Willingness to Pay for Solar Panels and Smart Grids in HK

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Motivation (1): Integrating RE is a challenge

- Often asserted that RE, such as wind and solar power, will replace fossil fuels
  - In HK 25% of the global electricity consumption comes from residential buildings, ⇒ RE investments at the HH level can significantly contribute to the expansion of RE

- Challenges associated with a higher penetration of RE generation
  - RE is variable + intermittent.

- The economic profitability of PV installations is usually appraised in the literature using the concept of LCOE (Levelized Cost Of Electricity) that completely ignores the intermittency feature of PV electricity generation as it is based on annual electricity generation

- Smart grids?
Motivation (2) : Smart grids as a way to integrate renewable energies

- We account for 2 levels of equipment in SG
  - Installation of smart meters
  - Energy storage

- What is the consumers’ Willingness To Pay (WTP) for:
  - solar panels (3kW peak PV system)?
  - smart meters?
  - batteries (Tesla Powerwall)?

→ better design of public policies
Optimal energy source mix for electricity generation (fossil fuels and renewables) when intermittency is considered (see Ambec and Crampes, 2012, 2015).

Energy dispatch problem when storage can take care of peak electricity or excess nuclear energy production (see Jackson, 1973; Gravelle, 1976; Crampes and Moreaux, 2010).

More technical studies have been conducted and show, for instance, that with a PV size below 5 kW peak, electricity consumption in UK passive houses needs to be reduced by 70% to reach zero-energy targets (Ridley et al., 2014).
Electricity demand management and smart grids have recently received a lot of attention

- in the academic literature (De Castro and Dutra, 2013, Léautier, 2014, Hall and Foxon, 2014 or Bigerna et al., 2016 and Brown and Sappington, 2017),

- in the media (The Economist, 2009; The Telegraph, 2015b,a),

not much work has been done that investigates the WTP of HHs for solar PV systems and smart devices.
3 bedroom apartment located on the 10th floor of a 20 floor Harmony public housing block.

Floor area of 73m2. Window area : 8 m2

Constructed from medium weight concrete with 100mm thick walls.

Overshadowed by the other apartments in the block.

The modelled apartment is located in the south east quadrant of the Harmony double cross shaped floor plan.
AC is provided in the main living room, and in the bedrooms, 75% of the floor area is conditioned.

Week day : AC in the living room operates from 16:00 to midnight, AC in the bedroom operates from 10pm to 6am.

Weekends : AC in the living room operates from 9:00 to midnight.

AC operates from May to October inclusive, with a thermostat set point of 26 deg C.

COP of the AC is 4.
- 3kW peak PV system covers 18 m² of the south and east façade of the apartments walls.
- PV panels are applied to the south walls of the living room and bedroom 1 and 2 and the south and east facades of the master bedroom.
- The PV panels occupy 27% of these wall facades.
- The total annual electricity consumption is 3919 kWh, with AC consumption of 725 kWh accounting for 18% of the total.
- After inverter lose the PV system generates 995 kWh, equivalent to 25% of consumption.
- Net metering
- No storage capability
Solar power generation and electricity consumption in the flat

Scenarios (365 days x 24 hours)

Averaged scenario (smoothed)

Solar generation and electricity consumption (kWh)

Solar gen.
Elec. cons.
Solar power generation and electricity consumption in the flat
Solar power generation and electricity consumption per season in the flat

Averaged scenario (smoothed) – Spring

Averaged scenario (smoothed) – Summer

Averaged scenario (smoothed) – Fall

Averaged scenario (smoothed) – Winter
Data: Village house in the New Territories

- Detached dwelling, with a floor area on 100m².
- South facing pitched roof with a slope angle of 22 degree facilitating the PV installation.
- Total glazed area of the dwelling is 32 m² (window to wall ratio of 0.32, with 16m² on the south façade and 16 m² on the north façade).
- Dwelling constructed from medium weight concrete with 100mm thick walls.
- Not overshadowed.
AC provided in the main living room, and in the bedrooms, 75% of the floor area is conditioned.

**Week day**: AC in the living room operates from 16:00 to midnight, AC in the bedroom operates from 10pm to 6am.

**Weekends**: the AC in the living room operates from 9:00 to midnight.

AC operates from May to October inclusive, with a thermostat set point of 26 deg C.

COP of the AC is 4.

The baseline electricity consumption including lights, appliances, and cooking, but not AC use is 8.75 kWh per day, with the peak load being 700 kW between 9 and 10pm each evening.
3kW peak PV system covers 18 m² of the south side of the pitched roof.

Average efficiency of the panes is 17%. The simulation is run using the standard CityU Energy Plus weather file. The PV system produces an annual yield of 1400 kWh/KW peak.

Total annual electricity consumption is 4433 kWh, with AC consumption of 1239 kWh accounting for 28% of the total.

After inverter lose the PV system generates 3847 kWh, equivalent to 87% of consumption.

