The Impact of Solar Panel Installation on Electricity Consumption and Production

Economic Assessment of European Climate Policies
University of Edinburgh
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Motivation

- Countries use regulatory and fiscal policies to promote the entrance and deployment of renewable energy production:
  - feed-in-tariffs (FITs), electric quota obligations (RPS), net metering, tax incentives
- In 2010 Uruguay foster a "net metering" policy

Motivation

Research Questions

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    - Magnitude is an empirical question

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1. Alters electricity extracted and injected into the grid
   - Magnitude is an empirical question

2. Back-of-the-envelope calculations on:
   - Rebound effect

3. Propose an alternative policy: households/firms could store the electricity in batteries and sell it when optimal
   - CO_2 emissions
   - Equity problem

Contributions

- We expand the literature on agents' use of solar panels (Borenstein, 2017; Boccard & Gautier, 2021; Sexton et al., 2021; Feger et al., 2022; Pretnar & Abajian, 2023; Beppler et al., 2023).
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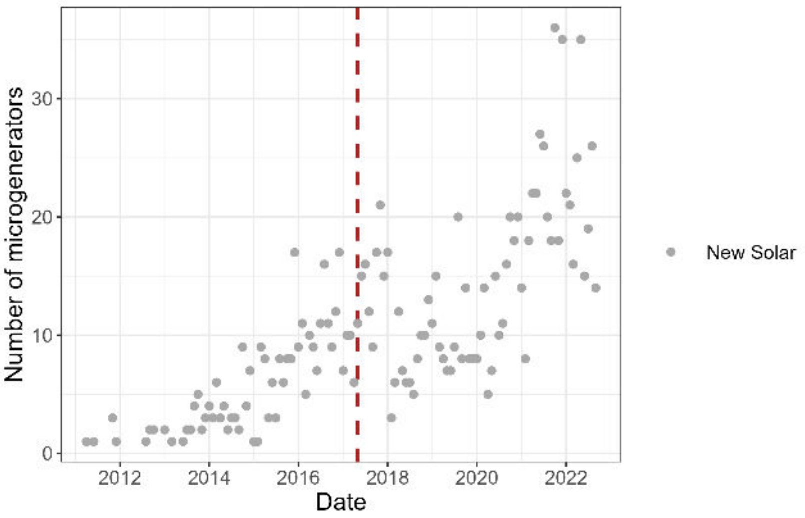
- Expand the scope. Most research has been focused entirely on the developed world (Feger et al., 2022; De Groote & Verboven, 2019; Islam & Meade, 2013; Jeong, 2013)

Data and Descriptive statistics



Data and Descriptive statistics

- Household or firm-level data:
  - Electricity consumption from the grid 12 months before the solar panel installation
  - Electricity extracted and injected into the grid 12 months after the solar panel installation
  - 0.72% of the capacity installed
  - 1275 Agents
- CO_2 emission from the thermal electricity generation from monthly data on gas oil, fuel oil, and natural gas consumption from UTEi (2022)

Data and Descriptive statistics

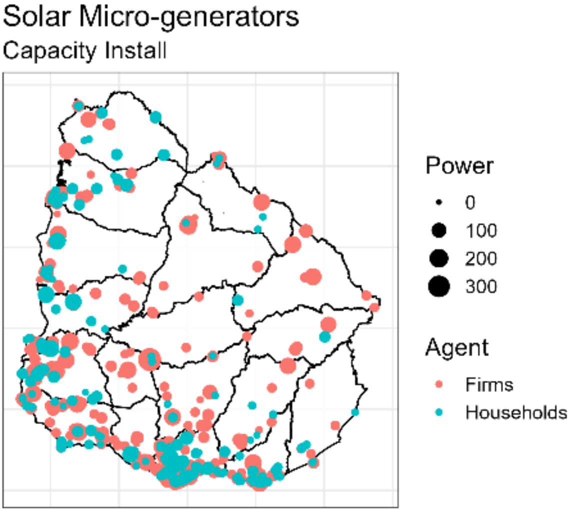


Figure: Location of Microgenerators (UTEi, 2022)

