Photovoltaic Power installation in Wallonia: Estimating the rebound effect

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Introduction

- Ambitious EU RES share objective → 2020 → 2030
- Implementation left to Member States
    - Feed-in-Tariff
    - Tradable Green Certificate
    - Net Metering
    - Capital Subsidies: Grant, Tax Rebate
    - Renewable Portfolio Standard
- Wallonia: generous incentives cover investment cost
- Focus on subsequent consumption behavior
- Is household elec. consumption rising after PV installation ?
- How much of the solar electricity is send back to the network ?
- Estimating rebound effect
- Country ability to swap “brown” electricity by “green” one
- Policy choice: citizen driven (decentralized) vs. market (centralized)

Efficiency vs. Energy use

- New technologies: LED, isolation, electronics, smartphone
- Greater efficiency: need less electricity per unit of service
- Same total service with less total input
- Lower household energy use
- Key assumption: linear & direct (one-to-one)
- Khazzoom (1980) observes unintended consequences
- Apply today for home production of electricity:
  - appliance becomes economical, triggers acquisition
  - more disposable income to spend on gizmos
  - swap gas for electric heating
  - swap bus/train for electric car
  - leave lights on all night
  - run washing cycle during day instead of night
- Rebound Effect: true savings lesser than potential ones

Rebound Effects

- Direct

Income	$\nearrow$ efficiency $\Rightarrow$ marginal cost of electricity $\searrow$ for user $\Rightarrow$ $\nearrow$ electricity demand
Substitution	$\nearrow$ efficiency $\Rightarrow$ electricity cheaper vs. technologies $\Rightarrow$ switch towards electricity driven technologies

- Indirect

Spillover	$\searrow$ electricity cost $\Rightarrow \nearrow$ income $\Rightarrow \nearrow$ general expenses $\Rightarrow \nearrow$ electricity demand
Psychology	$\nearrow$ moral licensing, $\searrow$ responsibility, $\searrow$ consequences $\nearrow$ efficiency $\Rightarrow$ motivation reappraisal $\Rightarrow$ $\nearrow$ electricity
Free lunch	PV electricity is a "free good" $\Rightarrow \nearrow$ consumption
Macro	$\searrow$ electricity bill $\Rightarrow \nearrow$ growth $\Rightarrow \nearrow$ electricity use
Network	$\searrow$ cost new tech. $\Rightarrow \nearrow$ adoption $\Rightarrow \nearrow$ electricity use
Downstream	$\searrow$ electricity demand $\Rightarrow$ $\searrow$ market price $\Rightarrow$ $\nearrow$ electricity demand

Measurement Approach

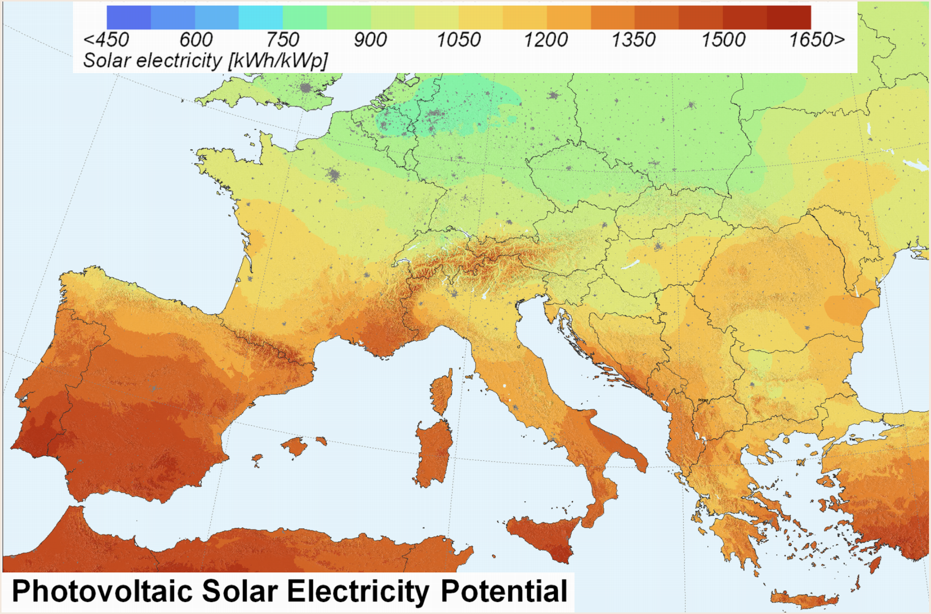
- Two methods to test for direct rebound effect
- #1: estimate elasticities of energy demand (price or energy efficiency)
- #2: compare energy demand before and after energy improvement
- Challenges: confounding factors, measurement errors
- Control group not appropriate ? prosumers ≠ consumers
- Controls: temperature and tariff (electricity price)
- Large sample (+70 000 households) → law large numbers

