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Feed-in tariff policy for solar microgeneration in Great Britain: Policy evaluation and capacity projections using a realistic agent-based model

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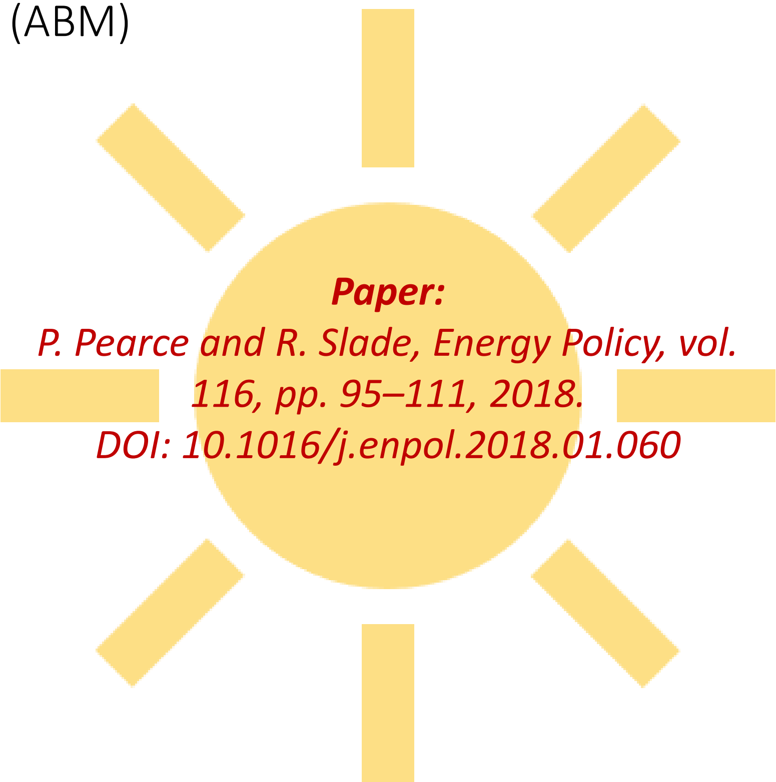
Outline

- Feed-in tariffs & PV installation in Great Britain
- Introduction to agent-based modelling (ABM)
- Model development & operation
    - Data used for the model
- Historical simulations
- Projections
- Conclusions & further work

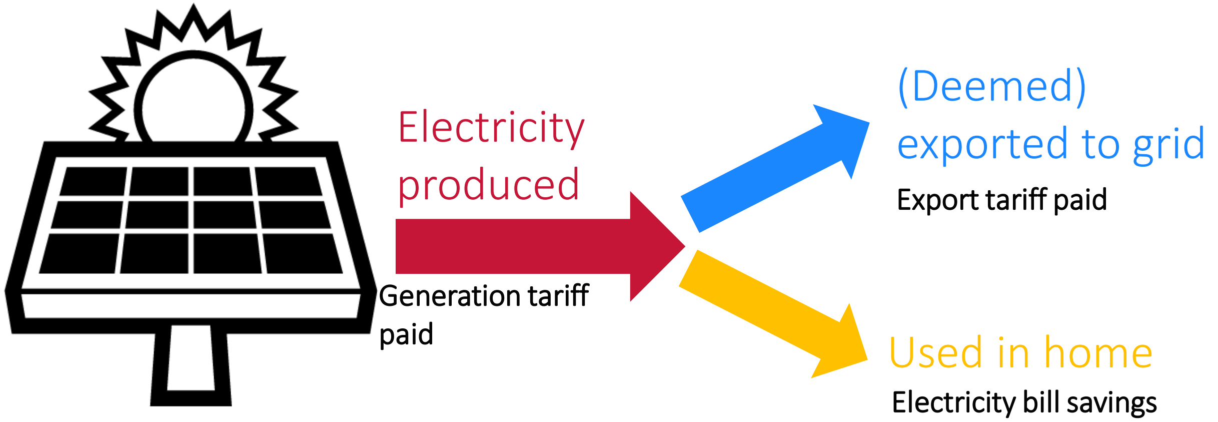


Paper:

P. Pearce and R. Slade, Energy Policy, vol. 116, pp. 95–111, 2018.
DOI: 10.1016/j.enpol.2018.01.060

Feed-in tariffs in GB

- Set out in the 2008 Energy Act, available since **April 2010**
- For systems up to 5MW capacity (lower rates for larger installations)
  - **99%** of registered systems are **solar PV**
  - **58%** of solar PV installations **≤ 10 kW**
- Generation & export tariff paid to installers by their electric utility
  - Guaranteed for 20/25 years
- For most domestic installations, does not actually function as a *feed-in* tariff but as a *generation* tariff