Data and Descriptive statistics

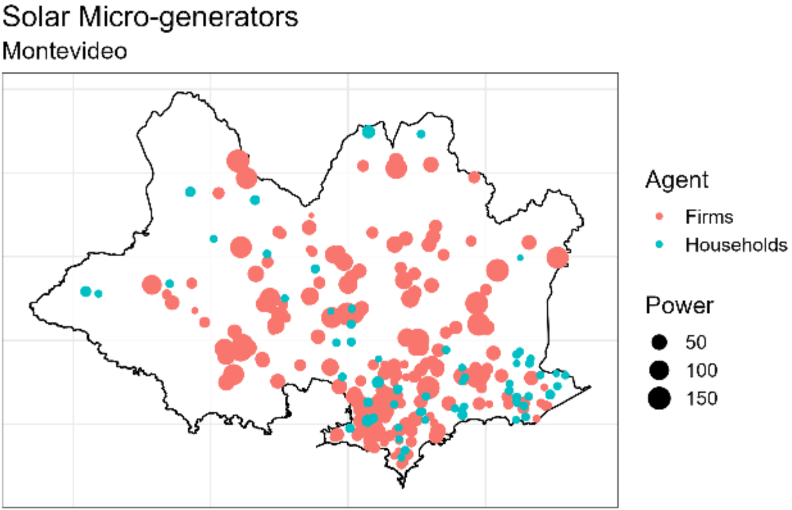


Figure: Capital city - Location of Microgenerators (UTEi, 2022)

Data and Descriptive statistics

	Mean	S.D	Min.	Max.
Extractions (KWh)	6096.03	14064.05	0.08	297253.2
Firms	8174.38	16145.46	0.08	297253.2
HH	910.12	1800.41	0.43	33108.8
Injections (KWh)	1545.98	3272.36	0	136844.1
Firms	1449.4	3344.24	0	136844.1
HH	287.91	771.80	0	24405.6
Household	0.29		0	1
Firms	0.71		0	1
N	24,386	24,386	24,386	24,386
CO_2 emissions kg (Mill)	10.81	10.41	3.44e-06	35.02
N	132	132	132	132

Data obtained from UTEi (2022). CO_2 emissions from UTEi (2022).

Methodology

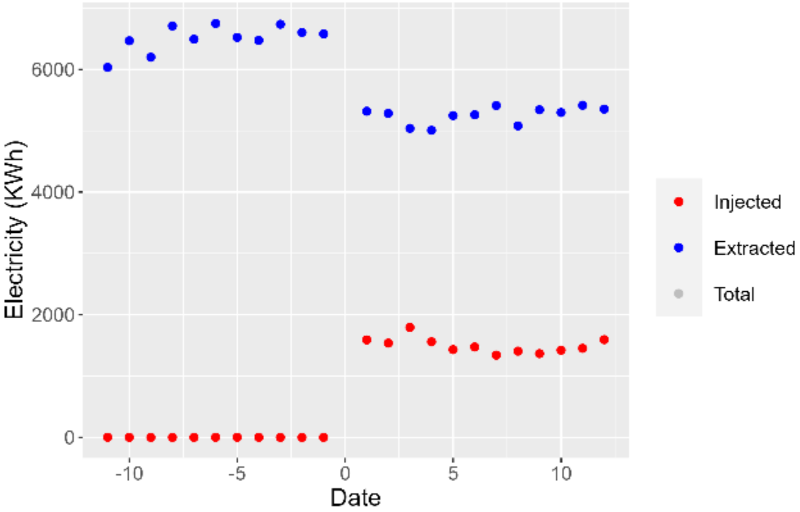


Figure: Electricity extracted and injected into the grid

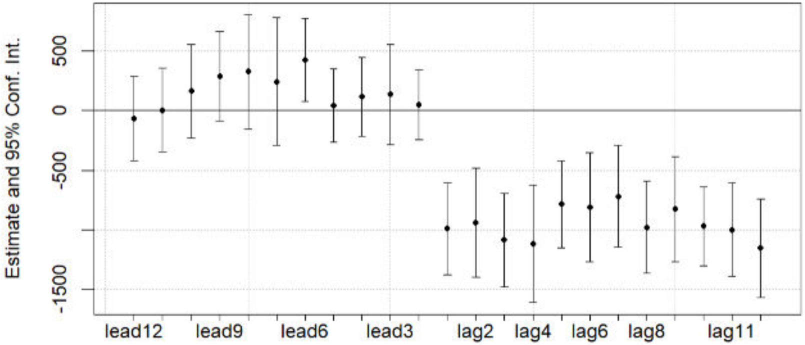
Methodology

(Dynamic) Event - study:

$$y_{ist} = \alpha_i + \sum_{\tau=-12}^{-2} \rho_\tau D_{is\tau} + \sum_{\tau=1}^{12} \lambda_\tau D_{is\tau} + \delta_t + \epsilon_{ist} \qquad (1)$$

- y_{ijt} - Electricity extracted/injected into the grid for agent i, state s, at month t
- Treatment is at time 0
- α_i - Agent fixed effect
- δ_t is - Time fixed effect
  - month $*$ year or month $+$ year fixed effect
- ϵ_{ist} - Eror term which is cluster at state level

Results: Electricity *extracted* from the grid - Plot



Event study plot using 12 leads/lags before/after the solar panel installation, controlling for ID + month fixed effects.