Literature

- Large literature on rebounds after energy efficiency improvement
- Few articles on households equipped with PV modules
- Keirstead (2007): UK survey data, self-assessed 5.6% elec. saving
- Wittenberg (2016): DE questionnaire with prosumers vs. consumers
  no significant prosumer effect
  prevalence of storage and automatic load shifting
- Deng (2017): AU billing data sample prosumers vs. consumers
  20% rebound
- Oberst *et al.* (2018): DE small sample prosumers vs. consumers
  electricity consumption proxied by heating expenses
  no significant prosumer effect, no rebound

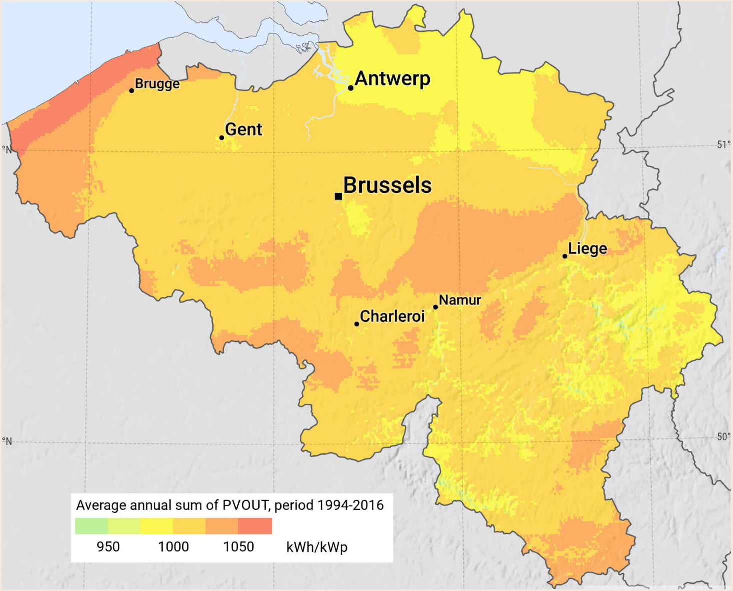
Solar Irradiation over Europe

- Intermittent source: daily and seasonal scales
- Photovoltaic module ideally inclined and south facing
- Potential in Sahara ≈ 3000 kWh/m^2/year
- Potential in Sicily ≈ 2200 kWh/m^2/year
- Potential in Wallonia ≈ 1100 kWh/m^2/year
- Solar panel not perfect: inverter and transformer losses
- Effective output in kWh/year: 75% of local theoretical maximum



<450 600 750 900 1050 1200 1350 1500 1650>
Solar electricity [kWh/kWp]
Photovoltaic Solar Electricity Potential

Photovoltaic power potential of Belgium

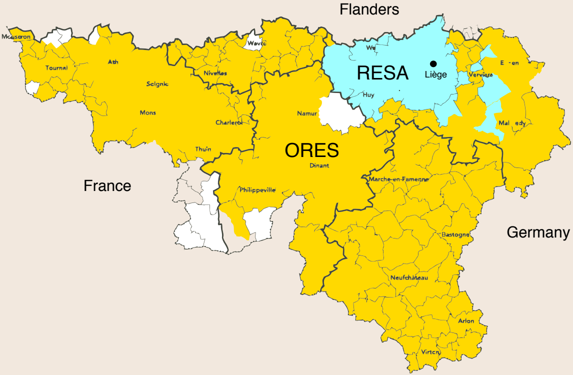


Household PV Electricity production

- Solar irradiation map: flat distribution over Wallonia
- Effective PV output (monitored by TSO): 10.3%
- Module: 2m×1m@300Wp ⇒ 268 kWh/year
- Residential maximum PV size for support:10 kWp
- Up to 33 modules (6m×11m) ⇒ 8930 kWh/year
- Household consumption in Wallonia: 1700 kWh/pc/year
- Maximum PV installation may sustain family of 5
- Large household may reduce net imports with PV
- Small household with large house may produce in excess of need
- Or consume more ...

