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Solar power consumer behaviour: Diminishing rebound effects or reinstations of the old habits?

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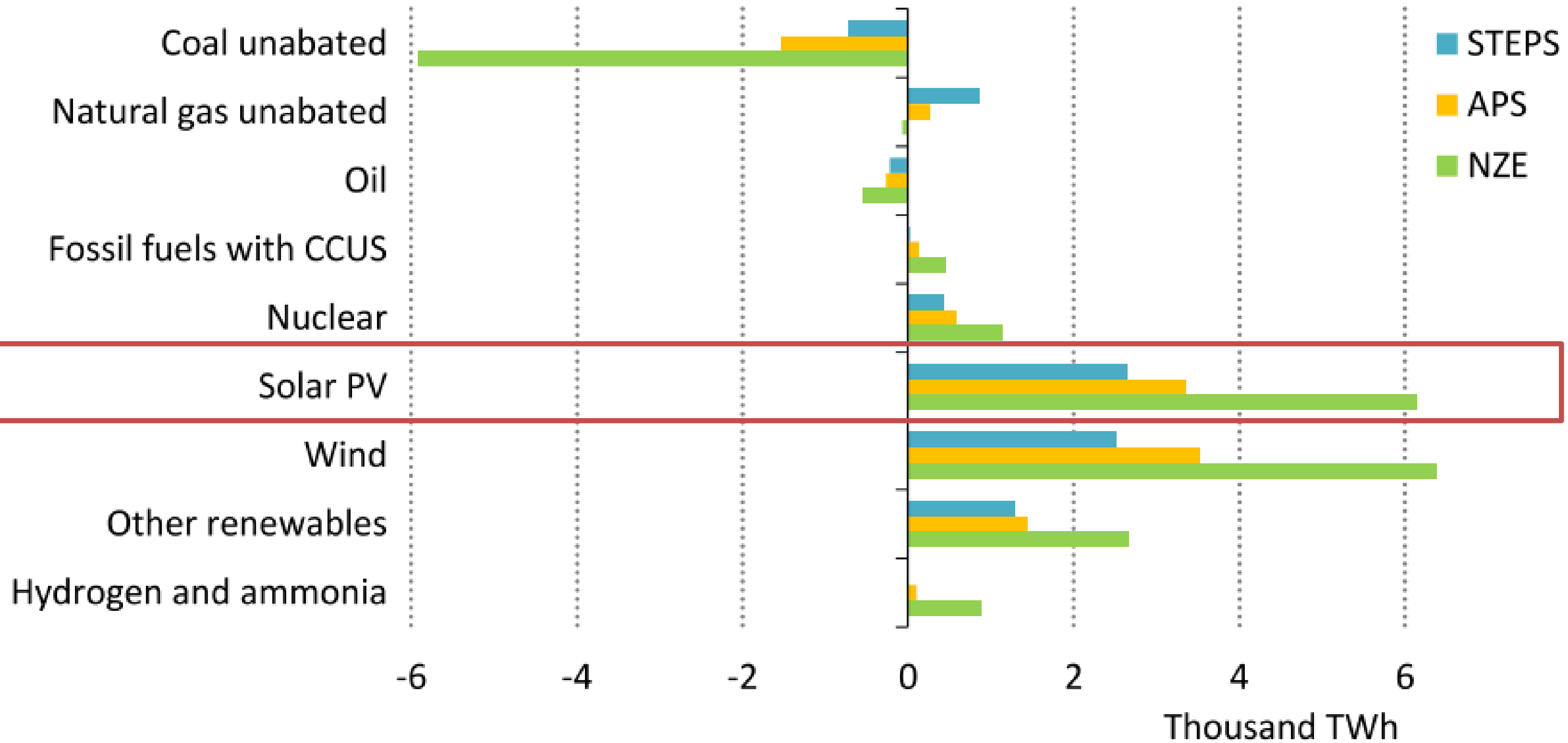
Introduction



Solar PV and wind take the lead in each scenario by 2030, but their strong growth at the expense of coal in the APS falls short of what is needed for net zero emissions by 2050

Source: World Energy Outlook 2021, IEA.

Introduction

- Whether residential solar energy effectively reduces carbon-intensive energy consumption?

