

URBAN SOLUTIONS AND SUSTAINABILITY R&D CONGRESS 2023

BUILDING SUSTAINABLE, RESILIENT, AND LIVEABLE CITIES OF TOMORROW

4TH - 5TH OCTOBER 2023

Accelerating PV Adoption in Singapore: The Potential of Advanced Energy Communities

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Institutes: (FCL) **FUTURE
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RESILIENT
SYSTEMS**



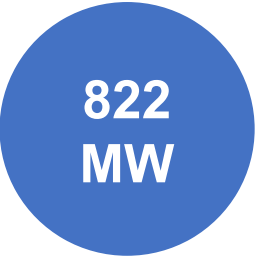
ETH zürich

Background

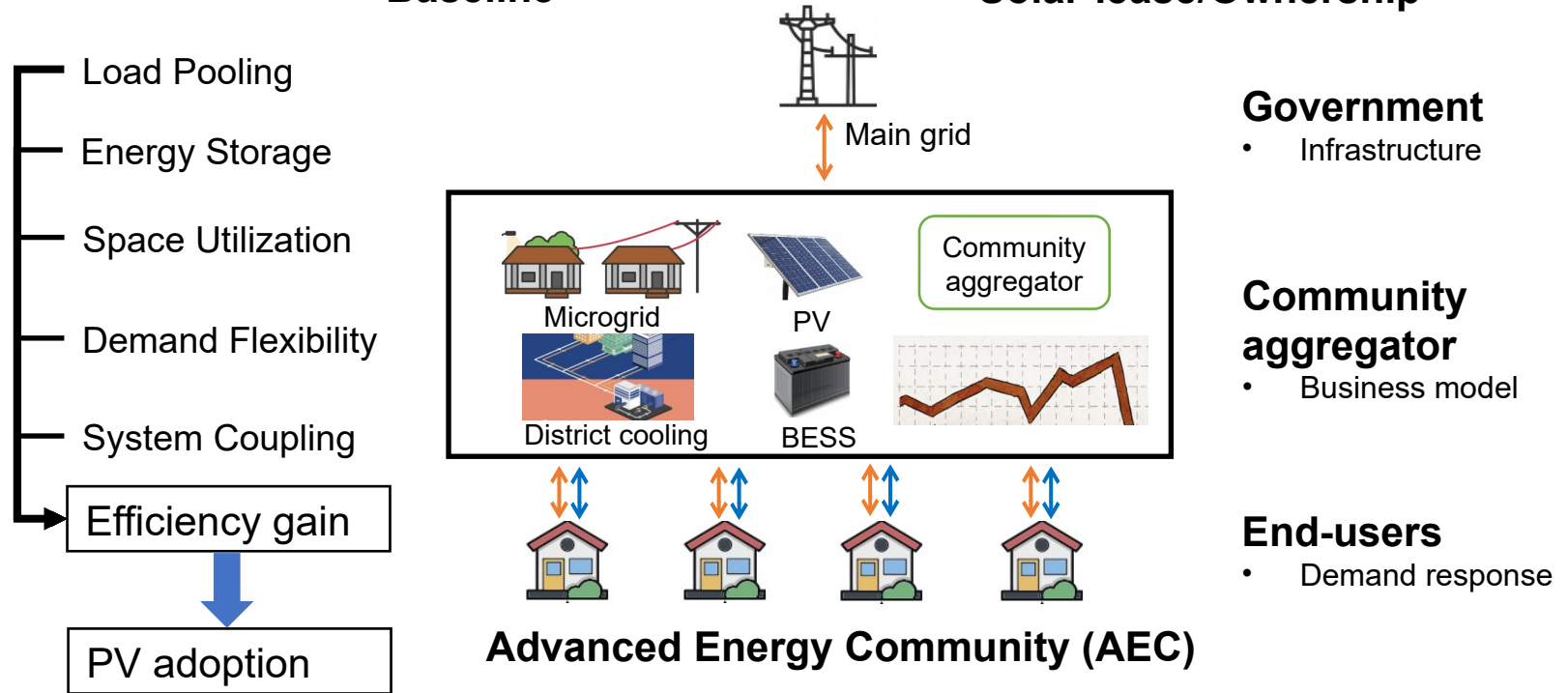
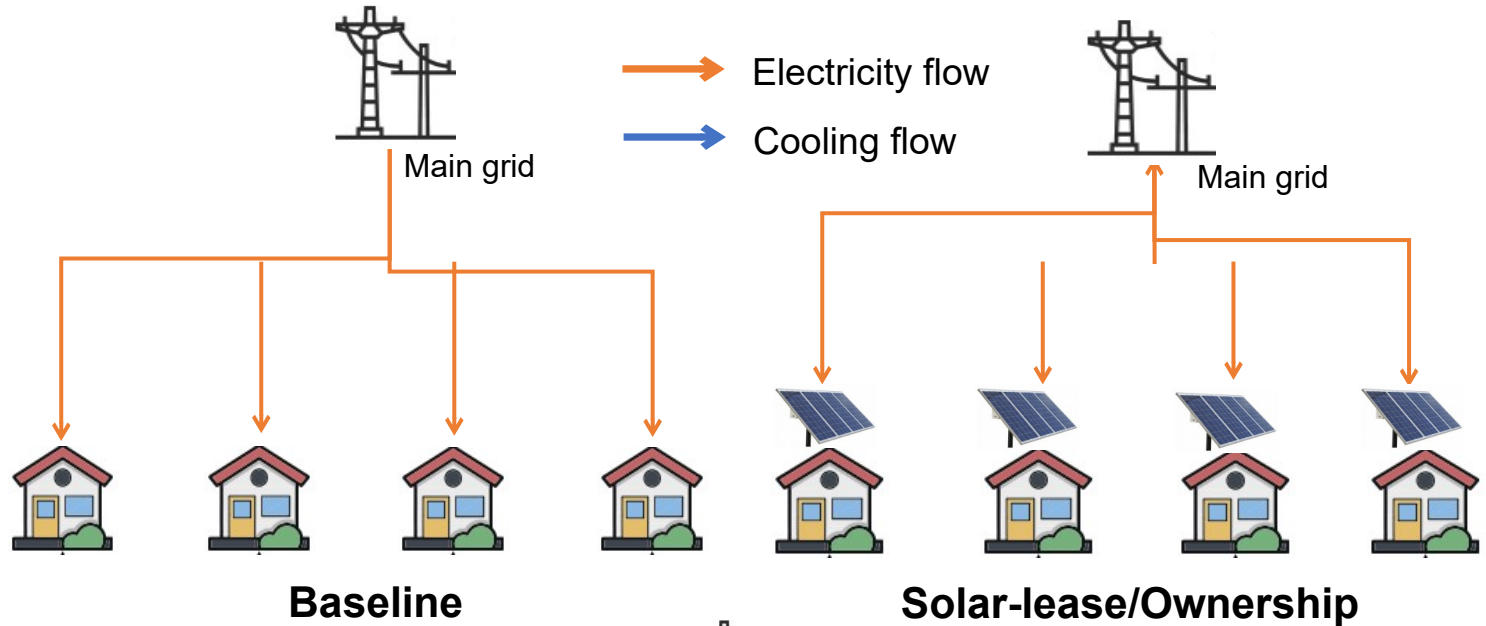
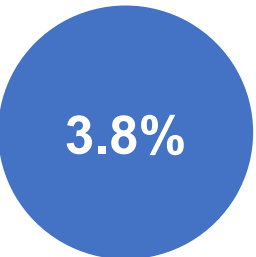
Target:



Current:



Private residential properties:



Definition

PV adoption rate =

(Self-sufficiency rate)

Research questions

1. How much efficiency gain can be created by AEC?
2. What are the sources of efficiency gain of AEC?
3. Efficiency gain → PV adoption?

Contribution

- ▮ A coherent optimization framework to study the interface between user demand and supply technologies.
- ▮ Evaluate the various technology components and business model.
- ▮ Apply to various building archetypes in Singapore.

Methods

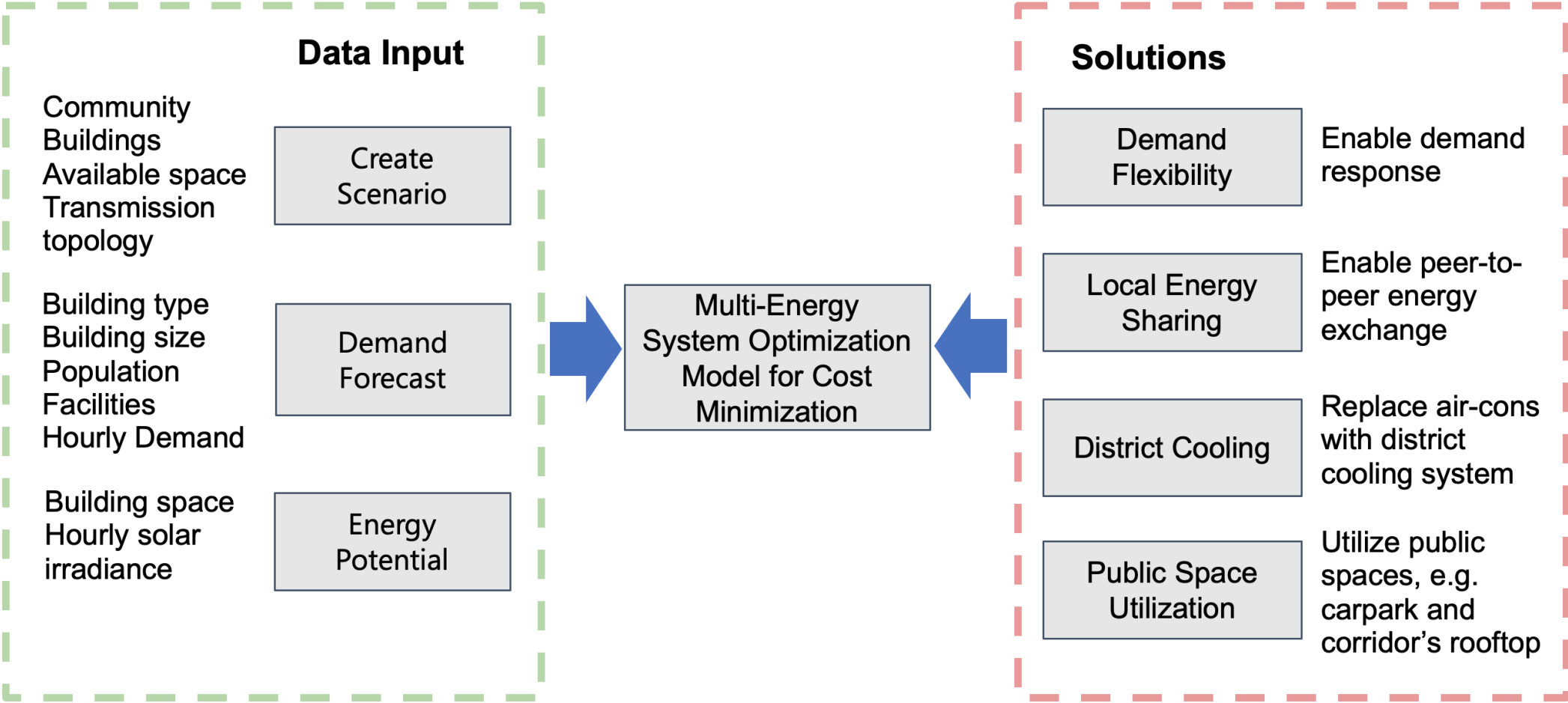


Fig. 3 Methodological framework for data simulation and optimization

9 building architypes



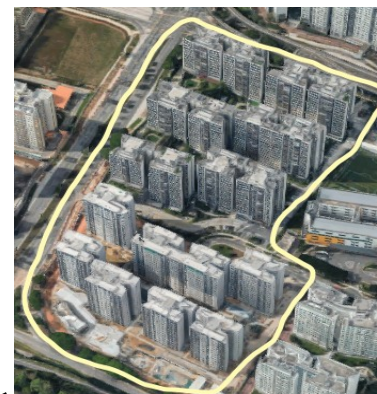
Landed_Punggol
(23 buildings)



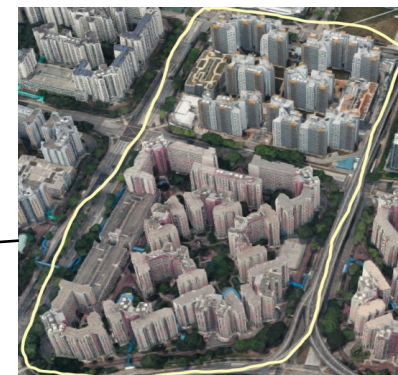
Industrial_Woodlands
(19 buildings)



HDB_Punggol
(23 buildings)



