How time-of-use rates affect the arbitrage potential in a local peer-to-peer energy market

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June 8th 2021

1st IAEE Online Conference

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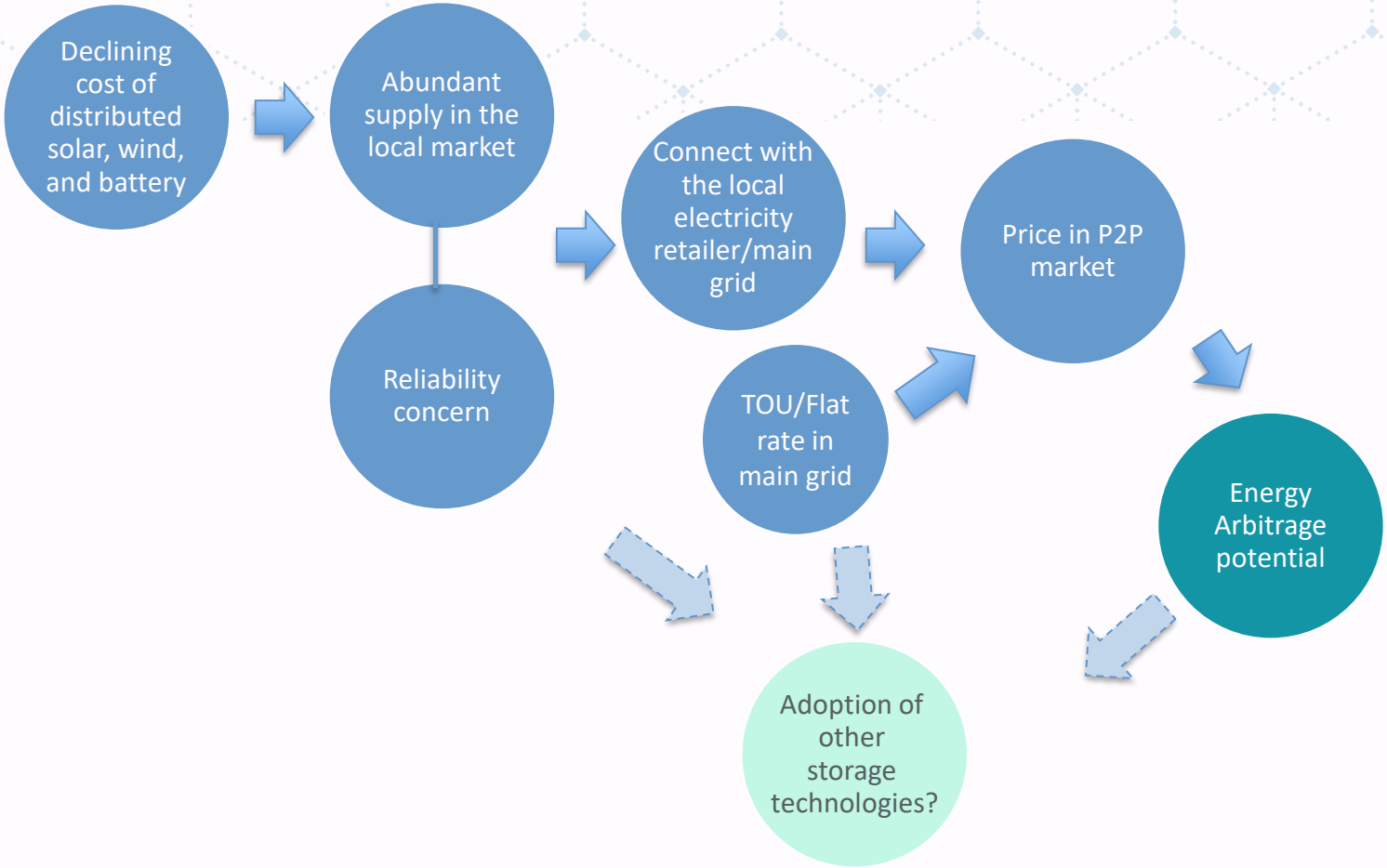
Background

