FCL Global — Powering the City

WP 4 – Socioeconomics

Investigating drivers and barriers of urban PV deployment, market mechanisms, business models, novel concepts for local energy trading and their significance on PV investment decisions.

Integrated Land Use and Solar Energy Planning

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The idea

A systems approach to energy transition and climate resilience

Coupling:

Energy transition — from a fuel-based energy system to a renewable energy system

Cooling Singapore — reducing UHI and air con use

Car-lite city — reducing car use and improving walkability and bicycle friendliness

Each urban transformation is necessary and helps the other transformations.

Aligning these efforts can maximize the co-benefit of each transformation.

Singapore's solar potential for energy self-sufficiency

Data: annual solar irradiation is between 1580 to 1620 kWh/m2

Assumption 1: PV efficiency = 25%

Annual solar electricity generation rate = 25%×1.58 tWh/sqkm = 0.395 tWh/sqkm

Table 1

Land Use https://www.mnd.gov.sg/docs/default-source/mnd-documents/publications-documents/land-use-plan.pdf	Planned supply, *ha* (2030)	Land-use share	PV coverage ratio	Annual solar electricity generation, tWh	Annual electricity consumption. tWh (2022)	Solar power surplus, tWh/year
Housing	13,000	17.0%	1/3	17.1	7.9	9.2
Industry and commerce	12,800	16.7%	1/3	16.9	43.9	-27.0
Community, Institution and Recreation Facilities	5,500	7.2%	1/3	7.2	0.2	7.0
Land Transport Infrastructure	9,700	12.7%	1/3	12.8	2.9	9.9
Reservoirs	3,700	4.8%	1/3	4.9	0	4.9
Others: Parks and Nature Reserve, Utilities, Ports, Defence, etc	31,900	41.6%	0.0	0.0	0	0.0
Total	76,600	100.0%		58.9	54.9	4.0

How can we achieve high PV coverage in urban areas?

Achievable by integrating PV deployment with cool roof and open space shade policy.

There is evidence that PV reduces heat gain by converting solar irradiation to electricity and providing passive shading.

The co-benefit of shading

Economic and environmental benefits:

- Energy savings as a result of shading on buildings.

Social benefits:

- Improving outdoor thermal comfort and hence activating street life and encouraging active mobility

Architectural benefits:

- Enriching landscape diversity

Open Space Shade Policy Planning Guidelines

For Landscaping & Architectural Design Plans and Municipal Projects

Table 1: Shade guidelines in the Urban Space

Type of Shaded Area	Shade Quantity Requirement
The public open space	
a. Streets, paths and walkways (including walking and bike lanes in the different types of spaces)	**Continuous shade with a minimum cover of 80%** Of the walking and bike lane route on at least one of the sidewalks (on either side of the street), path or walkway (1) (2) (3)
b. Landscaped areas in parks and gardens	**A minimum of 20%** Of the entire landscaped area (4)
c. Open areas (paved) City squares and plazas	**A minimum of 40%** Of the entire paved open area Landscaping alternatives in line with the City Architect's guidelines (5)
Public buildings	
d. The yards of educational and community facilities	**A minimum of 50%** Of the entire yard space At schoolyards, excluding sports fields (6)
e. Sports fields	**A minimum of 20%** Of the total open area at the sports fields
Parking lots	
f. Above-ground parking lots	**A minimum of 50%** Of the total area of the parking lot (7)
General guideline for each space type	
Points of interest and gathering places **Seating areas -** benches, tables, etc. **Playgrounds and fitness facilities**	**Continuous shade of 80% cover** Of the area of the point of interest or gathering place Playground equipment for children - 100% (8)

The benefit of PV is amplified through coupling with cooling and car-lite strategies

- Evidence that combining PV with reflective surface or green surface can increase the energy yield of PV
- Extensive shading improves outdoor thermal comfort and walkability, accelerating the car-lite transition, which in turn enhances outdoor thermal and acoustic comfort and frees up road space for pedestrians, public life, and retail and services, which further reduces the demand for driving… and more space to be shaded.
- With improved outdoor thermal and acoustic comfort, building facades can be opened to allow natural ventilation and lighting, minimizing reliance on air con, and reducing the energy use for cooling and lighting. Buildings with more open interfaces with external spaces also contribute to the activation of streets and public spaces.