Electricity Distribution Operators in Wallonia

- Study universe: Wallonia (262 municipalities)



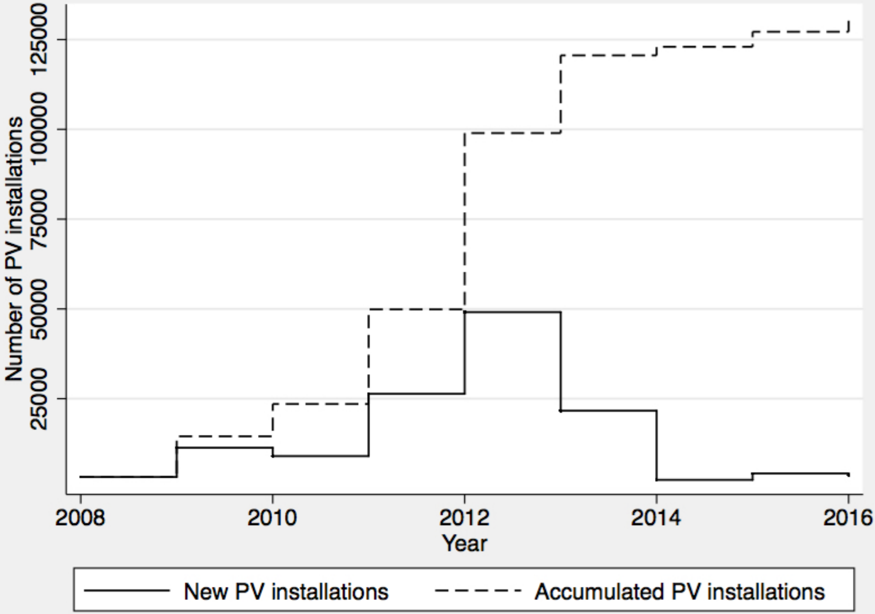
- First stage: exclude Liège region (54 municipalities)
- RESA: merger of 7 smaller DSOs, ≠ electricity tariffs
- About 100 000 households, from 2010 until 2017
- EAN, yearly meter readings, PV installation date and size (kWp)

Photovoltaic support in Wallonia

- Regional government support schemes
- Solwatt 2007-2014: very generous
- Tradable Green Certificates

Program	Application period	Grant rate (TGC/MWh)	Grant period (years)
Solwatt 1	Jan. 2008 - Nov. 2011	7	15 years
Solwatt 2	Dec. 2011- Mar. 2012	7	10 years
Solwatt 3	Apr. 2012 - Aug. 2012	6	10 years
Solwatt 4	Sep. 2012 - Mar. 2013	5	10 years
Solwatt 5	Apr. 2013 - Feb. 2014	1,5	10 years

- TGC market: RES producers vs. retailers under RPS
- Fixed bounds: floor at 65€/MWh & “no show” fine at 100 €/MWh
- Price fell from 90 to 70 €/MWh between 2007 and 2015


Number of PV installations
25000
50000
75000
100000
125000
2008
2010
2012
2014
2016
Year
New PV installations
Accumulated PV installations

Photovoltaic development in Wallonia

- Boom in 2012: 50 000 households mount rooftop solar panels
- Germany: 82 M people, 1 M residential solar panels
- Density: Wallonia 1 PV per 29 people, Germany = 1/86
- Solwatt: great success at a great cost
- 2013: reduced TGC allocation, 2014 termination
- Qualiwatt 2014-2018: fixed premium per panel
- Guarantees return on investment, same 10 kWp limit
- Both schemes: NET METERING
- Meter runs backwards when PV output > household load
- Values PV electricity at retail rate $\approx 4\times$ market price
- Limitation: no negative bills if meter difference is negative
- Consequence: excess yearly PV output “given for free” to DSO

