

# Investigation of the impact of urban planning regulations on distributed energy system performance

Jidong Kang, Chenyi Cai, Pieter Herthogs, Yuming Fu, Christoph Waibel

Keywords: Distributed energy system (DES), Urban planning regulation (UPR), Optimization model, Cities Knowledge Graph (CKG)

## Background

- Urban energy system has been transformed from **centralized energy system** to **distributed energy system (DES)**.
- DES performance, e.g., **levelized cost of energy (LCOE)** and **solar energy self-sufficiency (SESS)**, heavily depends on **urban forms**.
- Though relationship between urban forms and DES performance has been extensively studied, those studies are conducted without the consideration of **urban planning regulations (UPRs)**.
- UPRs include, for example, *Street Block Plans*, *Urban Design Guidelines*, *Height Control Plans* and *Landed Housing Areas*. These regulations impose limitations and requirements on factors like **gross floor areas (GFA)**, **building height**, and **setbacks**. Their aim is to enhance urban livability, safety, and environmental sustainability.

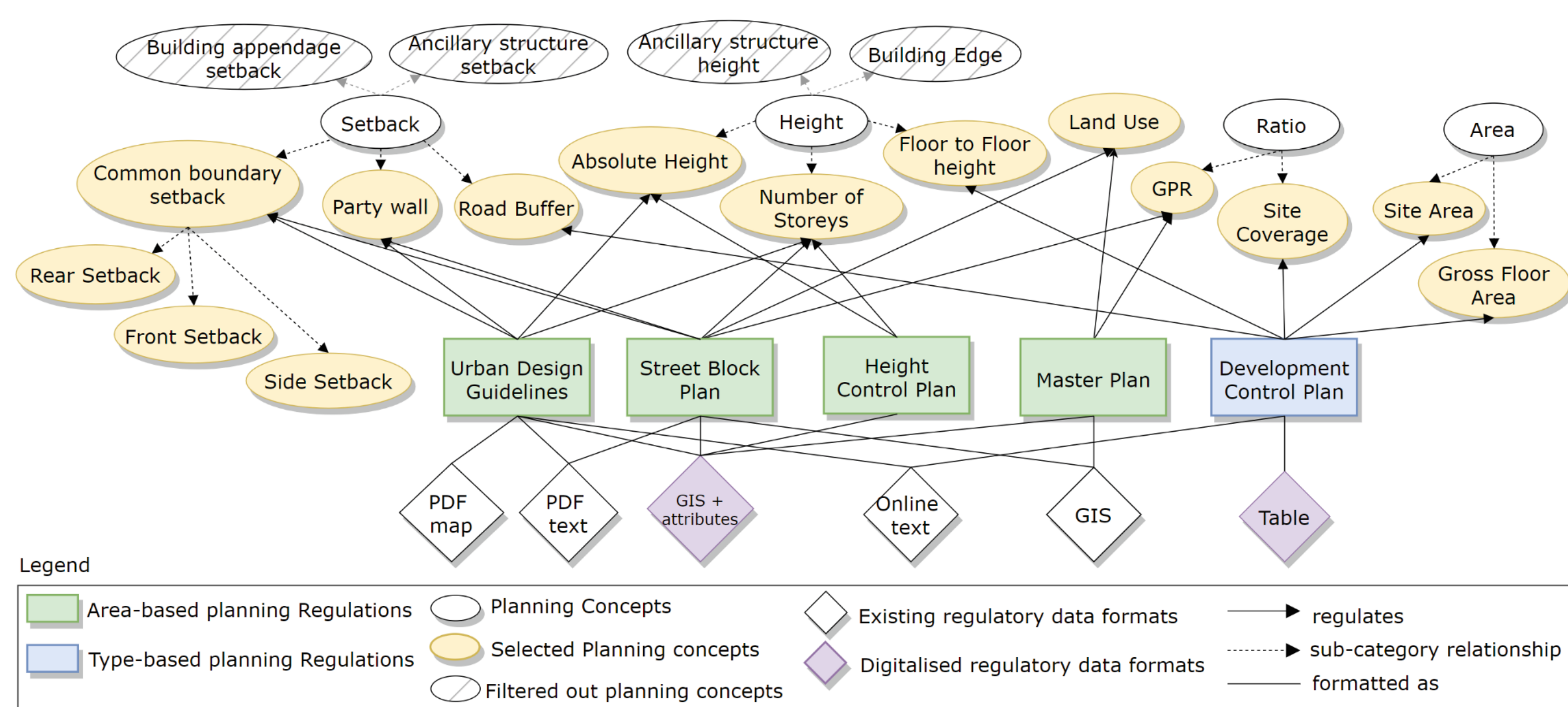


Fig. 1 UPRs and restrictions extracted from Cities Knowledge Graph (CKG) <sup>1,2</sup>

## Research Questions

What is the impact of UPRs on the performance of urban distributed energy systems?