Condo_Punggol
(17 buildings)



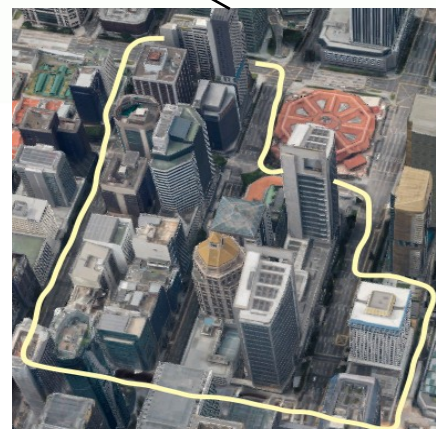
HDB_SengKang
(21 buildings)



University_NUS
(21 buildings)



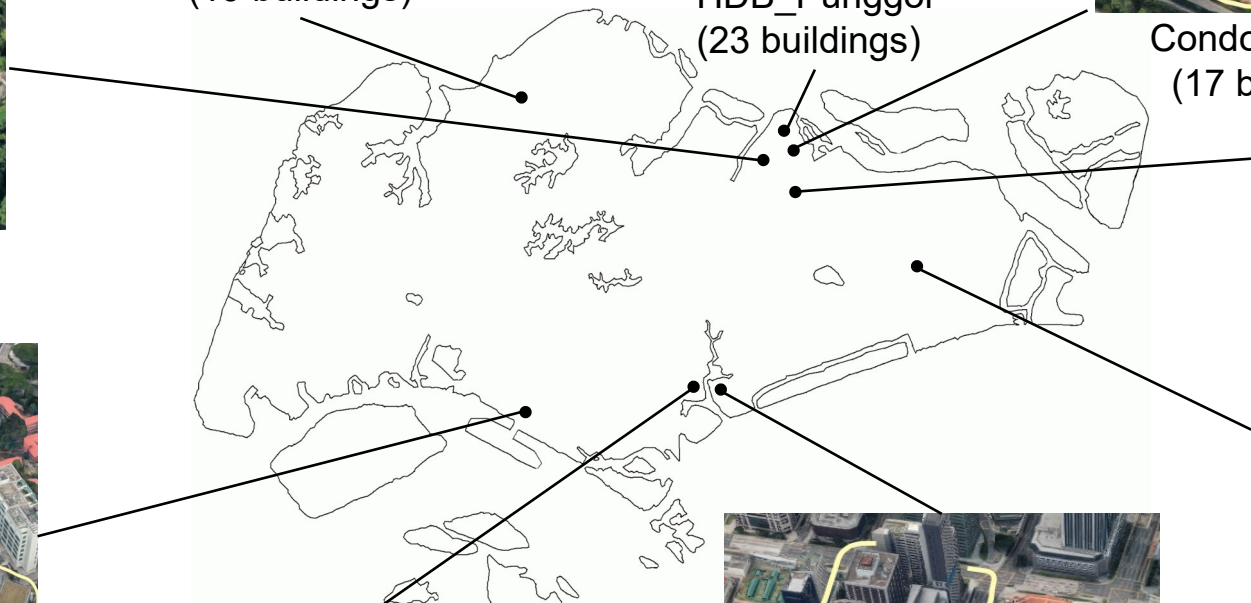
Shopping_Suntec
(21 buildings)



Commercial_CBD
(23 buildings)



Industrial_Changi
(19 buildings)



Results

(Electricity tariff = 20 cents/kWh, feed-in tariff = 8 cents/kWh)

