The University of Manchester

Designing and applying water resource planning approaches in the UK

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Water resource planning

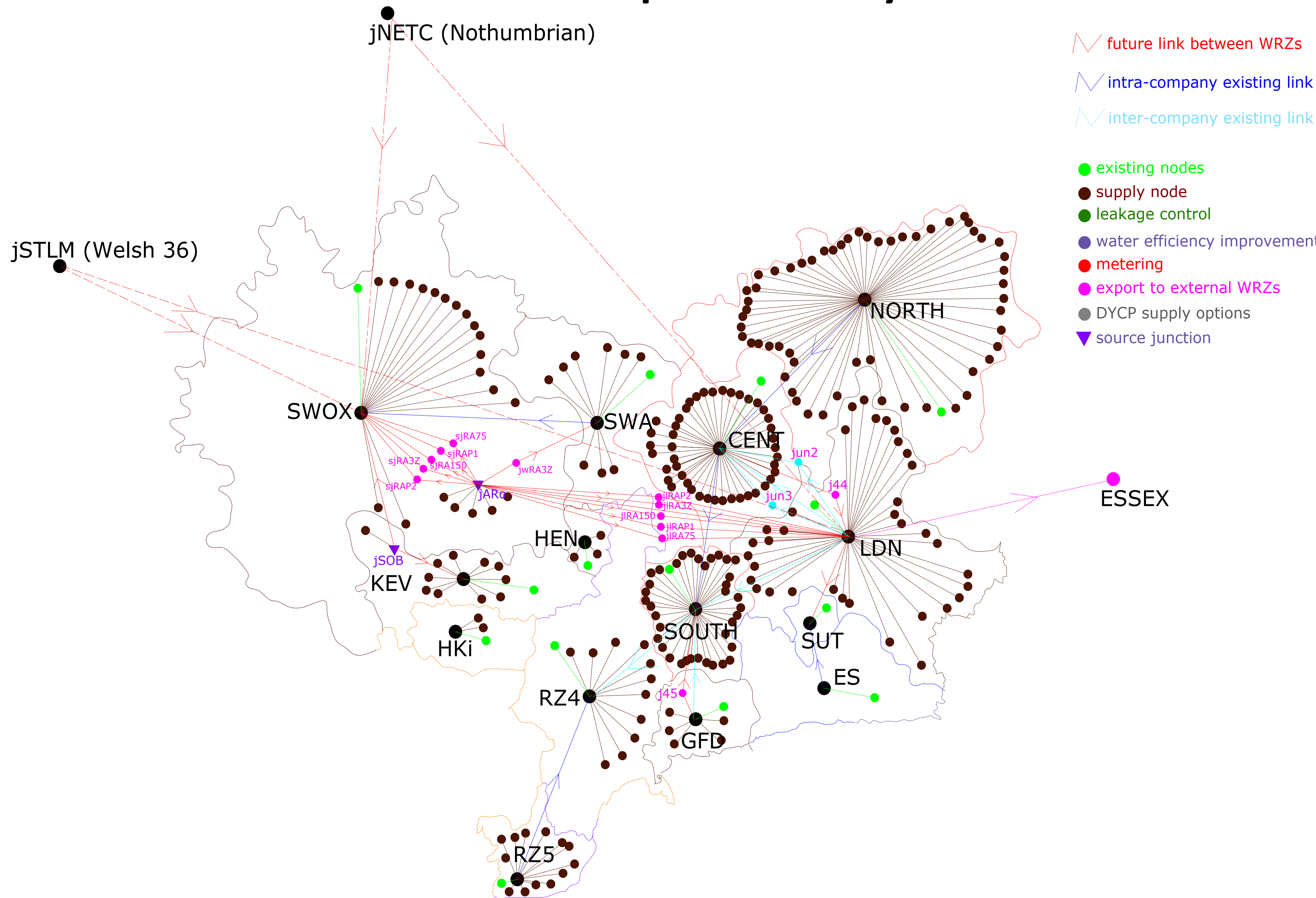
- WRMPs, drought plans can include:
  - new supply options
  - new demand management schemes
  - new policies (e.g. reservoir release rules)
- Even if just a few options, number of combinations large
- How can we identify the most promising plans? How to reach a shared vision on which to choose?