Economic Model of Investment

Representative household may invest into PV system

- $\tilde{k}$ PV installation capacity (kWp)
- ρ PV module price (€/kWp)
- β capacity factor of typical PV installation (%)
- $k = \beta\tilde{k}$ PV installation output (kWh)
- η PV subsidy (€/kWh)
- q electricity consumption (kWh)
- $\hat{q} = q - k$ net metered consumption (kWh)
- p retail price of electricity (€/kWh)
- w, z income & composite good (unit price)
- $\bar{r}$ roof size capacity for PV installation (kWp)
- $\bar{k}$ eligibility threshold (kWp)

Consumer Problem

- Standard utility function $u(q,z)$
- Total revenue: $w+\eta k$, expenses $z+p\max[0,\hat{q}]$
- Consumer's choice problem: $\max_{\hat{k},q,z} u(q,z)$

$$z+p\max[0,\hat{q}]+\rho\tilde{k}\leq w+\eta k,$$
$$\tilde{k}\leq \min[\bar{r},\bar{k}]$$

- No PV benchmark: (q_0,z_0) s.t. $\frac{u_q}{u_z}=p$ and $z_0+q_0p=w$
- Case 1: $\rho\leq\beta\eta$, subsidy covers investment cost
- Maximum investment: $\tilde{k}_1=\min[\bar{r},\bar{k}]$
- Let $\tilde{k}^*$ solve $\frac{u_q(\beta\tilde{k}^*,w^*)}{u_z(\beta\tilde{k}^*,w^*)}=p$ and $w^*=w+\tilde{k}^*(\beta\eta-\rho)$

Equilibrium

Proposition When $\rho \leq \beta\eta$, consumers choose the largest possible PV installation $\tilde{k}_1 = \min[\bar{r}, \bar{k}]$ and

- if $\tilde{k}_1 \geq \tilde{k}^*$ then eq. is $q_1 = k_1$ and $z_1 = w + \tilde{k}_1(\beta\eta - \rho)$
- if $\tilde{k}_1 \leq \tilde{k}^*$ then eq. is (q_2, z_2) s.t. $\frac{u_q(q_2,z_2)}{u_z(q_2,z_2)} = p$, $z_2 = z_1 - p(q_2 - k_1)$

- Property: $q_1 \geq q^* \geq q_2 \geq q_0$ and $z_1 \geq z^* \geq z_2 \geq z_0$
- If $\tilde{k}_1 \leq \tilde{k}^*$: $\nearrow$ consumption due to **income** effect
- If $\tilde{k}_1 > \tilde{k}^*$: added **zero marginal price** effect
- Prosumers consume more than standard (no PV) consumers
- Net Metering $\Rightarrow$ discontinuous electricity price at $q = k$

Equilibrium (cont.)

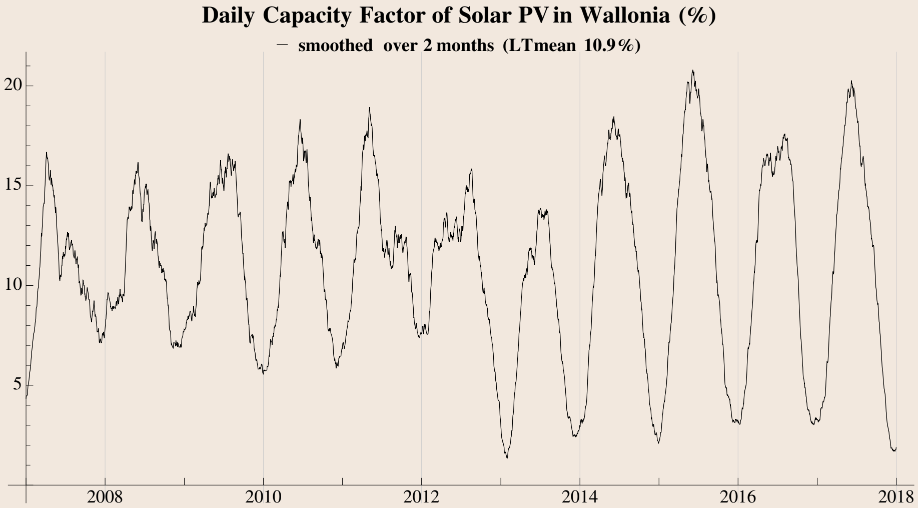
- Case 2 $\beta\eta \leq \rho \leq \beta(\eta + p)$, net metering $\Rightarrow$ investment profitable
- Investment profitable only if $q \geq k = \beta\tilde{k}$ (no wasted generation)
- Consumer's choice problem: $\max_{\tilde{k},q,z} u(q,z)$

$$z + p\hat{q} + \rho\tilde{k} \leq w + \eta k,$$
$$\tilde{k} \leq \min\left[\frac{q}{\beta}, \bar{r}, \bar{k}\right]$$