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The solar energy self-sufficiency scenario requires Integrated land-use and energy planning

Integrated land-use and energy planning is required to localize solutions to solar intermittency and thus reduce the demand for grid transmission capacity and backup supply capacity.

Localized solutions can be managed by energy communities through energy-as-service business models. Energy communities operate

- Community solar assets
- District cooling and other energy assets
- Internal dynamic energy pricing
- Solar leasing

Spatial planning for energy demand and storage

Demand pooling

Internal dynamic pricing

Supply aggregation

Local energy storage and trade with the grid

Community solar business models

Role of energy communities for energy transition

- Energy communities engage professionals to provide energy asset operating services, investment financing and risk management, and urban design and building retrofitting for optimal PV coverage.
- Energy communities can participate in capacity markets, energy markets, and ancillary service markets.
- Policies—such as solar energy mandates, cool roof and shade targets, and electricity tariff design—can encourage the development of energy communities.

FCL research capabilities
Community solar performance modeling

- Integrating land-use data models (e.g. City Knowledge Graph), energy simulation models, and energy system optimization models.
- Modeling community solar energy self-sufficiency and demand for grid services
- Modeling community internal dynamic pricing and financial return on energy asset investment

Simulations can
- inform the design of energy communities and solar asset investment choices.
- evaluate the impact of policies on energy community profitability

General modelling logic

(A) Digital Urban Regulatory Model

LURs

URBAN REDEVELOPMENT AUTHORITY

> Urban Design Guidelines
> Street Block Plans
> Height Control Plans
> Master Plans
> Development Control Plans

LUR Digitalisation

> Land Use
> Site Coverage
> Site Area
> GPR
> Absolute Height
> Gross Floor Area
> Floor to Floor Height
> Road Buffer
> Number of Storeys

LUR Parameters

(a) Allowable land uses per plot
(b) Allowable building height
(c) Allowable Gross Floor Area per land use
(d) Allowable site coverage

(B) Building Energy Simulation Model

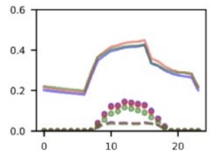
Building and Climate Data Collection

> Climate and weather data
> Solar irradiance
> Building surface area
> Shadings
> Building types

Building Solar Potential and Load Simulation

> Cooling demand
> Heat demand
> Electricity demand
> Rooftop solar generation
> Facade solar generation

Building Load and Solar Generation Density



(a) Building load per GFA
(b) Solar generation per m2

(C) Energy and Urban Form Optimization

Optimization process

+

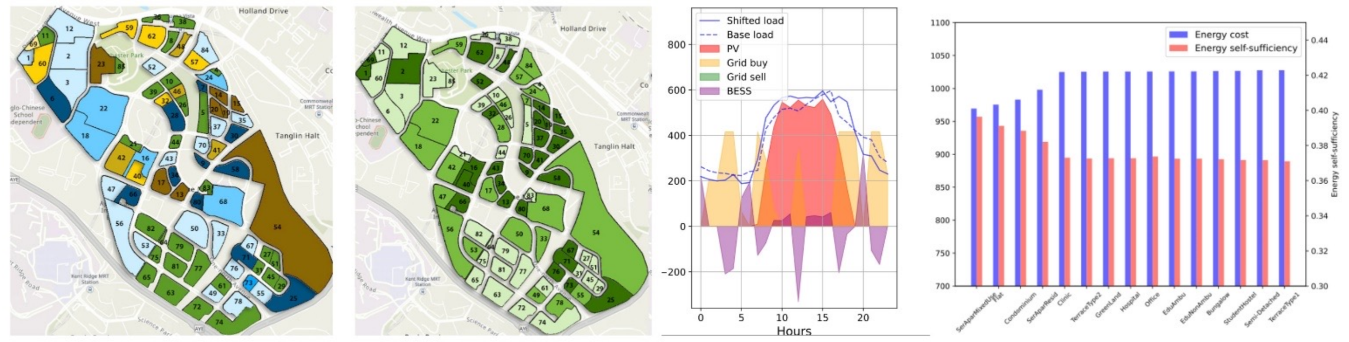
Objective

- Minimizing energy cost
- Maxmizing energy self-sufficiency

Decision variables

(a) land use developments (b) urban density (c) energy system expansion and operations