Electricity produced

Generation tariff paid

(Deemed) exported to grid

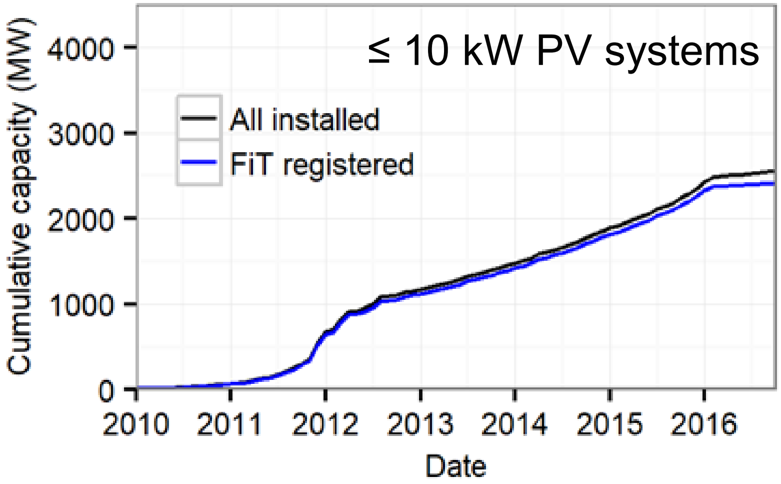
Export tariff paid

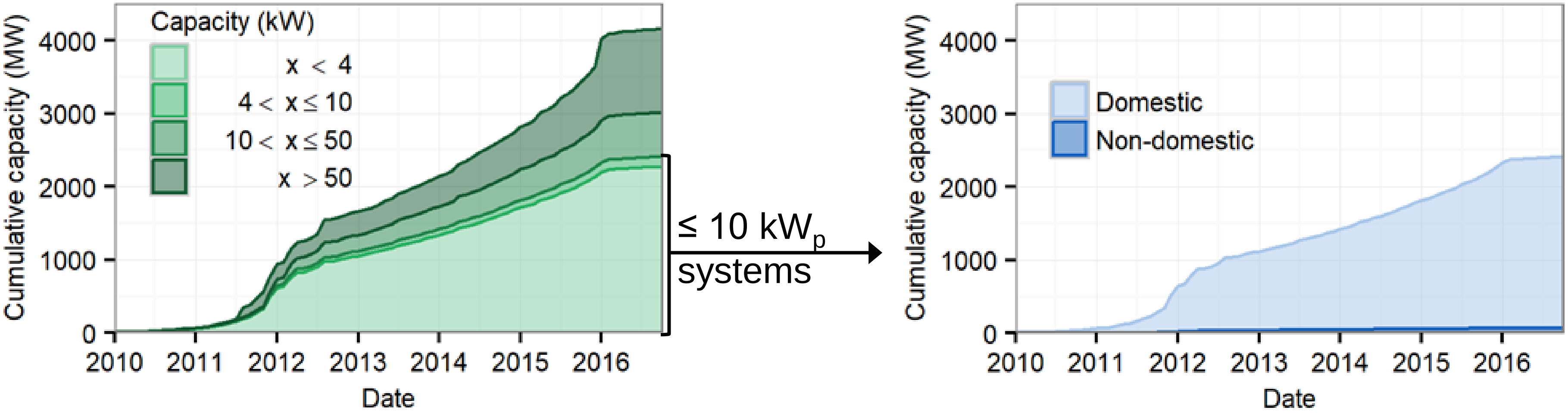
Used in home

Electricity bill savings

PV installations in GB

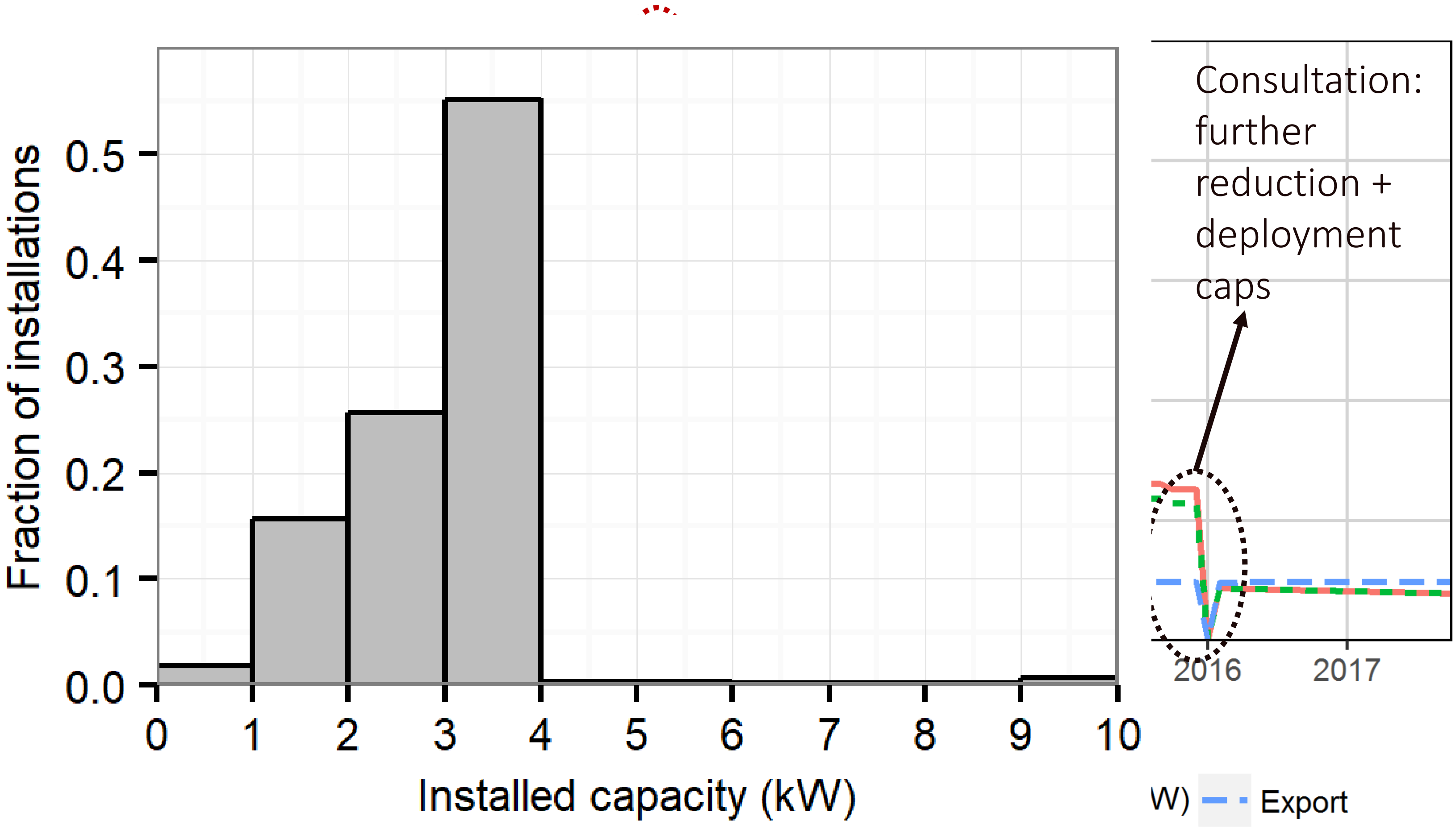
- **4.1 GW_p** total capacity as of October 2016
- **2.4 GW_p** small-scale (up to 10 kW systems)
  - **£600 million/year** supporting small-scale solar
  - Very little installed since then (<100 MW)
- Comparison: Germany has **40 GW** installed under EEG, costing €10 billion/year [1]





[1] Fraunhofer Institute for Solar Energy Systems ISE, 2017. Recent Facts about Photovoltaics in Germany.

