# Who pays, Who adopts? Efficiency and Equity of Residential Solar Policy

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# German econ min considers phasing out subsidies for new small-scale solar PV

*#Solar #Cost & Prices #Policy*

**Germany's economy minister told the newspaper Augsburger Allgemeine that new small-scale solar installations should be able to go without a subsidy which remunerates the electricity they feed into the grid. The proposal was both celebrated and rejected, with some saying the end of the feed-in tariffs for small solar units are long overdue and others warning that the move could stifle the expansion of the important power source. [UPDATE: Adds reactions from energy sector, Greens, ministry response]**

# Dabate on Residential solar PV subsidies

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## EU solar energy rollout slows for first time in decade as subsidies cut

By **Kate Abnett** and **Riham Alkousaa**

July 24, 2025 7:25 PM GMT+2 · Updated July 24, 2025

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# Design good subsidies considering multiple objectives

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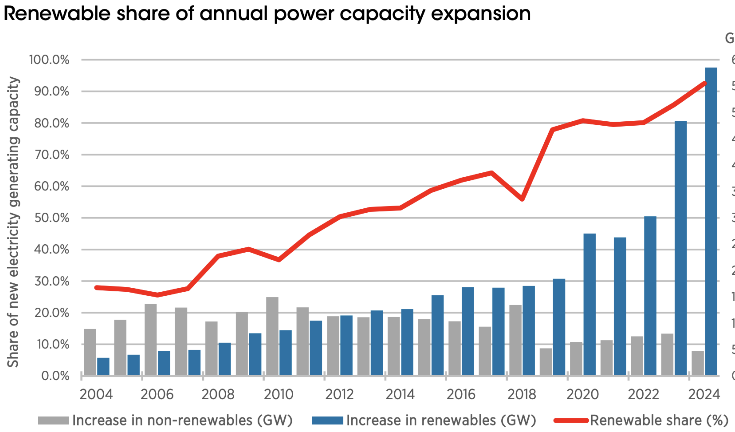
- **Low installation costs**: Large PV sizes reduces average installation costs.
- **Low grid cost**: More self-consumption lowers grid costs.
- **Low fiscal costs**: Less infra-marginal effects lowers fiscal costs.
- **Fairness**: Both high and low-income households receive subsidies.

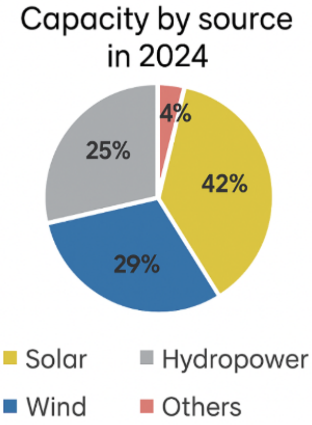
# Renewables take over the power sector to tackle climate change

- In 2024, 92.5% of new power capacity was renewable.



# Solar power is a major component of renewables

- By 2024, **solar power accounted for 42%** of global renewable power capacity.



# Residential solar PV has unique advantages

- Not require new land; installed on rooftop.
- Engage households in the energy transition.

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- Not require new land; installed on rooftop.
- Engage households in the energy transition.
- Global residential solar takes 20% in total solar capacity (23% commercial, 57% utility-scale).

# Contribution to literature

- The effect of subsidies on solar PV adoption:
  - simulation & reduced form: Eid et al. (2014), Londo et al. (2020), Burr (2016), Böning et al. (2025), etc.
  - structural (different topic and specification): De Groote and Verboven (2019), Feger et al. (2022).
  - This paper: structural model with endogenous capacity choice, heterogenous preference, diverse subsidy design.
- Redistribution effect of industrial policies:
  - Wolak (2018),Feger et al. (2022), Känzig (2023), Ito et al. (2023)
  - This paper: specific in solar subsidies, integrating the subsidy allocation& financing.
- Data contribution:
  - This paper: population of Dutch households with capacity choice.

# Residential solar PV subsidies

## Investment-based policies

(1) **Lump-sum transfer**

Upfront payment conditional on adoption; independent of capacity.

(2) **Investment subsidy**

Upfront payment proportional to installed capacity.

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## Production-based policies

(1) **Feed-in tariff**

fixed regulated payment per kilowatt hour (kWh) of all electricity feed-in.

(2) **Net metering**

retail-price payment per kWh of electricity feed-in, only up to total consumption.

