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BUILDING SUSTAINABLE, RESILIENT, AND LIVEABLE CITIES OF TOMORROW
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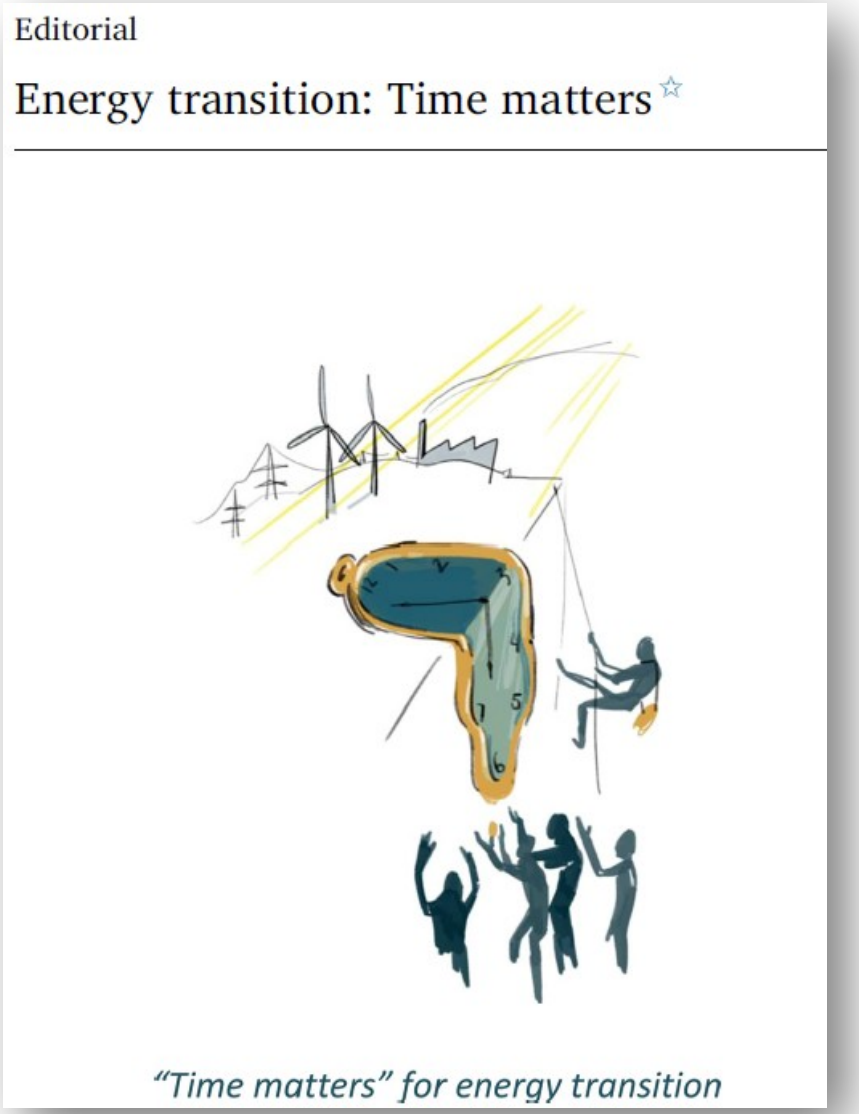
Institute of High Performance Computing
IHPC

Significant carbon mitigation potential from installed rooftop photovoltaics in Singapore: A GIS-integrated life cycle assessment

Rui Zhu
Senior Scientist
Systems Science Department
Institute of High Performance Computing
Agency for Science, Technology and Research, Singapore
zhur@ihpc.a-star.edu.sg
https://felix-rz.github.io

- Cities take only 3% of the land surface on Earth,
- But account for 75% of all energy consumption and 80% of all CO_2 emissions.
- Cities are the main battlefield for climate change mitigation.

Time matters for energy transition


Editorial

Energy transition: Time matters ☆

"Time matters" for energy transition

"*Time matters for*

- *smart balancing of variable renewable energy supplies*
- *maximizing the benefits of energy prosumers*
- *optimizing energy system integration*"

Yan J. (2022). Energy transition: Time matters. *Advances in Applied Energy*, 5, 100082.

A sustainable solar city

A solar city is a sustainable power system that effectively collects and stores solar energy to flexibly power a variety of urban sectors.

Land surface solar irradiation

Estimating spatio-temporal solar distribution on land surface.

3D urban surface

Building 3D city models using geospatial technologies.

Solar potential distribution

Modelling spatiotemporal distribution of solar potential on 3D urban surfaces.