- Behavioural changes may paradoxically offset the benefits of solar energy
  - mental accounting consumption behavioural concept (Thaler, 1985, 1999): “free electricity”
  - reinstatement of older habits: effectiveness of behavioural interventions was observed only over short periods in literature

Introduction

Objectives: Solar rebound effect and its dynamics

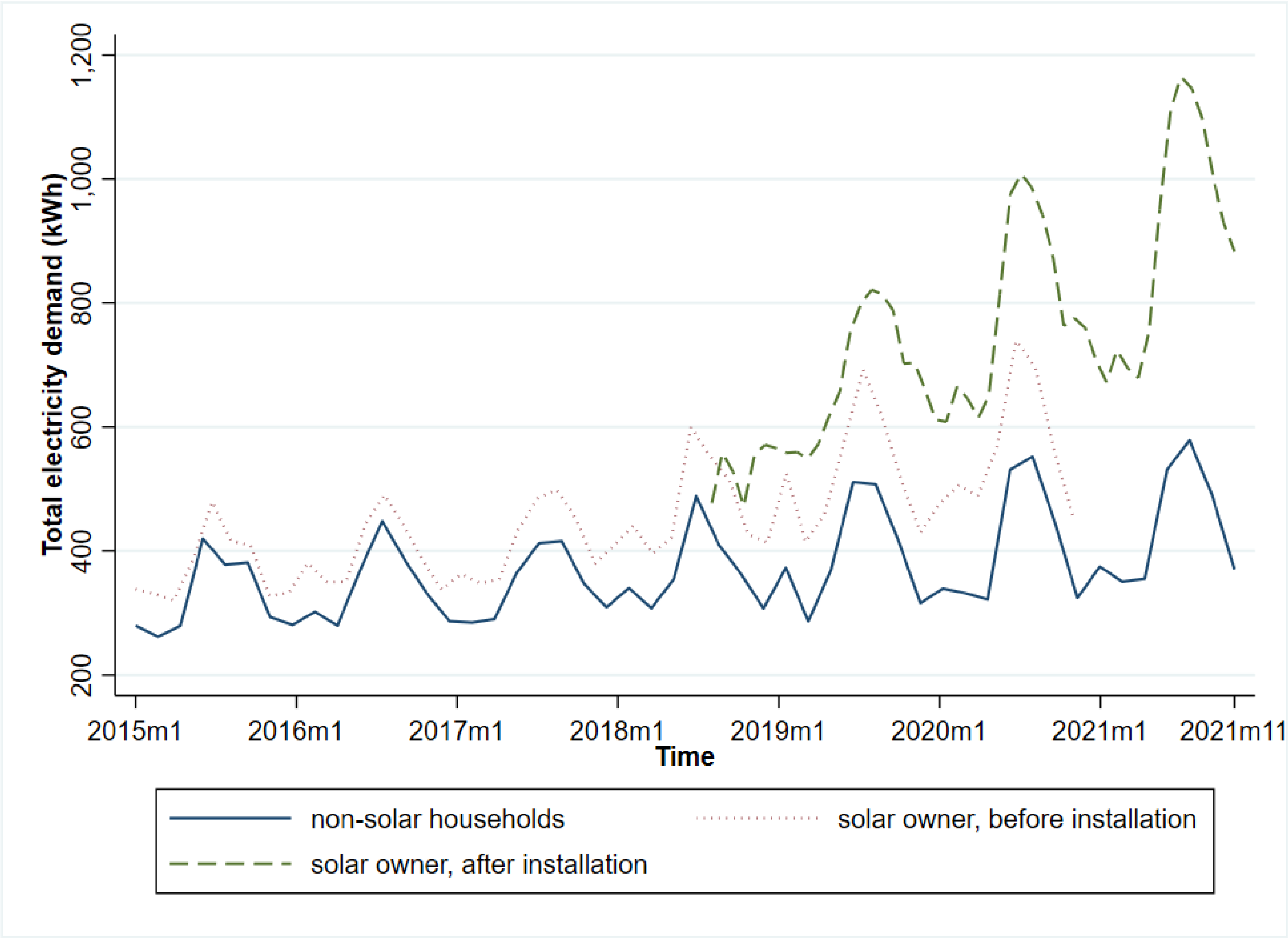
Our data: panel data set on the energy consumption

- 3,500 households in Hanoi, Vietnam
- from 2015 Jan to 2021 Nov

Contributions:

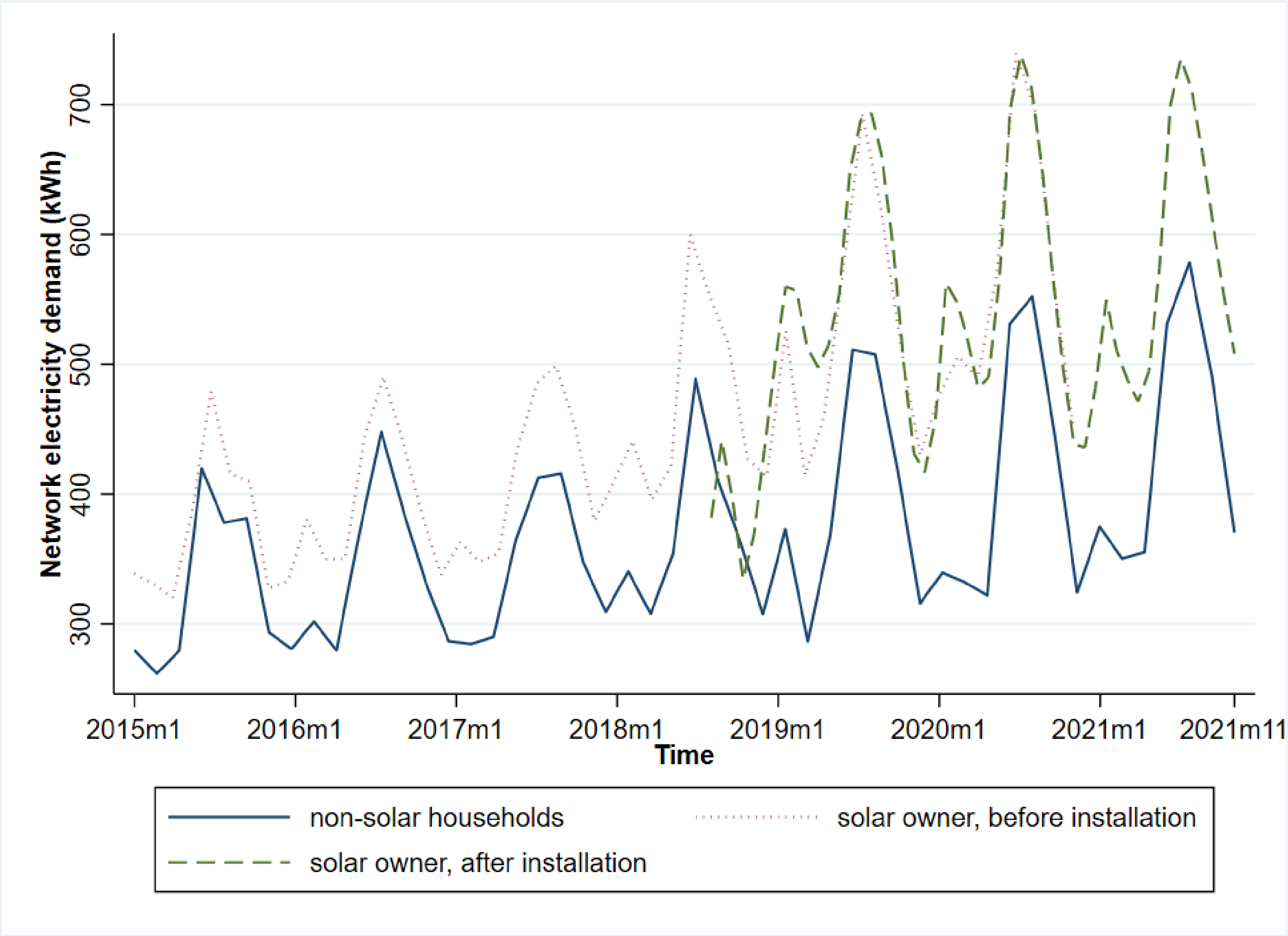
- Solar rebound effect
- Dynamics of the rebound effect
- Case study & policy implications for developing country

Power demand trends



Parallel trends between Households with and without Rooftop Solar

Power demand trends (contd.)



Parallel trends between Households with and without Rooftop Solar

Baseline models

- Panel Difference-in-Differences model

$$y_{it}^{E} = \alpha_i^{E} + \lambda_t^{E} + \theta^{E} y_{it-1}^{E} + \underline{\delta^{E} D_{it}} + \mathbf{x}_{it}'\boldsymbol{\beta}^{\boldsymbol{E}} + \varepsilon_{it}^{E}$$

  - y_{it}^{E}: electricity demand of household i at months t
  - $E = 1$: overall power demand; $E = 0$: electricity purchased from grid
  - D_{it}: dummy for the treatment, i.e., solar installation
  - $\mathbf{x}_{it}'$: vector of exogenous variables and interaction terms