Building archetypes	Solar density (kWp/kWh)	LCOE (Cents/kWh)		Total drop in LCOE	Incremental reduction in LCOE					Sell back to grid (MWh)		Self-sufficiency (PV adoption)		Dynamic real-time price
		Solar lease	AEC		Load pooling	Storage battery	Space Utilization	Demand Flexibility	System Coupling	Solar lease	AEC	Solar lease	AEC	
Commercial (CBD)	0.13	20	19.1	4.3%	0.0%	0.0%	0.3%	0.0%	4.0%	0.03	0	6.3%	7.4%	
Condo (Punggol)	0.92	16.4	15	8.7%	1.3%	0.0%	1.4%	1.3%	4.7%	0.27	0.09	36.4%	41.4%	
HDB (Punggol)	1.06	16.9	15.5	8.2%	0.9%	0.0%	1.5%	0.8%	5.0%	0.12	0.04	36.6%	42.7%	
HDB (Sengkang)	1.21	15.7	14.1	10.3%	2.2%	0.0%	1.2%	2.4%	4.5%	1.79	1.21	44.9%	48.9%	
Industrial (Changi)	0.3	17.6	16.5	6.5%	0.0%	0.0%	1.7%	0.0%	4.8%	0	0	24.6%	28.7%	
Industrial (Woodlands)	0.19	18.8	17.7	5.5%	0.0%	0.0%	1.0%	0.0%	4.5%	0	0	15.5%	18.1%	
Shopping (Suntec)	0.12	19.7	18.6	5.7%	0.0%	0.0%	0.4%	0.0%	5.2%	0.01	0	8.9%	10.4%	
University (NUS)	0.21	19.8	19.3	2.5%	0.0%	0.0%	0.3%	0.0%	2.3%	0	0	9.8%	11.1%	
Landed (Punggol)	3.74	11.1	9.5	14.5%	0.0%	0.0%	3.4%	6.1%	5.0%	0.89	0.99	196.1%	226.7%	

Table 1. Potential and drivers of AEC for efficiency gain and PV adoption

Results

(Electricity tariff = 20 cents/kWh, feed-in tariff = 8 cents/kWh)

Building archetypes	Solar density (kWp/kWh)	LCOE (Cents/kWh)		Total drop in LCOE	Incremental reduction in LCOE					Sell back to grid (MWh)		Self-sufficiency (PV adoption)		Dynamic real-time price
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Building archetypes	Solar density (kWp/kWh)	LCOE (Cents/kWh)		Total drop in LCOE	Incremental reduction in LCOE					Sell back to grid (MWh)		Self-sufficiency (PV adoption)		Dynamic real-time price
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HDB (Punggol)	1.06	16.9	15.5	8.2%	0.9%	0.0%	1.5%	0.8%	5.0%	0.12	0.04	36.6%	42.7%	
HDB (Sengkang)	1.21	15.7	14.1	10.3%	2.2%	0.0%	1.2%	2.4%	4.5%	1.79	1.21	44.9%	48.9%	
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Landed (Punggol)	3.74	11.1	9.5	14.5%	0.0%	0.0%	3.4%	6.1%	5.0%	0.89	0.99	100.1%	220.7%	

Table 1. Potential and drivers of AEC for efficiency gain and PV adoption

Results

(Electricity tariff = 20 cents/kWh, feed-in tariff = 16 cents/kWh)

Building archetypes	Solar density (kWp/kWh)	LCOE (Cents/kWh)		Total drop in LCOE	Incremental reduction in LCOE					Sell back to grid (MWh)		Self-sufficiency (PV adoption)		Dynamic real-time price
		Solar lease	AEC		Load pooling	Storage battery	Space Utilization	Demand Flexibility	System Coupling	Solar lease	AEC	Solar lease	AEC	
Commercial (CBD)	0.13	20	19.1	4.3%	0.0%	0.0%	0.3%	0.0%	4.0%	0.03	0	6.3%	7.4%	
Condo (Punggol)	0.92	16.2	14.9	8.1%	0.4%	0.0%	2.0%	0.8%	4.9%	1.05	0.93	45.1%	52.2%	
HDB (Punggol)	1.06	16.8	15.5	7.7%	0.3%	0.0%	1.6%	0.6%	5.1%	0.54	0.15	40.7%	44.4%	
HDB (Sengkang)	1.21	15	13.5	9.6%	0.5%	0.0%	2.8%	1.0%	5.4%	3.35	2.82	54.5%	60.2%	
Industrial (Changi)	0.3	17.6	16.5	6.5%	0.0%	0.0%	1.7%	0.0%	4.8%	0	0	24.6%	28.7%	
Industrial (Woodlands)	0.19	18.8	17.7	5.5%	0.0%	0.0%	1.0%	0.0%	4.5%	0	0	15.5%	18.1%	
Shopping (Suntec)	0.12	19.7	18.6	5.7%	0.0%	0.0%	0.4%	0.0%	5.2%	0.04	0	8.9%	10.4%	
University (NUS)	0.21	19.8	19.3	2.5%	0.0%	0.0%	0.3%	0.0%	2.3%	0	0	9.8%	11.1%	
Landed (Punggol)	3.64	0	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.9	0.96	198.1%	217.4%	