Optimizaiton outcomes

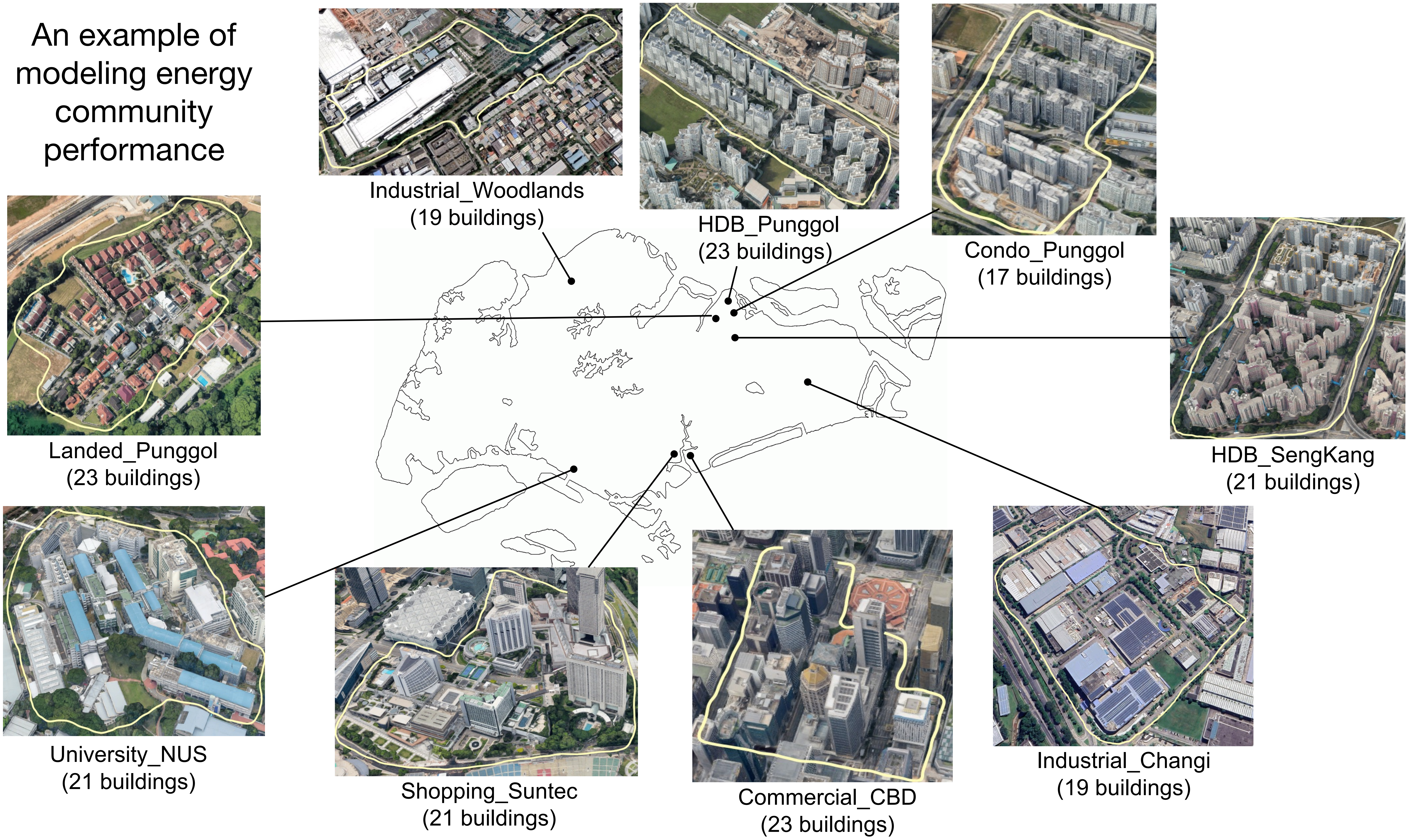


Distributed Energy System Performance

- Energy system cost per GFA
- Energy self-sufficiency
- Peak hour load

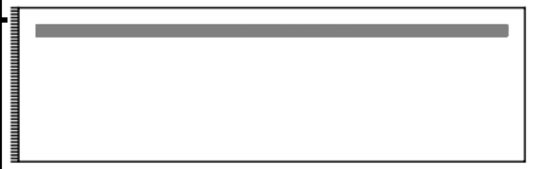
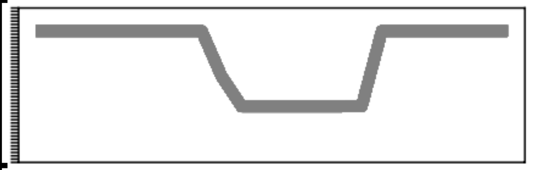
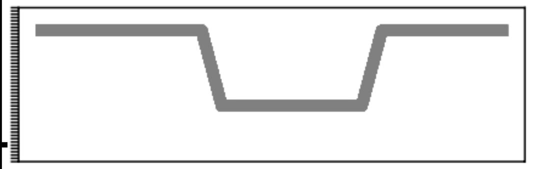
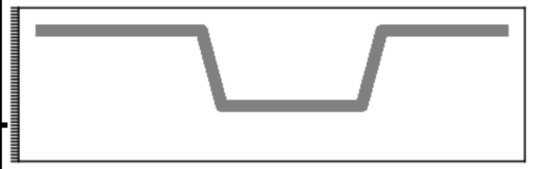
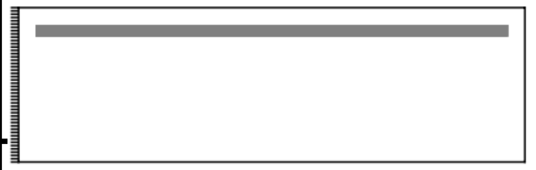
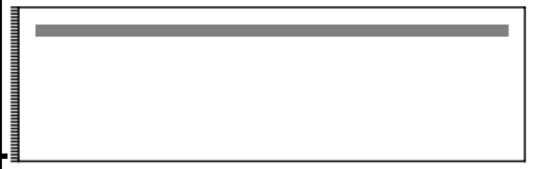
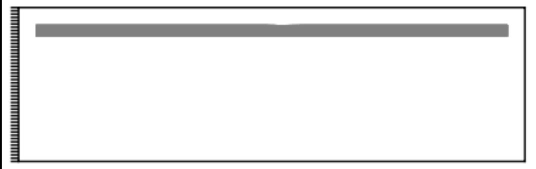
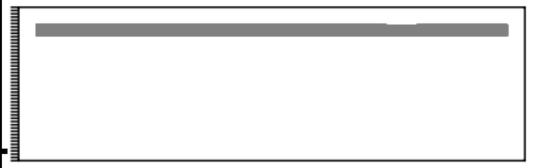
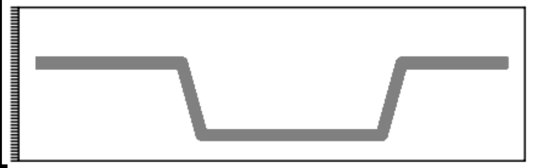
Land use development

- determine optimal developments of land use
- determine optimal developments of density


An example of modeling energy community performance
Industrial_Woodlands
(19 buildings)
HDB_Punggol
(23 buildings)
Condo_Punggol
(17 buildings)
Landed_Punggol
(23 buildings)
HDB_SengKang
(21 buildings)
University_NUS
(21 buildings)
Shopping_Suntec
(21 buildings)
Commercial_CBD
(23 buildings)
Industrial_Changi
(19 buildings)