## Findings

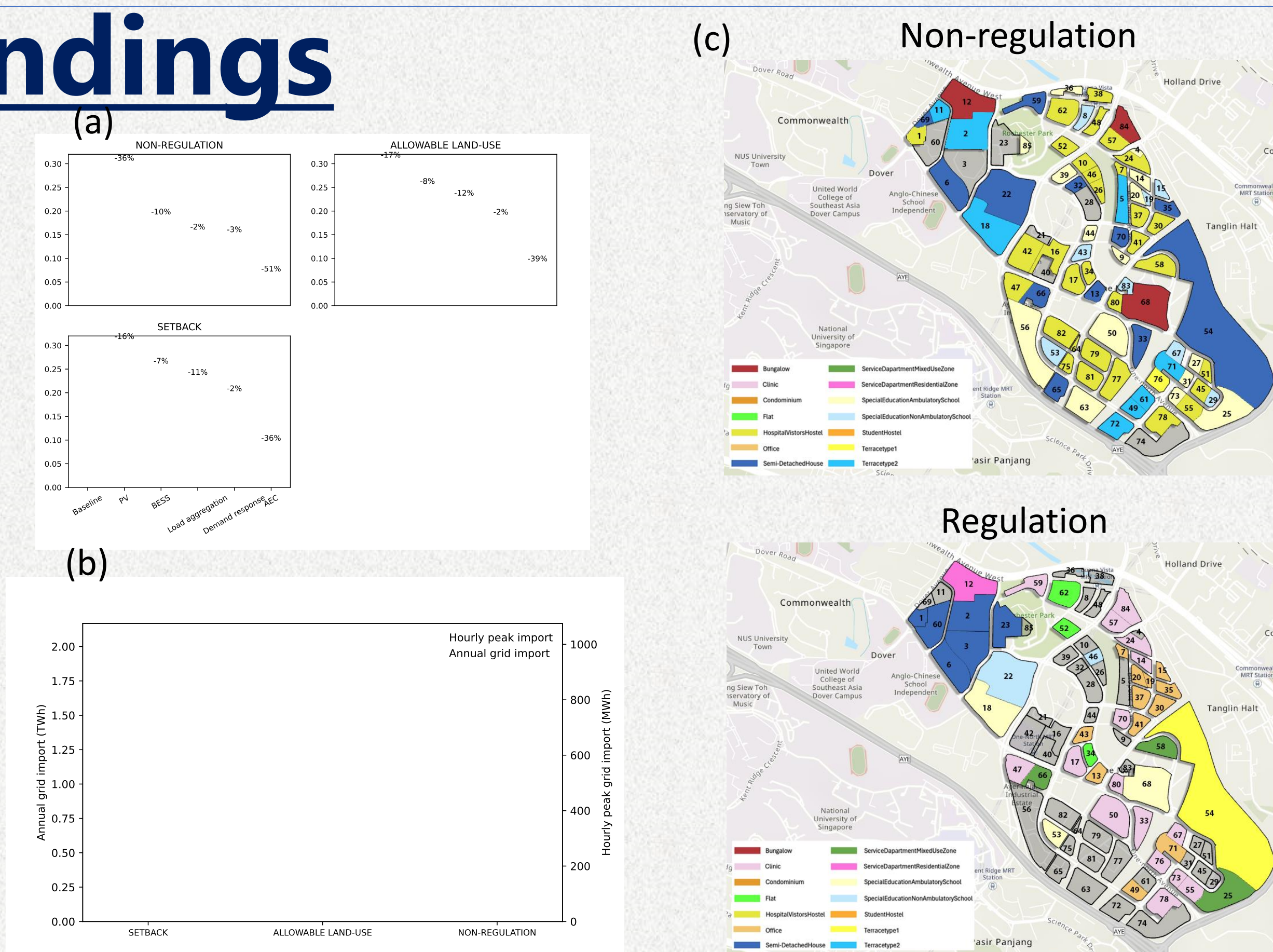


Fig. 4 LCOE (a), peak demand and grid import (b), and optimal energy-driven land-use assignment plan (c)

## Conclusions

- UPRs, including restrictions on allowable land-use and building setback, have a **substantial impact** on DES performance.
- The energy performance of DES can be improved through strategical adjustments of UPRs from the following main channels. Adjust **restriction on allowable land-use** for improvement of PV generation potential and investment cost of microgrid. Adjust **restrictions on setbacks of certain buildings** so that the load aggregation and demand response potential can be improved.

### Contact

Kang Jidong, Postdoctoral researcher, Powering the City, Singapore-ETH Center, Singapore, [jidong.kang@sec.ethz.ch](mailto:jidong.kang@sec.ethz.ch)

Cai Chenyi, Postdoctoral researcher, Semantic Urban Elements, Singapore-ETH Center, Singapore, [chenyi.cai@sec.ethz.ch](mailto:chenyi.cai@sec.ethz.ch)