- Diagnostics:
  - ✓ Parallel trends
  - ✓ Placebo effect $y_{it}^{E} = \alpha_i^{E} + \theta^{E} y_{it-1}^{E} + \lambda_t^{E} + \delta^{E} D_{it} + \sum_{f=1}^{3} \delta_f^{E} D_{it+f} + \mathbf{x}_{it}'\boldsymbol{\beta}^{\boldsymbol{E}} + \varepsilon_{it}^{E}$
  - ✓ Stability analysis (Balancing test) $\mathbf{x}_{it} = \alpha_i^{LHS} + \lambda_t^{LHS} + \boldsymbol{\pi} D_{it} + u_{it}$
  - ✓ Nickell's bias

Variable Descriptive Statistics

Variable	Description	Mean	Std. dev.	Min	Max
y_{it}^{1}	Total electricity demand (log form)	5.79	0.82	3.69	8.35
y_{it}^{2}	Amount of electricity purchased from the network (log form)	5.71	0.81	0.00	8.34
$month_t$	t-1 dummy variables for t months	44.66	23.99	1.00	83.00
D_{it}	Dummy variable of the installation period - D_{it} = 1: the solar system is installed - D_{it} = 0: not installed yet	0.13	0.34	0.00	1.00
$family_{it}$	No. of families in the household	1.11	0.44	0.00	8.00
$income_{dt}$	Log of average households' income (by district)	8.99	0.21	8.30	9.51
$price_{dt}$	Log of average electricity retail price (by district)	7.57	0.15	6.22	7.77
$urban_{dt}$	Urbanization rate (by district)	60.92	45.78	1.56	100.00
emp_{dt}	The employment rate (by district)	37.85	22.56	2.25	125.18
$solarcount_{dt}$	Number of the new solar system installations (by district)	1.12	2.96	0.00	44.00
$thirdchild_{dt}$	The rate of households have more than two children (by district)	4.62	4.39	0.10	20.20

Baseline Estimations

	y_{it}^1	y_{it}^1	y_{it}^2	y_{it}^2
Solar installation (treatment)	0.163***	0.181***	-0.036***	-0.032***
	(0.006)	(0.006)	(0.005)	(0.005)
Log of total electricity demand (lagged)	0.693***	0.699***		
	(0.005)	(0.005)		
Log of grid electricity demand (lagged)			0.701***	0.702***
			(0.005)	(0.005)
Average electricity price (log)	-0.150***		0.025*	
	(0.017)		(0.014)	
Urbanisation rate (%)	0.004		0.011**	
	(0.005)		(0.005)	
Average electricity price (log)* Urbanisation rate	0.002***		-0.00007	
	(0.000)		(0.000)	
Income (log)	3.454***		2.261***	
	(0.470)		(0.467)	
Squared income (log)	-0.191***		-0.126***	
	(0.026)		(0.026)	
Number of families	0.017**		0.019**	
	(0.007)		(0.008)	
Employment rate	-0.001		-0.001**	
	(0.000)		(0.000)	
Rate of household having more than 3 kids	0.0003		-0.0003	
	(0.001)		(0.001)	
Observations	223,562	223,562	223,562	223,562
Groups	3,544	3,544	3,544	3,544
Panel-level standard deviation (σ_u)	0.720	0.195	0.427	0.217
Standard deviation of ϵ_{it} (σ_e)	0.286	0.287	0.294	0.295
R-squared within model	0.660	0.658	0.594	0.594
R-squared overall model	0.507	0.852	0.647	0.842
R-squared between model	0.559	0.991	0.721	0.997

