Metaheuristic modelling to generate alternatives in non-linear energy system models

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I. Introduction

Modern energy system planning relies on large, complex models and advanced optimisation. However, ever more complexity introduces uncertainties which impact the validity of optimisation results. Contributing factors include: uncertainty in input data, uncertainty in future policy settings, and uncertainty in objective. Modelling to Generate Alternatives (MGA) focuses on assisting problem insight rather than identifying a single optimal solution [1].

MGA encompasses a range of techniques but the characteristic common feature is the identification of distinct solutions inside a near-optimal region (see figure 1.). MGA is used to identify near-optimal solutions which are qualitatively different from the optimal solution. These near-optimal solutions inform decision makers on the available design space within which to pursue competing objectives. Various applications of MGA also enable users to search for near-optimal solutions which may better satisfy specific secondary objectives.

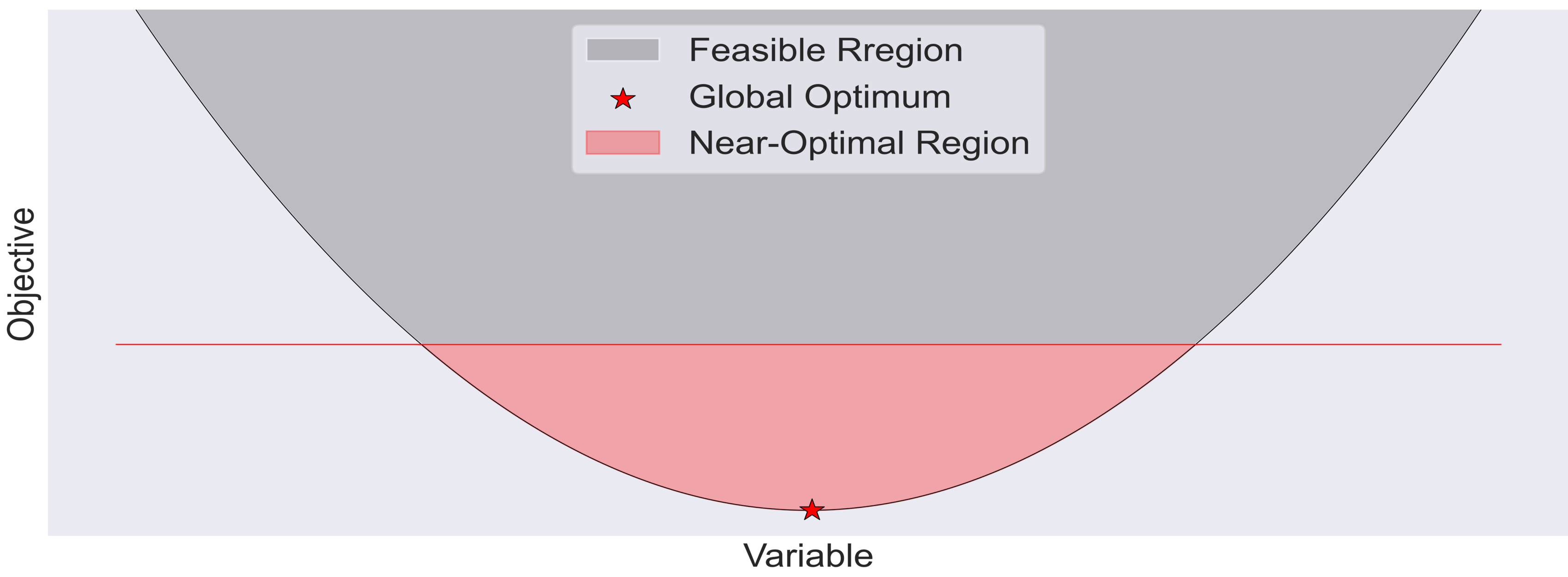

Figure 1: A near-optimal region defined by a user-determined cost slack

The vast majority of MGA work has focussed on linear models and emerging techniques are outperforming established techniques [2]. We introduce a novel MGA approach based on space partitioning and demonstrate the approach on a non-convex formulation of a 100% renewable, Australian electricity system model.

We identify diverse solutions within 10% of optimal cost and identify high-level trends in system cost and behaviour. Grids with high penetrations of solar relative to wind and found to require similar volumes of energy storage but at higher power capacity. High solar grids also favour larger interregional transmission capacities.

II. Methods

We size a simplified, 5-node copper plate model of the Australian National Energy Market. The system considers utility PV, onshore wind, and existing hydro with storage supplied by pumped hydro to meet operational demand. The size of assets are optimised while the operations are determined by rules-based dispatch. An energy balance over 10 years at half hourly resolution is evaluated to ensure technical operation.

A space partitioning algorithm simultaneously optimises and identifies alternatives. The solution space is split into half-spaces at the centres of which, the cost and feasibility are evaluated. Each iteration, near-optimal feasible sub-spaces are likewise partitioned, rotating through the solution dimensions if necessary. When there are no feasible, near-optimal sub-spaces, neighbouring sub-spaces are likewise evaluated.