## Methods

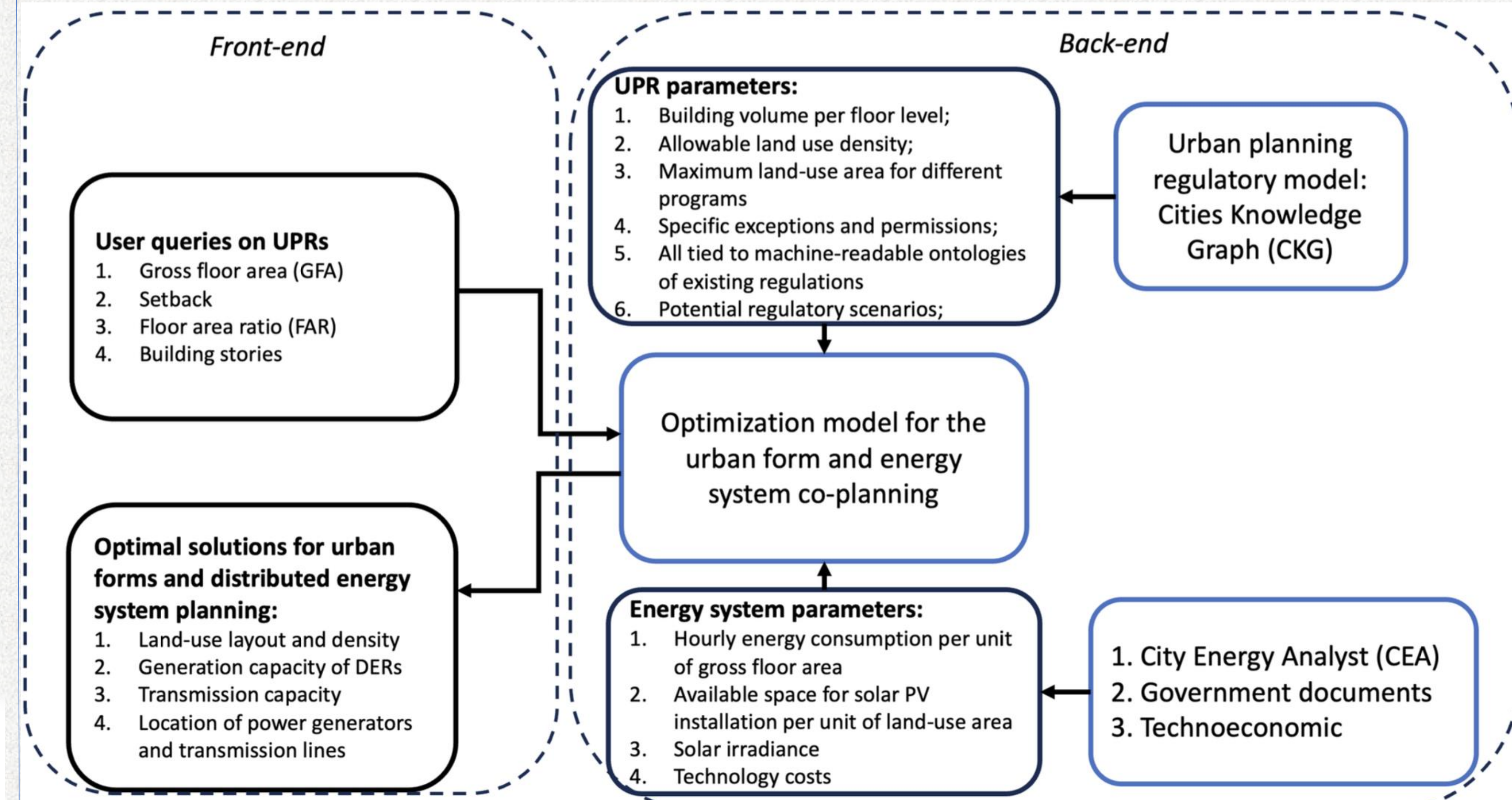


Fig. 2 Methodological framework of UPR energy impact evaluation model

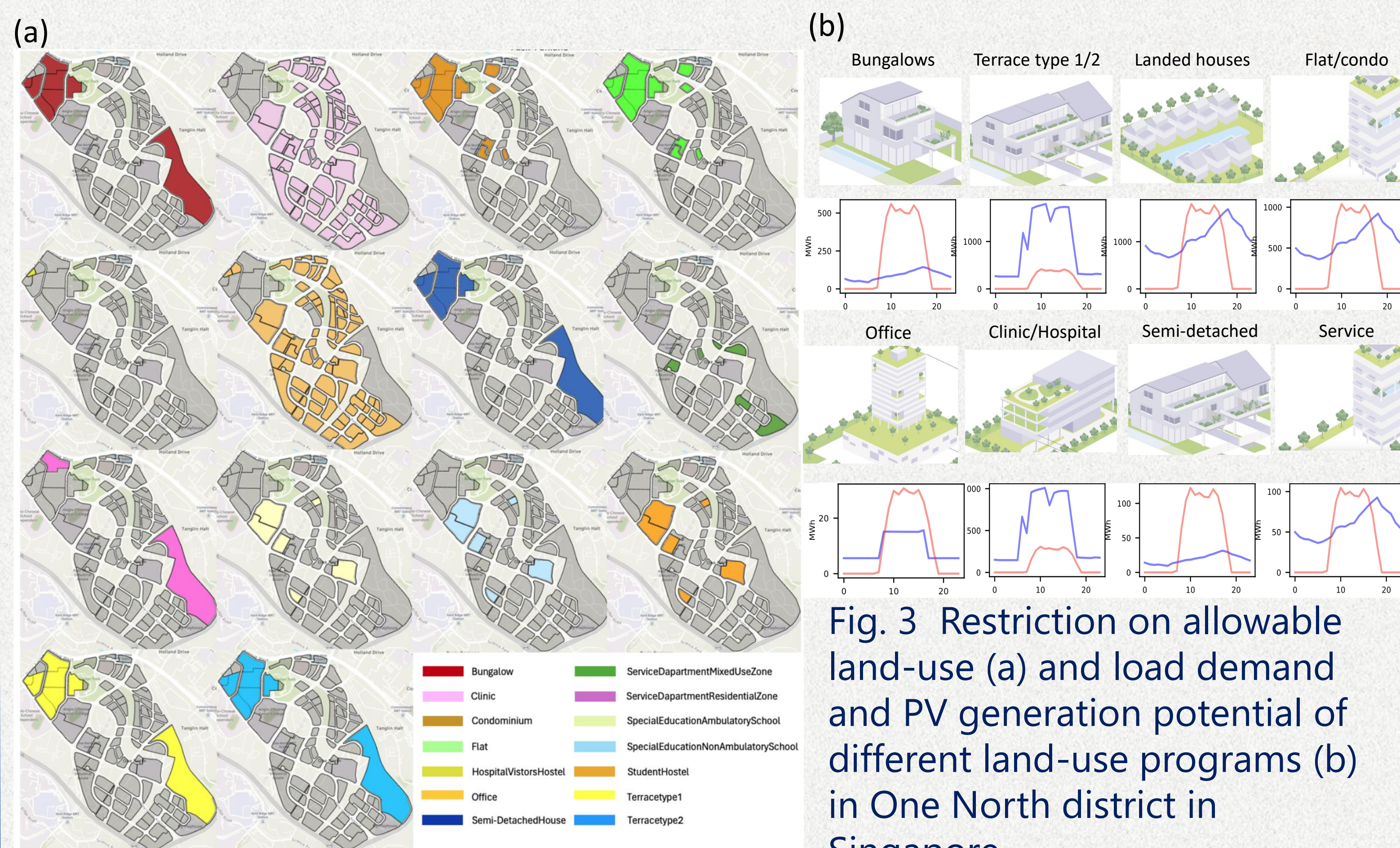


Fig. 3 Restriction on allowable land-use (a) and load demand and PV generation potential of different land-use programs (b) in One North district in Singapore

## Key discussion points

- The main UPR variable influencing DES performance is the **allowable land use**, which **increase LCOE by 25%**, **reduce SESS by 62%**, and **increase peak hourly grid import by 65%** compared to the non-regulation scenario. **Building setback regulation** had a relatively small impact on DES performance, increasing LCOE by **5%**, **reducing SESS by 8%**, and **increase peak hourly grid import by 7%**.
- The main contributor of LCOE reduction from adjusting allowable land-use restriction is the **increased PV generation potential**.