- TOU rate may increase the adoption of battery, solar, EV, and other emerging energy technologies
  - Empirical: Liang, Jing, et al. "Time-of-use electricity pricing and residential low-carbon energy technology adoption." The Energy Journal 41.3 (2020).
  - Simulation: Schwarz, Marius, Quentin Auzepy, and Christof Knoeri. "Can electricity pricing leverage electric vehicles and battery storage to integrate high shares of solar photovoltaics?." Applied Energy 277 (2020): 115548.
  - …
- What if there is a local P2P electricity market? Will TOU still incentivize storage adoption?
  - The energy arbitrage potential would be important to affect the adoption of storage system

Background

- P2P market is emerging with declining cost of distributed resources and related infrastructure like blockchain.
- Price in the local market is usually estimated through
  - An optimization to maximize local welfare through a system manager
  - Find equilibrium in a cooperative/non-cooperative game
  - Simulate the auction process
- Not many consider the effect of the tariff design of local retailer
  - An, Jongbaek, et al. "Determining the Peer-to-Peer electricity trading price and strategy for energy prosumers and consumers within a microgrid." Applied Energy 261 (2020): 114335.
    - Analyze the minimum and maximum price in local market based on self-consumption rate prosumers

Background


Declining cost of distributed solar, wind, and battery
Abundant supply in the local market
Reliability concern
Connect with the local electricity retailer/main grid
TOU/Flat rate in main grid
Price in P2P market
Energy Arbitrage potential
Adoption of other storage technologies?

Assumption and method

$$\min_{p_t} \sum_{t=0}^{23} (p_t - d_t)^2$$

$s.t.$

$$\forall\, t, p_t \leq p_{main,t}$$
$$\forall\, t, p_t \geq p_{feedin,t}$$

p_t : Price of the local market at time t;

d_t: Normalized demand at time t;

$p_{main,t}$: Price of the main grid at time t;

$p_{feedin,t}$: feed-in price

Assumption:

1. Still connect to the main grid
2. Price shape the same as demand profile
3. Bounded by feed-in price and retail price

Metrics

$$P_p \times E \times \eta > \mathrm{P_{op}} \times E$$

$$\eta > \frac{\mathrm{P_{op}}}{P_p}$$

P_p : Peak Price of the day

P_{op} : Off-peak price of the day

E: Charged energy

η: Round-trip efficiency

To make energy arbitrage for at least one time interval (one hour) in a day, the round trip efficiency need to be higher than the OP/P price ratio

Metrics

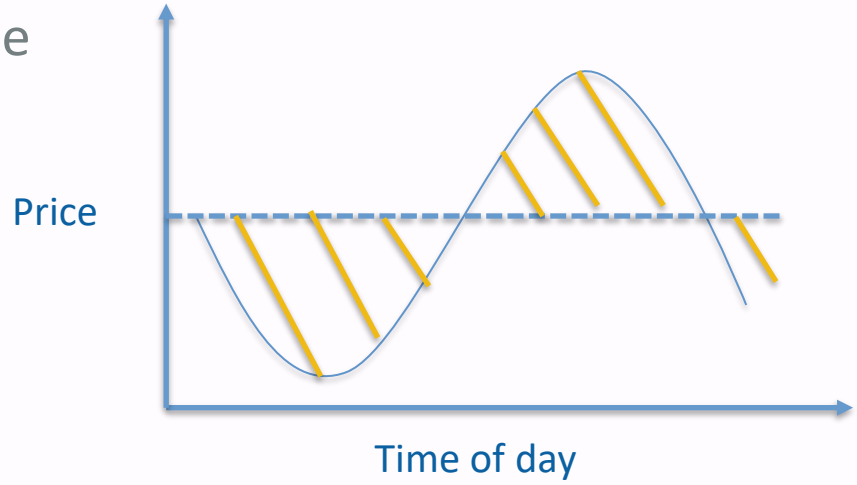
$$P_d = \sum_t |P_t - \mathrm{P_{ave}}|$$

P_{ave} : Average price of the day;

P_t : Price at time t;

P_d : Accumulated price difference of the day

Daily maximum energy arbitrage potential can be estimated as the differences between real-time price and average price of the day.



Data and Scenarios

Pecan Street Inc provides 15-min electricity consumption of 25 household in Austin for a whole year of 2018

It can be decomposed by some appliances and areas. We add back the generation from residential solar to get the total demand.