Economic optimisation of the supply-demand balance

Currently in England: search for least-cost set of investments over planning period that maintain the supply-demand balance (‘EBSD approach’):

1. Split region into independent interconnected supply zones,
2. Define cost curve for all options in each zone, and transfers between zones (i.e., identify yields-DO, capital costs, fixed & variable operating costs of all options)
3. Identify annual demand projections by zone
4. Find least-cost mix of options and schedule that meet reliability requirements

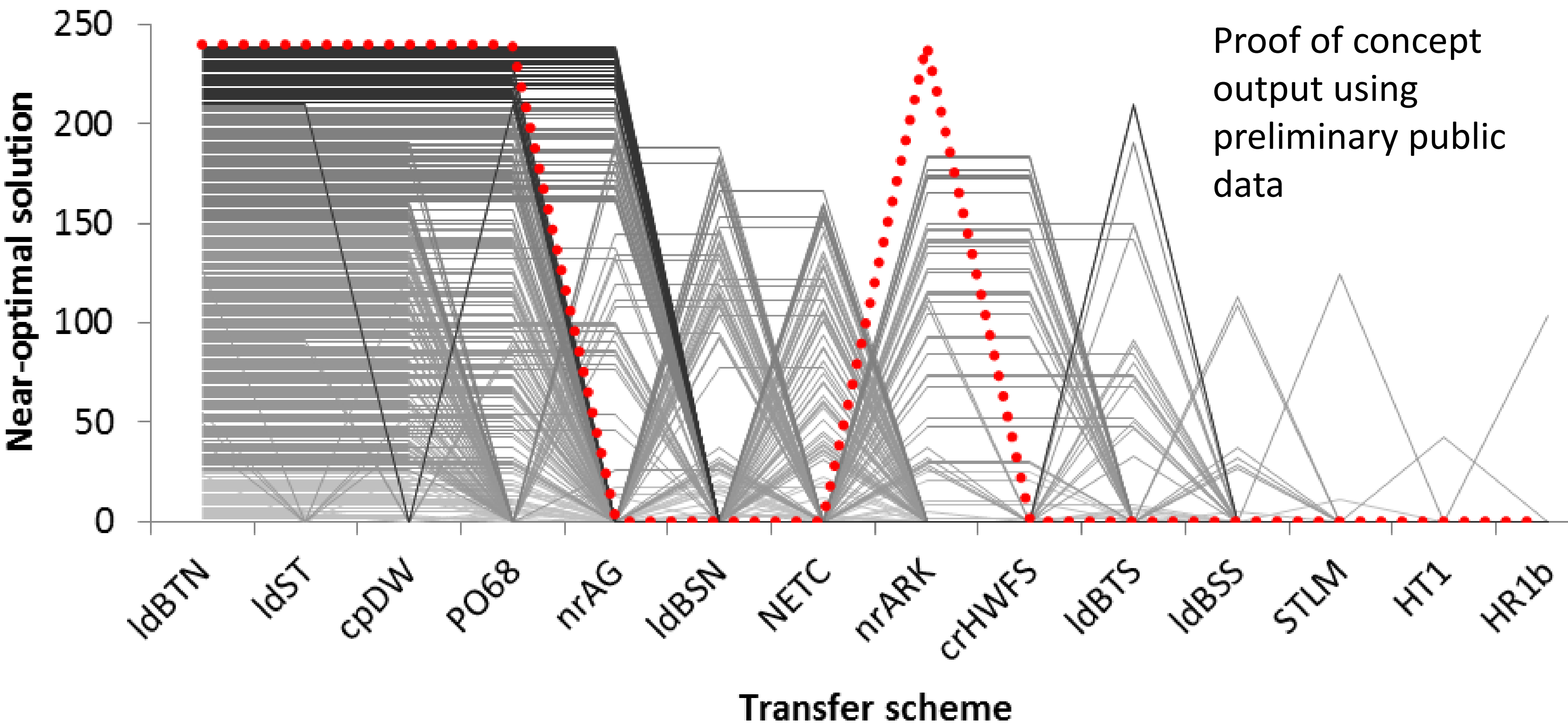
Investment options by zone



Limitations of current least-cost approach

- **Monetised benefits only**: must monetise all societal goals if they are to be considered
- **Conservative**: seeks to prevent worst supply-demand annual imbalance, rather than work well across a range of plausible futures
- **Potentially inaccurate**: non-linear interactions between schemes not considered
- **Many similar solutions**: many different portfolios are nearly least-cost

Diversity in the frequency of WRSE **transfer** scheme selection amongst the 240 near-optimal solutions within 10% of the optimum



- Each line is one of the 240 near-optimal solutions
- Darkest lines are closest to least cost
- Densely colored transfers: selected in all or most 240 near-optimal solutions

Is economic optimisation the ideal tool?

