THE UNIVERSITY of EDINBURGH
School of Engineering
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Integrated grid planning model under uncertainty: Towards sustainable future grid

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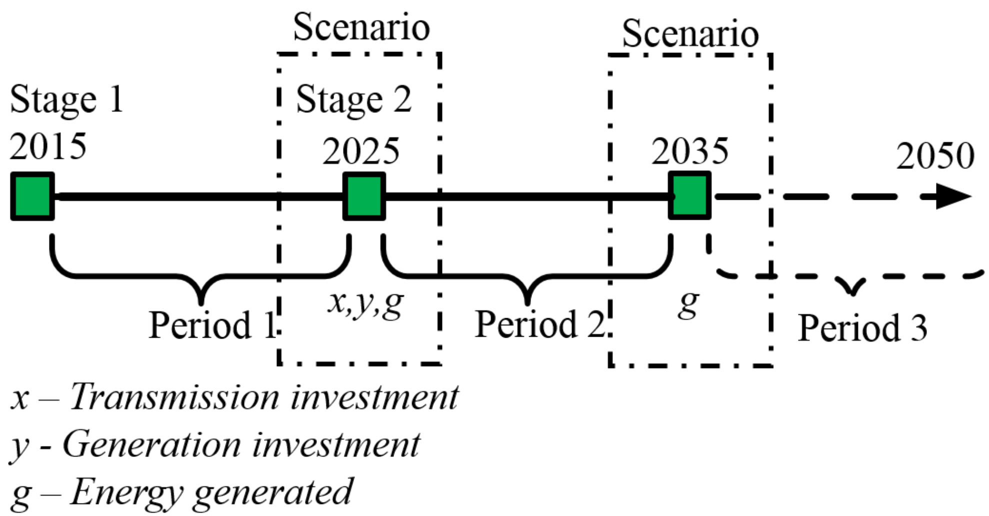
Problems

- Rapid growth of renewable energy generations
- Significant amount of solar generation & storage are connected to the distribution network
- Power flow constraints and voltage are likely to be violated without additional reinforcement (hosting capacity enhancement)
- Also, introduce more uncertainty
- Many researches and modelling efforts are directed to finding least-cost transmission-level expansion planning

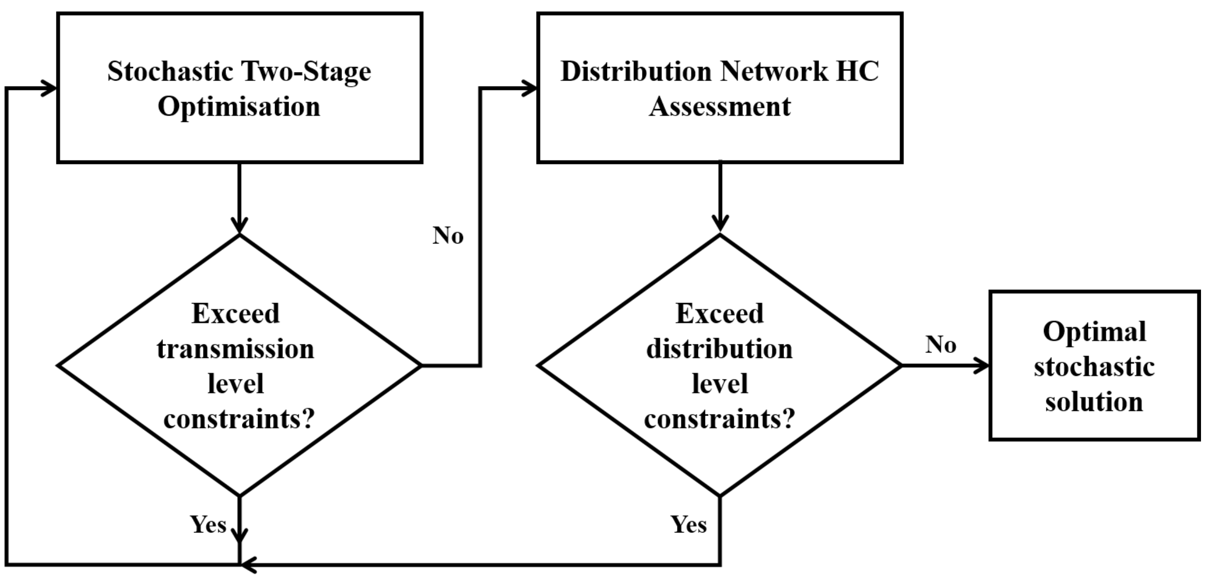
Motivations

- But, do not consider distribution-level constraints in analysis
- Separately, risk of uncertainty in not always properly considered
- We are interested to know:
  1. How **distribution constraints** and **uncertainty** influence optimal generation and transmission expansion plans
  2. The benefit of integrating **distributed solar PV** and **battery storage** in grid planning
  3. The effect of co-optimizing battery storage investment with grid planning
  4. Practical approach for transition planning towards sustainable grid