- The main contributors of LCOE reduction from adjusting building setback are **energy sharing** and **BESS**.

## Future applications

- Sensitivity analysis:** Compute the shadow costs of different UPRs on DES performance using optimization model.
- Stakeholder benefit analysis:** Analyze how the benefits allocated to different stakeholders will change through the changes in UPRs.

### Reference:

[1] Gisiute, A., Silvennoinen, H., Li, S., Chadzynski, A., Raubal, M., Kraft, M., ... & Herthogs, P. (2023, July). A Semantic Spatial Policy Model to Automatically Calculate Allowable Gross Floor Areas in Singapore. In *International Conference on Computer-Aided Architectural Design Futures* (pp. 455-469). Cham: Springer Nature Switzerland  
Silvennoinen, H., Chadzynski, A., Farazi, F., Grišūtė, A., Shi, Z., von Richthofen, A., Cairns, S., Kraft, M., Raubal, M., & Herthogs, P. (2023). A semantic web approach to land use regulations in urban planning: The OntoZoning ontology of zones, land uses and programmes for Singapore. *Journal of Urban Management*. <https://doi.org/10.1016/j.jum.2023.02.002>

### Acknowledgements

This research was conducted at the Future Cities Lab Global and Future Resilient Systems at Singapore-ETH Centre and ETH Zurich. Future Cities Lab Global and Future Resilient Systems are supported and funded by the National Research Foundation, Prime Minister's Office, Singapore under its Campus for Research Excellence and Technological Enterprise (CREATE) programme and ETH Zurich (ETHZ), with additional contributions from the National University of Singapore (NUS), Nanyang Technological University (NTU), Singapore and the Singapore University of Technology and Design (SUTD).