- Results indicate that economic criteria alone is not sufficient to coalesce around one plan
- Because of cost inaccuracy, nearly least cost portfolios are roughly of equal worth
- There are too many intangibles to consider to select one

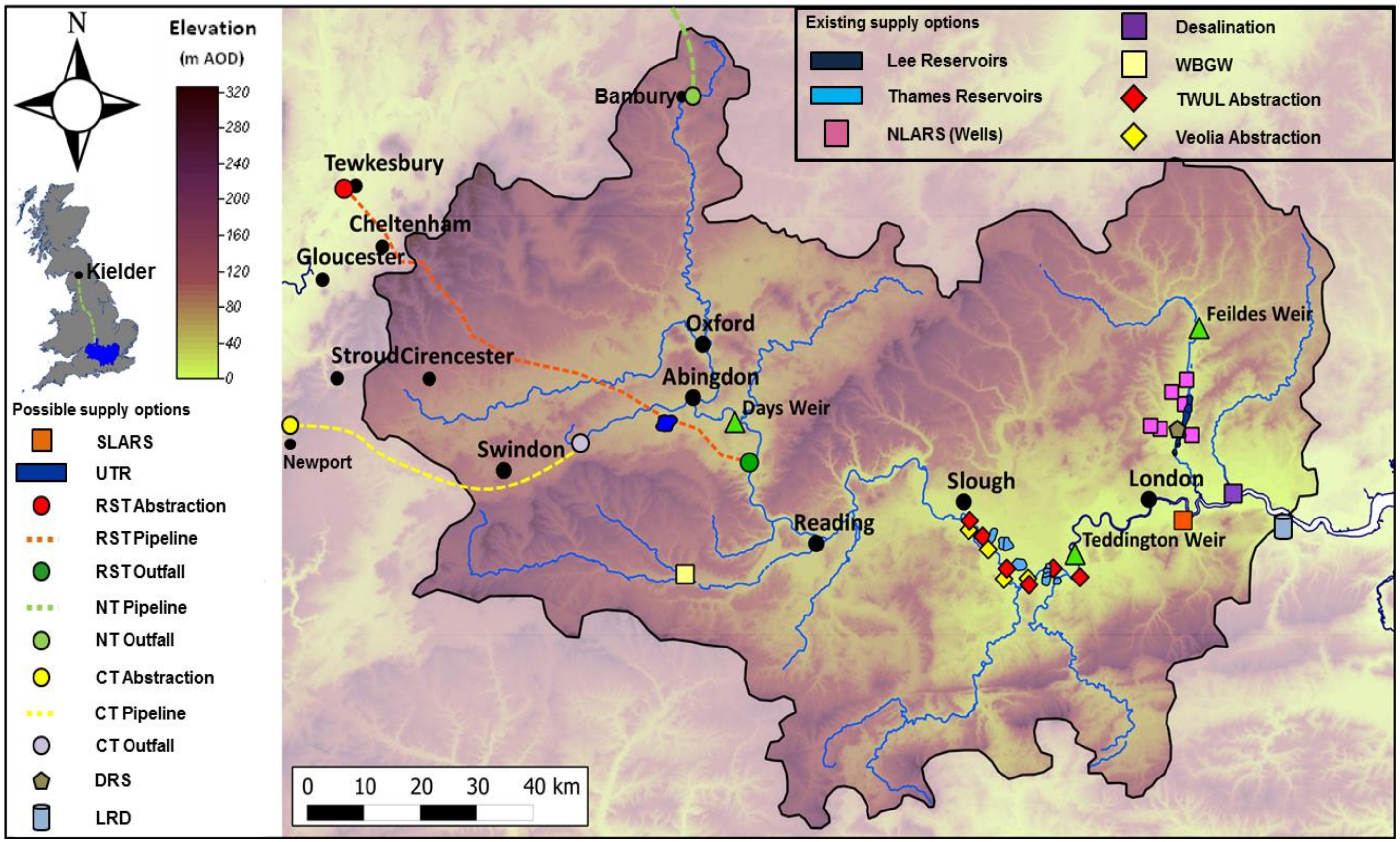
- What if we could:
  - Address EBSD limitations
  - Visually assess least-cost plans, and the intangibles too …

Planning based on scenario simulation approaches

- Rather than only tracking the annual supply-demand balance …
- Why not use integrated water resource management system models that track multiple engineering, environmental, economic and social performance metrics
- Link system simulator to decision-making under uncertainty approaches:
    1. RDM
    2. Robust search

Case study – Thames Basin, UK

Stressed water resource system with population over 13 million including London



Demand management options

- Active Leakage Control
- Pipe repair campaign
- Enhanced Efficiency Improvements
- Installation of Smart Meters
- Seasonal Tariffs

What mix of supply and demand interventions (portfolio)? At what capacity?

What type of solution are we searching for?