5 households have records about electricity consumption from office suite/room and we identify them as work from home life style.

Scenario 1: Business as Usual, 25 households local market

Scenario 2: Work from Home, 5 WFH households local market

Data and Scenarios

Flat:

Energy Charge (~1000kWh)+Power Supply adjustment(vary by months) + others*

Time of Use (TOU)^:

Peak:14:00-20:00 Mon-Fri, Summer

Mid-peak:

1）6:00-14:00；20：00-22：00；Mon-Fri, Summer

2）6：00-22：00 Sat-Sun, Summer

3) 6：00-22：00 everyday, Non Summer

Feed-in-tariff: Energy component of the Value of Solar(VOS)

VOS**=energy(0.032)+ environmental (0.015)+ transmission(0.020) =0.085$/kWh

*Others include basic charge($/mon), community benefit and regulatory charge

^TOU rate was suspended in 2018

**Transmission value is the avoided transmission cost from reduced load due to PV

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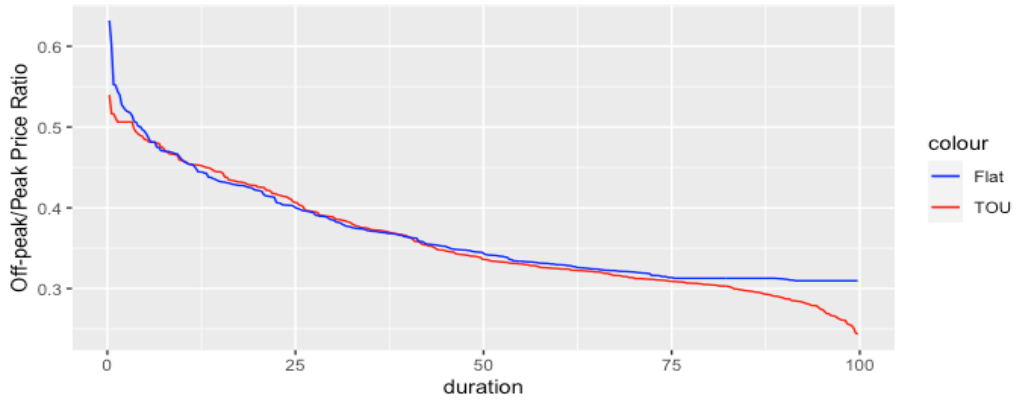
Result

Business as usual

Accumulated Price Difference:
Total daily potential in TOU design is slightly higher

OP/P Price ratio:
TOU allows lower round trip efficiency technology to make a profit in some days of the year



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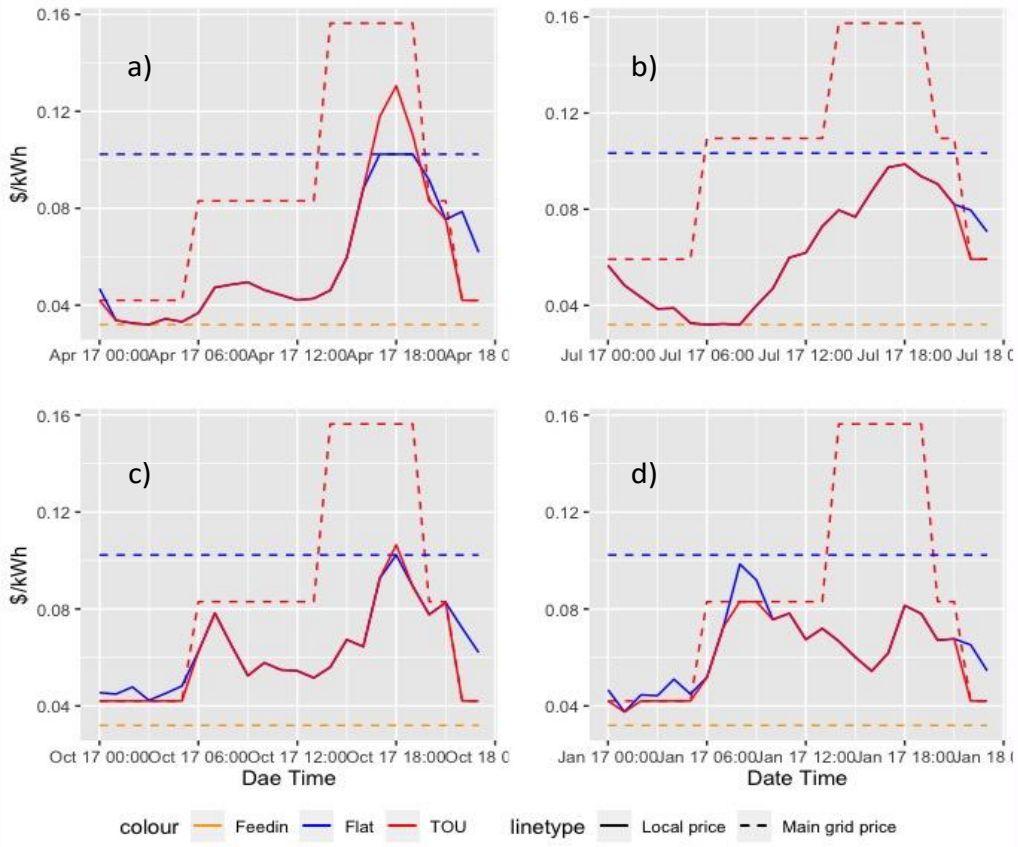
Result