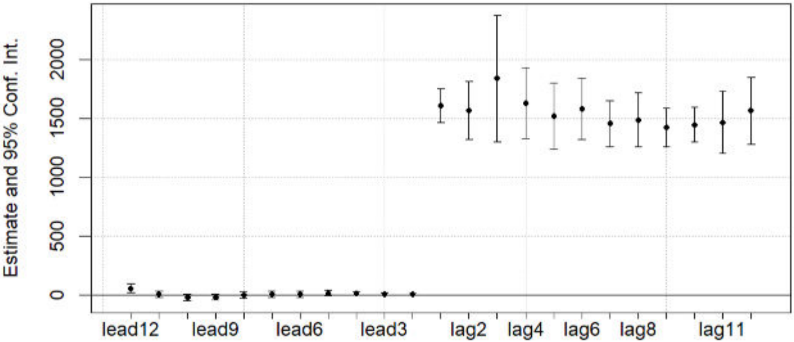
Electricity *extracted* from the grid - Heterogeneity by agent

	Panel (a): Electricity taken from the grid - Firms		
Solar panel installation	-1491.19***	-1427.34***	-1439.81***
	(97.51)	(204.10)	(200.91)
N	17,409	17,409	17,409

	Panel (b): Electricity taken from the grid - HH		
Solar panel installation	-108.872***	-191.25**	-193.71**
	(25.87)	(89.55)	(89.523)
ID Fixed Effects	Y	Y	Y
month	Y	Y	N
year	N	Y	N
month $*$ year	N	N	Y
N	6,977	6,977	6,977

This table shows the effect of installing a solar panel on the electricity taken from the grid, using different sets of fixed effects and different types of agents. Panel(a) uses only firms, whereas Panel (b) uses only households. Column (1) uses ID + month fixed effects; column (2) uses ID + month +year fixed effects; finally, column (3) uses ID + month $*$ year. Standard errors are cluster at state level. Significance levels: ***0.01 **0.05 *0.1.

Results: Electricity *injected* into the grid - Plot



Event study plot using 12 leads/lags before/after the solar panel installation, controlling for ID + month fixed effects.

Electricity *injected* into the grid - Heterogeneity by agent

	Panel (a): Electricity injected into the grid - Firms		
Solar panel installation	2135.82***	2286.01***	2257.25***
	(109.20)	(137.41)	(136.88)
N	13,033	13,033	13,033

	Panel (b): Electricity injected into the grid - HH		
Solar panel installation	455.28***	495.76***	491.71***
	(33.39)	(42.62)	(43.02)
ID Fixed Effects	Y	Y	Y
month	Y	Y	N
year	N	Y	N
month $*$ year	N	N	Y
N	5,931	5,931	5,931

This table shows the effect of installing a solar panel on the electricity injected into the grid, using different sets of fixed effects. Column (1) uses ID + month fixed effects; column (2) uses ID + month +year fixed effects; finally, column (3) uses ID + month $*$ year. Standard errors are cluster at state level. Significance levels: ***0.01 **0.05 *0.1.

Value to consumers

Using only the injection estimation

- Firms: save between 120 and 270 USD (at 2017 prices)
  - “middle consumers” rate: peak, off-peak, and plain rate
- Households: save between 25 and 55 USD (base 2017)
  - “intelligent rate”: peak, off-peak, and plain

Back of the envelope calculations

Detalle de Facturación

CONCEPTO	IMPORTE
Acuerdo de servicio: 3360746979	
Total de Conceptos Energéticos	83.415,60
Total de Otros Conceptos	0,00
----------------	----------------
Otros Conceptos de la Cuenta	**-7.328,03**
----------------	----------------
SUBTOTALES	
Importe Gravado 22%	83.415,60
IVA Tasa Básica 22%	18.351,43
Saldos a Favor	-7.328,03
Total	94.439,00