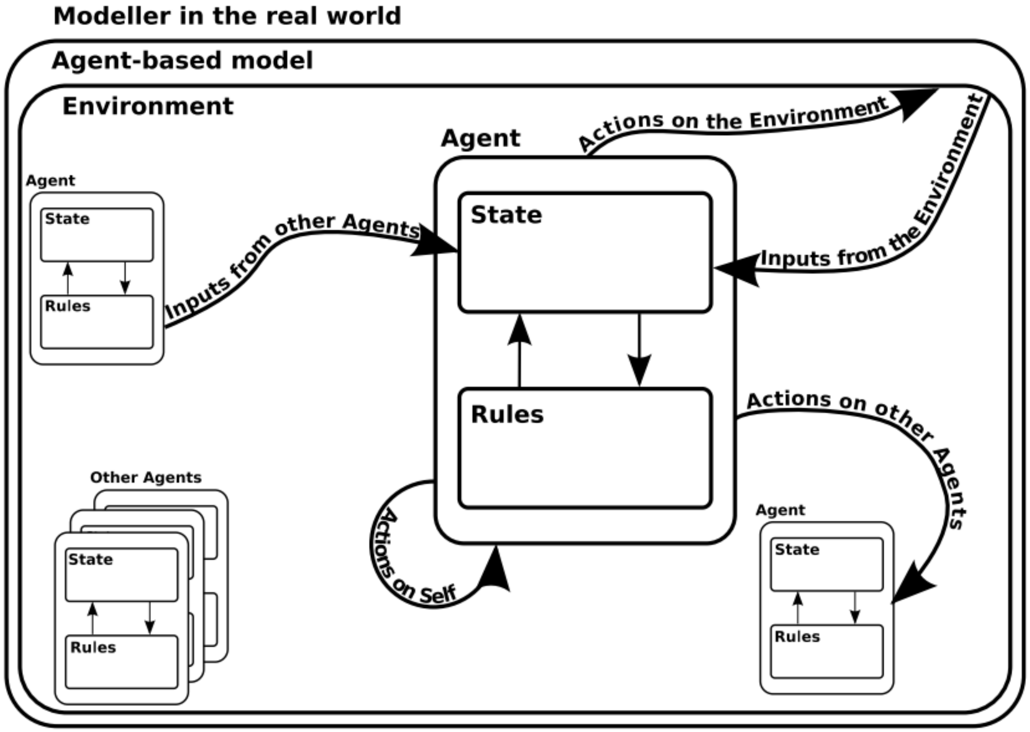
Feed-in tariff levels



Consultation: further reduction + deployment caps

Agent-based modelling

- Beyond optimization models
- Population **heterogeneity**
- Individual decisions lead to **emergent behaviour**
- Realistic environment, technology & household characteristics

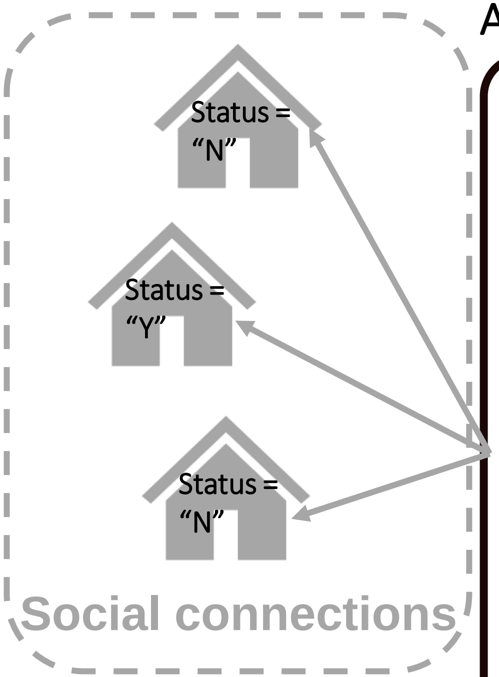


[1] K. H. van Dam, I. Nikolic, and Z. Lukszo, Agent-Based Modelling of Socio-Technical Systems. Dordrecht: Springer, 2013.

Model structure

Environment

- ➢ Electricity price
- ➢ PV installation cost
- ➢ Demographic data
- ➢ Load factor data
- ➢ Feed-in tariffs (generation and export)
- ➢ *Number of owner-occupiers (scale factor)*
- ➢ Adoption threshold
- ➢ Partial utility weights



Agent (representing a household)

Status: "Y" (has installed), "N" (not installed)
Income
Household size
GB region
Load factor
Electricity consumption
PV capacity
Social network

Generation and export tariff
Installation date

Only set if an agent has installed

Partial and total utilities:

- *Income*
- *Payback period (economic)*
- *Social network*
- *Capital cost barrier*