Business as usual

- The lowest price is similar in Flat rate and TOU design;
- TOU allows higher local electricity price in some hours, especially the afternoon demand peak;
- Flat rate allows slightly higher price in morning peak period.



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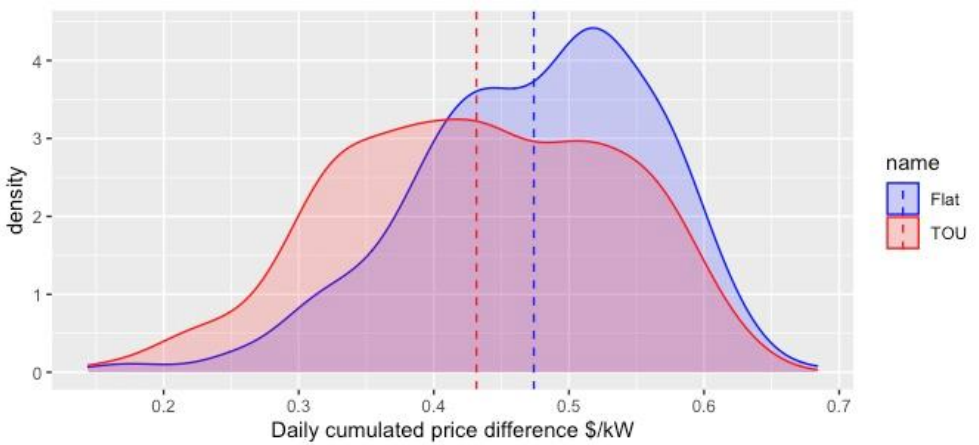
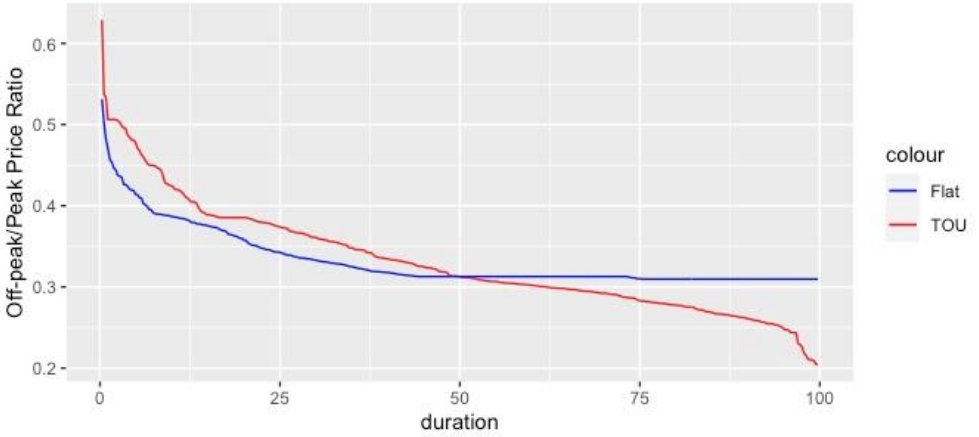
Result

