retail activities	1256	0.43	0.02	-0.00	-0.02*
		[0.50]	(0.01)	(0.05)	(0.01)
Business engaged in manufacturing activities	1256	0.21	0.01	-0.01	0.00
		[0.41]	(0.01)	(0.03)	(0.01)
Business engaged in other service activities	1256	0.36	-0.02*	0.01	0.02
		[0.48]	(0.01)	(0.05)	(0.01)
Business activity likely using electricity	1256	0.20	0.01	0.02	-0.00
		[0.40]	(0.01)	(0.03)	(0.01)

Notes: This table shows the difference-in-differences results from the main equation, by dropping the geographically close control sites. We define distance by the shortest path to a treatment site, and we drop any control site that is within 1.3 km from a treatment site, where 1.3 km is the median distance to a treatment site. Each row represents an outcome. In all regressions, we control for respondent age, gender, education, whether the meter is paid directly by the user, number of meter users, whether the respondent is the business owner or a manager, whether the location includes both a household and a business, and district fixed effects. The control mean is the mean for control sites in the baseline period. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table C11: Correlations between voltage quality and primary outcomes

	N	Control Mean (SD)	Avg voltage (SE)	Hours below nominal-10 (SE)
Reported hours of bad voltage in past month	3130	43.05	-0.010***	0.028***
		[87.25]	(0.00)	(0.01)
Reported total outage hours in past month	3092	32.20	-0.009***	0.024***
		[31.09]	(0.00)	(0.01)
Max monthly WTP for perfect reliability	3150	3.62	-0.006***	0.014***
		[4.85]	(0.00)	(0.00)
Max monthly WTP for half of curr. outages	3150	1.74	-0.005***	0.011**
		[2.98]	(0.00)	(0.00)
Max monthly WTP for half of curr. volt. fluc.	2000	2.14	-0.003**	0.008
		[3.68]	(0.00)	(0.01)
Voltage damage and protection index	3150	0.00	-0.003*	0.010**
		[1.00]	(0.00)	(0.00)
Any appliance damaged by voltage in past year	3150	0.25	-0.004**	0.010**
		[0.43]	(0.00)	(0.00)
Amt spent on burnt/broken apps in past year	3080	10.22	-0.003**	0.007*
		[37.23]	(0.00)	(0.00)
Any voltage protective devices	3150	0.25	-0.000	0.004
		[0.44]	(0.00)	(0.00)
Value of voltage protective devices	2668	6.05	-0.003	0.008*
		[25.51]	(0.00)	(0.00)
Uses an alternative energy source	3150	0.05	0.000	-0.001
		[0.22]	(0.00)	(0.00)
Total number of appliances	3150	8.59	0.001	-0.004
		[5.98]	(0.00)	(0.00)
Monthly electricity spending	3050	19.51	-0.001	0.005
		[18.67]	(0.00)	(0.00)
Total profit in past month	1104	108.61	-0.000	-0.000
		[158.44]	(0.00)	(0.00)
Total revenue in past month	1280	436.45	0.001	-0.006
		[689.48]	(0.00)	(0.00)
Total monthly reported business spending	1206	304.41	0.001	-0.006
		[395.39]	(0.00)	(0.00)
Total household monthly income	1358	360.69	-0.002	0.010*
		[491.13	(0.00)	(0.01)

Notes: This table shows the results from separate regressions of normalized outcomes on measures of voltage quality. Each row represents a different outcome pooling business and household respondents. The control mean is calculated for the original (non-normalized) outcome variable in column 2. Mean voltage in control sites is 219.5V at baseline and 224.6V at endline. Voltage is measured by assigning each respondent GridWatch data based on the nearest devices for either the last 30 days from the survey date or for the full baseline period (prior to November 1, 2020) and endline period (from April 1, 2021 - July 20, 2022). In all the regressions, we also control for respondent age, gender, education, whether the meter is paid directly by the user, number of meter users, whether the location includes both a household and a business, and district fixed effects. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Appendix D: Pre-specified analyses of socioeconomic outcomes

Table D1: Impact of transformer injection intervention on willingness to pay outcomes