Solar PV planning

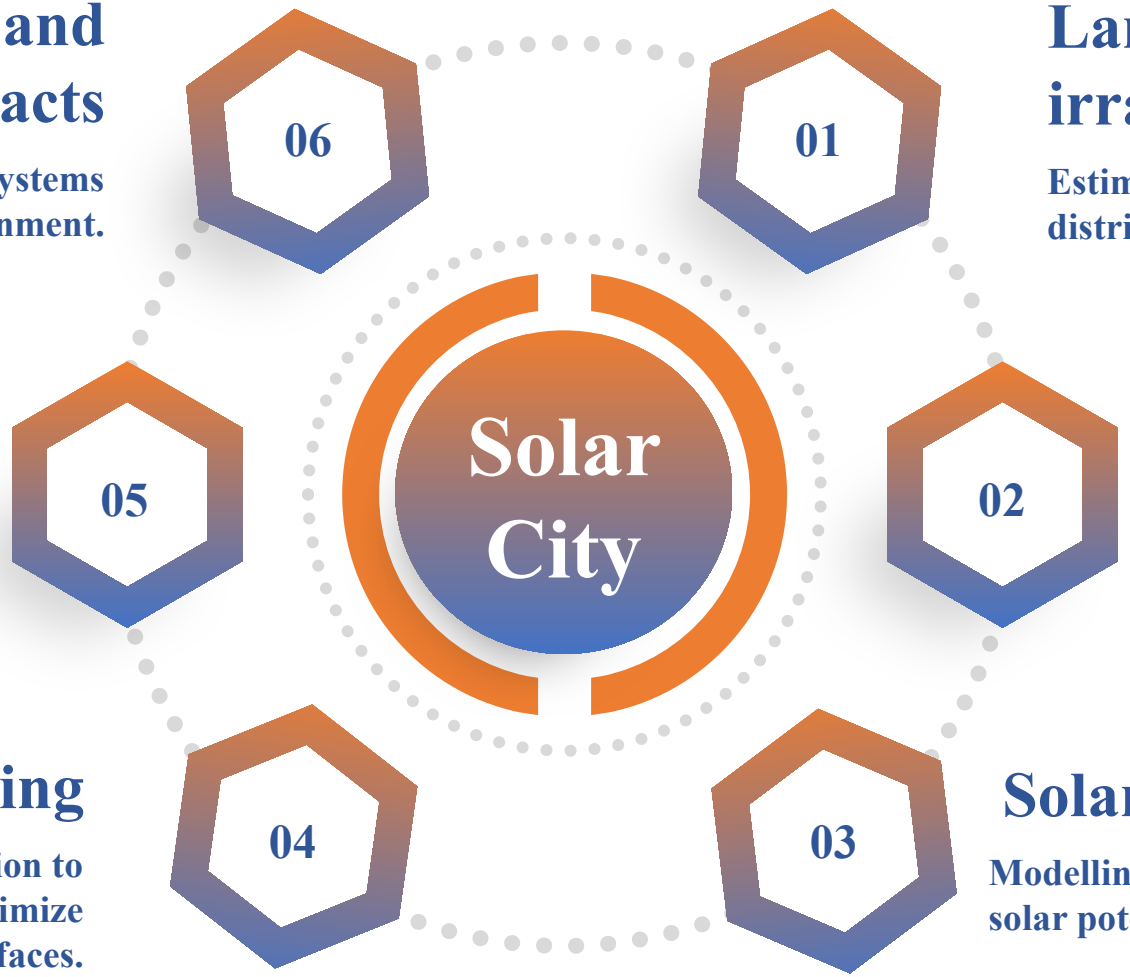
Planning and optimizing PV installation to maximize solar farming and minimize occupied urban surfaces.

Solar PV penetration

Penetrating PV systems into urban sectors by designing adaptive and efficient solar charging solutions.

Socio-economic and environmental impacts

Revealing interactions between PV systems and socio-economy and urban environment.



Zhu, R., Kwan, M.P., et al. (2023). GIScience can facilitate the development of solar cities for energy transition. *Advances in Applied Energy*, 10, 100129.