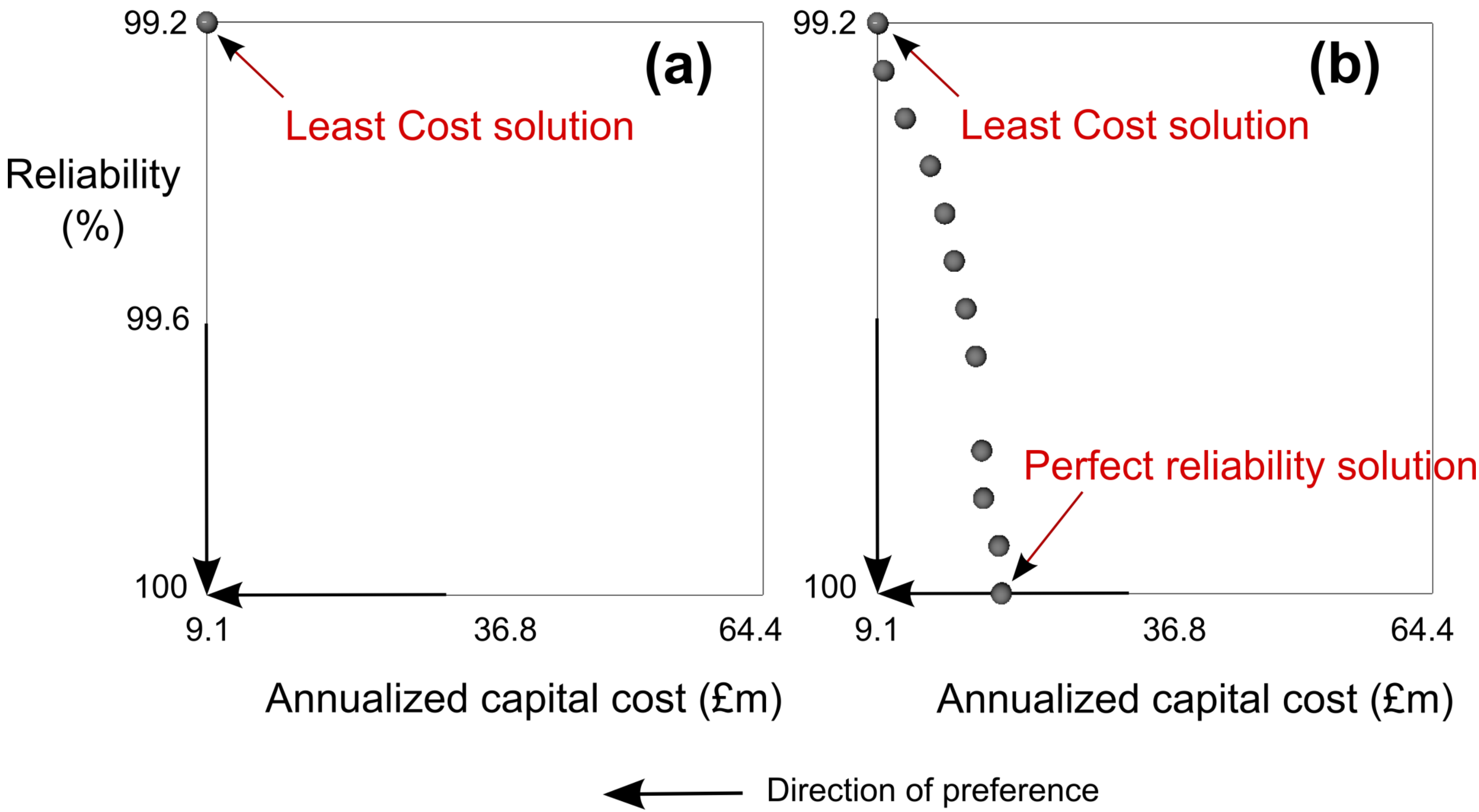
Our objectives:

- **Capital cost** – *Annualized capital cost of implementing new supply and demand options based on option's design life (£m)*
- **Supply deficit** – *Average annual experienced by London WRZ (%)*
- **Supply resilience** – *Maximum duration failure* (weeks)*
- **Supply reliability** – *Frequency of failures* (%)*
- **Eco-deficit** – *Difference between natural and simulated low flows (%)*
- **Energy cost** – *Annual average operating cost (£M/a)*