# Preview of Results

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- **Heterogenous preference**: Low-income households are more sensitive to fixed costs than the future revenue.
- **Intensive margin effect**: Investment-based policies lead to smaller average capacity than production-based policies.
- **Cost efficiency**:
  - Investment-based policies require higher subsidy level.
  - Screening based on heterogenous preference incurs a lower cost than uniform subsidy.
- **Distributional effect**:
  - Investment-based policies encourage more adoption of low-income.

# Household nested discrete choice model

- Household $i$, belonging to income quintile $q_i \in \{1,2,3,4,5\}$, chooses capacity $j \in \{0,1,2,3,4,5\}$ ($j=0$ means no adoption) in year $t$ to maximize the utility:

$$u_{ijt} = \boxed{\beta^R_{q_i} \cdot \mathcal{R}_{ijt} - \beta^C_{q_i} \cdot \mathcal{C}_{jt}} + \mathbf{\Phi}_j \cdot \text{HH characteristics}_i + \boldsymbol{\gamma} \cdot \text{FE} + \boxed{\zeta_{igt} + (1-\sigma)\epsilon_{ijt}}. \quad (1)$$

- Total revenue: $\mathcal{R}_{ijt}$ = market revenue + subsidy.

  Total cost: $\mathcal{C}_{jt}$ = installation cost - subsidy.

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- Total revenue: $\mathcal{R}_{ijt}$ = market revenue + subsidy.
  Total cost: $\mathcal{C}_{jt}$ = installation cost - subsidy.
- **Two comments on the specifications:**
  (1) Households endogenously choose capacity, and the choices are not independent.
  (2) Households have different price sensitivity to cost and revenue.

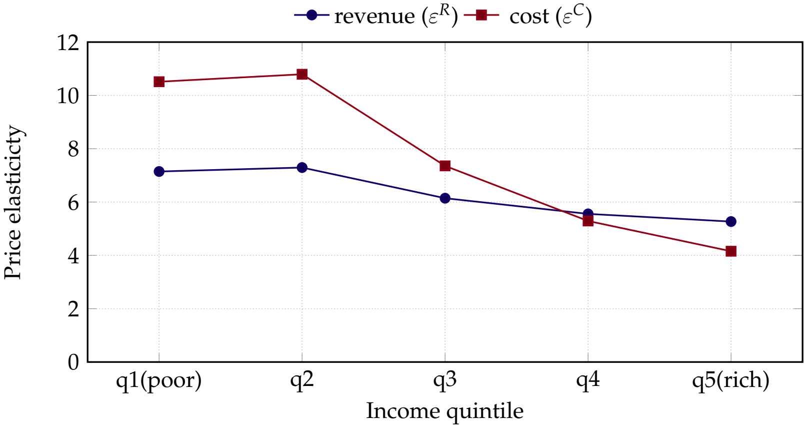
# Dutch Data: 2019-2022

- Main data for nested logit model:
  - Yearly retail electricity price (CBS);
  - Yearly solar PV installation cost (Milieu Centraal);
  - Household data: yearly electricity consumption, feed-in, solar PV capacity, dwelling characteristics, household characteristics (CBS).
- Data for calibrating exogenous parameters of PV, and for counterfactuals:
  - Quarter-hourly profile data for households' electricity consumption and feed-in (MFFBAS);
  - Hourly wholesale electricity price data (SMARD).
- Dutch subsidy: net metering.

# Summary statistics: Comparison by income quintile (2022)

| | N Obs | All | $< 20\%$ | $20 - 40\%$ | $40 - 60\%$ | $60 - 80\%$ | $> 80\%$ |
|---|---|---|---|---|---|---|---|
| Dispo-income (€) | 5444262 | 50859 | 19364 | 29607 | 42152 | 60110 | 100591 |
| Grid consumption (kWh) | 5444262 | 2623 | 1694 | 2048 | 2455 | 3032 | 3778 |
| Feed-in (kWh) | 5444262 | 523 | 152 | 237 | 458 | 730 | 994 |
| House size ($m^2$) | 5444262 | 118 | 83 | 99 | 116 | 130 | 156 |
| Ownership (%) | 5444262 | 62 | 9 | 40 | 72 | 84 | 93 |
| House (%) | 5444262 | 68 | 37 | 56 | 71 | 83 | 89 |
| **Adoption (%)** | 5444262 | 27 | **12** | **16** | **26** | **36** | **44** |
| | | | | | | | |
| **PV Capacity (kW)** | 1491062 | 3.62 | **2.40** | **2.77** | **3.33** | **3.79** | **4.27** |
| Feed-in (kWh) | 1491062 | 1910 | 1229 | 1469 | 1788 | 2005 | 2239 |

# Estimation Results: Poorer households are more sensitive to costs




- Difference in price elasticities is used to calculate counterfactuals.