Agent decision-making rule

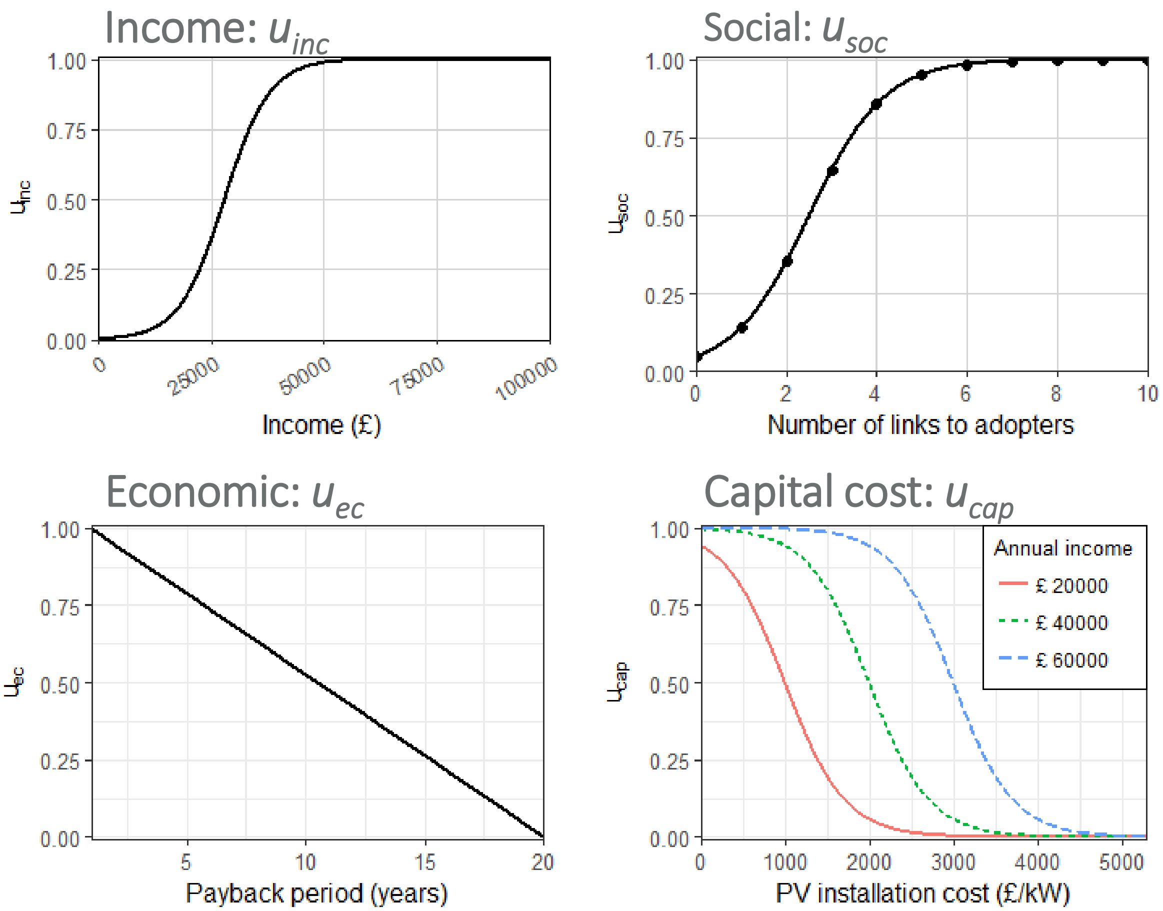
Agent decision-making

An agent will adopt if:

$$\underset{\text{Total utility}}{u_{tot,k}} = \sum_i \underset{\text{Partial utility weights}}{w_i}\,\underset{\text{Partial utilities}}{u_{i,k}} = \underbrace{w_{inc}u_{inc,k}}_{\text{Income}} + \underbrace{w_{ec}u_{ec,k}}_{\text{Economic}} + \underbrace{w_{soc}u_{soc,k}}_{\text{Social}} + \underbrace{w_{cap}u_{cap,k}}_{\text{Capital cost}} \geq \underset{\text{Threshold}}{t}$$

- All w_i, u_i and t lie in the range [0,1]
- The partial utility weights w_i sum to 1 → constraints
- So u_{tot} also lies in the range [0, 1]