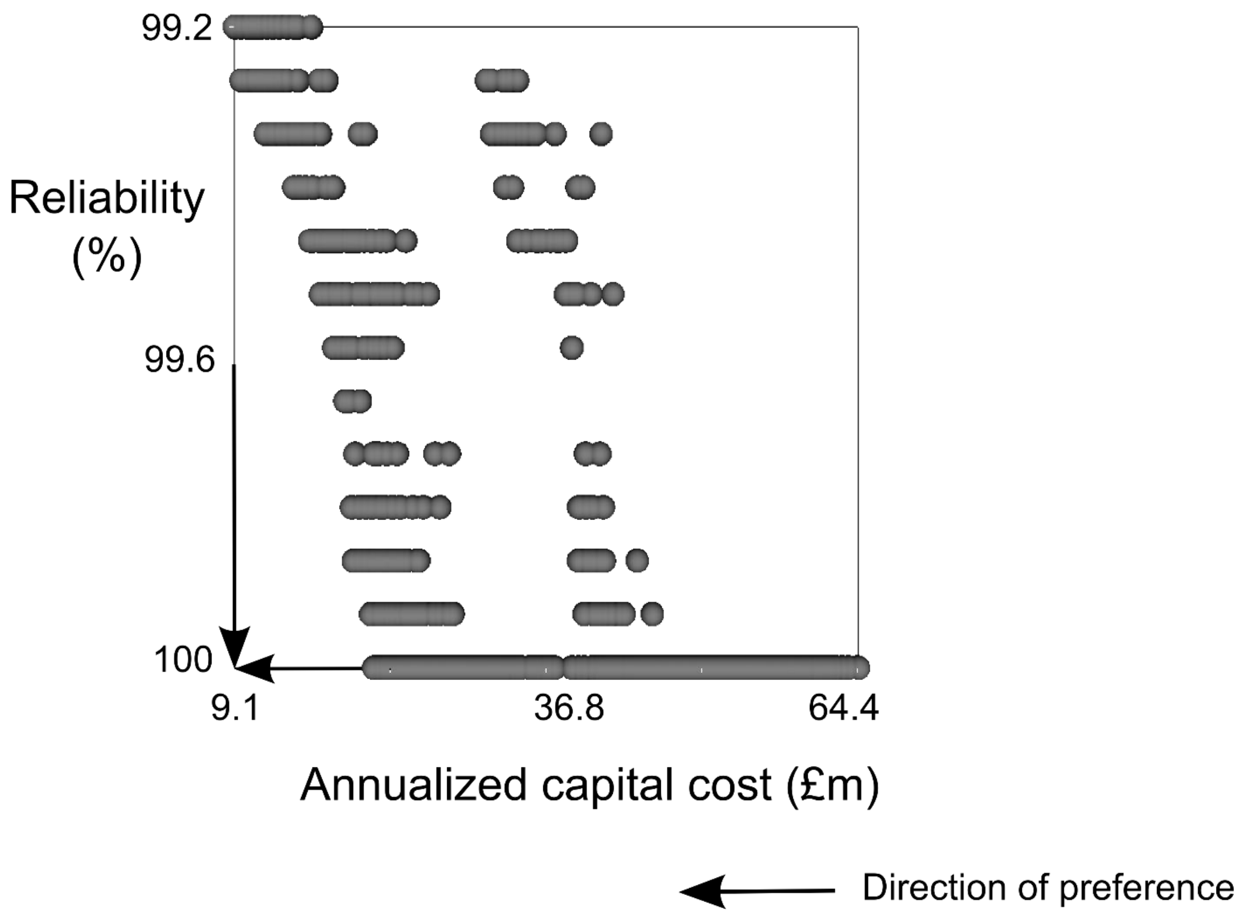
Our constraints

- **Levels of Service** *(max. frequency of imposing demand restrictions)*
- **Mutual exclusivity of some supply options**

Single and two objective optimization; Currently UK utilities find a) they should consider b)