# Counterfactual setup

**Uniform subsidy: same policy applies to all households**

- Four single policies:
  - Net metering (*status quo*)
  - Feed-in tariff
  - Investment subsidy
  - Lump-sum transfer
- Combinations of these policies

**Screening: A menu of policies offered and households choose preferred one.**

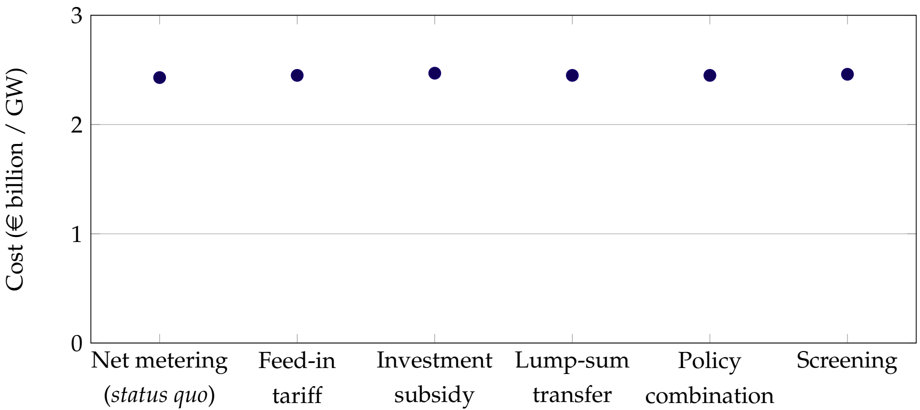
# Counterfactual setup

(1) Fix the adopted capacity $K^*$ and find the level of different subsidies.

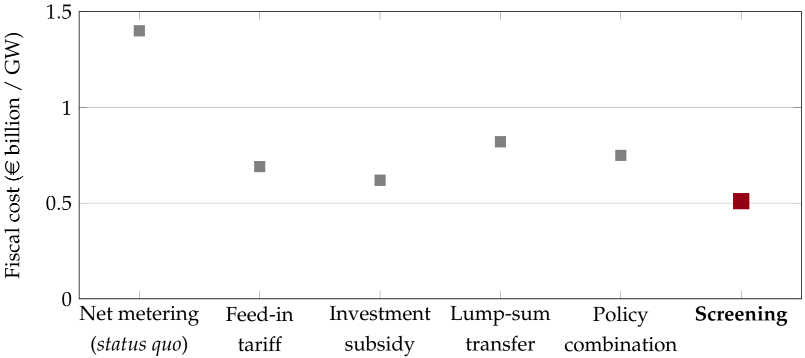
(2) Compare different subsidies by three policy objectives:

- Social cost minimization
- Fiscal budget minimization
- Equity maximization

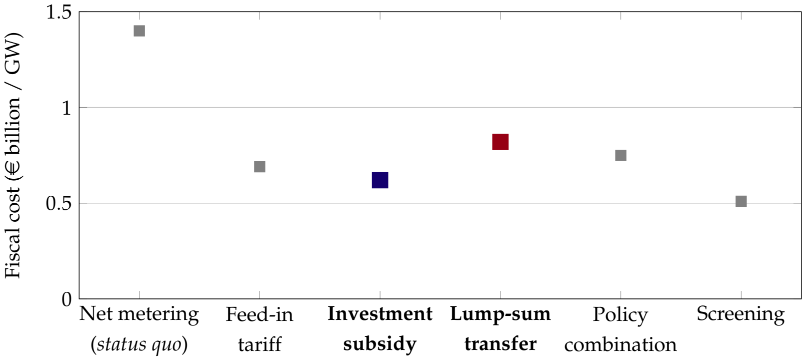
# Social cost is similar across different policies.



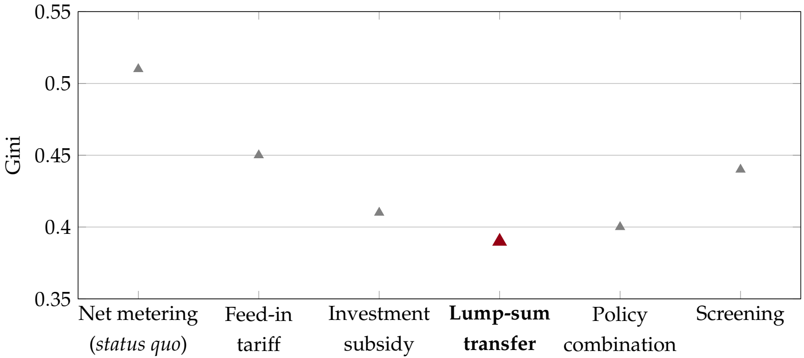
# Fiscal cost by screening is the lowest.



