Modelling of Energy Storage

Policy options for promoting distributed **solar PV + battery** Systems

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Solar PV installations worldwide

One of the key technologies in renewable energy transitions worldwide

- Significant cost reduction of solar PV modules in recent years
- Cheapest generation mode in many countries
- Modular, visually accepted, not complex installation, no water needs, maintenance-free
- Other benefits of distributed generation, (grid independence, reliability, etc.)
- System level benefits in many countries (no cost of Transmission and distribution (T&D))

Global installed capacity of solar PV by country

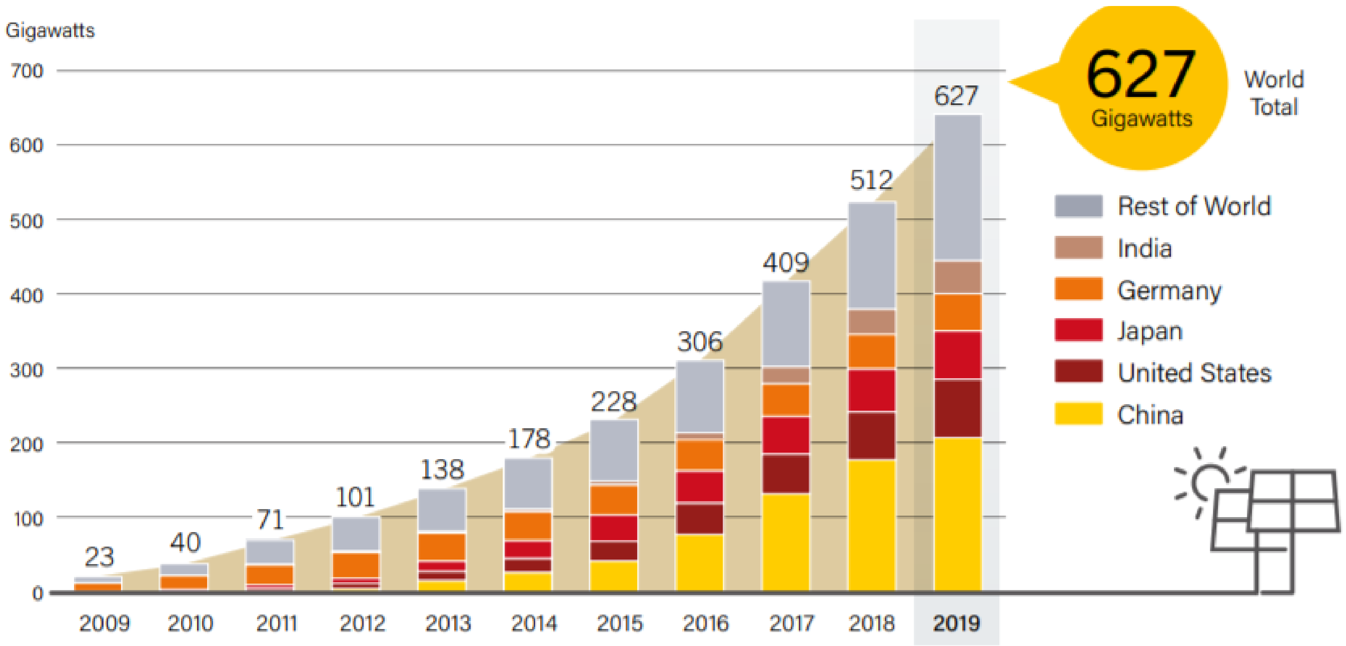


Chart: https://ren21.net

Solar PV in Europe

A diverse mix of policy support mechanisms

- Significant support, mostly feed-in-tariff in initial stages in different countries
- Continuous reduction of support as costs fall
- Receiving support in cold climate countries:

Denmark, UK, Sweden

Policy targets:

- Increasing self-consumption
- Export to the grid
- Recently: use of storage (battery) to

increase the self-consumption

Capacity additions of solar PV in Europe (2010-2019)