Case study – Thames Basin, UK



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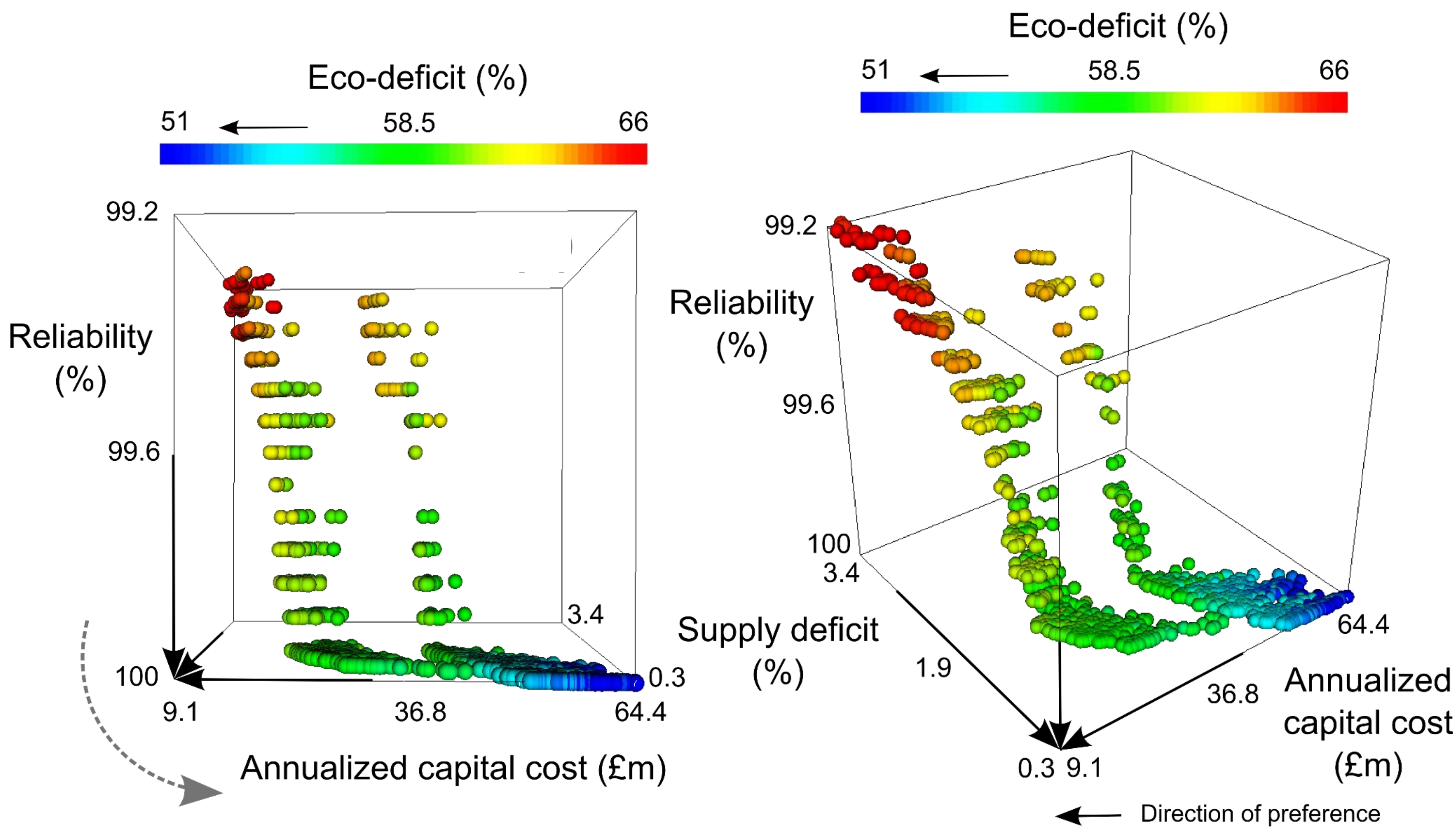
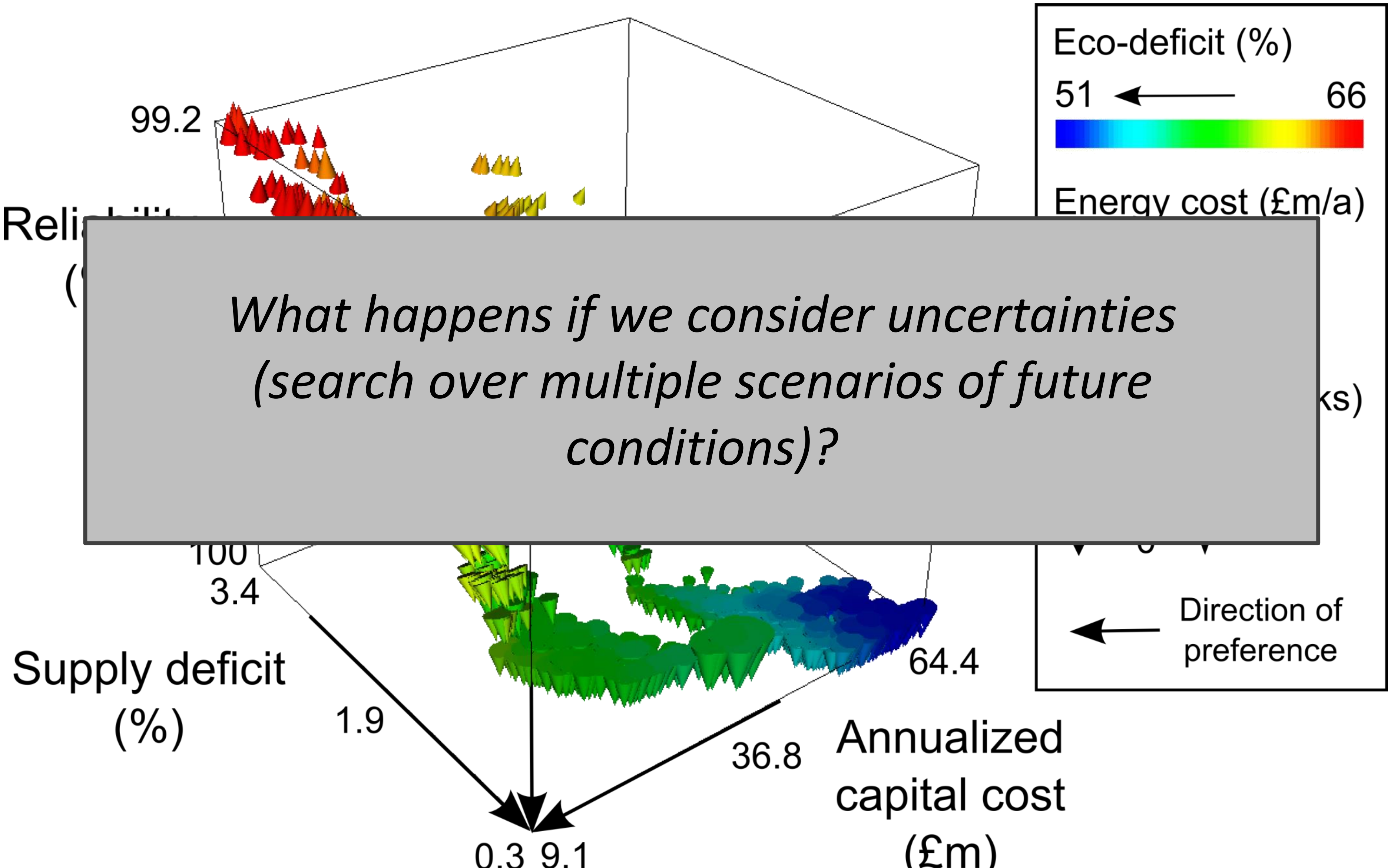
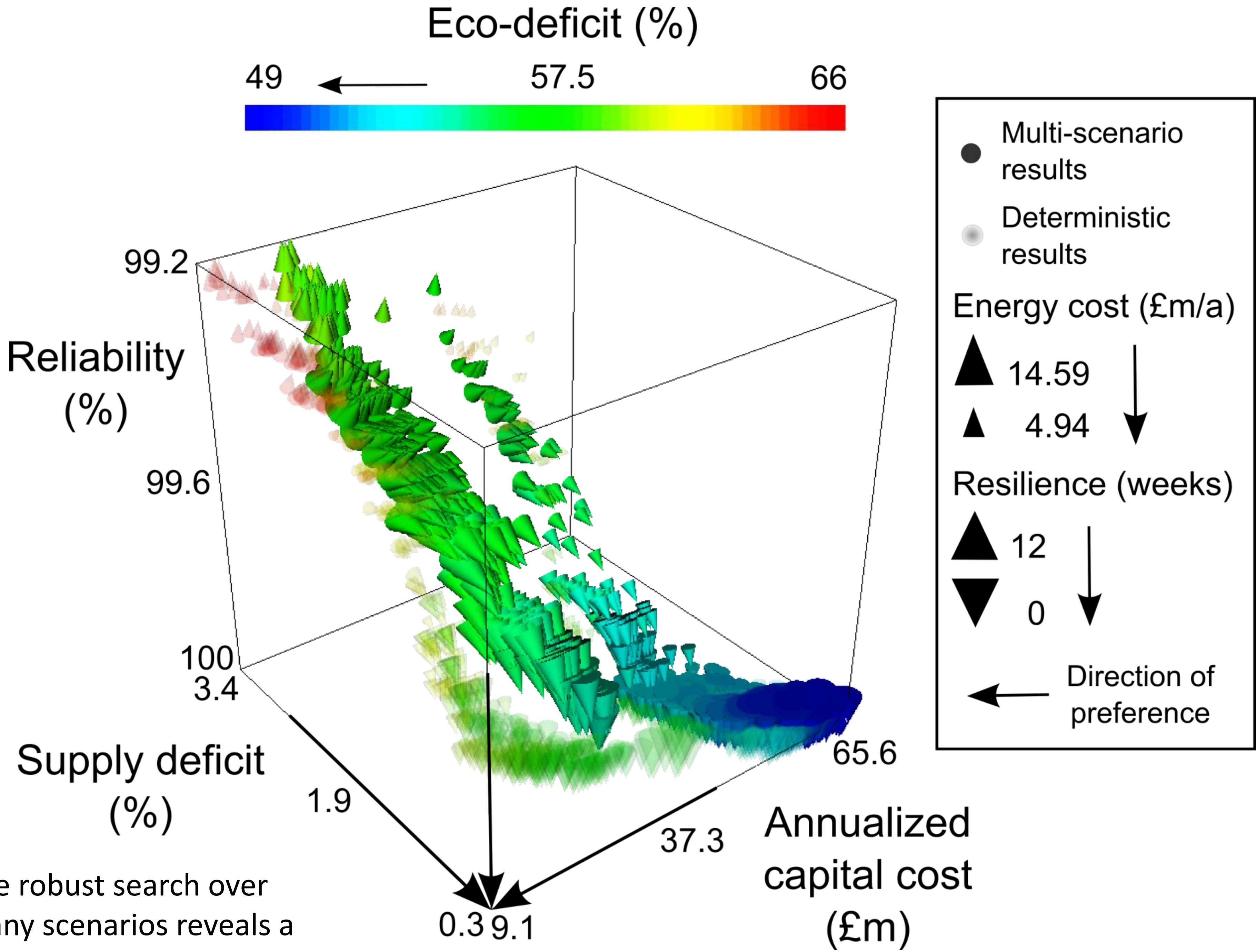