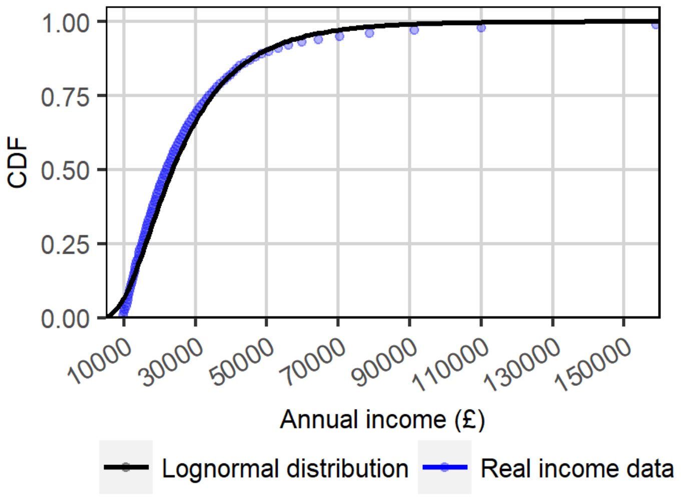
Utility functions

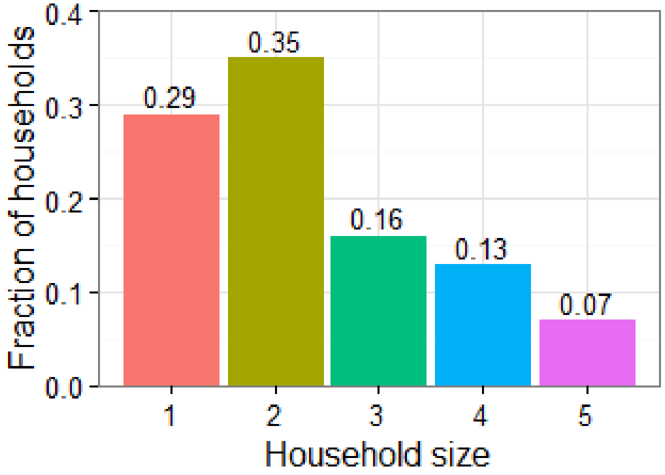


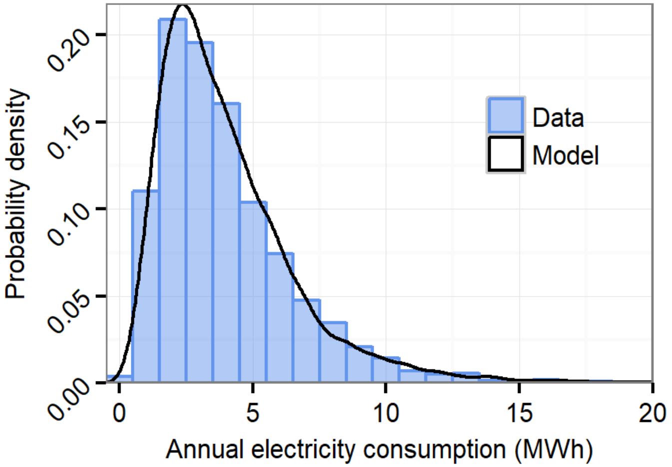
- **Utility function** translates relevant characteristic to a number which can be used to calculate the total utility
- Three logistic functions, one linear

Demographic data

- Annual household income
- Household size
- Electricity consumption
- Population per region & load facto per region

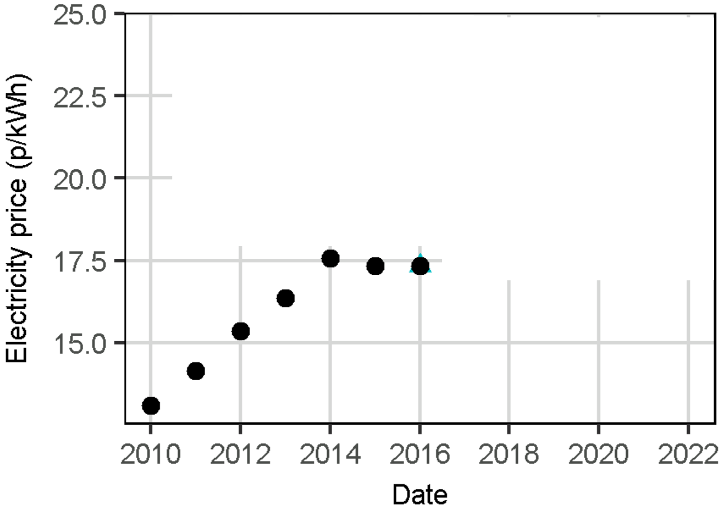


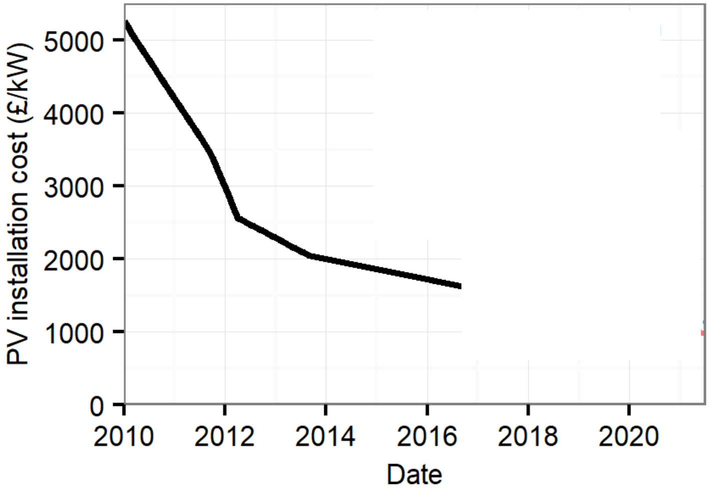




PV & electricity price scenarios

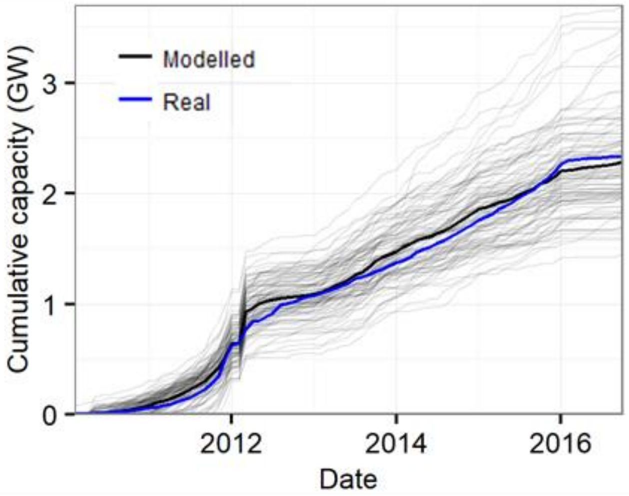
- For 2010-2016, use data from UK government.
  - Test different policy scenarios
- From 2016 onwards, make reasonable projections
  - 2 electricity price cases
  - 3 PV cost cases
  - Test different policy scenarios for each combination.

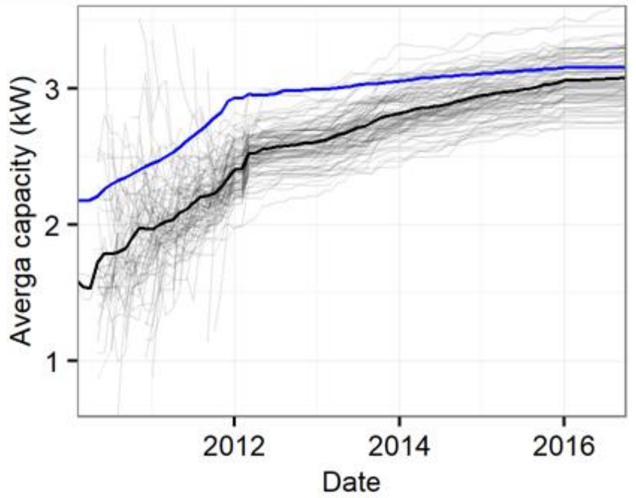




Model calibration

- Use data from January 2010 – October 2016
- Parameters: weights & threshold (constrained)
- **Approximate Bayesian Computation** [1]
  - Large (500,000) number of model runs with parameters sampled from **prior distributions**
  - Keep only small subset (0.2%) of runs which best match the data
  - These parameters form the **posterior distribution**
  - To run the model, sample parameters from the posterior distribution