Rebound effect and the dynamics

- Rebound effect:
  - increase the total electricity demand by approx. 16.3%

    Qiu et al. (2019): 18% in Arizona

    Deng and Newton (2017): 16.7% in Sydney

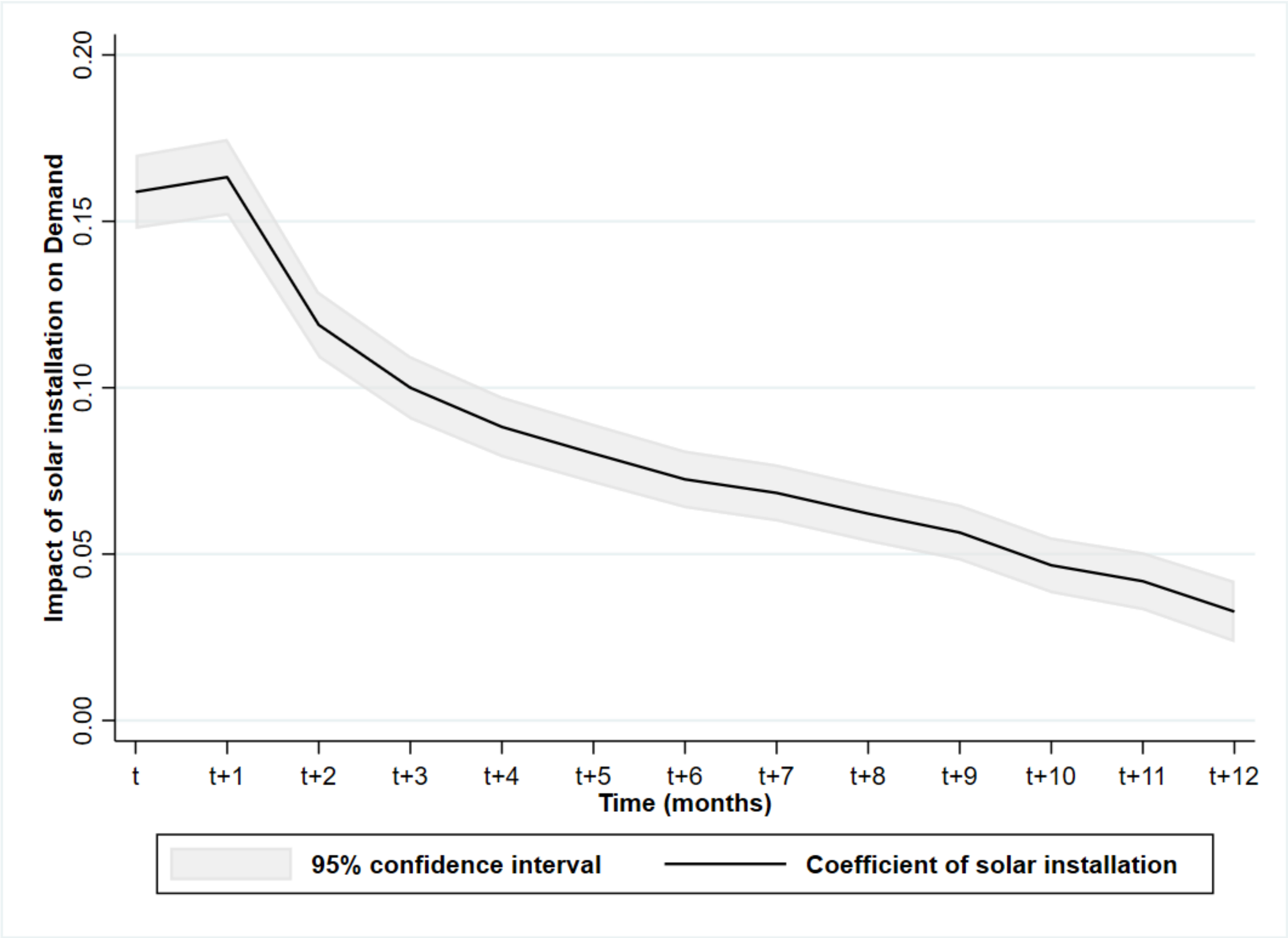
  - decrease of 3.6% in grid power demand

- Dynamics models

$$y_{it}^{E} = \alpha_i^{E} + \theta^{E} y_{it-1}^{E} + \lambda_t^{E} + \underline{\delta_k^{E} D_{it-k}} + \mathbf{x}_{it}' \boldsymbol{\beta}^{\boldsymbol{E}} + \varepsilon_{it}^{E}$$