Energy community performance under electricity tariff scenarios

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

Building architypes	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	9.3%	10.9%	
Condo (Punggol)	0.92	29	24.9	14.0%	1.1%	2.8%	1.7%	3.4%	5.1%	0.85	0	39.1%	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	40.4%	61.9%	
HDB (Sengkang)	1.21	27.8	23	17.4%	1.8%	4.5%	2.1%	3.6%	5.4%	2.93	0	41.3%	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	49.7%	100.0%	

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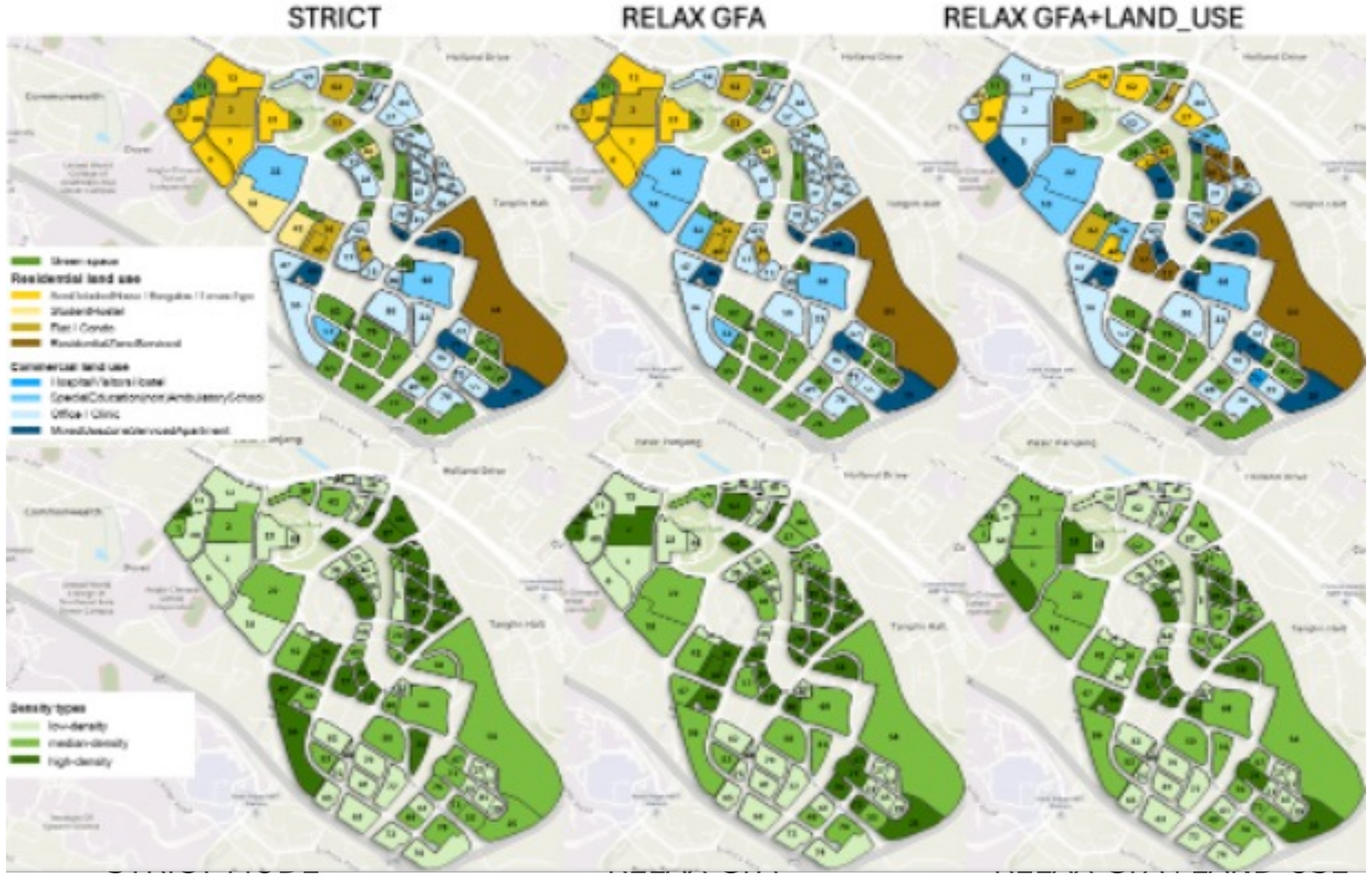
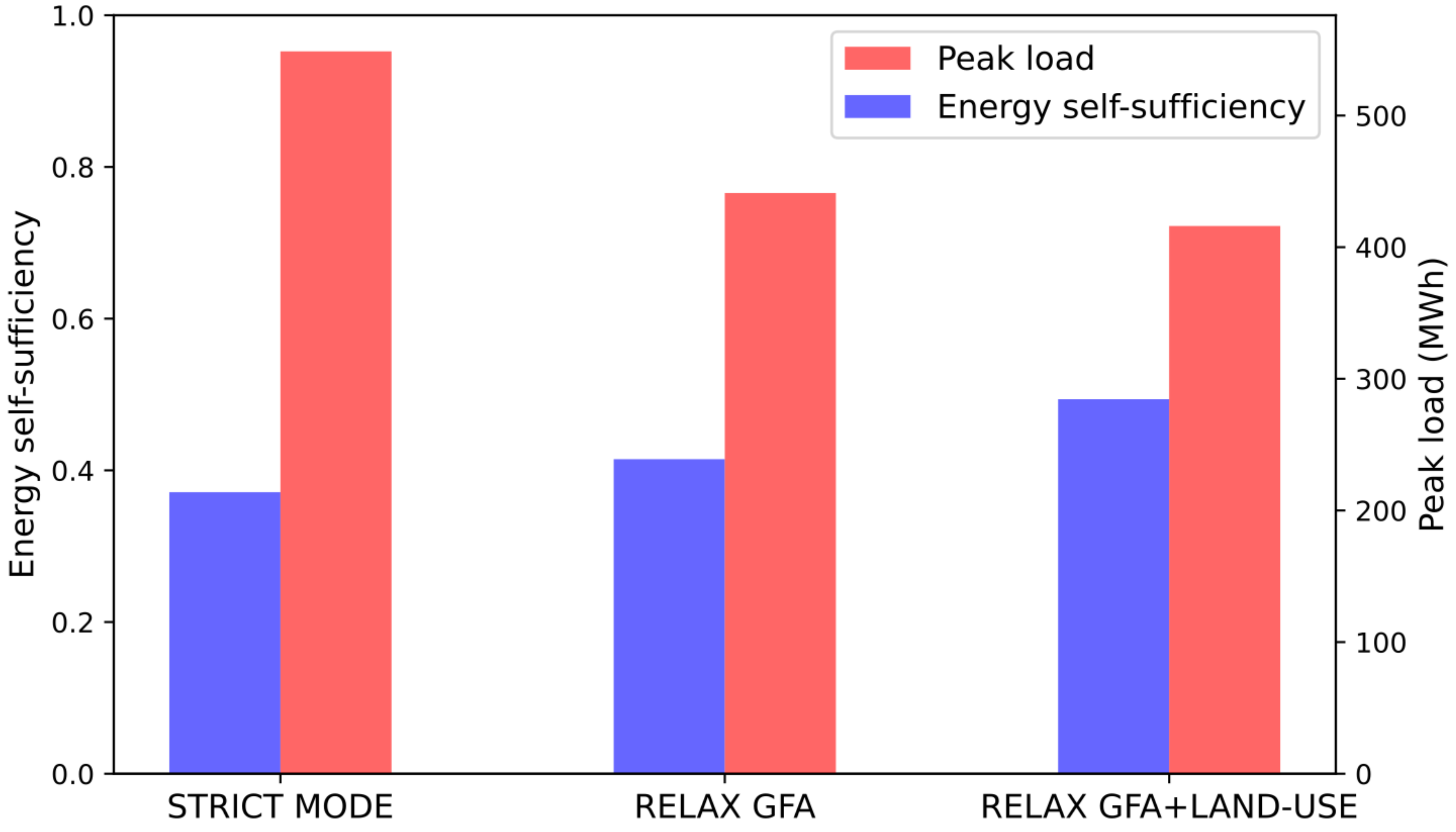
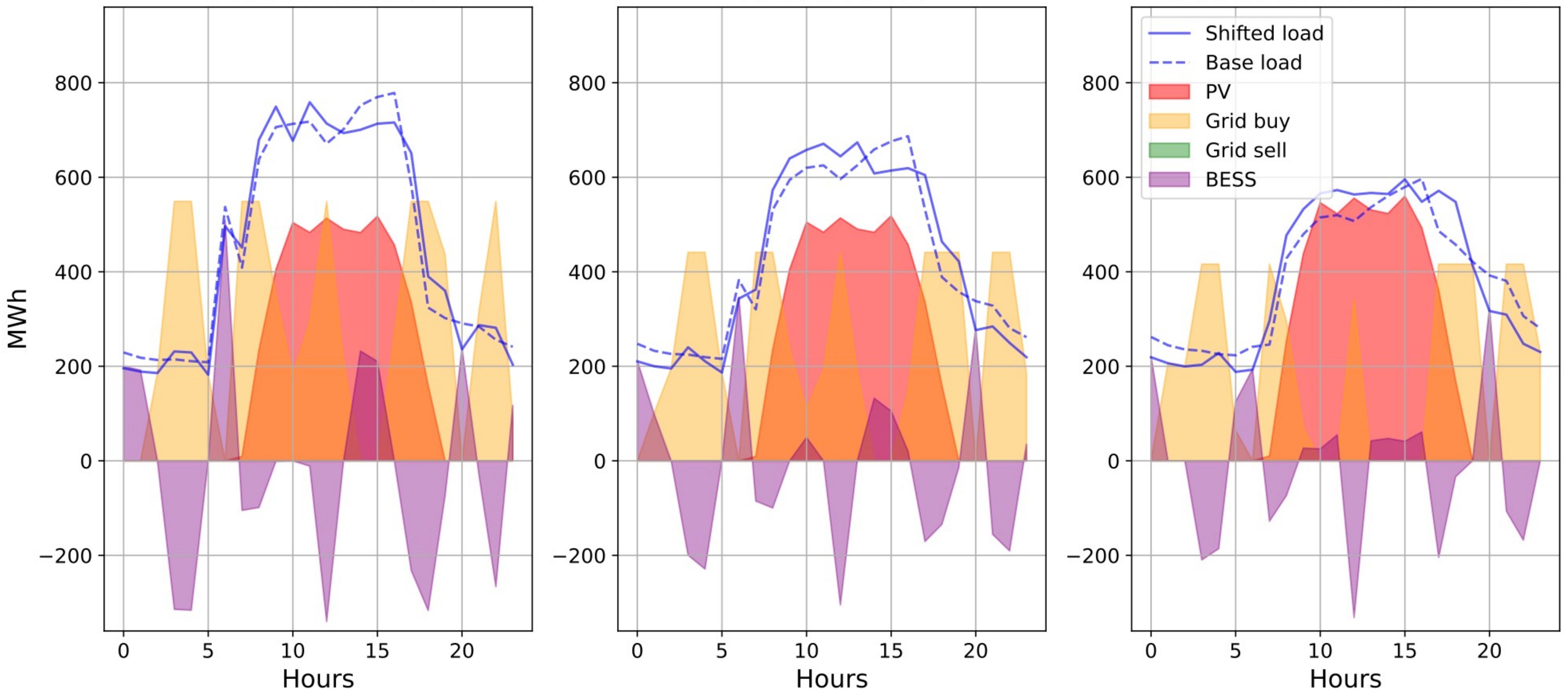
Example of energy community performance under different land-use scenarios