Rebound effect

$$Consumption_{\text{before solar panel}} = Extraction_{\text{bsp}} \tag{2}$$

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$$\begin{aligned} Consumption_{\text{after solar panel}} = & (Production - Injection) + \\ & (Extraction_{\text{bsp}} - Extraction_{\text{asp}}) \end{aligned} \tag{3}$$

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$$\begin{gathered} C_{\text{asp}} - C_{\text{bsp}} = (Production - Injection) + \\ (Extraction_{\text{bsp}} - Extraction_{\text{asp}}) - Extraction_{\text{bsp}} \end{gathered} \tag{4}$$

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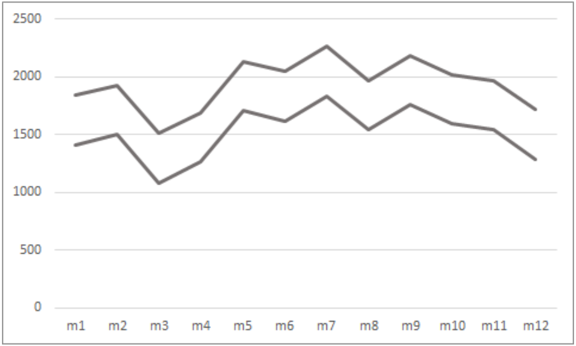
$$C_{\text{asp}} - C_{\text{bsp}} = (Production - Injection) - Extraction_{\text{asp}} \quad (5)$$

Rebound effect

	Rebound Effect		
	Total	Firms	Households
Sunlight = 4.52 hours	1338 (20%)	1477 (22%)	1260 (19%)
Sunlight = 5.0 hours	1764 (26%)	2019 (30%)	1454 (22%)

- 28.5 % Rebound (Beppler et al., 2023)



Results CO_2

- Short-term effect of microgenerators in CO_2:

$$\text{Fossil Fuels}_t = \alpha_1 + \beta W_t + \gamma S_t + \rho M_t + \phi D_t + \text{hour} * \text{month} + \text{month} * \text{year} + \epsilon_t \tag{6}$$

- Fossil Fuels_t is the observed quantity produced by thermal facilities at hour h, on day d, in month m, and year t
- M_t is the electricity injected from microgenerators
- W_t and S_t a total wind and solar electricity produced
- D_t is the electricity consumption
- ϵ_{ihdmt} is cluster at month*year to allow for serial correlation within a month (Fell, Kaffine, & Novan, 2021).

Results CO_2

	Fossil fuel
Microgenerators	-0.026
	(0.194)
Wind	-0.245***
	(0.028)
Solar	-0.111
	(0.049)
Consumption	0.321***
	(0.026)
Total Exports	0.271**
	(0.026)
hour $*$ month	Y
month $*$ year	Y
N	33,600

Linear minimization model

$$
\begin{aligned}
&\min_{q^i_{th}, F_{ht}} \sum_{h=0}^{23} \alpha^{CO_2}_{th} \times F_{th} \\
&s.t \; \sum_{h=0}^{23} q^i_{th} \leq Q^i, \forall i \\
&\mathrm{RD}_{th} \leq F_{th} + \sum_{i} q^i_{th}, \forall h
\end{aligned}
\tag{7}
$$

- q^i_{th} is the electricity sold to the grid from solar panels for agent i on day t at hour h
- F_{th} is the fossil-fuel-based electricity production
- $\alpha^{CO_2}_{th}$ is the CO_2-emissions-factor
- Q_i is the total electricity production
- RD_{th} is the residual demand