	N	Control Mean (SD)	Post (SE)	Treat (SE)	Post x Treat (SE)
Max monthly WTP for perfect reliability	3150	3.62 [4.85]	-1.84*** (0.22)	-0.37 (0.27)	0.47 (0.30)
Max monthly WTP for half of curr. outages	3150	1.74 [2.98]	-0.59*** (0.17)	-0.18 (0.19)	0.22 (0.22)
Max monthly WTP for 1 unnan. 8hr outage	906	1.11 [1.78]	-0.55*** (0.16)	-0.18 (0.17)	0.13 (0.21)
Max monthly WTP for 1 announ. 8hr outage	924	1.45 [2.22]	-0.95*** (0.20)	-0.05 (0.24)	0.27 (0.27)
Max monthly WTP for 4 unnan. 2hr outages	884	1.19 [2.10]	-0.71*** (0.15)	0.29 (0.22)	-0.19 (0.23)
Max monthly WTP for half of curr. volt. fluc.	2000	2.14 [3.68]	-0.42 (0.30)	-0.42 (0.36)	0.57 (0.39)
Max WTP for generator	2887	356.03 [452.35]	-61.97** (24.41)	29.91 (25.69)	-37.43 (32.41)

Additional results from **??**. All variables measuring values are in USD. Results are qualitatively unchanged when using logs. Sample sizes are lower for reliability scenarios that were only presented to a random subset of respondents. In all the regressions, we control for respondent age, gender, education, whether the meter is paid directly by the user, number of meter users, whether the respondent is part of the household or business sample, whether the location includes both a household and a business, and district fixed effects. The control mean is the mean for control sites in the baseline period. Standard errors are clustered at the site level. $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table D2: Impact of transformer injection intervention on alternative energy and defensive investment outcomes

	N	Control Mean (SD)	Post (SE)	Treat (SE)	Post x Treat (SE)
Uses an alter. energy source	3150	0.05 [0.22]	-0.01 (0.01)	0.00 (0.01)	-0.00 (0.01)
Value of alter. energy sources	3084	223.44 [3711.51]	-62.94* (35.06)	558.72 (691.33)	-615.79 (641.94)
Count of voltage defensive invest.	3150	0.35 [0.70]	-0.06*** (0.01)	-0.01 (0.04)	0.01 (0.02)
Value of voltage protective devices	2843	8.10 [34.09]	-0.45 (3.50)	-0.31 (1.85)	-0.47 (3.76)
Has multi-phase system	2810	0.04 [0.20]	0.01 (0.01)	0.01 (0.01)	-0.01 (0.01)
Frequency of switching phases (z-score)	3150	0.02 [1.18]	-0.03 (0.05)	0.11 (0.08)	-0.08 (0.07)
Cost of installing phase system	2732	10.15 [110.88]	-4.14 (4.47)	3.60 (6.65)	-6.59 (6.19)

Notes: This table shows the difference-in-difference results from the main equation. Each row represents an outcome. All variables measuring values are in USD; 1 USD≈5.8 GHS during the baseline survey and ≈8.5 GHS during the endline survey. Results are qualitatively unchanged when using logged versions of continuous outcomes. In all the regressions, we control for respondent age, gender, education, whether the meter is paid directly by the user, number of meter users, whether the respondent is part of the household or business sample, whether the location includes both a household and a business, and district fixed effects. The control mean is the mean for control sites in the baseline period. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table D3: Impact of transformer injection intervention on energy/electricity spending and burnt appliance outcomes

	N	Control Mean (SD)	Post (SE)	Treat (SE)	Post x Treat (SE)
Monthly electricity spending	3098	19.37	-6.26***	-2.05*	0.75
		[18.58]	(0.67)	(1.10)	(0.87)
Has generator	3150	0.04	-0.01	-0.00	0.01
		[0.20]	(0.01)	(0.01)	(0.01)
Generator fuel and maintenance costs in past 3 months	3150	5.15	-3.89***	-2.37	1.60
		[48.99]	(1.41)	(1.94)	(1.66)
Has solar panels	3150	0.01	-0.00	0.00	-0.00
		[0.08]	(0.00)	(0.00)	(0.00)
Amount spent on solar panel repairs in past 3 months	3145	0.52	-0.52	-0.53	0.52
		[14.41]	(0.52)	(0.52)	(0.52)
Count of alternative fuels used in past 3 months	3150	0.92	0.05*	-0.01	0.01
		[0.85]	(0.03)	(0.03)	(0.04)
Amount spent on all alt. fuels in past month	3150	8.73	-0.93	-1.53	0.89
		[31.42]	(1.08)	(1.23)	(1.20)
Amount spent on charcoal as alt. fuel in past month	2993	12.21	13.37***	-0.18	-3.25
		[26.11]	(2.94)	(1.48)	(3.66)
Amount spent on gas as alt. fuel in past month	2996	27.56	14.58***	-0.73	-0.40
		[38.74]	(2.03)	(1.94)	(4.12)
Amount spent on wood as alt. fuel in past month	3140	5.40	-4.28	-5.52	5.64
		[144.29]	(4.42)	(5.36)	(4.51)
Total hrs per day lightbulbs are on	3150	9.17	-0.96***	0.25	-0.58
		[5.68]	(0.34)	(0.38)	(0.46)
Any appliance damaged by voltage in past year	3141	0.25	-0.05*	0.04	-0.05
		[0.43]	(0.03)	(0.03)	(0.04)
Has burnt/broken apps. that were not replaced in past year	3141	0.08	-0.02*	0.02	-0.01
		[0.28]	(0.01)	(0.02)	(0.02)
Amt spent on burnt/broken apps in past year	3114	10.11	-6.82***	0.33	1.17
		[36.99]	(1.46)	(1.94)	(2.03)