Table 1. Potential and drivers of AEC for efficiency gain and PV adoption

Results

(Electricity tariff = 20 cents/kWh, feed-in tariff = 16 cents/kWh)

Building archetypes	Solar density (kWp/kWh)	LCOE (Cents/kWh)		Total drop in LCOE	Incremental reduction in LCOE					Sell back to grid (MWh)		Self-sufficiency (PV adoption)		Dynamic real-time price
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Condo (Punggol)	0.92	16.2	14.9	8.1%	0.4%	0.0%	2.0%	0.8%	4.9%	1.05	0.93	45.1%	52.2%	
HDB (Punggol)	1.06	16.8	15.5	7.7%	0.3%	0.0%	1.6%	0.6%	5.1%	0.54	0.15	40.7%	44.4%	
HDB (Sengkang)	1.21	15	13.5	9.6%	0.5%	0.0%	2.8%	1.0%	5.4%	3.35	2.82	54.5%	60.2%	
Industrial (Changi)	0.3	17.6	16.5	6.5%	0.0%	0.0%	1.7%	0.0%	4.8%	0	0	24.6%	28.7%	
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Table 1. Potential and drivers of AEC for efficiency gain and PV adoption

Results

(Electricity tariff = 40 cents/kWh, feed-in tariff = 8 cents/kWh)

Building archetypes	Solar density (kWp/kWh)	LCOE (Cents/kWh)		Total drop in LCOE	Incremental reduction in LCOE					Sell back to grid (MWh)		Self-sufficiency (PV adoption)		Dynamic real-time price
		Solar lease	AEC		Load pooling	Storage battery	Space Utilization	Demand Flexibility	System Coupling	Solar lease	AEC	Solar lease	AEC	
Commercial (CBD)	0.13	38.3	36.2	5.5%	0.0%	0.0%	0.6%	0.0%	4.9%	0.03	0	9.4%	10.9%	
Condo (Punggol)	0.92	29	24.9	14.0%	1.1%	2.8%	1.7%	3.4%	5.1%	0.85	0	45.4%	58.9%	
HDB (Punggol)	1.06	29.1	25.4	12.8%	0.5%	2.3%	1.4%	3.3%	5.2%	0.76	0	44.3%	61.9%	
HDB (Sengkang)	1.21	27.8	23	17.4%	1.8%	4.5%	2.1%	3.6%	5.4%	2.93	0	53.7%	76.2%	
Industrial (Changi)	0.3	32.6	29.8	8.6%	0.0%	0.0%	2.5%	0.0%	6.1%	0	0	25.3%	29.6%	
Industrial (Woodlands)	0.19	35.6	33.1	7.1%	0.0%	0.0%	1.4%	0.0%	5.6%	0	0	16.1%	18.9%	
Shopping (Suntec)	0.12	37.8	35.3	6.7%	0.0%	0.0%	0.7%	0.0%	6.0%	0.03	0	9.8%	11.5%	
University (NUS)	0.21	37.2	35.9	3.6%	0.0%	0.0%	0.8%	0.0%	2.7%	0.02	0	15.8%	17.9%	
Landed (Punggol)	3.74	21.2	13.6	35.5%	0.0%	23.7%	2.0%	5.9%	3.9%	0.89	0.71	196.1%	222.0%	

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Results

(Electricity tariff = 40 cents/kWh, feed-in tariff = 8 cents/kWh)