Net metering

No storage capability
Solar power generation and electricity consumption in the house
Solar power generation and electricity consumption in the house
Solar power generation and electricity consumption per season in the house
\[
\begin{align*}
    \max_{\{s_i, g_i\}} & \quad u_1 (g_1 - s_1 + s_0) - p_1 g_1 \\
    & + \int_0^1 \left[ u_2 \left( x \bar{K} + g_2(x) - s_2(x) + \phi s_1 \right) - p_2 g_2(x) \right] \\
    & + \int_0^1 \left[ u_3 \left( y \bar{K} + g_3(x, y) - s_3(x, y) + \phi s_2(x) \right) \right] \\
    & + u_4 (g_4(x, y) + \phi s_3(x, y)) - \sum_{i=3,4} p_i g_i(x, y) \right] dF^y(y) \right] dF^x(x) \\
\end{align*}
\]

s.t. \( s_i \leq \bar{s}, s_i \geq 0 \), and \( p_3 > p_4 \geq p_2 > p_1 \).

\( x \bar{K} \) and \( y \bar{K} \): solar power generation; \( g_j \): grid purchases (or sales); \( s_i \): amount of energy storage that is carried to the following period; \( \phi \): round-trip efficiency parameter. The model is solved recursively.
Using electricity consumption data, we calibrate a CRRA utility function (season $i$ and period $j$),

$$u_{ij}(c) = \frac{\alpha(c - \bar{c}_{ij})^{1-\gamma}}{1 - \gamma},$$

We approximate the data with Weibull distributions, whose scale and shape parameters are estimated using maximum likelihood estimation.

In line with the observation, we assume $p_3 = \frac{4}{3}p_2 = \frac{4}{3}p_4 = 2p_1$ where the average price equals 75 cents/kWh.
The pdfs for period 2 and 3 at each season in the flat

- Winter
  
- Spring
  
- Summer
  
- Fall
The pdfs for period 2 and 3 at each season in the house
Electricity price over the day

Example of variation in hourly electric power demand and price over a single day

electric power demand

gigawatts

day-ahead power price
dollars per MWh

12:00 AM
6:00 AM
12:00 PM
6:00 PM
12:00 AM
We consider 8 scenarios and compute welfares

1. optimal grid activity + storage + solar panels + dynamic pricing
2. optimal grid activity + solar panels + fixed pricing (storage irrelevant)
3. optimal grid activity + storage from solar panels only + dynamic pricing (note: we can decide whether to consume or store from PV)
4. optimal grid activity + storage from solar panels only and PV generation first fills the battery
5. optimal grid activity + storage but + no solar panels + dynamic pricing
6. optimal grid activity + no storage + solar panels + dynamic pricing
7. optimal grid activity + no storage + no solar panels + dynamic pricing
8. optimal grid activity + no storage + no solar panels + fixed pricing (storage irrelevant)
Results: WTP for smart meters

High rise apartment / House

- solar panel + storage

\[ W_1 - \hat{r} k_m \geq W_2 \equiv k_m \leq \frac{W_1 - W_2}{\hat{r}} \]

where \( \hat{r} \equiv (1 - \beta)/(1 - \beta^{21}) \) and \( k_m \) is the cost of installing a smart meter.

WTP = HKD 13,325, WTP = HKD 18,051 (£2677)

- no solar panels + no storage

WTP = HKD 279, WTP = - HKD 242 (-£362)

- solar panels + no storage

WTP = - HKD 1728, WTP = - HKD 6,702 (-£358)

Cost of installing a smart meter (DECC for the UK) = HKD 2158

PROFITABLE IF THERE IS STORAGE
Results: WTP for solar panels and storage

- **WTP for solar panels**
  - dynamic pricing+ with or without storage,
    \[ WTP = \text{HKD 11,424}, \ WTP = \text{HKD 44,812} (\text{£4382}) \]
  - fixed pricing (no storage)
    \[ WTP = \text{HKD 9,975}, \ WTP = \text{HKD 37,867} (\text{£3662}) \]

Cost of a 3 kW peak PV system = HKD 40,000 to 50,000
(a 1.9 kW peak PV system: £2755)

*Not profitable for the flat, about profitable for the house*

- **WTP for storage**
  - dynamic pricing+ with or without solar panels
    \[ WTP = \text{HKD 11,596}, \ WTP = \text{HKD 11,349} (\text{£2319}) \]

Cost of Tesla power wall home battery: HKD 23,139

*NOT PROFITABLE*
Conclusions

- Solar panels are not clearly immediately profitable: need for public support
  - small and temporary support for the houses (less needed if dynamic pricing)
  - more support for the flats
- What matter for storage
  - the cost of the device
  - dynamic pricing
- What matters for smart meters: storage
- We can also conduct the analysis without net metering
  ⇒ For the UK, the first public policy to be implemented should concern the possibility of net metering