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[1] *Thiele, J.C., Kurth, W., Grimm, V., 2014. J. Artif. Soc. Soc. Simul. 17, 1–45. doi:10.18564/jasss.2503*

Model operation

- Generate 5000 agents
- Run time evolution:
  - Monthly agent decision-making
  - 2010-2016 for historical
  - 2016-2022 for projections
- Collect results:
  - Installed capacity over time
  - Average capacity over time
  - Subsidy costs
  - …

Repeat x 100 *

↓

- Average results:
  - **Mean**: model outcome
  - **Standard deviation**: measure of uncertainty/sensitivity

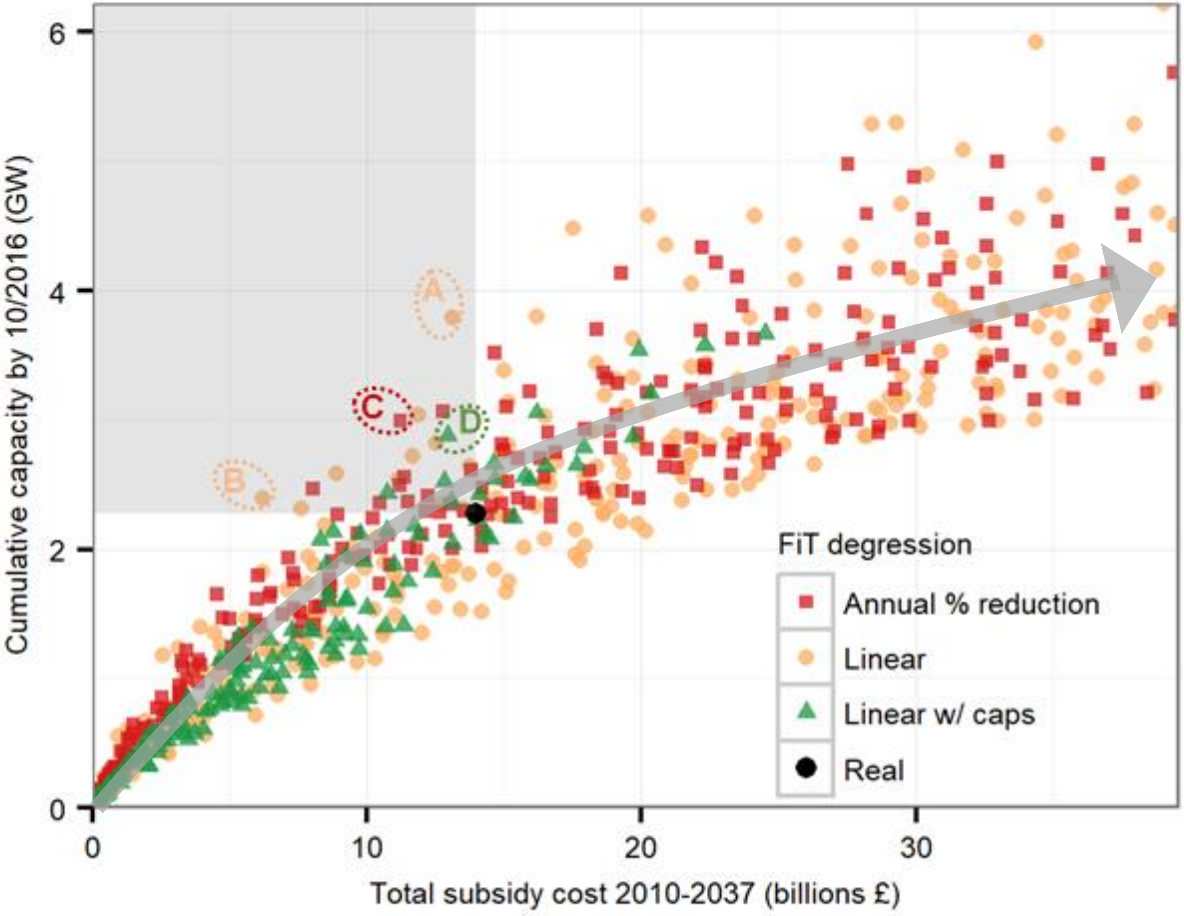
Model runs are **stochastic!**

* Access to a powerful computer/high performance cluster helps here!