Modelling approach



- Jointly model transmission and distribution networks
- Recognize distribution network constraints
- Acknowledge uncertainty (economic, regulatory and technology development)
- Two stage (allow staggered decision & delayed decision)
- Applied for stylized **Malaysia** grid



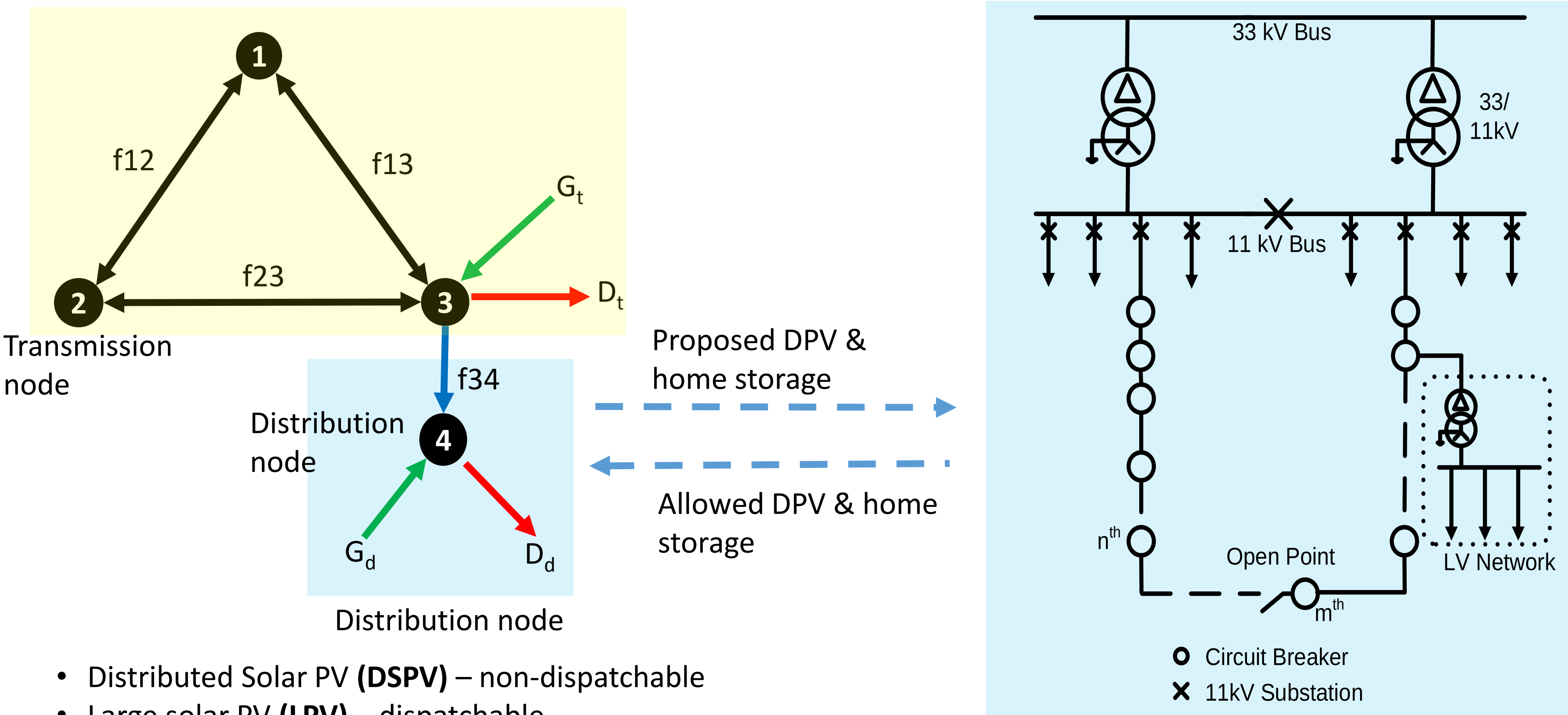
Scenario:

- Status quo
- Off-grid
- Decarbonisation
- No-storage
- Technology
- Low cost conventional

Modelling approach

Stochastic two-stage grid planning (linear)

Hosting capacity (HC) assessment (non-linear)



- Distributed Solar PV **(DSPV)** – non-dispatchable
- Large solar PV **(LPV)** – dispatchable
- **Grid** battery storage
- **Distributed DSO** owned storage
- **Domestic distributed** storage (uncontrollable)
- Line connecting T & D network (no constraint)
- 48 hours block (peak and of peak within a year)

Hosting capacity (HC) limit:

- **Reverse power flow**
- **Voltage rise**

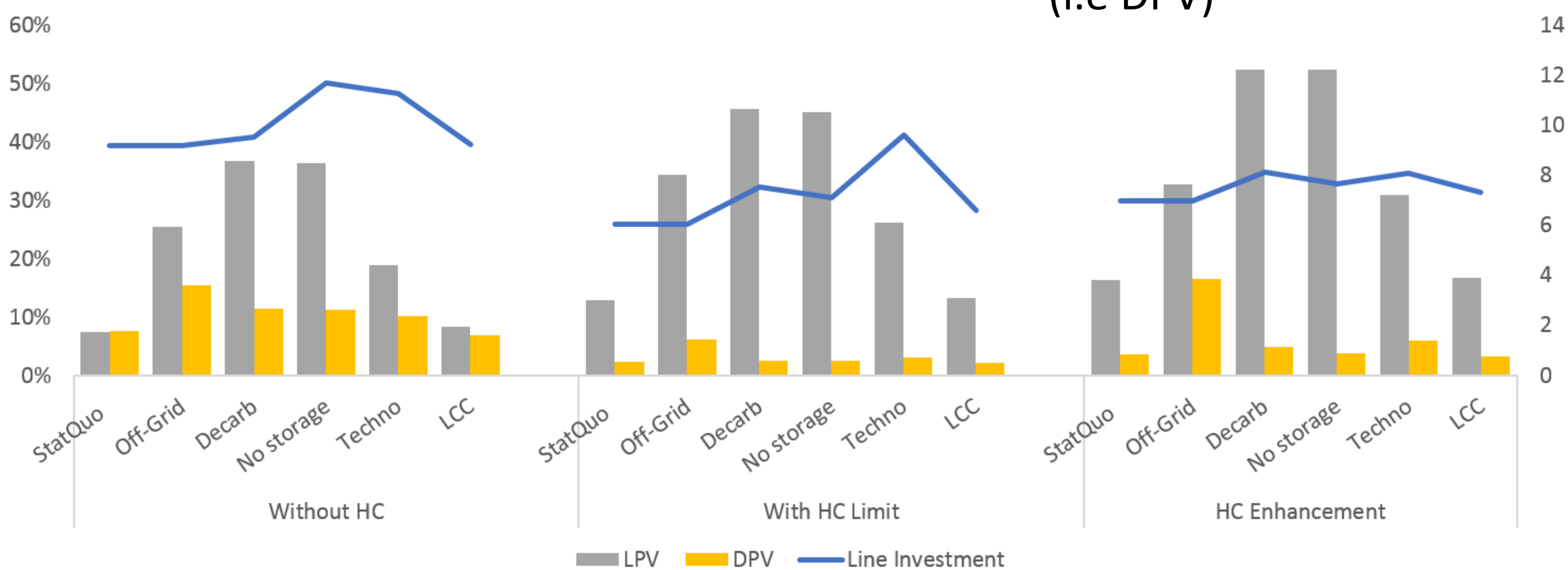
Result : Impact of hosting capacity (HC) constraints

	Without HC	With HC*	HCe**
Stage 1 Line (GW)	9.19	6.05	6.98
Stage 1 Cost ($ bil)	148.57	149.79	150.25
Expected cost ($ bil)	271.62	274.09	271.72