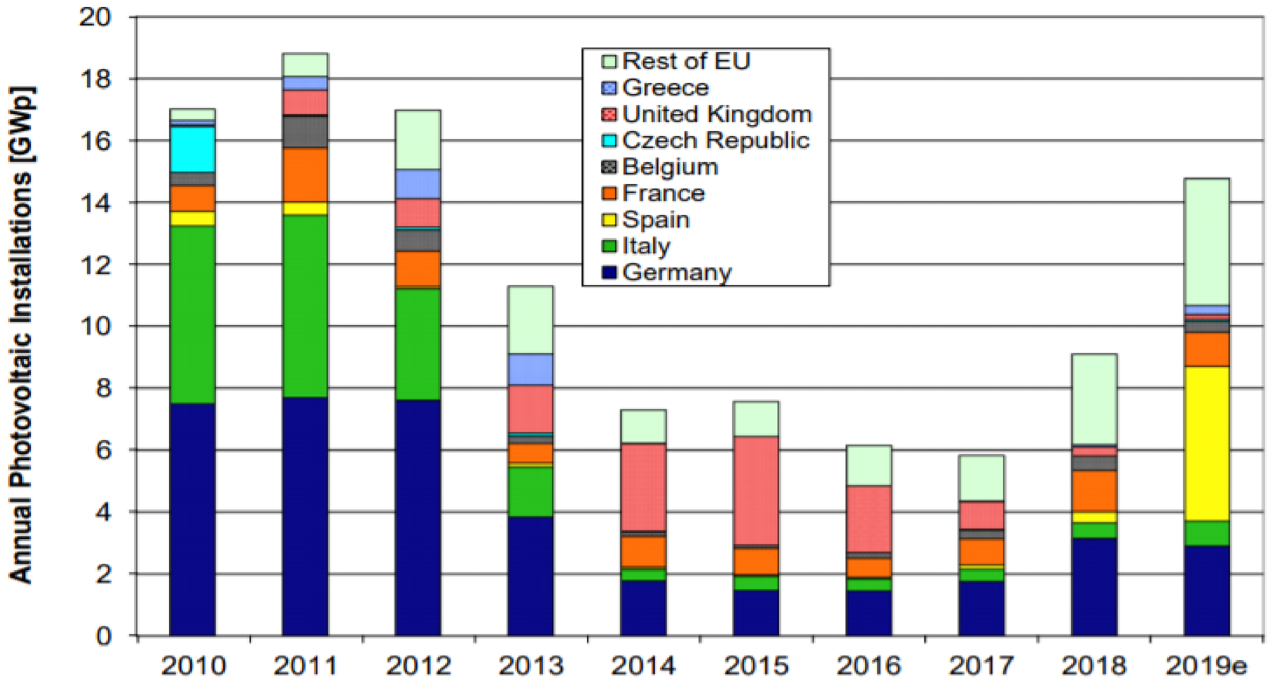


Chart: https://ec.europa.eu/jrc/sites/jrcsh/files/kjna29938enn_1.pdf

Solar PV self-Consumption

The amount of solar PV generation used onsite

- Depends on several parameters, including load pattern and solar irradiation, size, occupancy, …
- Self-consumption rate between 30-42% in UK

Daily self-consumption of residential solar PV (UK, summer)