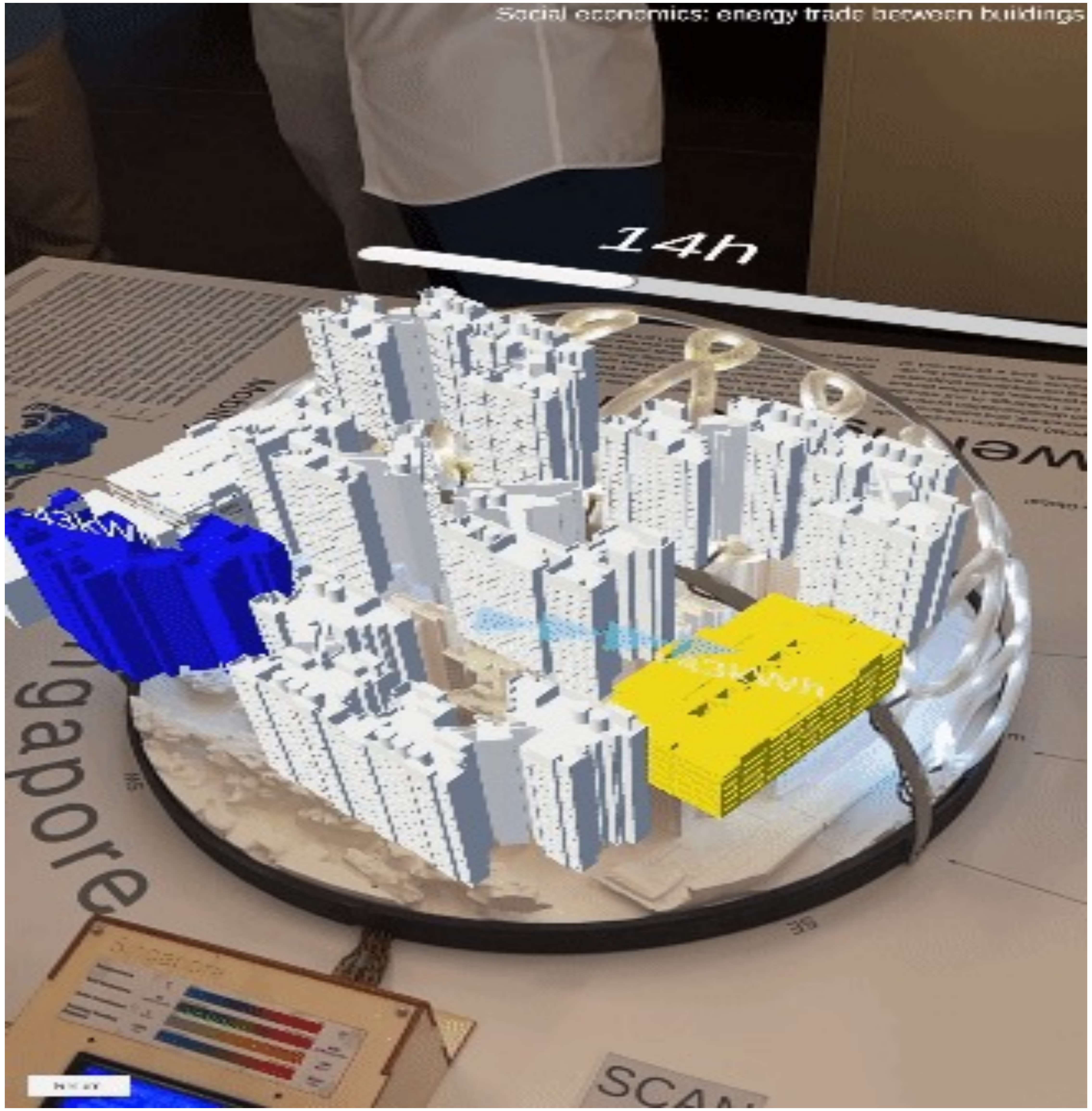




Energy simulation

Blue buildings export electricity and yellow buildings import electricity.

The simulation video shows hourly electricity flow in an energy community over a day



Thanks