- Solution: $\frac{u_q(q_3,z_3)}{u_z(q_3,z_3)} = p$ and binding investment
- Case 3 $\beta(\eta + p) \leq \rho$, solar panels unprofitable
- Solution $\tilde{k} = 0$ and no PV bundle (q_0, z_0)

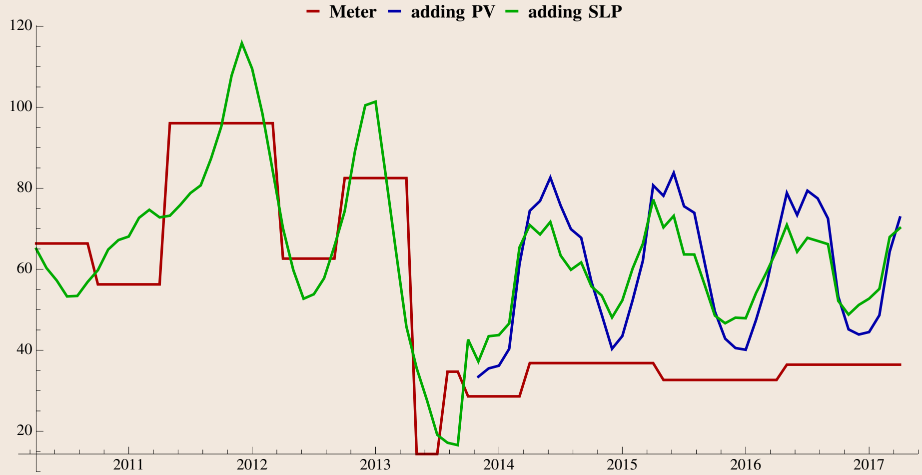
Reconstructing individual load curves

- Billing period $[t_1, t_2]$ with total consumption Q
- Daily equivalent consumption $\frac{Q}{t_2 - t_1}$
- Synthetic load curve (SLP) Liège region: temporal index
- Average index over billing period $\bar{s} = \frac{1}{t_2 - t_1} \sum_{t_1}^{t_2} s_t$
- Reconstructed household load: $q_t = \frac{s_t}{\bar{s}} \frac{Q}{t_2 - t_1}$
- PV installation month τ
- PV monitoring by TSO: capacity factor β_t from 2012 to 2018
- Pre-2012: Liège Airport Weather Station's daily sunshine minutes
- Household $\tilde{k}$ daily solar PV production $k_t = \beta_t \tilde{k}$



Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CF	10.5	10.8	11.5	10.9	12.1	11.	7.5	10.9	11.7	10.9	10.9

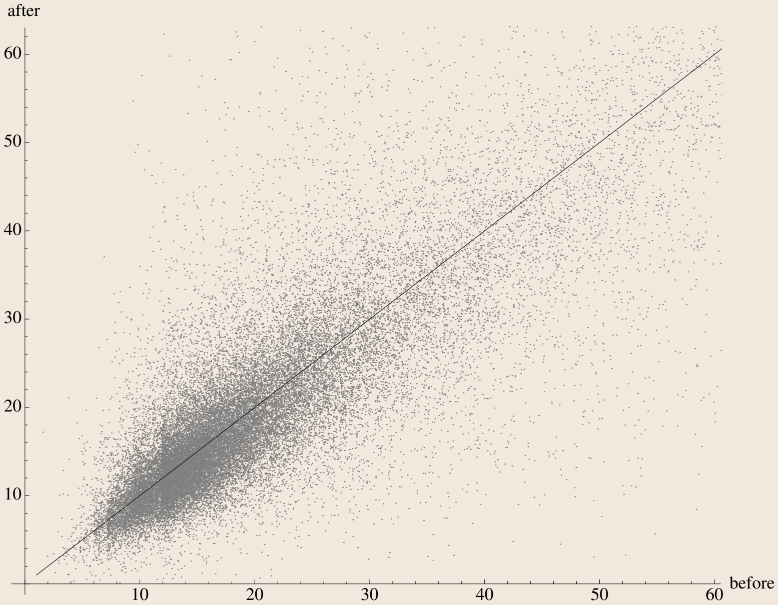
Reconstructed Household Load Curve including PV output