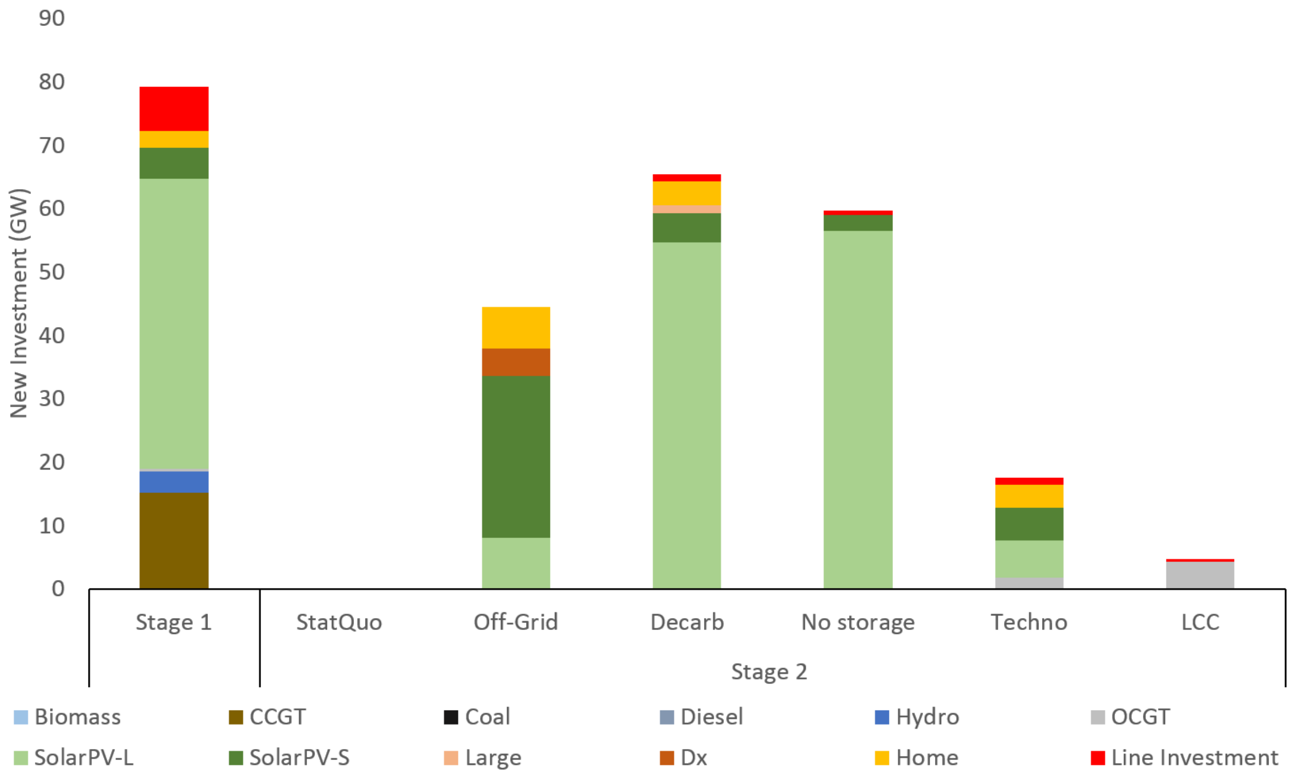
HCe** - with distributed storage

Table: First stage investment and expected cost

- Distribution constraints result in cost increase by 0.91% or $2.47
- Reduction of $2.37b NPV from the initial cost* after distributed storage is connected
- Significant change in solar mix (i.e DPV)



Result : Optimal solution (New investment)



- First stage decision propose LPV, DPV and distributed domestic storage
- DSO owned storage and home storage are proposed in the 'Off-grid' scenario to allow higher DPV penetrations
- 1st stage investment decision provides an indicative transition plan to be implemented accounting for future uncertainty