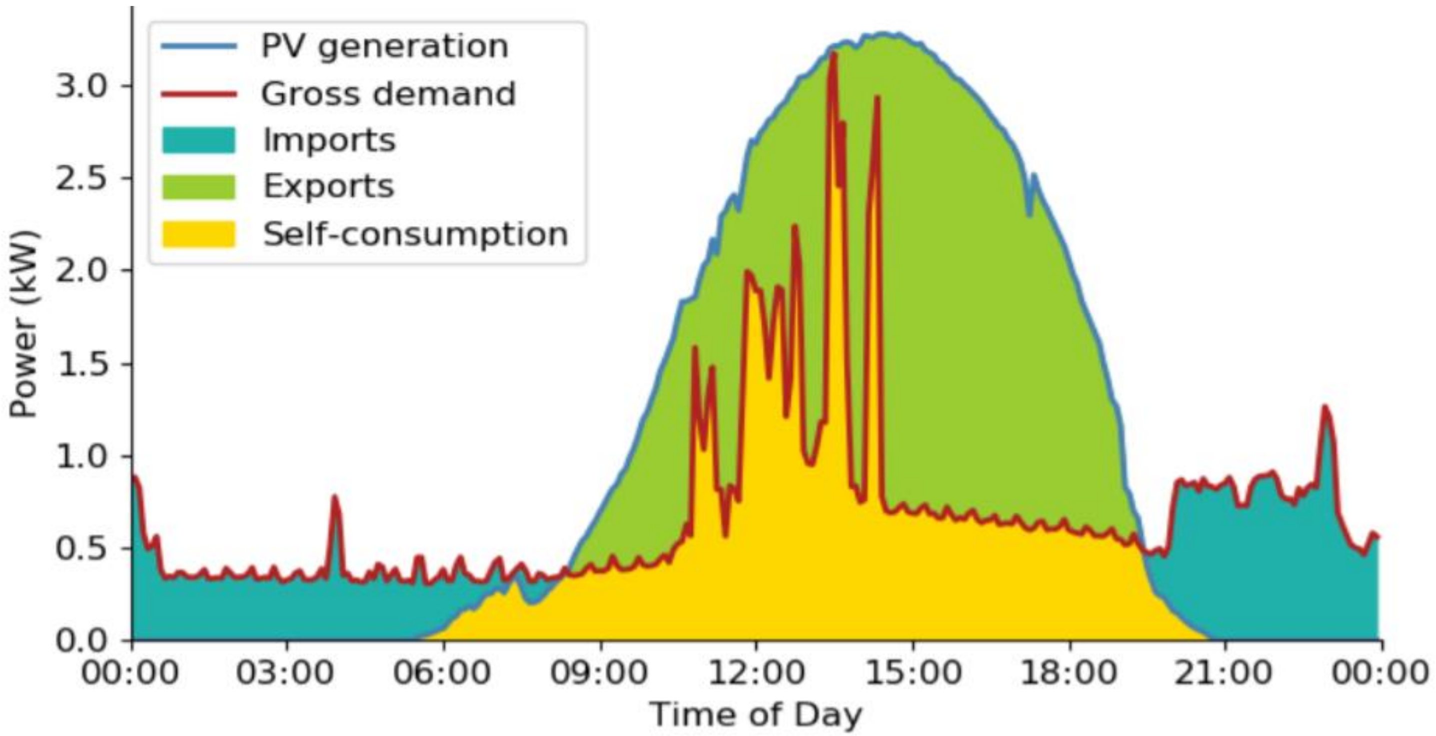


Chart: MkCenna et al, 2018: *Analysis of international residential solar PV self-consumption*

Solar PV self-Consumption (2)

How to increase the value of solar PV?

- Significant portion of solar PV generation must be exported to the grid
- Grid fees and export prices typically have lower value than self-consumption

Options for increasing self-consumption:

- Power to heat (electric heating) ➔ Finland (self-consumption 42% and more): not suitable for low-heat-demand seasons
- **Battery (electricity storage): focus of this analysis**
- Electric charging (?) ➔ Timing may not match (day-night)
- Sharing with the neighbors (?) (peer to peer, community pools, etc.)

Solar PV self-consumption vs. selling to grid in Denmark

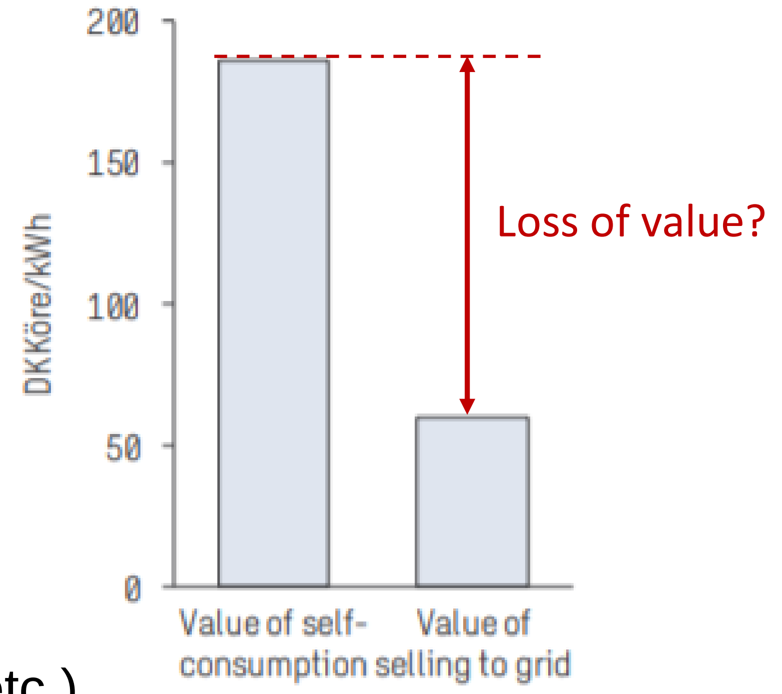


Chart: Sweco, 2020. *Distributed electricity production and self-consumption in the Nordics*

Solar PV paired with battery energy storage

How to calculate the cost-benefits?