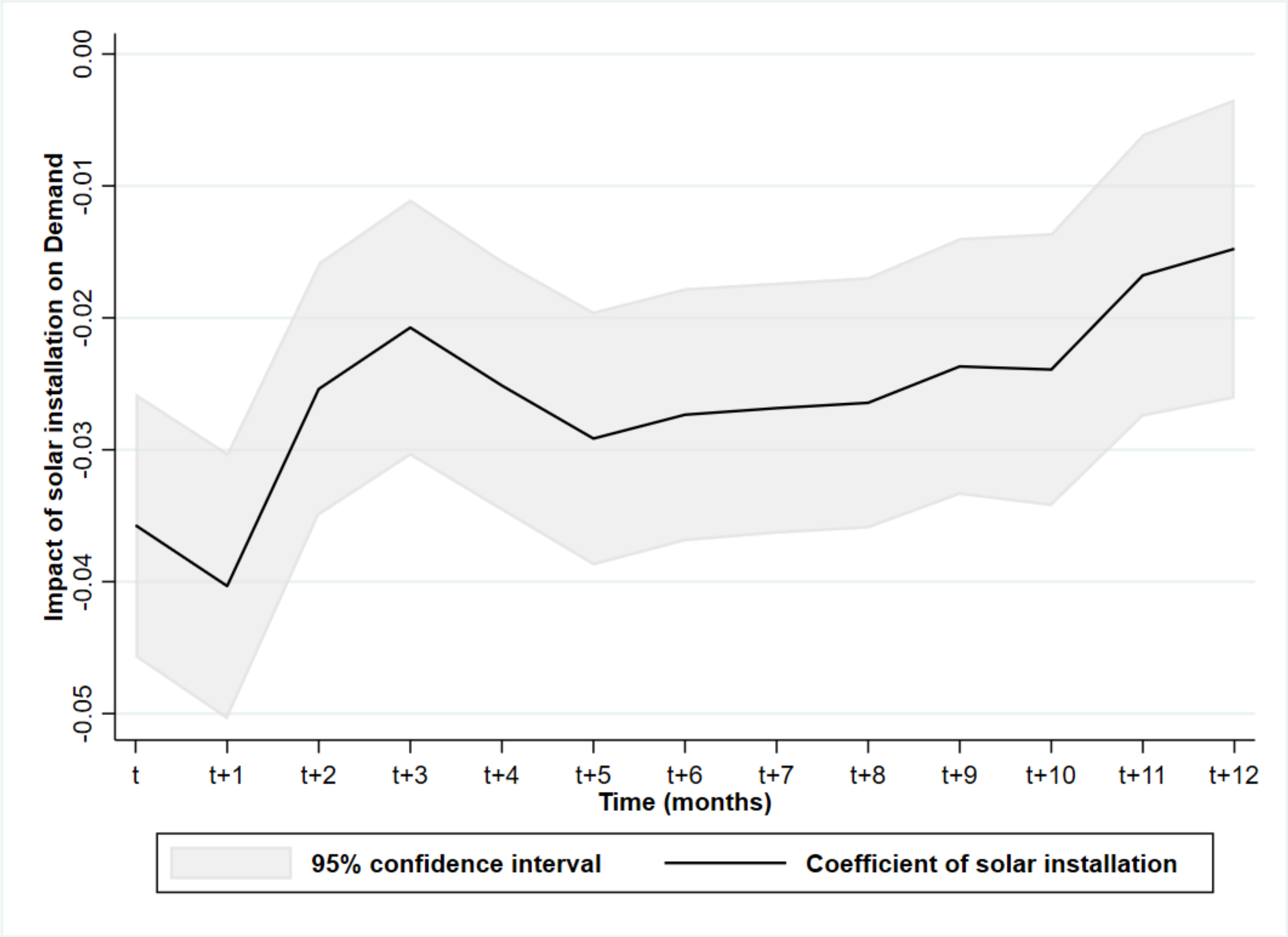
$$k = 0, \dots, 12.$$

Dynamics of the rebound



Dynamics of Rooftop Solar Installation's Rebound Effects: Overall demand

Dynamics of the rebound (contd.)



Dynamics of Rooftop Solar Installation's Rebound Effects: Grid demand

What happened?

- most family energy-used activities occurred in the evening that could not switch to daytime
- users rarely were equipped with solar batteries to store energy
- people did not sell solar energy to the grid
  - unattractive feed-in tariff

- Tier 1 (0-50 kWh):	7.24 cents/kWh
- Tier 2 (51-100 kWh):	7.48 cents /kWh
- Tier 3 (101-200 kWh):	8.69 cents /kWh
- Tier 4 (201-300 kWh):	10.94 cents /kWh
- Tier 5 (301-400 kWh):	12.22 cents /kWh
- Tier 6 (>400 kWh):	12.62 cents /kWh