Research framework

Module 1
Deep learning-based PV area Segmentation from satellite imagery

Module 2
Estimation of rooftop annual solar PV potential

Module 3
LCA-based estimation of carbon reduction potential

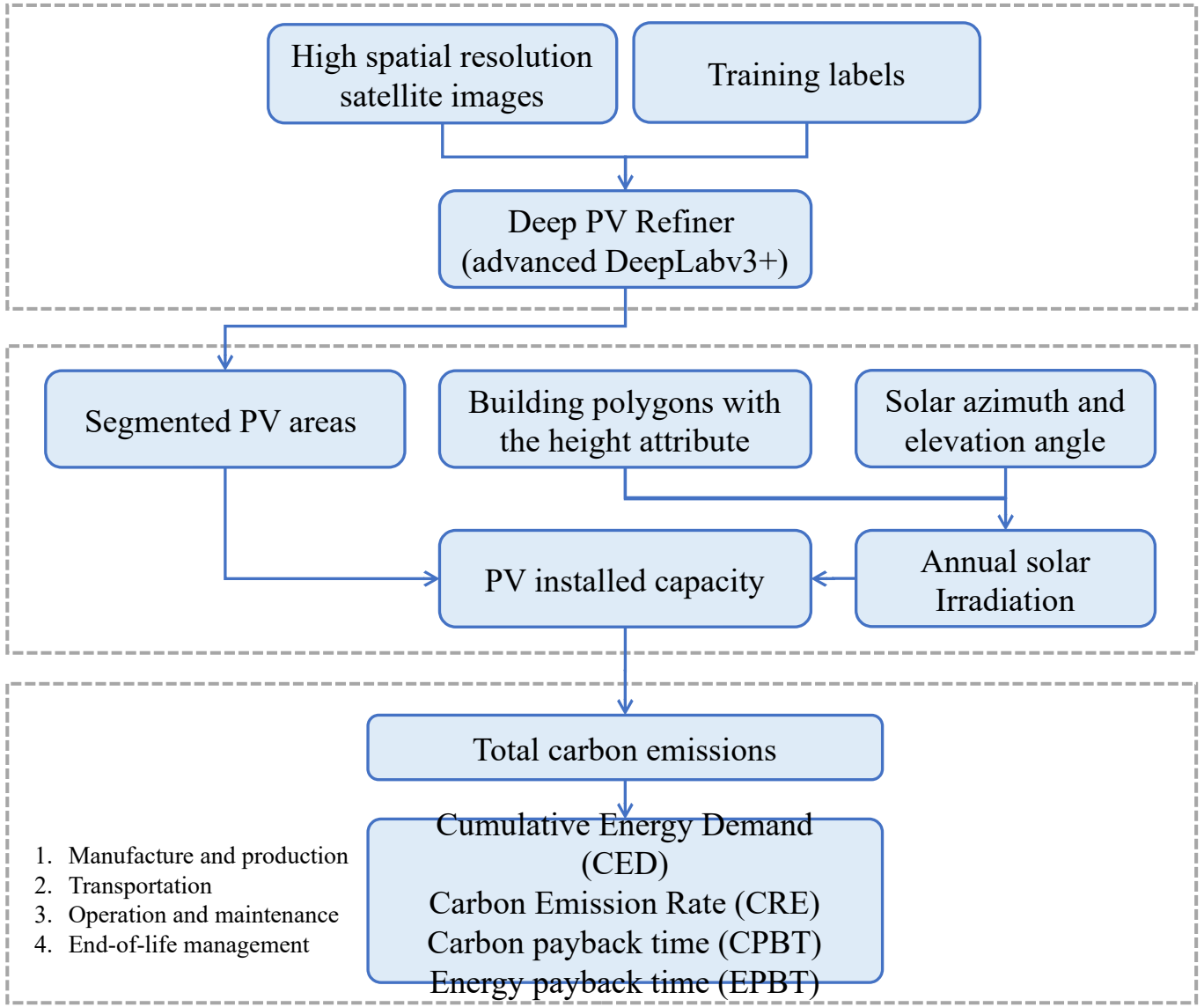


Fig 1. Research framework of the carbon mitigation estimation model.

PV area segmentation: Deep Solar PV Refiner

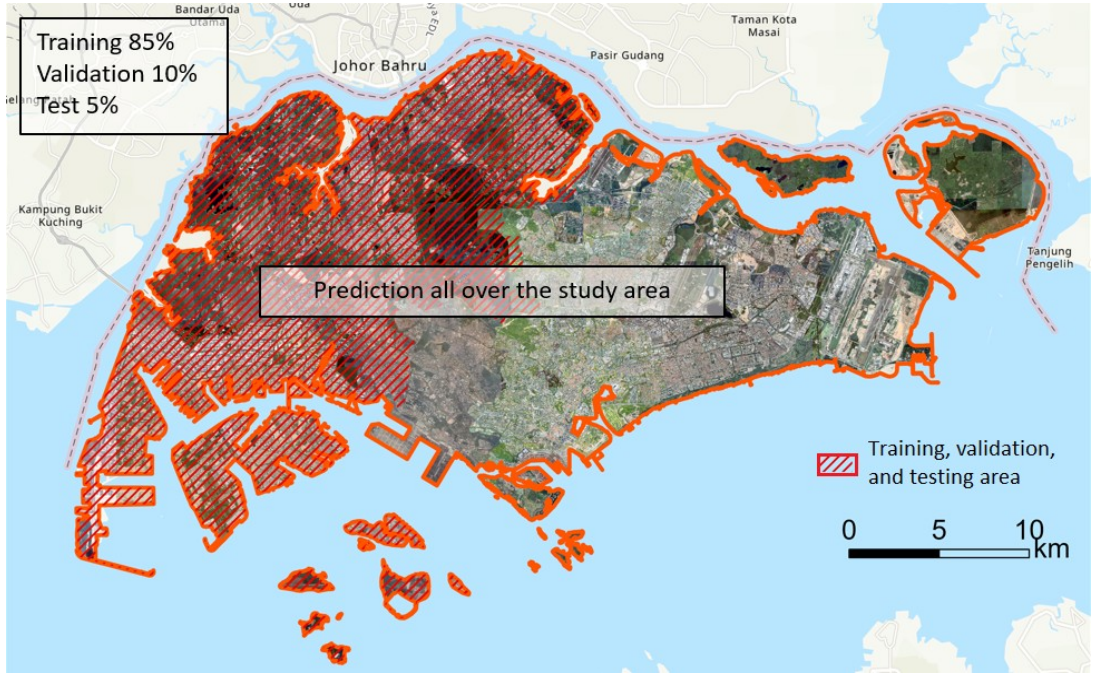


Fig 2. The study area covers the whole territory of Singapore.