- Cash flow metrics are commonly used to evaluate the financial viability of energy investments, such as Internal rate of return (IRR), net present value (NPV), etc.
- Revenues and costs should be known over the lifetime of the investment

For solar PV + battery it means:

- Estimating electricity prices for 20-30 years
- Amount of incentives/subsidies for years to come
- Grid selling price and tariffs for years to come
- Number of cycles battery can deliver (replacement?)

And several other parameters ➔

Complex and uncertain to calculate profitability

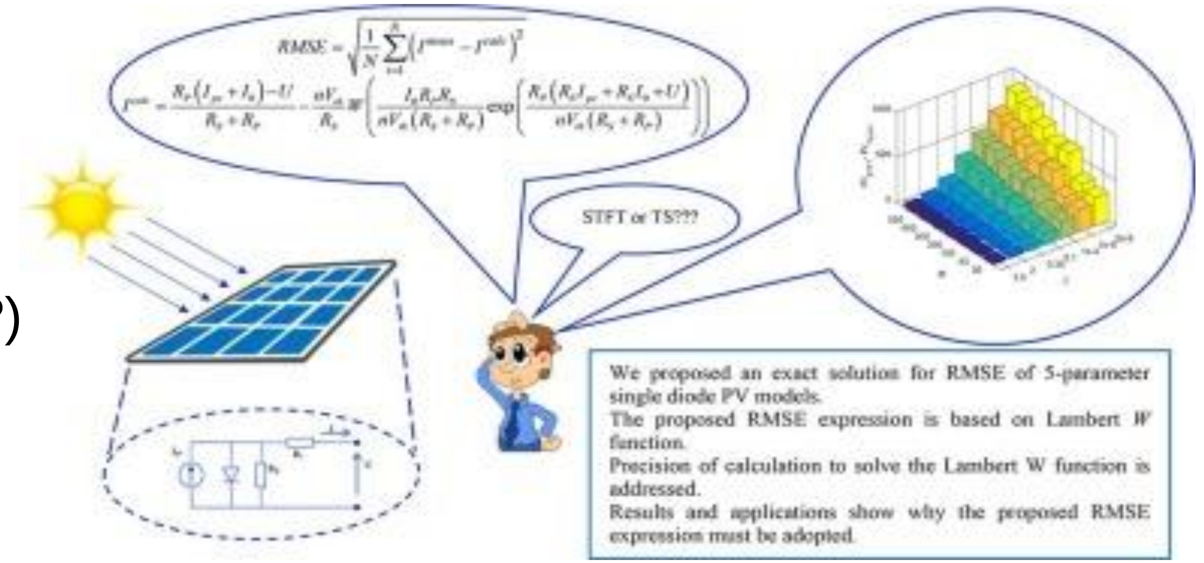


Image: Calasan et al. 2020

Solar PV + battery energy storage (2)

Feasibility studies: typically based on simplified assumptions

- Assuming fixed electricity prices and tariffs
- Assuming storage as a price taker technology

- Change of subsidy: the impact on the economics of distributed energy technology is significant