Notes: This table shows the difference-in-difference results from the main equation. Each row represents an outcome. All variables measuring values are in USD; 1 USD≈5.8 GHS during the baseline survey and ≈8.5 GHS during the endline survey. Unless shown, results are qualitatively unchanged when using logged versions of continuous outcomes. In all the regressions, we control for respondent age, gender, education, whether the meter is paid directly by the user, number of meter users, whether the respondent is part of the household or business sample, whether the location includes both a household and a business, and district fixed effects. The control mean is the mean for control sites in the baseline period. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table D4: Impact of transformer injection intervention on electricity-related indices

	N	Control Mean (SD)	Post (SE)	Treat (SE)	Post x Treat (SE)
Outage backup power index	3150	0.00	-0.06*	0.01	-0.01
		[1.00]	(0.04)	(0.05)	(0.04)
Freq. of wetcell batt./generator	3150	0.06	-0.06	-0.01	0.02
use during outage (normalized)		[1.26]	(0.04)	(0.06)	(0.05)
Share of apps. using	3131	0.10	-0.10	0.03	-0.04
solar/generator during outage (normalized)		[1.41]	(0.06)	(0.08)	(0.08)
Alternative energy/fuel sources	3150	-0.00	-0.04	0.03	-0.03
index		[1.00]	(0.05)	(0.06)	(0.07)
Uses an alter. energy source	3150	0.05	-0.01	0.00	-0.00
		[0.22]	(0.01)	(0.01)	(0.01)
Count of alt. light sources	3150	0.10	-0.11*	0.05	-0.05
(normalized)		[1.10]	(0.06)	(0.08)	(0.09)
Count of alt. fuel sources	3150	-0.08	0.06*	-0.01	0.01
(normalized)		[0.96]	(0.03)	(0.03)	(0.05)
Appliance protection index	3150	-0.00	-0.20***	-0.04	0.07*
		[1.00]	(0.03)	(0.05)	(0.04)
Count of voltage defensive apps.	3150	0.08	-0.10***	-0.02	0.02
(normalized)		[1.11]	(0.02)	(0.06)	(0.03)
Has multi-phase system	2810	0.04	0.01	0.01	-0.01
		[0.20]	(0.01)	(0.01)	(0.01)
Share of TVs plugged to TV guard	877	2.44	-2.42***	-0.19	0.26
(normalized)		[0.81]	(0.14)	(0.23)	(0.24)
Share of fridges plugged to fridge	805	1.27	-1.36***	-0.03	0.09
guard (normalized)		[0.51]	(0.10)	(0.09)	(0.14)

Additional results from **??**. The main outcomes are indices; we also show results for the index components for completeness. Indices are constructed as the sum of normalized components, and are then normalized to have mean 0 and SD 1 for control respondents in the baseline. In all the regressions, we control for respondent age, gender, education, whether the meter is paid directly by the user, number of meter users, whether the respondent is part of the household or business sample, whether the location includes both a household and a business, and district fixed effects. The control mean is the mean for control sites in the baseline period. Standard errors are clustered at the site level. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table D5: Impact of transformer injection intervention on business outcomes