Model - Results

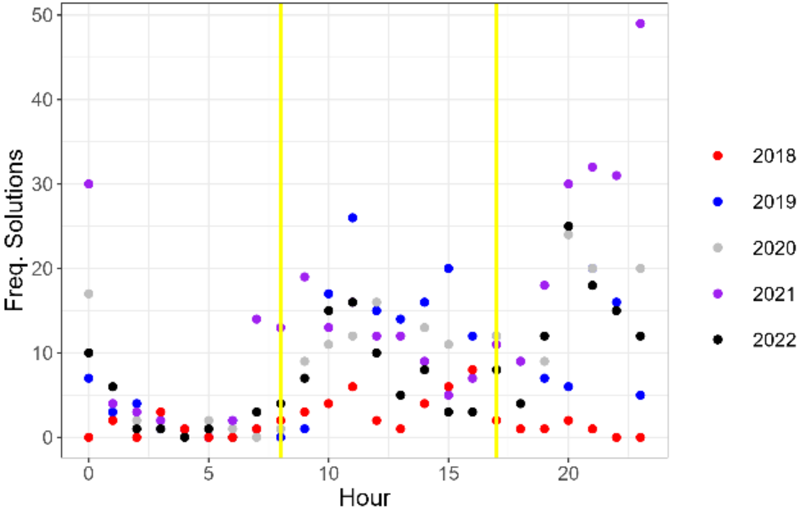


Figure: Model solution using CO_2

Model - Results

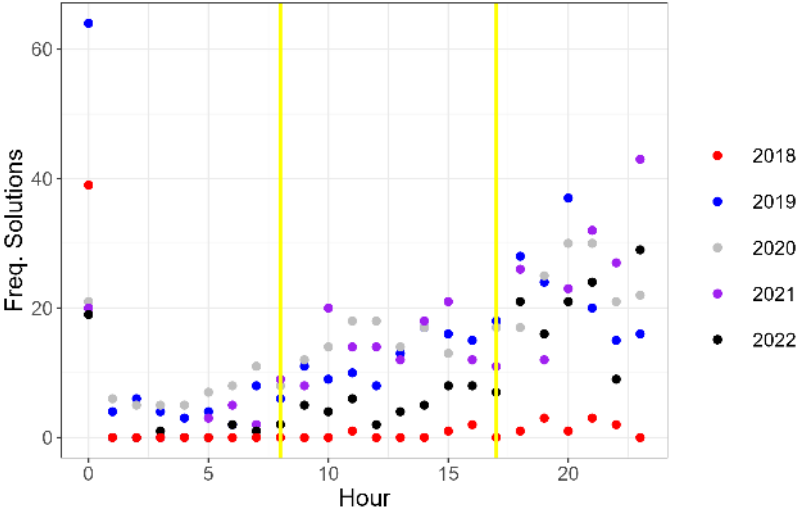


Figure: Model solution using spot prices

Conclusion

Use a novel dataset to study the effect of net-metering in Uruguay

- Electricity taken from the grid decreases by 1,100 kw*h* on av. - constant in time
  - Represents 18% reduction from the av. electricity consumption
- Electricity injected into the grid increases by 1,600 kw*h* on av. - constant in time
- Rebound effect between 20% and 26%
- No effect in CO2 emissions
- Lessen the equity implications and reduce CO_2 emissions - allow HH/firms to install solar panels and batteries.
  - Best hour to inject electricity is around 9 pm.

Questions?? Recommendations ??

Thank you!

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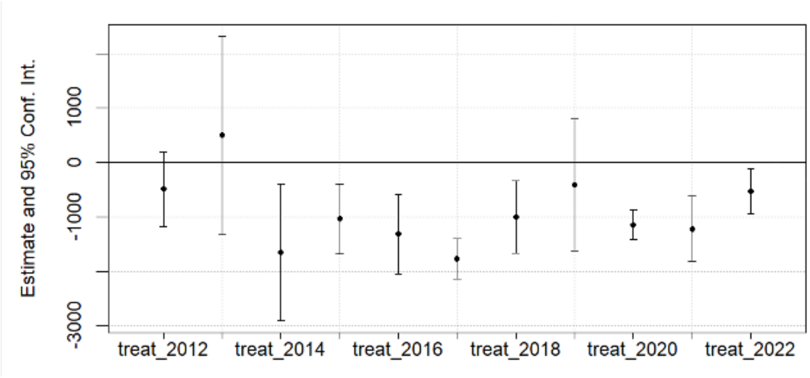
Problems in the Methodology

Potential problems:

- Decision to install solar panel is endogenous
- Timing of solar panel installation is endogenous
  - Bureaucratic processes - lack control of the timing of installation
- Early adopters may differ from future adopters:
  - We alleviate this concern by estimating the model year by year
  - We find no statistical difference between the yearly estimators Figure
- Read estimates as an upper bound effect of the policy

Appendix

Potential problems:



Appendix

- we compare the extraction estimation of 2013 versus 2014 and 2018

	P-values		
	Model 1	Model 2	Model 3
$\beta_{2013} - \beta_{2014} = 0$	0.145	0.197	0.201
$\beta_{2013} - \beta_{2018} = 0$	0.218	0.296	0.526
ID Fixed Effects	Y	Y	Y
month	Y	Y	N
year	N	Y	N
month $*$ year	N	N	Y
N	24,386	24,386	24,386

Back