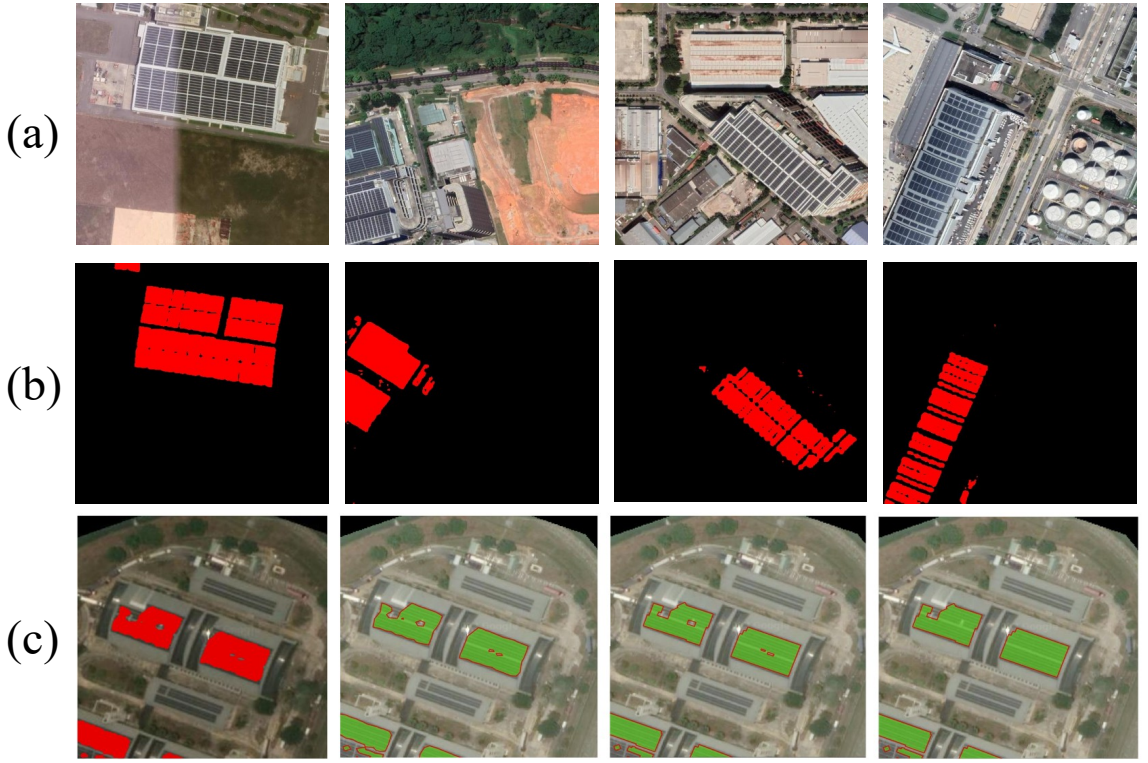


Fig 3. Segmentation results.
(a) Satellite images. (b) Segmented PV areas. (c) Post-processing.

Tab 1. Accuracy evaluation of the segmented PV areas.

No.	Accuracy (%)	F1-score (%)	Precision (%)	Recall (%)	IoU (%)
1	76.41	79.83	83.57	76.41	66.43
2	74.65	78.96	83.79	74.65	65.23
3	75.28	79.68	84.63	75.28	66.23
4	74.04	78.16	82.76	74.04	64.15
Mean	**75.01**	**79.16**	**83.69**	**75.01**	**65.51**
Improvement	+0.0013	+0.34	+0.1	+0.54	+0.35