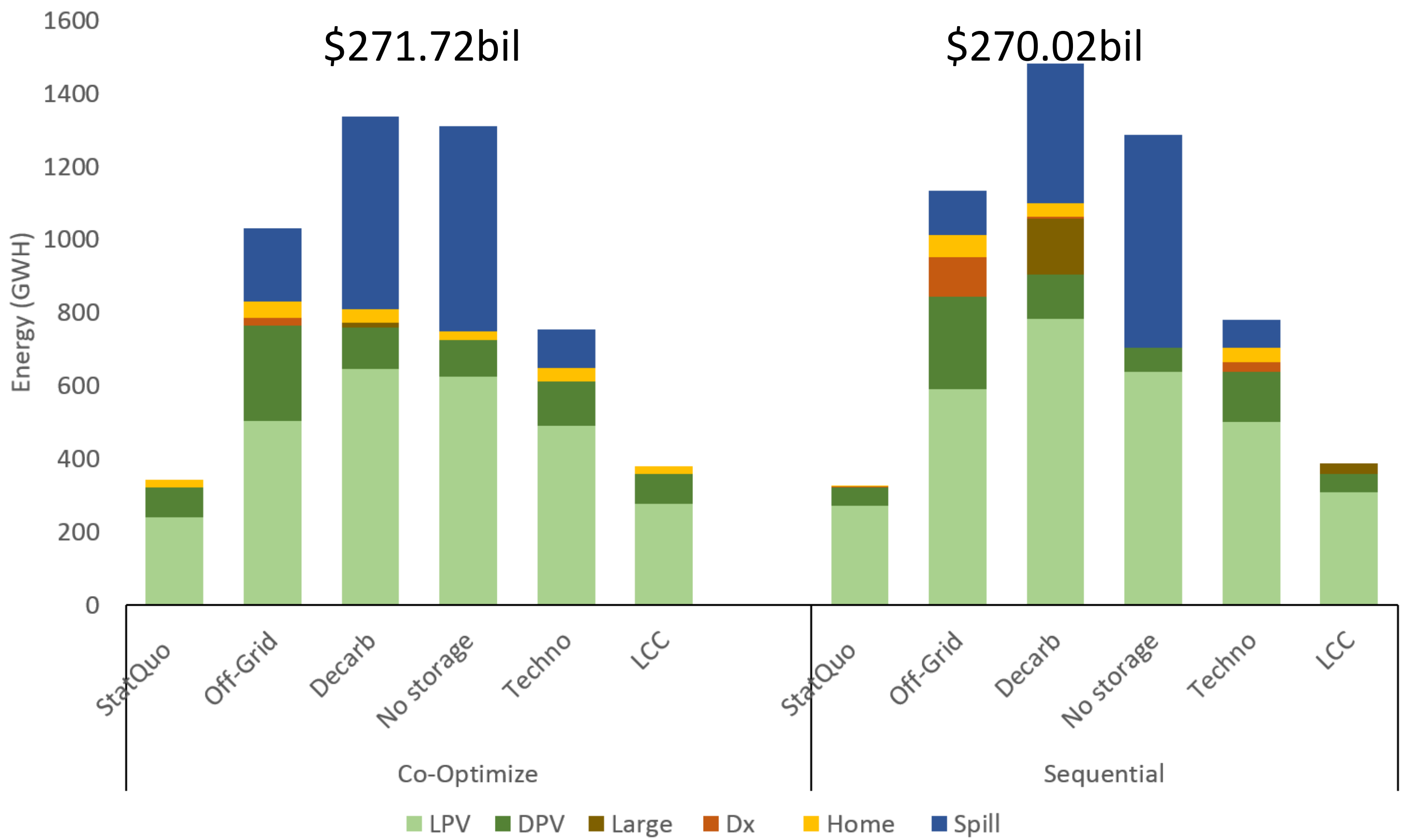
Result : Estimated value of perfect information (EVPI)

Scenario	EVPI	
	Total Cost ($Bil)	Savings from perfect info ($Bil)
Stochastic ($Bil)	**271.72**	
StatusQuo	159.11	112.61
Off-grid	237.43	34.29
Decarbonization	312.26	-40.54
No-ESS	318.72	-47
Techno	209.6	62.12
LCC	195.69	76.03
	EVPI	**24.81 (26.71)**
% Stochastic cost		**9.13% (9.88%)**

( ) – without HC

- EVPI for both cases (with and without HC limit) differ by nearly $1.9 billion or reduce by 7.1% after accounting for HC limits
- This indicates that uncertainty is especially important in a model that considers distribution network constraints
- Most importantly, distribution constraints account for 7.1% of the total EVPI

Result : Co-optimized and sequential approach



- Cheaper cost than co-optimized by 0.63% ($1.7 billion)
- Less curtailment
- More storage is built

Conclusion

- Distribution constraints have a significant impact on the overall investment cost **(≈1% of total cost)**
- Distributed battery storage can significantly improve DPV penetration and reduce grid investment cost by **0.86% ($2.37 b)**
- Ignoring uncertainty has significant cost implications depending on the first stage naïve decision
- The efforts to use models that can accommodate these constraints are at least as important as efforts to move to stochastic planning modelling methods.
- Decision on battery storage investment after the grid planning has been finalized could reduce the overall cost by 0.63%
- This demonstrates that there is value in waiting, and in reducing the lead time of energy storage investment.
- This paper has been a first attempt to address joint transmission and distribution network modelling for planning purposes

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