To avoid early convergence and accelerate evaluation, the program is ordered in steps with their own hyperparameters. Hyperparameters include maximum resolution, near-optimal cost slack, maximum population size, and maximum number of iterations.

The final output is an evenly sampled point-cloud representation of the near-optimal space which can be efficiently queried for analysis.

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III. Results

The distribution of generation capacities at varying near-optimal cost thresholds is show in figure 2. There are clear differences in behaviour between high– and low–solar near-optimal systems which are revealed by differences in disaggregated costs.

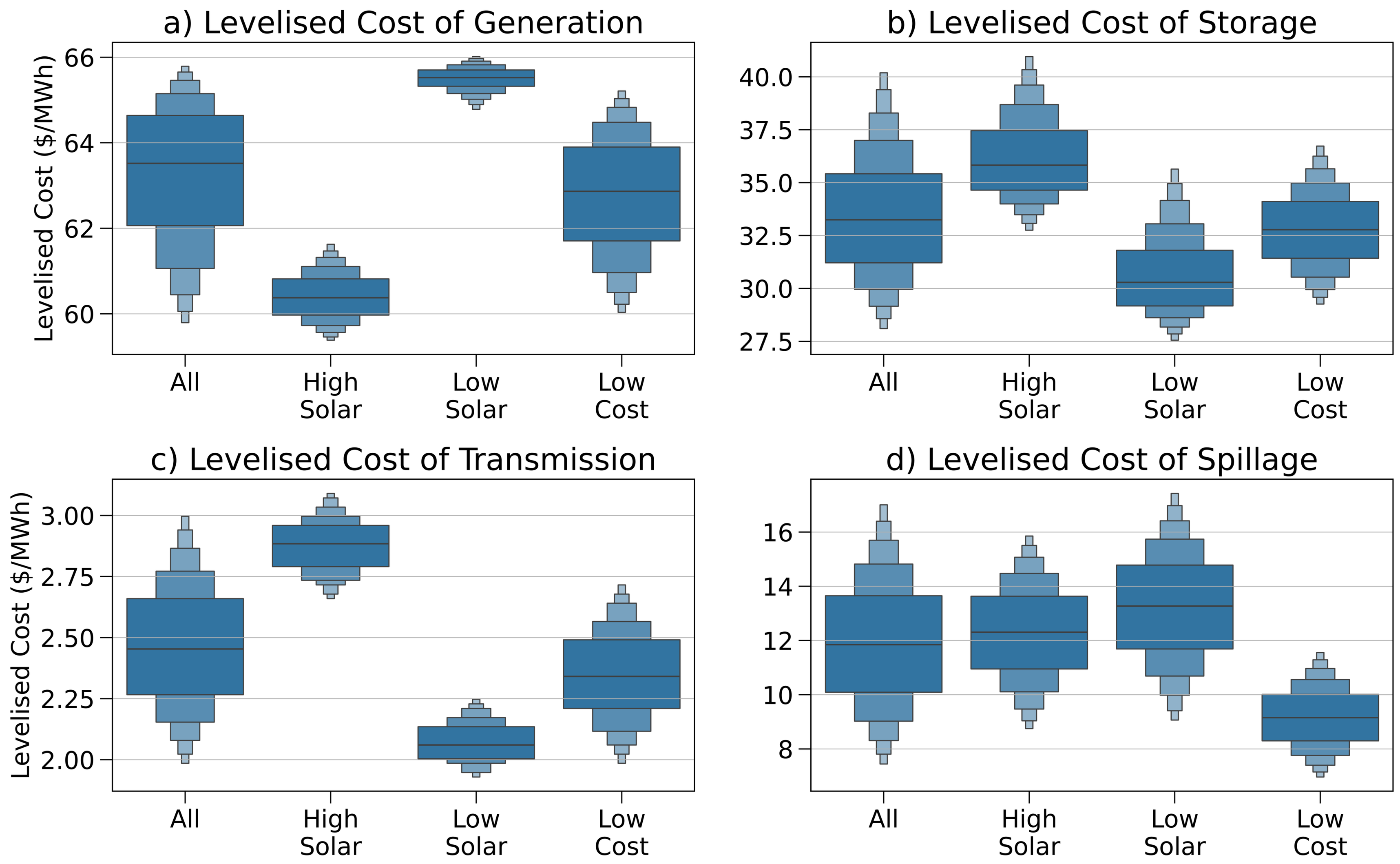

Figure 2: Distributions of the disaggregated components of LCOE of selected subsets of the near-optimal space

High-solar systems are observed to rely more heavily on transmission and storage infrastructure, but offer cost savings with respect to investment in generation infrastructure. Interestingly, figure 3 reveals that high-solar and low-solar configurations require similar volumes of energy storage but that high-solar systems require higher storage power capacities.