Solar PV self-consumption and Rate of Return (RoR) in UK

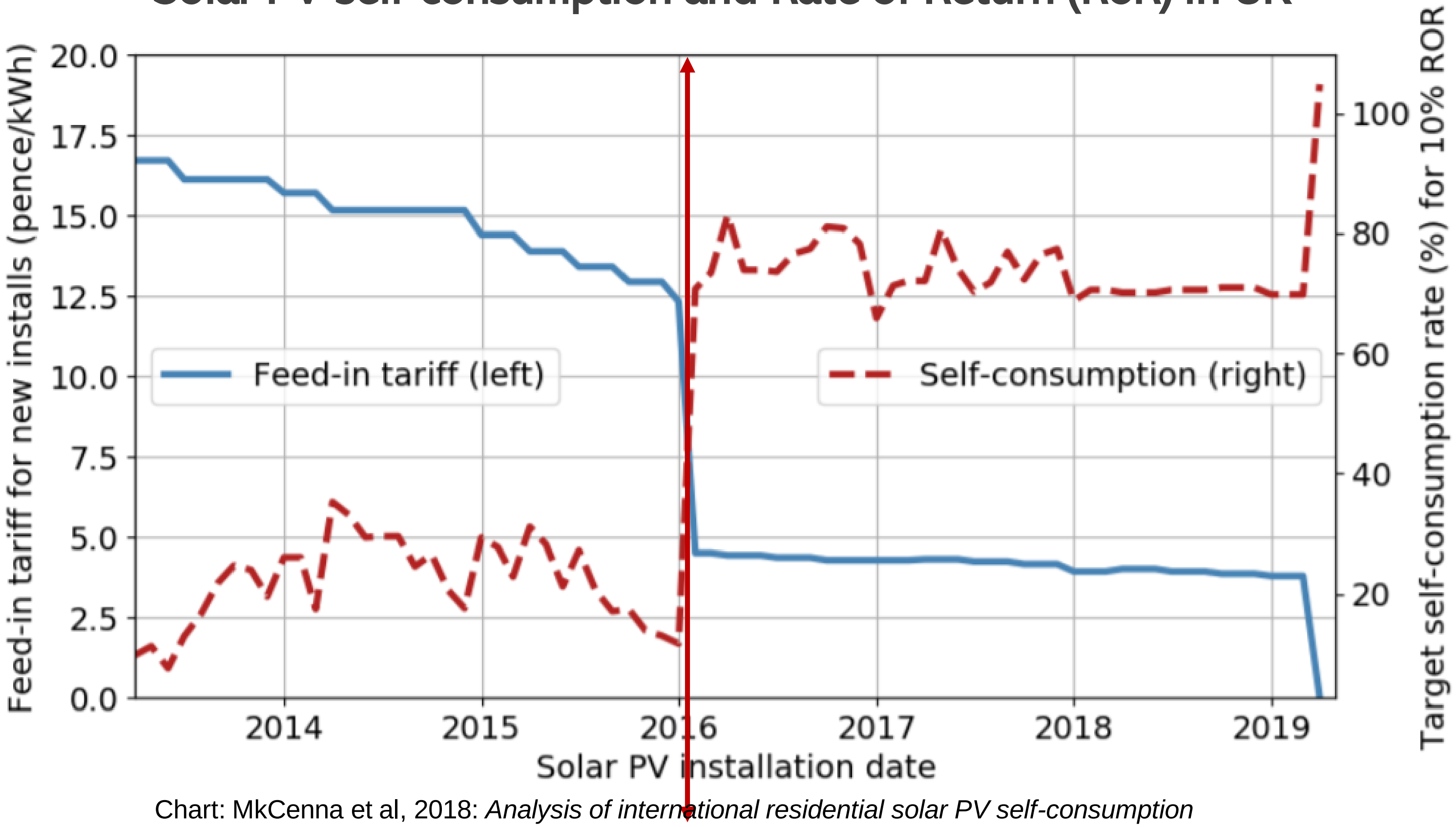
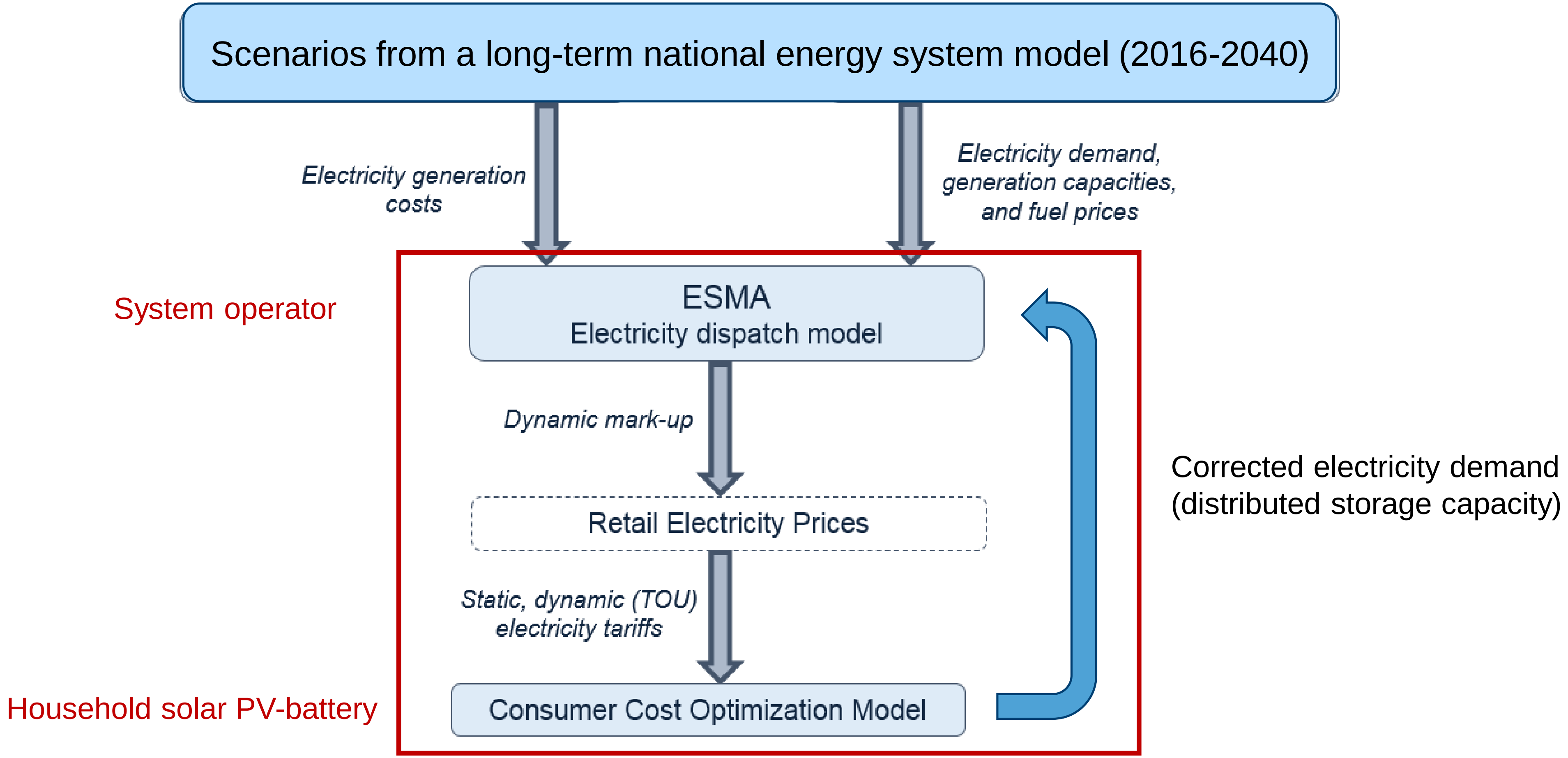