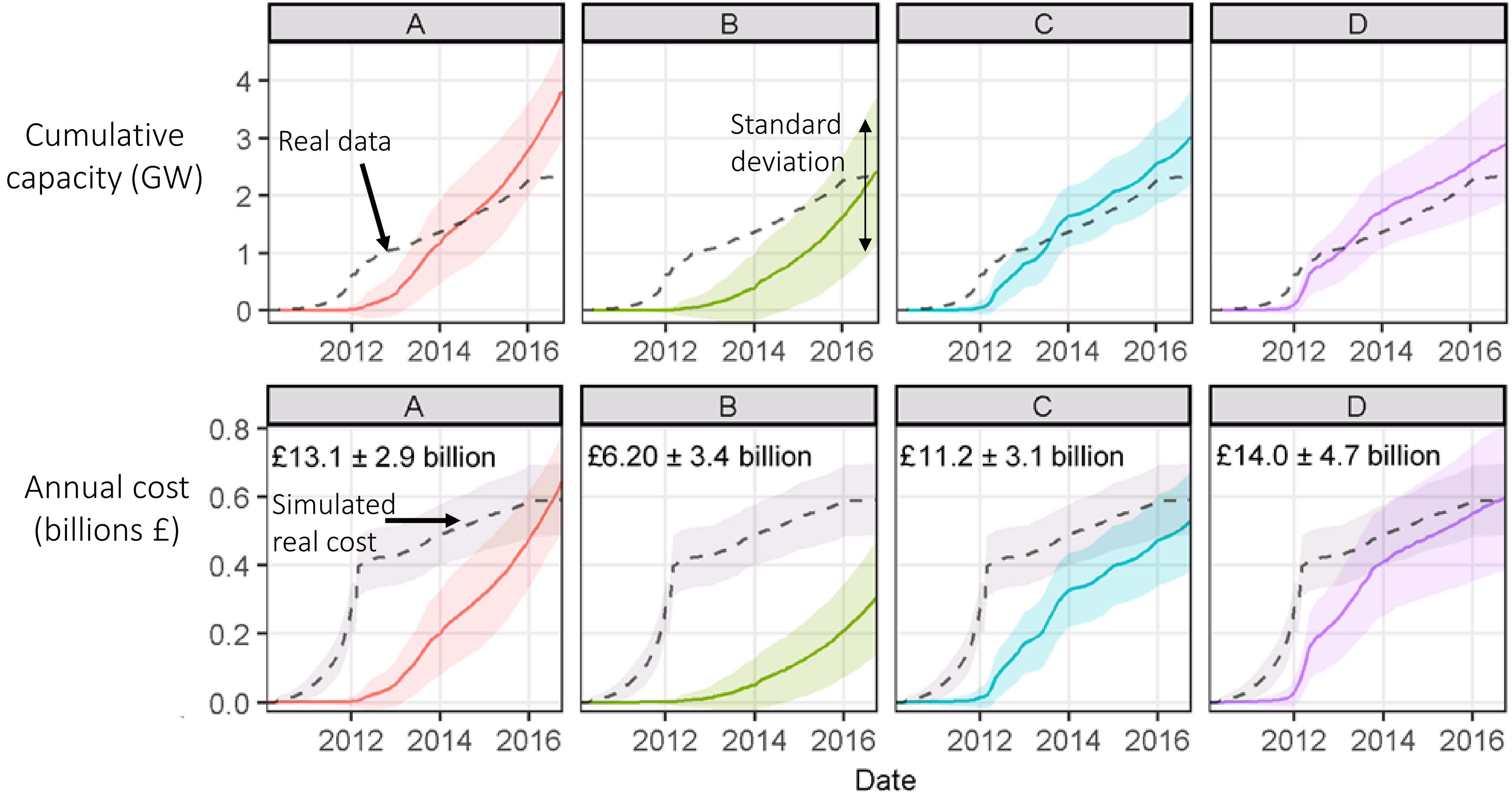
Historical scenarios

- Try **different degression strategies**:
  - Monthly linear degression
  - Fixed percentage reduction every year
  - Quarterly linear degression + deployment caps

- And vary:
  - Initial generation tariff (GT)
  - Final GT/reduction rate
  - Policy end date
  - Deployment caps
  - Export tariff



Historical scenarios: detailed results



Future policy scenarios

Projections: 2016-2022

a. ***No subsidies:*** No new FiT registrations after October 2016.

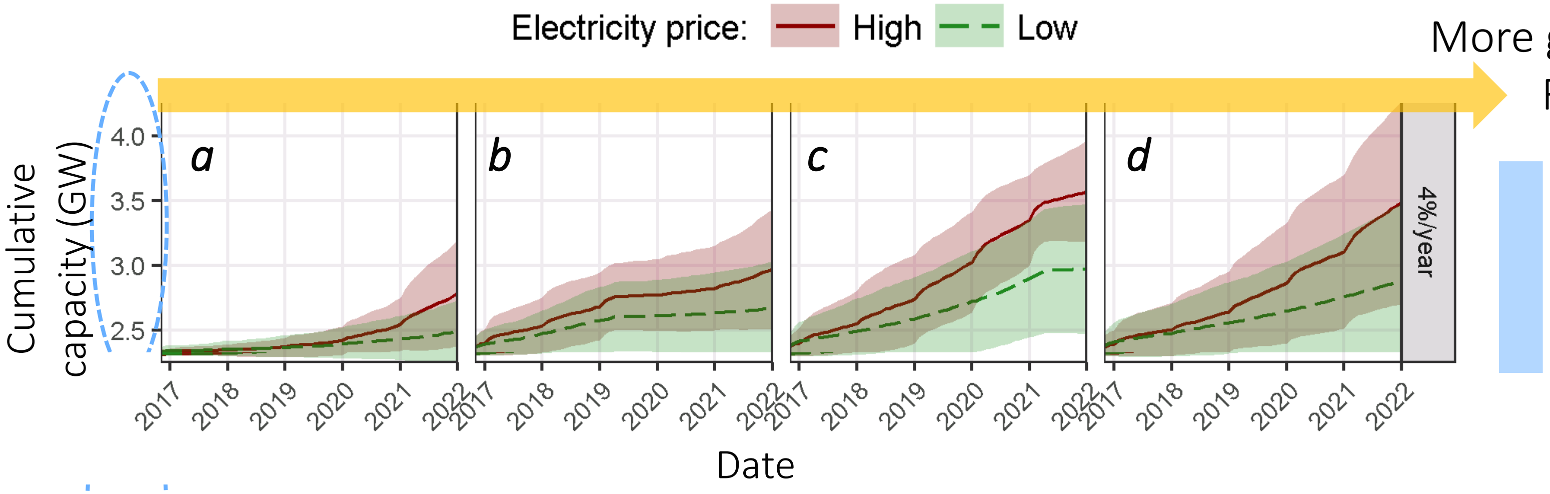
b. ***Real:*** FiTs with deployment caps available until March 2019.

c. ***Real + extension:*** Like ***b***, but extended until March 2021.

d. ***Linear degression, no caps:*** FiTs without caps, ending in December 2021.