Work from home

Accumulated Price Difference: Total daily potential in Flat rate design is higher



OP/P Price ratio:
TOU allows lower round trip efficiency technology to make a profit in some days of the year; Flat rate allows more days to earn profits for technology with efficiency higher than 30%



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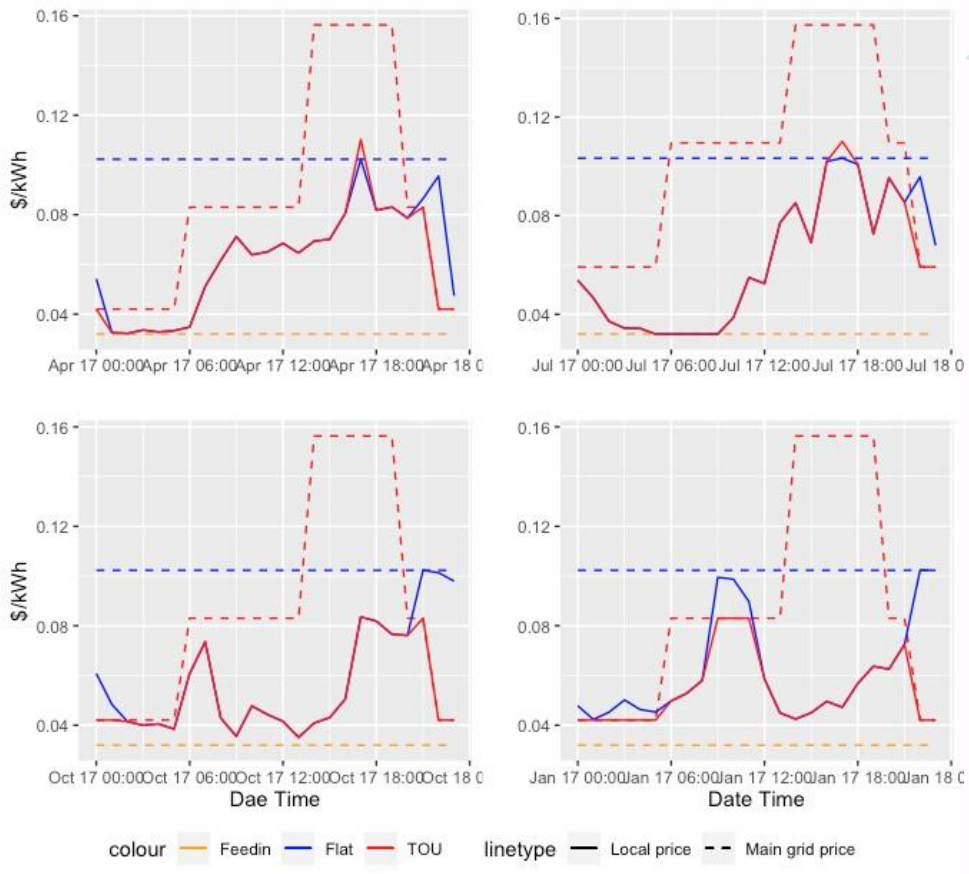
Result

Work from home

- Higher demand during the day in spring and summer compared with BAU;
- Highest demand of the day may appear in late night, inconsistent with the TOU design



Conclusion

- TOU rate may still increase the adoption of energy storage in BAU but flat rate may be preferred in WFH scenario for high efficiency storage technologies
- TOU allows low efficiency storage technologies to seize at least one energy arbitrage opportunity.
- WFH would require a new TOU design to reflect the peak and off peak hours

Future investigation

- Link the energy arbitrage potential with storage adoption
  - Cost of storage technologies
  - Price response
- Electric vehicle:
  - EV will change the demand and may also consider the energy arbitrage opportunities as a storage system.
- Flexible demand:
  - Smart HVAC may change the demand profile
- Equity:
  - Will underrepresented communities enjoy the same benefit of P2P and TOU design? Similar research has analyzed TOU without P2P market

THANK YOU!

Q&A

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