Distribution of segmented PV areas

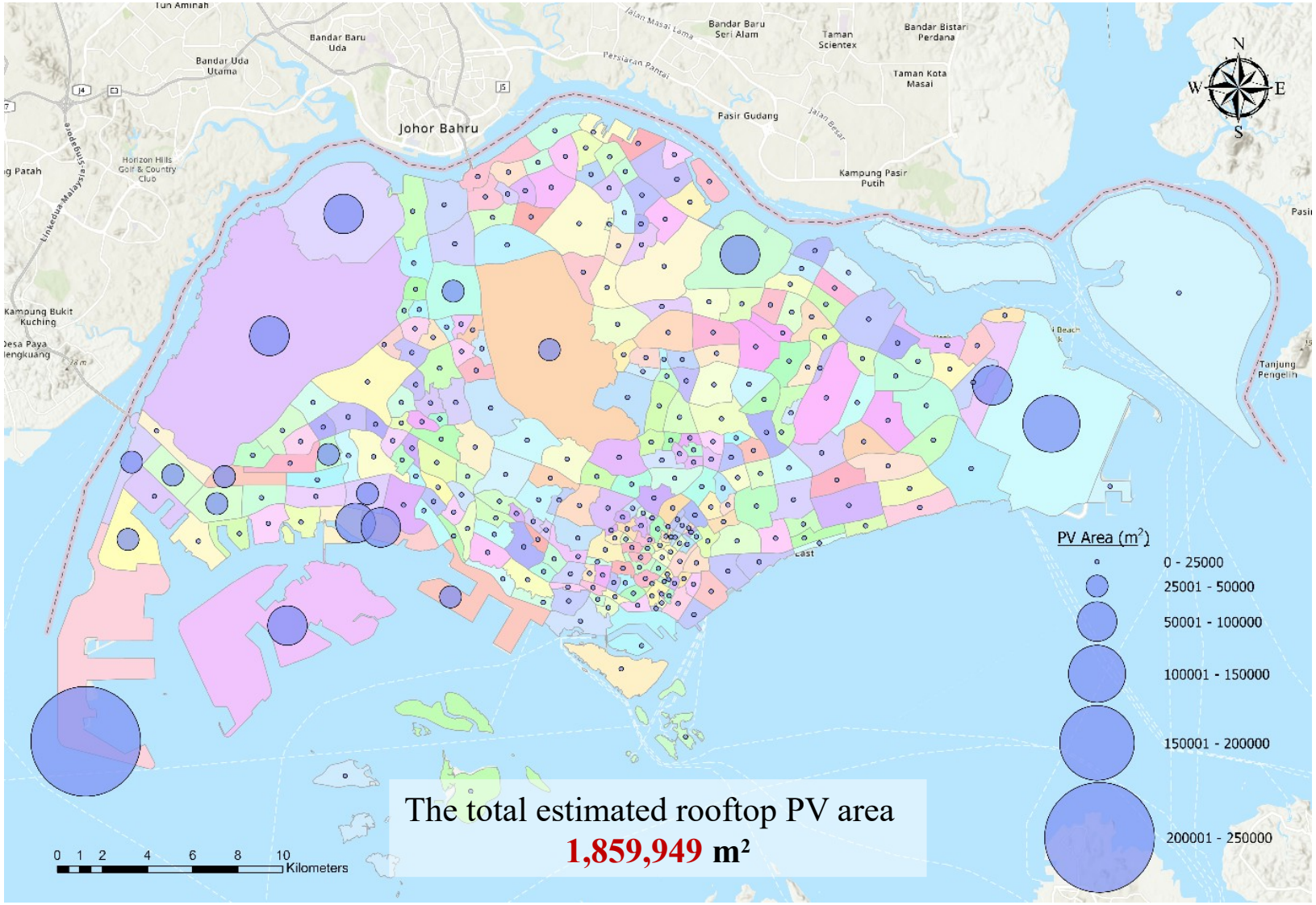


Fig 4. Distribution of rooftop PV areas categorized by subzones in Singapore.