➢ In each case, consider 2 electricity & 3 PV cost scenarios

Future scenarios: effect of policy



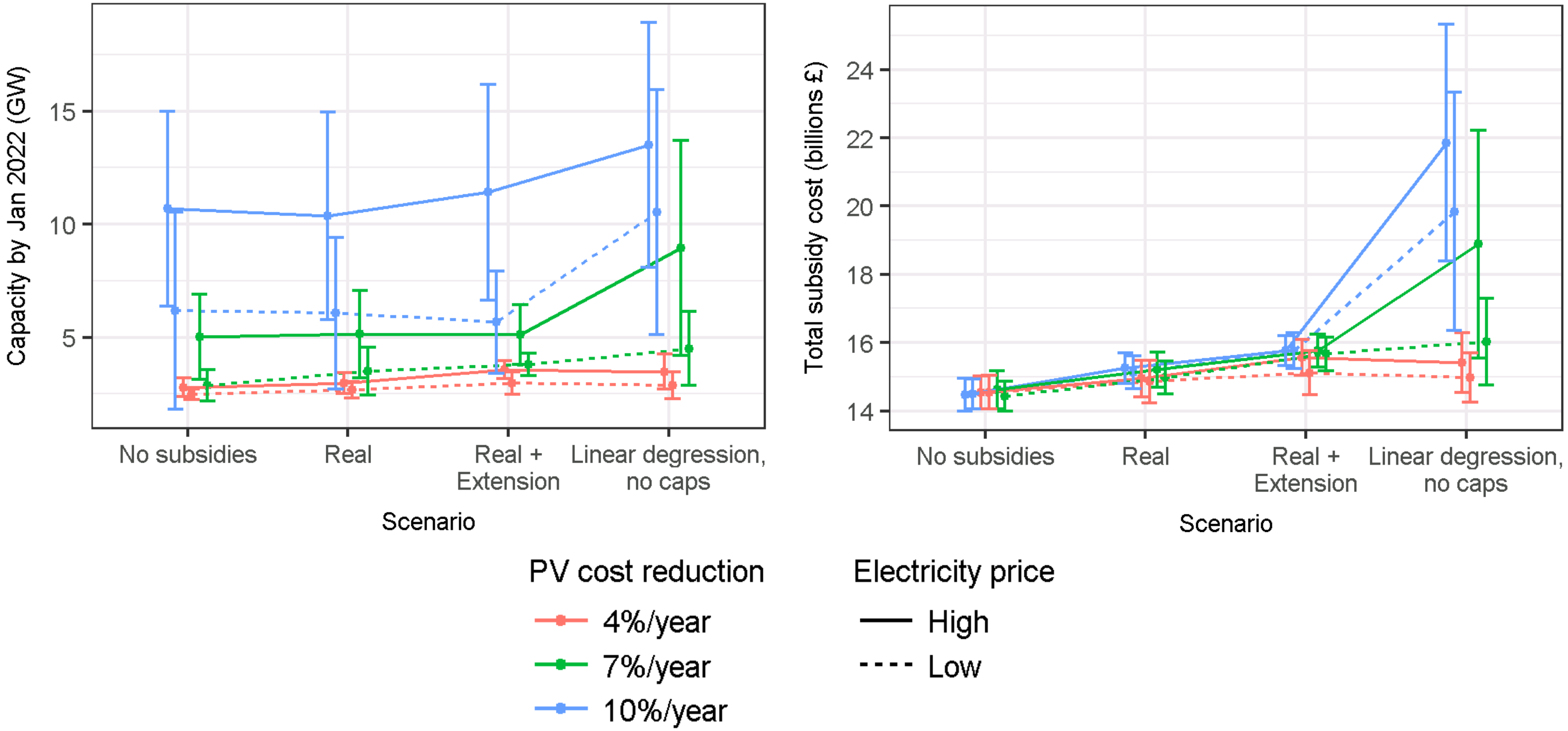
More generous FiTs

Cumulative cap

Cheaper PV

Date

Future scenarios: Summary



Conclusions

- Can model effect of FiTs with an ABM
  - Policy assessment
  - Capacity projections
- FiT policy was erratic & costly
- Logical alternatives with better outcomes
- Current & future FiTs so low they have almost no effect
  - Decreasing PV cost primary driver
  - High electricity prices provide further incentive

Next steps

- Compare model outcomes with reality 2017-2022
- Apply model to other countries/regions

Thank you for listening!

Questions?

Paper:

P. Pearce and R. Slade, “Feed-in tariffs for solar microgeneration: Policy evaluation and capacity projections using a realistic agent-based model,” *Energy Policy*, vol. 116, pp. 95–111, 2018. https://doi.org/10.1016/j.enpol.2018.01.060

Code:

github.com/phoebe-p/FiTABM

$$u_{inc,k} = \frac{1}{1 + \exp\left(\frac{\bar{I} - I_k}{5000}\right)}$$

$$u_{ec,k}(t) = \frac{20 - pp_k(t)}{19}$$

$$u_{soc,k}(t) = \frac{1}{1 + \exp\left(1.2 \times \left[\frac{L_k}{4} - A_k(t)\right]\right)}$$

$$u_{cap,k}(t) = \frac{1}{1 + \exp\left(-0.0007 \times \left[\frac{I_k}{5} - C_k(t)\right]\right)}$$

PV cost (£/kW)

PV capacity installed (kW)

$$pp_k(t) = \frac{PV(t)IC_k(t)}{R_k(t)}$$

Payback period (years)

Expected annual return (£/year)

Generation tariff (£/kWh)

Electricity price (£/kWh)

$$R_k(t) = O_k(t)\left[GT_k(t) + \frac{1}{2}ET_k(t) + \frac{1}{2}EP(t)\right]$$

Expected annual output (kWh)

Export tariff (£/kWh)

Aims of the FiT scheme

1) Encouraging deployment of **small-scale low-carbon** electricity generation (up to 5MW);
2) Empowering people and giving them a **direct stake** in the transition to a low-carbon economy;
3) Assisting the **public take-up** of carbon reduction measures;
4) Fostering **behavioural change** in energy use;
5) Helping **develop local supply chains** and **drive down energy costs**.