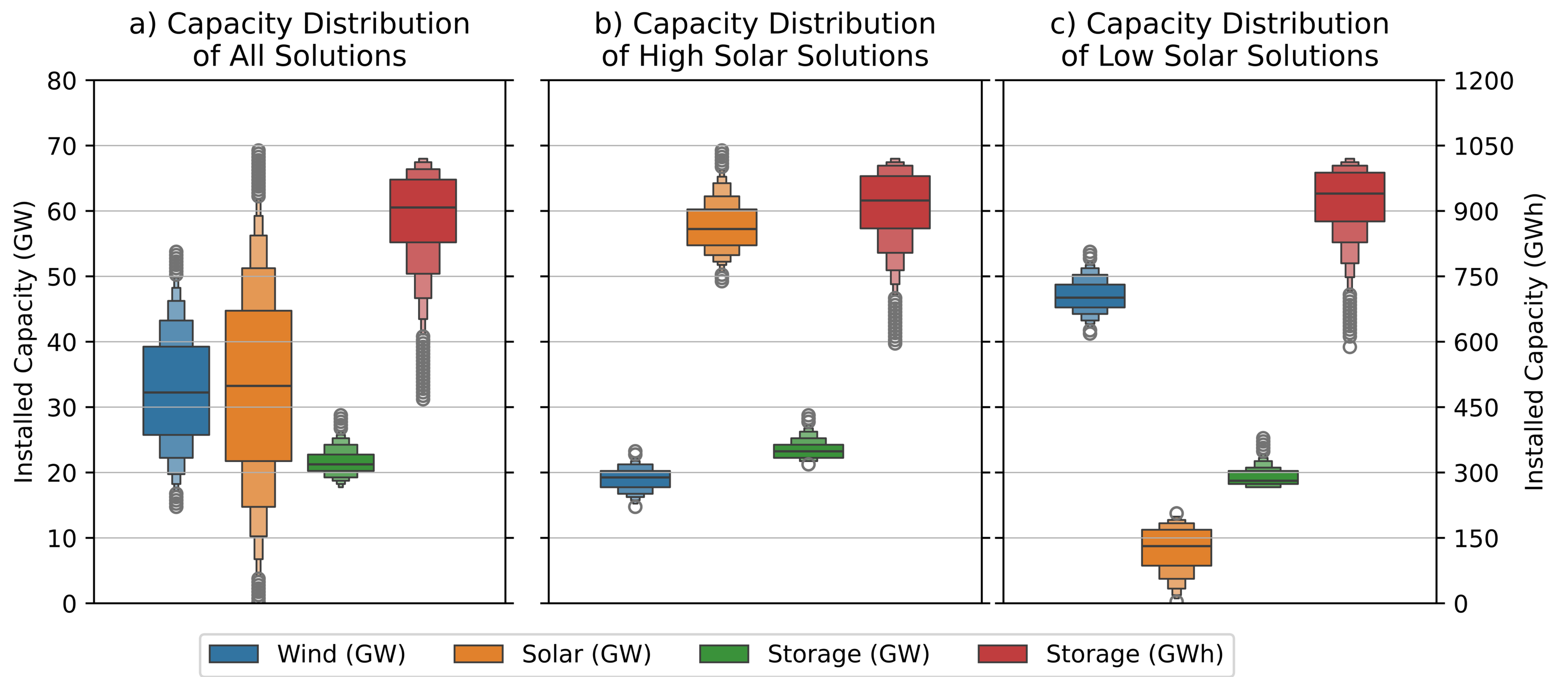

Figure 3: Distributions of capacities in selected subsets of near-optimal solutions

Pumped hydro storage, is relatively expensive per unit power capacity but relatively cheap per unit energy capacity while the opposite is true for chemical batteries. Modelling a system with both storage technologies would likely bring down storage costs significantly.

IV. Conclusions

We present and demonstrate a novel space-partitioning algorithm for MGA analysis. This algorithm opens MGA to non-convex optimisation models and facilitates rapid post-processing and analysis.

For a simplified 100% Australian energy network, we identify diverse solutions within 10% of optimal cost. We observe high-level trends in system cost and behaviour. For example, grids with high penetrations of solar relative to wind are found to require similar volumes of energy storage but at higher power capacity. High solar grids also favour larger interregional transmission capacities.

V. References

[1] E. D. Brill, S.-Y. Chang, and L. D. Hopkins, "Modeling to Generate Alternatives: The HSJ Approach and an Illustration Using a Problem in Land Use Planning," *Management Science*, vol. 28, no. 3, pp. 221–235, Mar. 1982, doi: 10.1287/mnsc.28.3.221.

[2] M. Lau, N. Patankar, and J. D. Jenkins, "Measuring exploration: evaluation of modelling to generate alternatives methods in capacity expansion models," *Environ. Res.: Energy*, vol. 1, no. 4, p. 045004, Oct. 2024, doi: 10.1088/2753-3751/ad7d10.