Statistics of installed rooftop PV areas

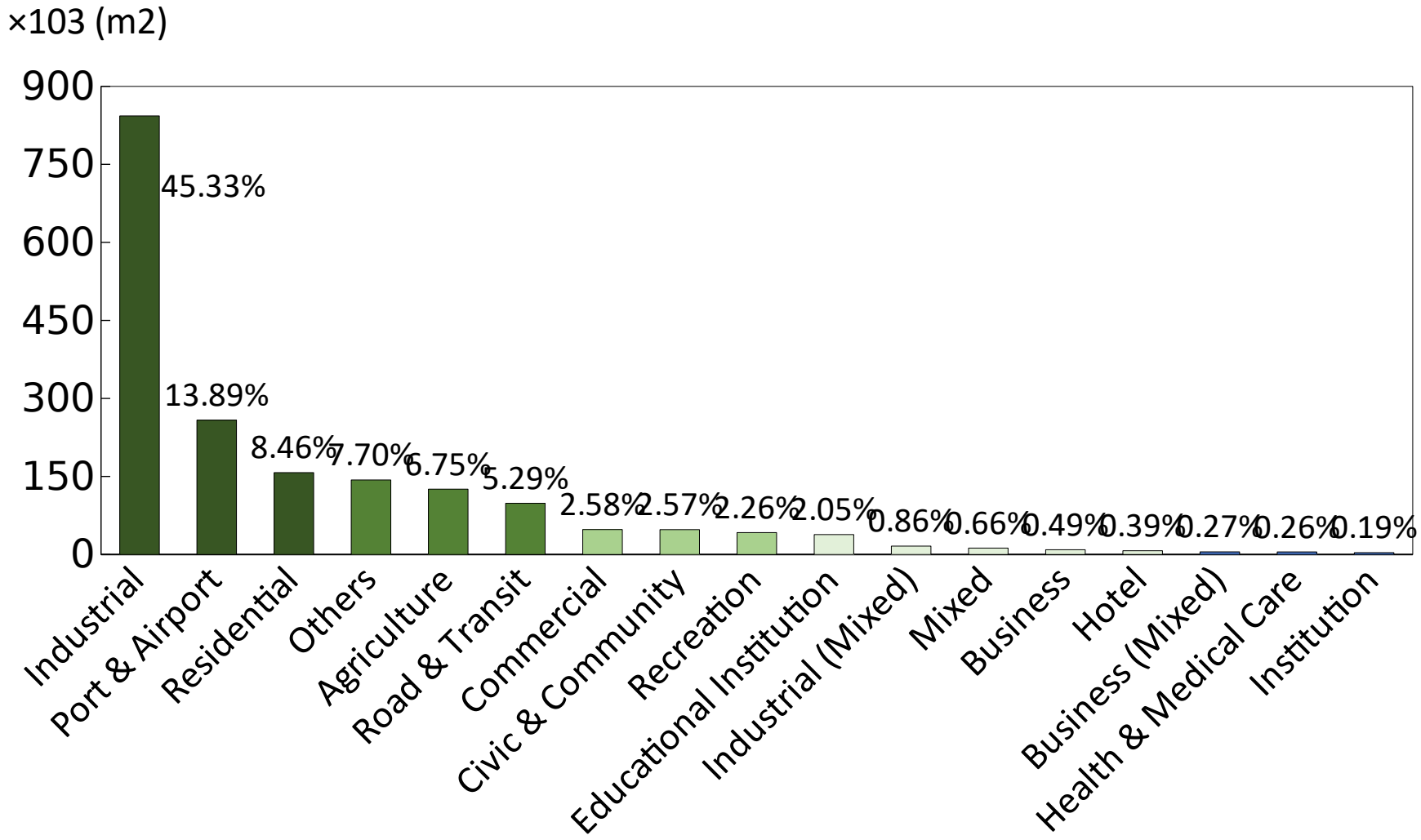


Fig 5. Installed rooftop PV size categorized by land use type in Singapore.

Distribution of PV electricity generation

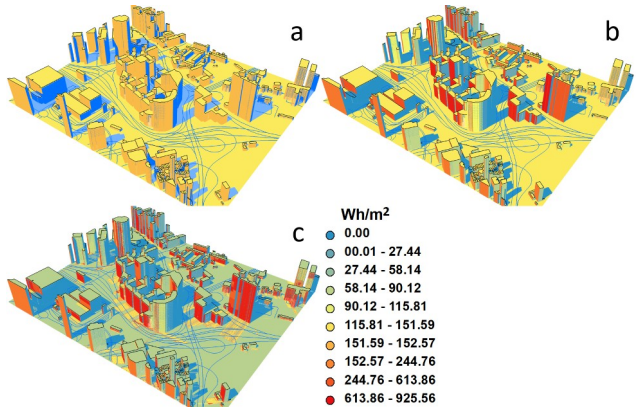


Fig 6. Visualization of 3D point clouds in three continuous processes at an instant in time on a particular day.

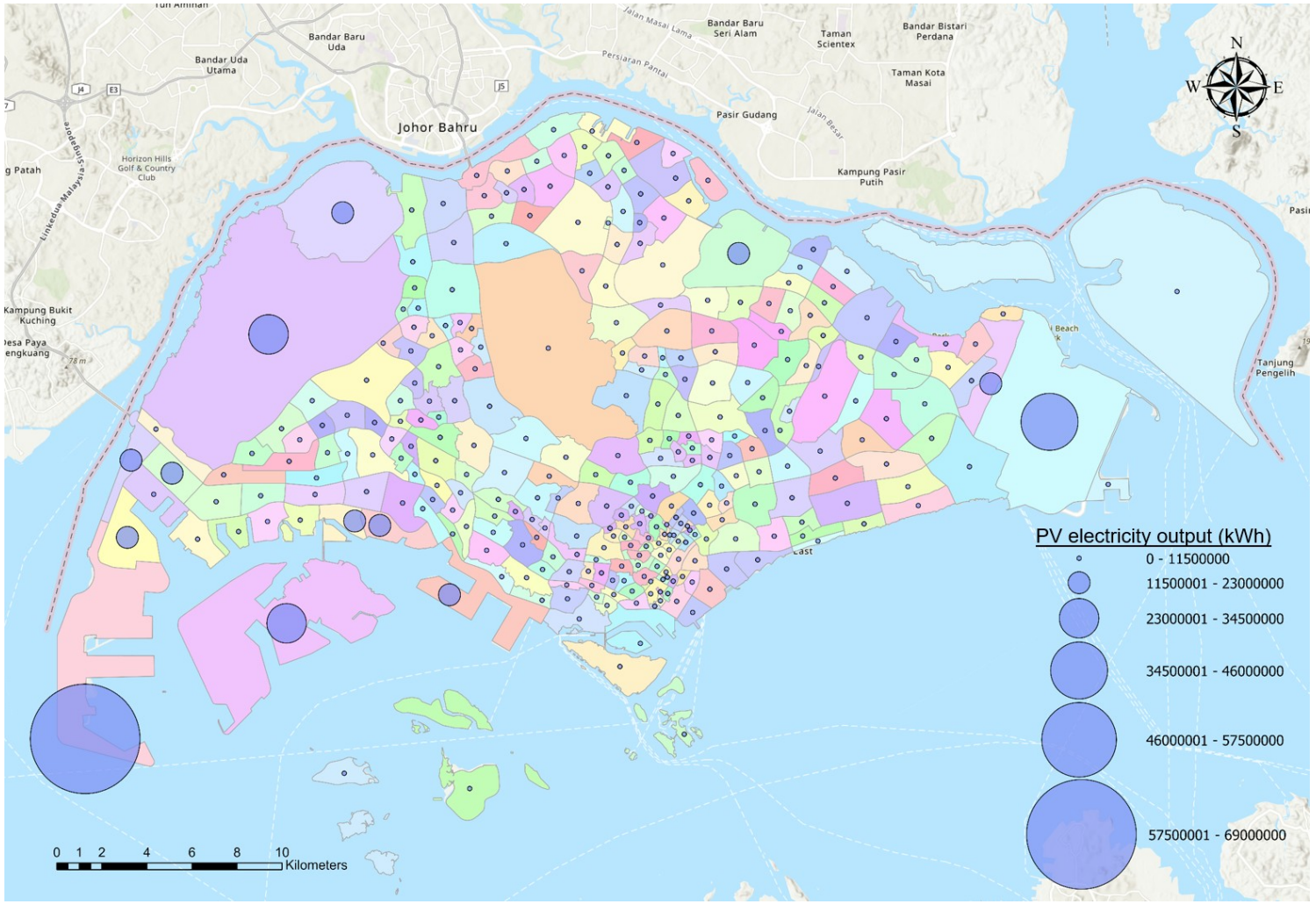


Fig 7. Annual electricity output of installed rooftop PV categorized by districts.