# Fiscal cost by investment-based subsidies could be expensive



# Investment-based subsidies are fairer.



# Mechanism I: Intensive margin

| Policy | Adoption rate (%) | Average capacity per adoption (kW) |
|---|---|---|
| Net metering (*status quo*) | 6.70 | 4.23 |
| Feed-in tariff | **6.04** | **4.69** |
| Investment subsidy | 7.14 | 4.03 |
| Lump-sum | **8.13** | **3.48** |

**Given total capacity target, investment-based** subsidies lead to:

- **smaller** capacity size per adoption.
- **higher** adoption rates.
- **higher** subsidy level.

# Mechanism II: Heterogeneous preference

| | $< 20\%$ | 20–40% | 40–60% | 60–80% | $> 80\%$ |
|---|---|---|---|---|---|
| **Panel A: conditional adoption rate (%)** | | | | | |
| Net metering (*status quo*) | **2.68** | 2.89 | 5.06 | 8.12 | **10.53** |
| Feed-in tariff | **2.76** | 2.94 | 4.74 | 7.20 | **9.14** |
| Investment subsidy | **3.95** | 4.25 | 5.80 | 8.08 | **9.87** |
| Lump-sum | **5.38** | 5.72 | 6.97 | 9.10 | **10.70** |

- Low-income households benefit more from investment-based subsidies.

# Conclusion

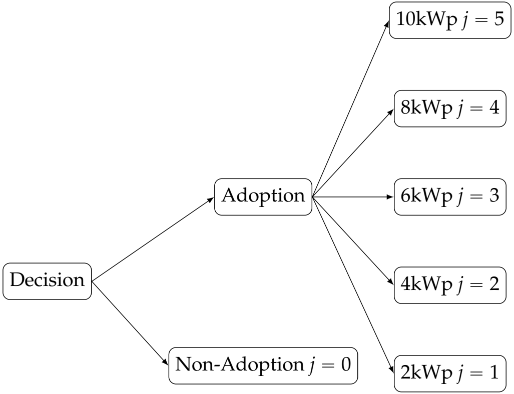
- A structural model of PV adoption, with **heterogeneous preferences** and **endogenous capacity choice**.
- Counterfactual analysis of **PV policy design** on cost and distributional effect.
  - Investment-based subsidies can incur high fiscal cost.
  - Investment-based subsidies are less regressive.
  - Screening can achieve the capacity target at a lower cost.

# Household decision tree

(1) Household $i$ chooses whether to adopt solar PV.

(2) If adopting, Household $i$ chooses the capacity type $j$ of PV.

(3) $j \in \{0, 1, 2, 3, 4, 5\}$, where 0 means non-adoption.



# PV costs and revenues I

- Cost $C_{jt}$ depends on the capacity size $K_j$ and the unit installation cost $p_{Ijt}$ at year $t$. Economies of scale exists:

$$C_{jt} = K_j p_{Ijt}(K_j) \tag{2}$$

- Without subsidy (*laissez-faire* scenario), households benefit $\mathcal{R}^{lf}_{ijt}$ includes saving from self-consumption and selling surplus electricity at wholesale prices:

$$\begin{aligned} R^{lf}_{ijt} = & \underbrace{\sum_{k=t}^{t+24} \rho^{k-t}(1-\pi)^{k-t}\mathbb{E}^k_t[R]\min\{\mathbb{E}^k_t[D_i], \alpha\mathbb{E}^k_t[Y_j]\}}_{\text{self-consumption}} \\ & + \underbrace{\sum_{k=t}^{t+24} \mathbb{E}^k_t[p_s]\rho^{k-t}(1-\pi)^{k-t}\max\{\mathbb{E}^k_t[Y_j]-\mathbb{E}^k_t[D_i], (1-\alpha)\mathbb{E}^k_t[Y_j]\}}_{\text{revenue from wholesale market}}. \end{aligned} \tag{3}$$

# PV costs and revenues II

- The cost reduction from subsidy $C_{jt}^{gs}$ is:

$$C_{jt}^{gs} = \underbrace{T}_{\text{lump-sum}} \cdot \mathbf{1}\{K_j > 0\} + \underbrace{\kappa C_{ijt}}_{\text{investment subsidy}} . \tag{4}$$