Chart: MkCenna et al, 2018: *Analysis of international residential solar PV self-consumption*

Modelling of solar PV + battery energy storage

An approach based on linking multiple models

Linking a consumer PV-battery model to a national-level electricity dispatch model



Modelling of solar PV + battery energy storage (2)

Evaluating consumer investments

- Considering a *system-based NPV* (SNPV)

➔SNPV internalizes the dynamics of electricity prices during the lifetime of investment

- Four future energy scenarios were examined

1. **Green ambition:** high renewables, high sustainability awareness
2. **Consumer power:** economics and energy security main drivers
3. **Slow progression:** reduced progression towards decarbonization
4. **No progression:** no significant changes

- Two electricity tariffs: static and time of use (ToU)
- Four technology options: no technology, PV-alone, battery-alone, and PV + battery

Results: consumer investments

Comparing system NPV (SNPV) of technology options for two scenarios

- Considering electricity bills and technology costs (not subsidies)

- PV with ToU tariffs offers highest benefits
(yet needs £0.4-0.5k to become profitable)

- Battery-alone is the costliest option

- PV + battery increases self-consumption **by 80%**
At an additional £2.6k–£3.9k (compared to PV-only)
- PV + battery is more beneficial in the scenario
with **higher RE** in the system (Gone Green)
- PV + battery more beneficial with static tariffs