- **Zhu, R.**, et al. (2020). The effect of urban morphology on the solar capacity of three-dimensional cities. *Renewable Energy*, 153, 1111–1126.
- **Zhu, R.**, et al. (2019). Transformation of solar accessibility in reforming urban areas: A case study in Kowloon East, Hong Kong. *Sustainable Cities and Society*, 51, 101738.

Life cycle assessment

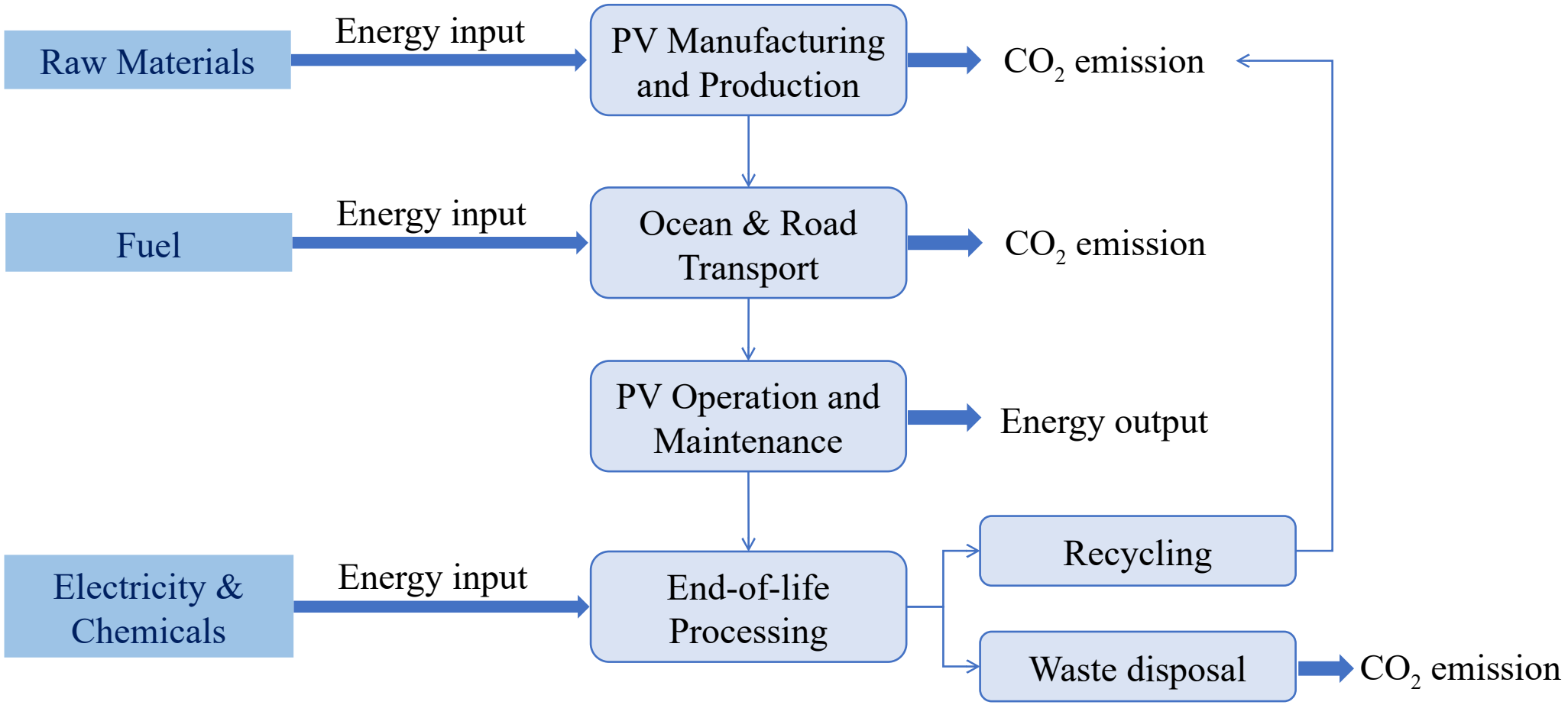


Fig 8. Life cycle assessment of the carbon mitigation potential.

Estimated carbon mitigation potential

Tab 2. Parameters used for calculations (National Solar Repository of Singapore, 2023; Climate Transparency, 2022; National Climate Change Secretariat, 2023).

Country	Marketing sharing of PV systems in Singapore	National CO_2 emission factor (kg CO_2/kWh)
China	41.2%	0.5572
Canada	4.0%	0.1197
Germany	2.7%	0.3288
Japan	0.4%	0.4615
USA	8.0%	0.3580
Singapore	43.7%	0.4057

Tab 3. Crucial parameters for PV transportation (Sea Distance ORG, 2023; Ali et al., 2022).