Building archetypes	Solar density (kWp/kWh)	LCOE (Cents/kWh)		Total drop in LCOE	Incremental reduction in LCOE					Sell back to grid (MWh)		Self-sufficiency (PV adoption)		Dynamic real-time price
		Solar lease	AEC		Load pooling	Storage battery	Space Utilization	Demand Flexibility	System Coupling	Solar lease	AEC	Solar lease	AEC	
Commercial (CBD)	0.13	38.3	36.2	5.5%	0.0%	0.0%	0.6%	0.0%	4.9%	0.03	0	9.4%	10.9%	
Condo (Punggol)	0.92	29	24.9	14.0%	1.1%	2.8%	1.7%	3.4%	5.1%	0.85	0	45.4%	58.9%	
HDB (Punggol)	1.06	29.1	25.4	12.8%	0.5%	2.3%	1.4%	3.3%	5.2%	0.76	0	44.3%	61.9%	
HDB (Sengkang)	1.21	27.8	23	17.4%	1.8%	4.5%	2.1%	3.6%	5.4%	2.93	0	53.7%	76.2%	
Industrial (Changi)	0.3	32.6	29.8	8.6%	0.0%	0.0%	2.5%	0.0%	6.1%	0	0	25.3%	29.6%	
Industrial (Woodlands)	0.19	35.6	33.1	7.1%	0.0%	0.0%	1.4%	0.0%	5.6%	0	0	16.1%	18.9%	
Shopping (Suntec)	0.12	37.8	35.3	6.7%	0.0%	0.0%	0.7%	0.0%	6.0%	0.03	0	9.8%	11.5%	
University (NUS)	0.21	37.2	35.9	3.6%	0.0%	0.0%	0.8%	0.0%	2.7%	0.02	0	15.8%	17.9%	
Landed (Punggol)	3.74	21.2	13.6	35.5%	0.0%	23.7%	2.0%	5.9%	3.9%	0.89	0.71	100.1%	222.0%	

Table 1. Potential and drivers of AEC for efficiency gain and PV adoption

Results

(Electricity tariff = 60 cents/kWh, feed-in tariff = 8 cents/kWh)









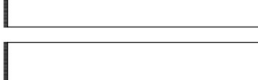
Building archetypes	Solar density (kWp/kWh)	LCOE (Cents/kWh)		Total drop in LCOE	Incremental reduction in LCOE					Sell back to grid (MWh)		Self-sufficiency (PV adoption)		Dynamic real-time price
		Solar lease	AEC		Load pooling	Storage battery	Space Utilization	Demand Flexibility	System Coupling	Solar lease	AEC	Solar lease	AEC	
Commercial (CBD)	0.13	56.4	53	6.1%	0.1%	0.0%	0.8%	0.0%	5.2%	0.04	0	10.2%	11.9%	
Condo (Punggol)	0.92	40.8	29.2	28.4%	0.9%	14.7%	4.0%	2.9%	5.9%	1.67	0	53.6%	84.7%	
HDB (Punggol)	1.06	40.7	28.4	30.2%	0.7%	16.4%	3.8%	3.3%	6.0%	1.76	0	51.8%	96.3%	
HDB (Sengkang)	1.21	39.4	24.2	38.5%	1.3%	23.6%	4.7%	3.5%	5.5%	3.93	0	59.5%	100.0%	
Industrial (Changi)	0.3	47.5	43.1	9.4%	0.0%	0.0%	2.8%	0.0%	6.7%	0	0	25.4%	29.6%	
Industrial (Woodlands)	0.19	52.4	48.3	7.7%	0.0%	0.0%	1.6%	0.0%	6.1%	0	0	16.2%	18.9%	
Shopping (Suntec)	0.12	55.8	51.9	7.1%	0.0%	0.0%	0.9%	0.0%	6.2%	0.06	0	9.9%	11.7%	
University (NUS)	0.21	53.8	51.5	4.2%	0.1%	0.0%	1.2%	0.0%	3.0%	0.02	0	18.1%	20.6%	
Landed (Punggol)	3.74	31.2	13.6	56.3%	0.0%	48.3%	1.4%	4.0%	2.6%	0.91	0.71	200.3%	222.0%	

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Table 1. Potential and drivers of AEC for efficiency gain and PV adoption

Discussion

- **Residential communities** have high potential (high solar density).
- **Electricity tariff needs to rise** to fully reflect the carbon emission cost of fossil-fuel-based electricity generation, so that to provide incentive to BESS.
- **Demand management** is needed, **system coupling** (with district cooling) also helps.
- Potential improvement in **space utilization** for BIPV deployment, hence raising solar density.

Future extension

- ▮ **Allowing heterogeneous demand flexibility among AEC participants**

To investigate the potential for more flexible users to contribute to AEC performance (by reducing the optimal BESS capacity).

- ▮ **Between AEC P2P trade**

To investigate the mechanism for residential AEC (with day-time energy surplus) to trade with non-residential AEC (with day-time energy deficit) to reduce the optimal BESS capacity.

- ▮ **AEC Business model design**

The internal dynamic pricing provides the incentive for optimal user load scheduling to reduce the community LCOE. The surplus from the reduced LCOE needs to be properly divided among the AEC participants to create efficient participation incentives.

Thank you!