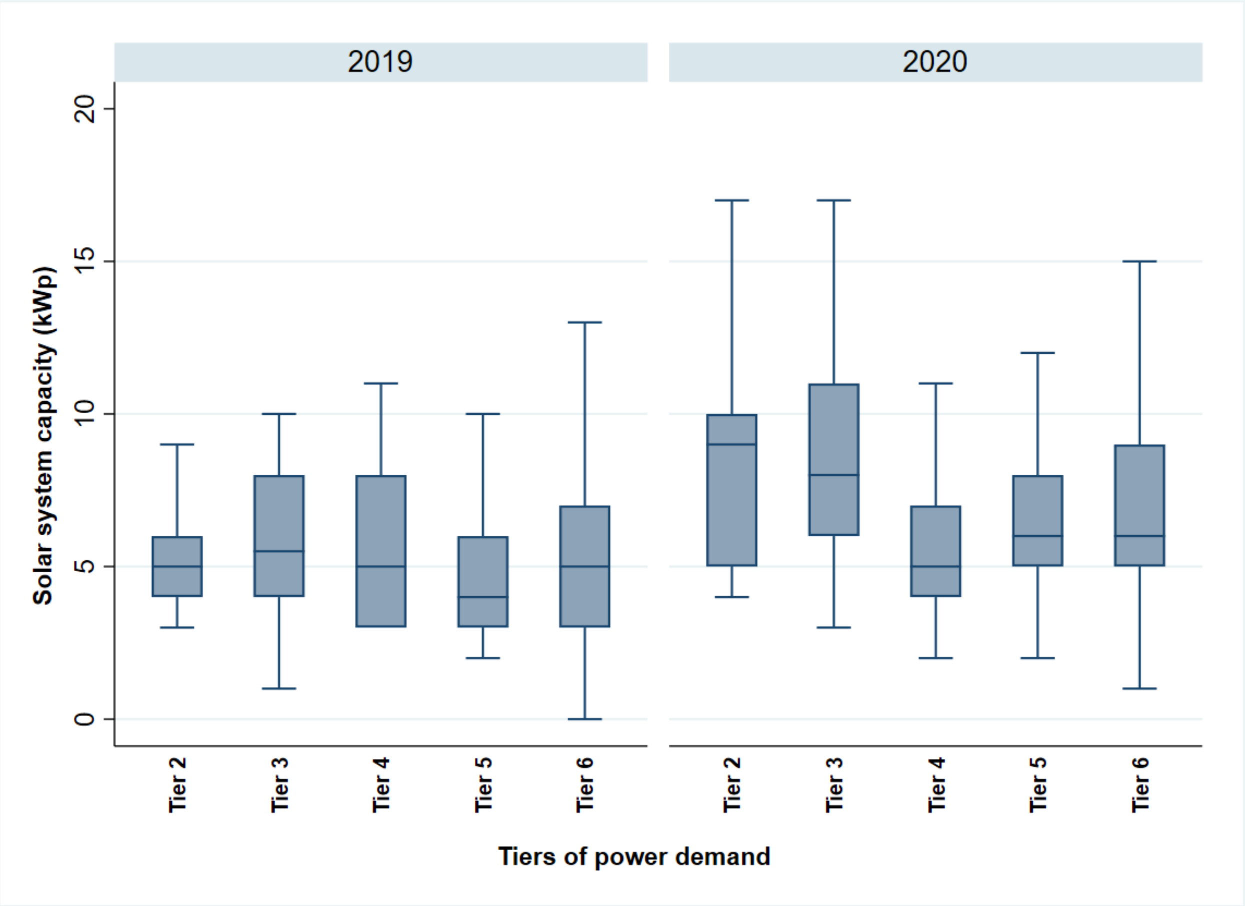
feed-in tariff of rooftop solar:
8.38 cents/kWh

  - complicated procedure
  - lack of comprehensive instructions

Solar capacity & Production

- Oversized installation …
  - Potential solar energy production in Hanoi:

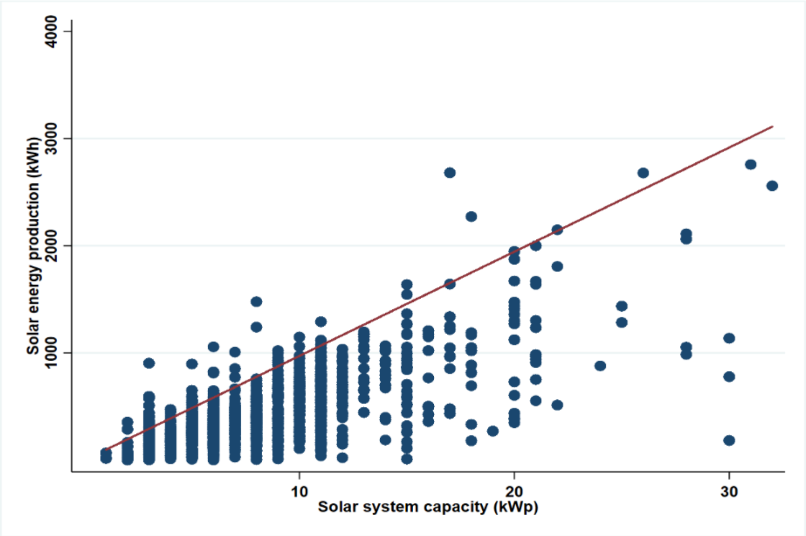
3.3 kWh/kWp per day ~ 100 kWh/kWp/month

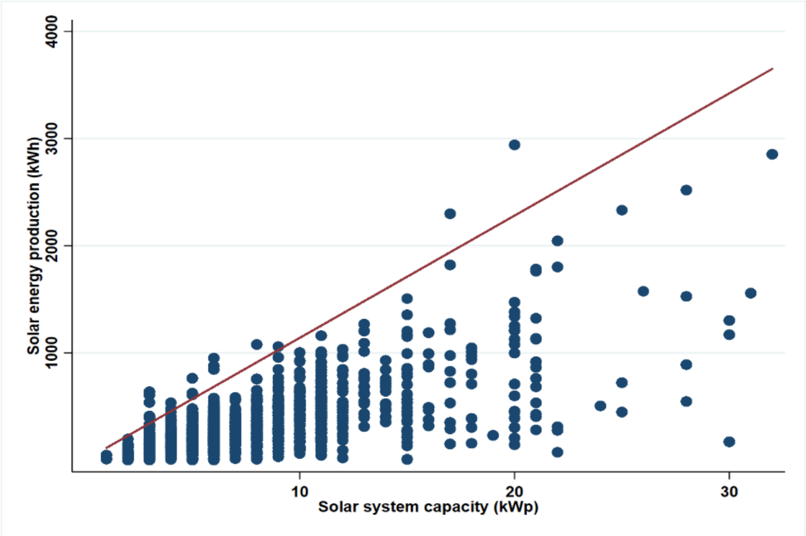


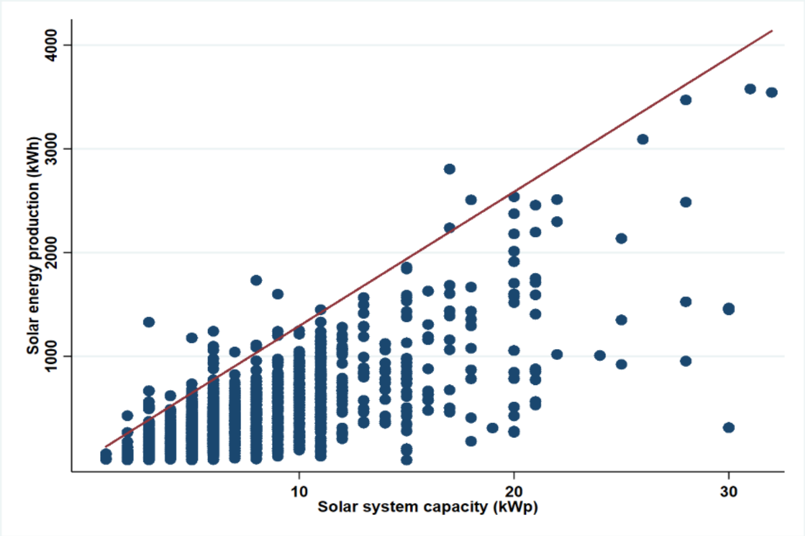
Distribution of Installed Solar Capacity

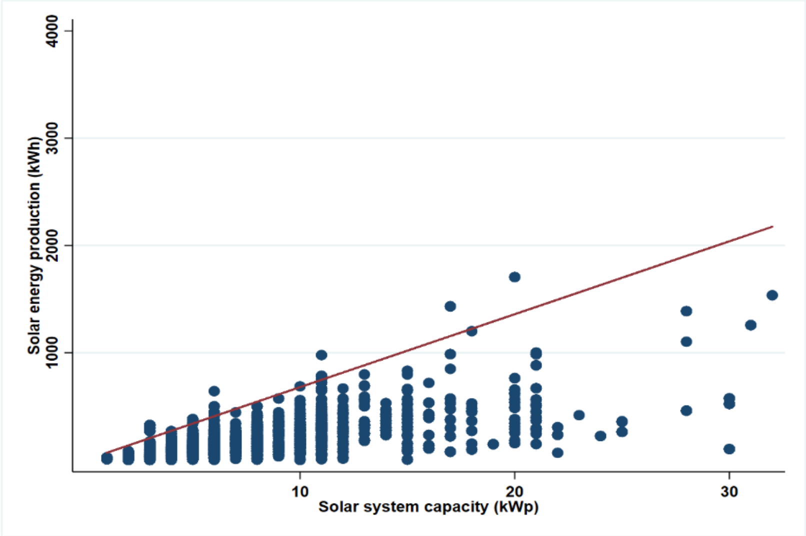
Solar capacity & Production

- ... but underproduction









Conclusion

- Solar energy has the potential to help mitigate the carbon footprint
- Solar energy development could not achieve the desired positive impacts without technical considerations
- Policies also play a vital role in delivering the highest outcome for solar energy development
  - Feed-in tariff threshold requires careful studies: evidence that high feed-in tariffs cause more severe rebound effects (La Nauze, 2019; Tanaka et al., 2022)

Thank you!

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