- The revenue from the subsidy $R_{ijt}^{gs}$ is:

$$\begin{aligned} R_{ijt}^{gs} = & \underbrace{\sum_{k=t}^{t+24} (p_c - \mathbb{E}_t^k[p_s])\rho^{k-t}(1-\pi)^{k-t} \max\{\mathbb{E}_t^k[Y_j] - \mathbb{E}_t^k[D_i], (1-\alpha)\mathbb{E}_t^k[Y_j]\}}_{\text{feed-in tariff}} \\ & + \underbrace{\sum_{k=t}^{t+24} (\mathbb{E}_t^k[R] - \mathbb{E}_t^k[p_s])\rho^{k-t}(1-\pi)^{k-t} \min\{\mathbb{E}_t^k[D_i] - \alpha\mathbb{E}_t^k[Y_j], (1-\alpha)\eta\mathbb{E}_t^k[Y_j]\}}_{\text{net metering}} . \end{aligned} \tag{5}$$

# Dutch subsidy: net metering

No cost reduction: $T = 0, \kappa = 0$.

$$\mathcal{C}_{ijt}^{gs} = 0. \tag{6}$$

# Dutch subsidy: net metering

## Full net metering $\eta = 1, p_c = p_s$.

$$R^{gs}_{ijt} = \underbrace{\sum_{k=t}^{t+24} (\mathbb{E}^k_t[R] - \mathbb{E}^k_t[p_s])\rho^{k-t}(1-\pi)^{k-t} \min\{\mathbb{E}^k_t[D_i] - \alpha\mathbb{E}^k_t[Y_j], (1-\alpha)\mathbb{E}^k_t[Y_j]\}}_{\text{net metering}} . \tag{6}$$

## Simple expectation.

$\mathbb{E}^k_t[R] = R_t$

$\mathbb{E}^k_t[p_s] = p_{st}$

$E^k_t[D_i] = D_{i,t-1}$

$\mathbb{E}^k_t[Y_j] = (1-\lambda)^{k-t}\iota K_j$

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## Parameters.

Literature: $\rho = 0.85, \pi = 0.03, \lambda = 0.03/0.007$

Calibration: $\alpha = 0.33, \iota = 0.91$

# Summary statistics: comparison of PV adopters and non-adopters (2022)

| | (1) **Non-Adopter** | (2) **PV-Adopter** | (3) **p-value of difference between (1) and (2)** |
|---|---|---|---|
| Age | 57.47 | 56.37 | 0.00 |
| Household (HH) size | 2.01 | 2.57 | 0.00 |
| Ownership | 0.55 | 0.79 | 0.00 |
| **Single family house(SFH)** | 0.59 | 0.94 | 0.00 |
| Wealth percentile | 50.00 | 62.41 | 0.00 |
| Income percentile | 47.50 | 63.63 | 0.00 |
| House area (HA) $m^2$ | 108.82 | 140.88 | 0.00 |
| Electricity Consumption (kWh) | 2547.37 | 2821.91 | 0.00 |
| # of obs | 3955200 | 1491062 | 5446262 |

# Sample construction

- Homeowners only;
- Households not moveing during 2019-2022;
- Households installing in year $t-1$ are excluded from the potential market of year $t$.
- Data in 2019 cannot be used because of missing information on year 2018 adoption status.
- 4245805 observations left

# Screening

Screening: A menu of policies offered and ouseholds choose preferred one.

$$\frac{\beta_H^C}{\beta_H^R} < \frac{\mathcal{R}^{\text{production-based}}}{\mathcal{R}^{\text{investment-based}}} < \frac{\beta_L^C}{\beta_L^R} \tag{7}$$

High-income households choose the production-based policy. Low-income households choose the investment-based policy.

# Policy objectives

I consider three policy objectives:

(1) Social cost minimization:

$$\min \sum_i (G_i + C_i) \tag{8}$$

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(3) Equity maximization:

$$\max \frac{1}{2n^2 \overline{\text{EV}^{gs}}} \sum_i \sum_{-i} |\text{EV}_i^{gs} - \text{EV}_{-i}^{gs}| \tag{10}$$

where EV is the equivalent variation:

$$EV_i^{gs} = \frac{1}{\bar{\beta}_i} \left\{ \log[1 + \exp(I_{igt}^{gs})] - \log[1 + \exp(I_{igt}^{base})] \right\} \tag{11}$$