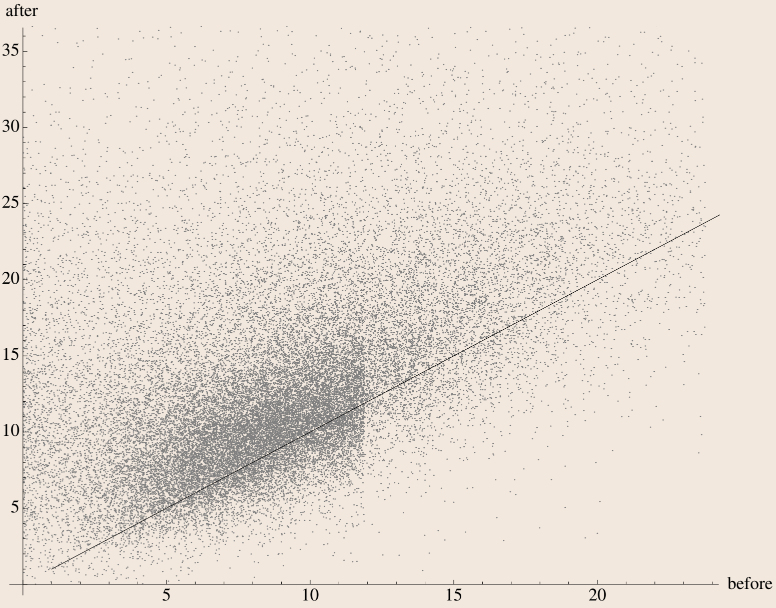
Estimation strategy

- Before vs. After: load over $[\tau - 24, \tau]$ and $[\tau, \tau + 24]$ months
- Load change: $\Delta q = \mathbb{E}[q_t | t > \tau] - \mathbb{E}[q_t | t \leq \tau]$
- Temperature: $\Delta\zeta = \mathbb{E}[\zeta_t | t > \tau] - \mathbb{E}[\zeta_t || t \leq \tau]$
- "Oversized" indicator $\theta = \mathbb{E}[k - q) | k > q]$ (over $[\tau - 24, \tau]$)
- Mean tariff p over $[\tau - 24, \tau + 24]$
- Meter reading is error prone (e.g., re-intialization)
- Algorithmic recognition not enough
- Exclude top and bottom 2% data points for q_t distribution
- Graphical look at differences in behavior: oversized vs. undersized

Consumption before/after, undersized group



Consumption before/after, oversized group



Results

- Equation: $\Delta q = \alpha + \beta_1 \Delta\zeta + \beta_2 p + \beta_3 \tilde{k} + \beta_4 \theta + \epsilon$
- Run: 63 691 observations, $R^2 = 0.25$

Variable	Estimate	Standard Error	t-Statistic	P-Value
α	1.3481	0.1697	7.94506	$1.9*10^{-15}$
p	-0.1164	0.01841	-6.32335	$2.5*10^{-10}$
$\tilde{k}$	-0.0122	0.00538	-2.26794	0.02333
θ	0.9722	0.00712	136.572	$3.4*10^{-3555}$
$\Delta\zeta$	2.1087	0.0676	31.1784	$8.2*10^{-212}$

- Coefficients significant at the 1% level
- Tariff impact as expected
- Large PV owners have slightly lower consumption increase
- Rebound (θ): for oversized households (low original consumption)
- Every additional kWh generated is consumed (almost)

Conclusion & Future Work

- Article test rebound effect of solar PV residential installation
- Exhaustive dataset from Wallonia
- Oversizing PV installation due to generous support scheme
- Net metering creates strong “free electricity” illusion
- Households almost entirely consume this free energy
- Beware: net generation in summer, net load in winter
- Additional stress on DSO grid, possible added local pollution
- Few RES electricity reverted to network for Climate Change action

- Extend to Liège région
- Improve econometrics
- Thank you