Category	Country	Transport distance (km)	Emission factor (kg CO_2/m²)	Energy input (MJ/m²)
Ocean transport to Singapore	China	4142	0.3541	1.1832
	Canada	13108	1.1207	3.7444
	Germany	15729	1.3448	4.4931
	Japan	5378	0.4598	1.5363
	USA	14203	1.2144	4.0572
Road transport	Singapore	64	0.0778	0.0022

Tab 4. Estimated results for CED, CER, CPBT, and EPB.

Item	Value	Unit
Total rooftop PV area	1,859,949	m²
Total annual energy output from PV	553,456,428	kWh
Total installed rooftop PV capacity	360.9464	MWp
Annual energy output per meter square	297.57	kWh/m²
Cumulative Energy Demand (CED)	1006.19	MJ/m²
Carbon Emission Rate (CER)	13.20	g CO_2-eq/kWh
Carbon Payback Time (CPBT)	0.81	year
Energy Payback Time (EPBT)	0.94	year

* NOTE: All estimations were based on the data collected in 2021/22.

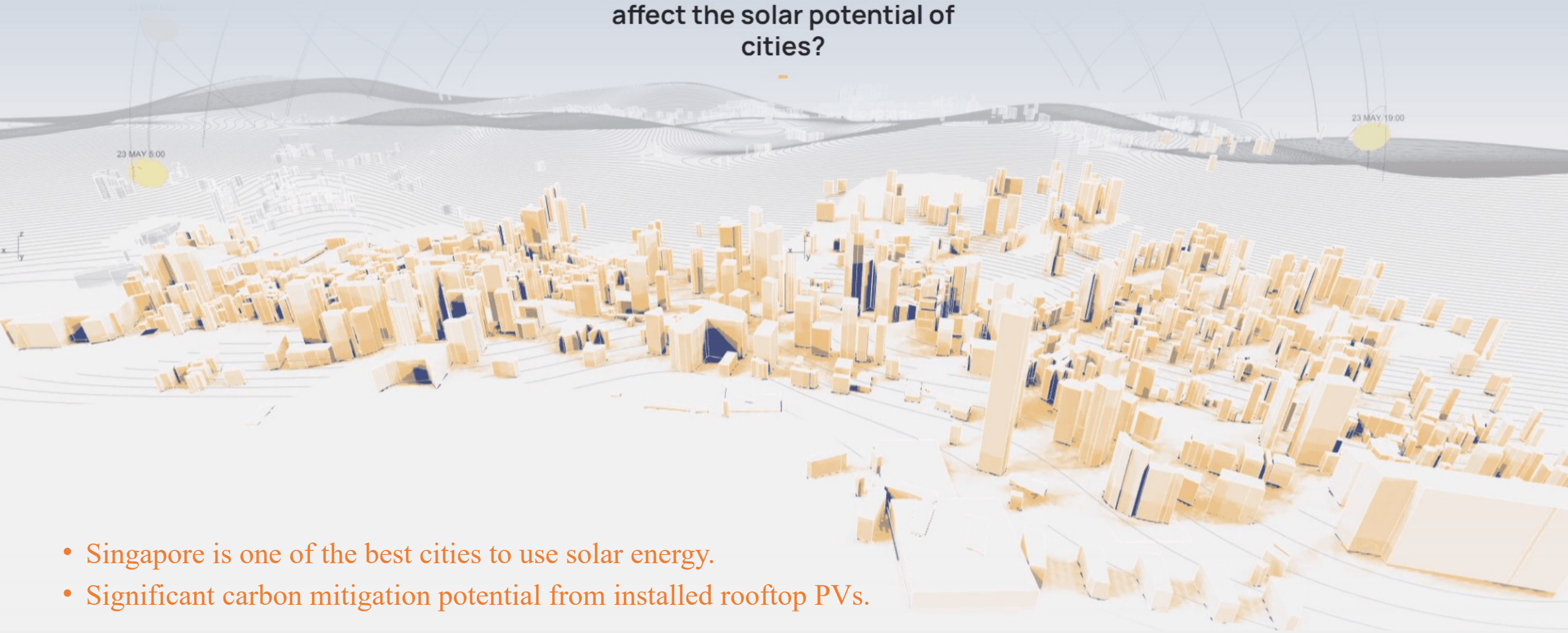
- Net carbon reduction benefit: **2919.87 kg CO_2/m²**
- Total carbon reduction amount: **5,430,819.69 tonne**

https://senseable.mit.edu/solar-cities/

senseable city lab.

solar cities

How does urban morphology affect the solar potential of cities?



- Singapore is one of the best cities to use solar energy.
- Significant carbon mitigation potential from installed rooftop PVs.

Zhu, R., Zhang, F., Yan, J., Ratti, C., Chen, M. (2023). A sustainable solar city: From utopia to reality facilitated by GIScience. *The Innovation Geoscience*, 1(1), 100006.

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THANK YOU

www.a-star.edu.sg

Rui Zhu

Senior Scientist
Systems Science Department
Institute of High Performance Computing
A*STAR, Singapore

zhur@ihpc.a-star.edu.sg
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