Compared to “No technology”

Electricity tariff	Consumer technology	Future Energy Scenario: No Progression $SNPV$ (£k)	No Progression $\Delta SNPV_P$ £) k)	Gone Green $SNPV$ (£k)	Gone Green $\Delta SNPV_P$ £) k)
Static tariff	No technology	-9.5	N/A	-8.8	N/A
	battery-only	-16.2	-6.7	-15.0	-6.2
	PV-only	-10.9	-1.4	-10.1	-1.3
	PV+battery	-13.7	-4.2	-12.7	-3.9
TOU tariff	No technology	-9.0	N/A	-8.4	N/A
	battery-only	-12.8	-3.8	-11.9	-3.5
	PV-only	-9.5	-0.5	-8.8	-0.4
	PV+battery	-13.3	-4.3	-12.4	-4.0

4 kWp Solar PV ~ 8 **£**k; 6.4 kWh (3.3 kW) Battery (Li-ion) ~ 7 **£**k

Results: policy options

Existing and new incentives

➔Without incentives, using battery for self-consumption is not economically feasible for consumers

Deficit of 3.9 – 4.4 (£k)

The policy options examined:

1. Capital subsidy for pairing battery with PV

2. Eliminating incentives to export to the grid and adding a generation tariff (***enhanced tariff***)

3. Introducing a ***storage tariff:***

- Payment for each kWh of electricity stored (and discharged)
- Reflects the value created by the battery relative to an investment in solar PV alone
- A function of electricity tariff ➔ can encourage battery owners to shift to ToU

Results: policy options (2)

What policy option should be adopted?

- Capital subsidies are among the most effective policy for consumers, but with the highest cost for the system

- Enhancing tariffs improves profitability by 21% at no cost

- Storage tariff has benefits both for consumers and the system (helping balancing the grid)

Policy	Change in NPV (£k)	Change in NPV per £ invested in storage (%)	Enhancing operation of the system	Additional cost to the system operator	Complexity
30% Capital subsidy	3.4	54	Low	High	Low
Tariff enhancement	1.7	21	Medium	No	Low
Introducing storage tariff	1.4	18	High	Low	Medium to high
Switching to ToU tariffs	0.5	6	Medium	No	No
Switching to real-time tariffs	0.2	3	Medium	No	No

Results: policy options (3)

Final notes

- None of the policy options can make PV + battery net profitable (unless higher than 50% subsidy on battery)
- Barriers to some policies, like storage policy, is the need for metering of storage operation
- **Centralized coordination** of batteries through an aggregator will offer 11% cost savings for consumers compared to distributed operation, as well as system-level benefits
- Policy options that allow batteries to participate in ancillary services market offer significant improvement in profitability (the case of ***Enhanced Frequency Response*** in the UK)
- Uncertainty in future electricity prices and tariffs makes tariff-based policies complex for the consumer
- Providing modeling tools for the consumer to estimate the revenues under different future energy scenarios ➔ the consumer makes informed decisions: *high-renewable energy scenarios offer higher private benefits*
- Optimal sizing of storage and PV should not be neglected

More information:

- G. Castagneto Gissey , B. Zakeri, P. E. Dodds, Dina Subkhankulova, ***Evaluating consumer investments in distributed energy technologies***, Energy Policy, 2020 (in press), https://doi.org/10.1016/j.enpol.2020.112008

- E. Pusceddu, Behnam Zakeri, G. Castagneto Gissey: ***Synergies between arbitrage and fast frequency response for battery storage systems***, Applied Energy, 2020 (accepted)

- B. Zakeri, P.E. Dodds, G. Castagneto Gissey, ***What policy options can promote distributed solar PV with battery energy storage?*** Applied Energy, 2020 (under review)

Thank you very much for your attention!

Please contact us for your feedback or for more information:

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Results of Consumer Investments

Input data and assumptions: Tariffs

Tariff scheme	Base value, 2016 (kWh^{-1})	Future value
Static	0.15£	Based on quarterly average of modeled electricity prices*
Dynamic (ToU) (Economy7)	Night (0-7h): 0.07£ Day (7-24h): 0.16£	Proportional to corresponding static tariff

* These prices are endogenously calculated from the results of the electricity system model for the future years