	N	Control Mean (SD)	Post (SE)	Treat (SE)	Post x Treat (SE)
Total profit in past month	1339	112.81	-24.29**	-10.05	-10.73
		[166.13]	(10.58)	(12.75)	(19.48)
Total monthly reported business spending	1407	316.09	29.35	26.51	-94.98*
		[417.09]	(37.18)	(38.80)	(49.36)
Total wages and benefits paid in past month	1483	63.89	8.55	-3.40	-9.25
		[159.07]	(9.49)	(11.53)	(12.43)
Total materials cost in past month	1438	212.79	36.09	40.06	-90.48**
		[337.94]	(29.11)	(29.38)	(40.00)
Total revenue in past month	1443	438.36	15.74	-0.67	-99.30*
		[675.55]	(42.47)	(53.22)	(56.60)
Estimated change in revenue with perfect electricity	1302	544.86	-329.84***	-102.81	9.04
		[1958.40]	(118.00)	(132.79)	(138.45)
Number of workers	1658	1.99	0.11*	-0.02	0.07
		[1.90]	(0.06)	(0.13)	(0.09)
Share of men employees	1652	0.31	-0.01	0.00	0.00
		[0.42]	(0.01)	(0.01)	(0.02)
Share of full-time employees	1643	0.91	-0.05***	0.01	-0.00
		[0.21]	(0.02)	(0.02)	(0.02)
Business open during any 'dark' hours	1658	0.77	-0.08***	-0.01	-0.02
		[0.42]	(0.03)	(0.03)	(0.04)
Total hours typically open	1658	12.16	-0.58***	-0.13	-0.16
		[2.46]	(0.13)	(0.19)	(0.22)
Temporary busines response type index	1658	0.00	-0.09	0.02	0.07
		[0.73]	(0.06)	(0.08)	(0.10)
Temporary switch to alternative energy due to reliability (0-2)	1652	0.06	0.04**	0.01	-0.01
		[0.30]	(0.02)	(0.02)	(0.03)
Temporary stop working, work less due to reliability (0-2)	1652	0.43	-0.03	0.01	-0.01
		[0.71]	(0.04)	(0.06)	(0.06)
Temporary postpone working, work same due to reliability (0-2)	1652	0.33	-0.12***	-0.02	-0.01
		[0.63]	(0.03)	(0.05)	(0.05)
Temporary switch tools/labor due to reliability (0-2)	1652	0.16	0.02	-0.01	0.03
		[0.44]	(0.03)	(0.03)	(0.04)
Temporary switch business activities due to reliability (0-2)	1652	0.15	-0.03	0.02	0.04
		[0.41]	(0.03)	(0.03)	(0.04)
Temporary reduce labor due to reliability (0-2)	1652	0.21	-0.05	0.01	0.02
		[0.49]	(0.04)	(0.04)	(0.05)
Other temporary response due to reliability	1652	0.02	-0.02*	0.00	0.02
		[0.17]	(0.01)	(0.01)	(0.02)
Temporary business response intensity index	1658	-0.17	-0.32***	0.62	-0.61
		[0.79]	(0.06)	(0.42)	(0.41)
Days of switching to solar energy	1658	0.00	-0.00	0.00	0.00
		[0.02]	(0.00)	(0.00)	(0.00)
Days of switching to generator	1658	0.01	-0.01*	0.04	-0.05
		[0.06]	(0.00)	(0.04)	(0.04)
Days of switching to wetcell	1658	0.00	-0.00	0.01	-0.01
		[0.01]	(0.00)	(0.01)	(0.01)
Days stopping or postponing work in past 1 month	1658	-0.18	-0.32***	0.01	-0.01
		[0.75]	(0.05)	(0.07)	(0.07)
Percentage of business hours stopping work	1658	-0.19	-0.34***	0.08	-0.07
		[0.75]	(0.06)	(0.09)	(0.09)
Permanent business response index	1658	0.00	-0.12*	-0.09	0.27**
		[0.73]	(0.07)	(0.07)	(0.12)
Permanently substitute to non-electric tools or machines (0-1)	1652	0.02	-0.01	-0.01**	0.01
		[0.13]	(0.01)	(0.01)	(0.01)
Permanently substitute to more labor (0-1)	1652	0.01	-0.01	0.00	0.02
		[0.09]	(0.00)	(0.01)	(0.01)
Permanently change industry/business (0-1)	1652	0.01	-0.01	-0.01	0.03**
		[0.12]	(0.01)	(0.01)	(0.01)
Purchase generator (0-1)	1652	0.01	-0.01	-0.01	0.01
		[0.12]	(0.01)	(0.01)	(0.01)
Business qualitative assessments index	1658	-0.05	-0.76***	0.02	-0.06
		[0.89]	(0.07)	(0.08)	(0.09)
Perceived safety in area (1-5)	1657	3.40	0.02	-0.06	0.15
		[1.02]	(0.08)	(0.10)	(0.11)
Importance of electricity as obstacle to business (1-5)	1652	3.89	-0.23***	0.03	-0.07
		[0.99]	(0.08)	(0.08)	(0.11)
Belief that Dumsor is back (1-5)	1652	2.91	1.49***	0.12	-0.05
		[1.29]	(0.10)	(0.11)	(0.12)
Expected reliability one year from today (1-3)	1338	2.34	0.30***	-0.02	0.08
		[0.80]	(0.07)	(0.07)	(0.09)
Importance of finance/access to credit as a business obstacle (1-5)	1658	2.79	-0.38***	0.02	0.11
		[1.29]	(0.11)	(0.10)	(0.15)

Additional results from **??**. All variables measuring values are in USD. Results are qualitatively unchanged when using logs. All regressions control for baseline socioeconomic characteristics. The control mean is for the baseline period. SEs clustered by site. *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$