Six objective trade-offs



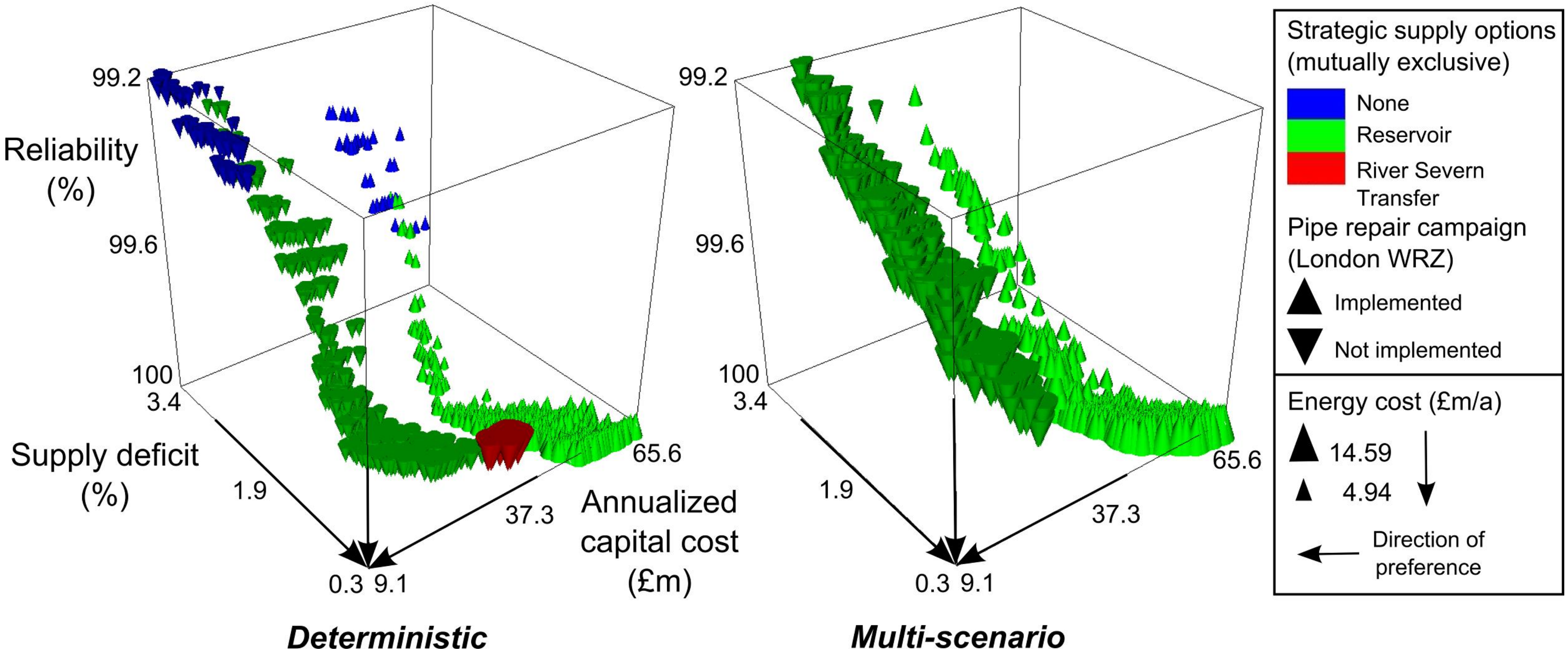
What happens if we consider uncertainties (search over multiple scenarios of future conditions)?



The robust search over many scenarios reveals a new trade-off surface

How do investments map to the trade-offs?

Automated filtering was performed under historical (left panel) and multiple future scenarios (right panel)



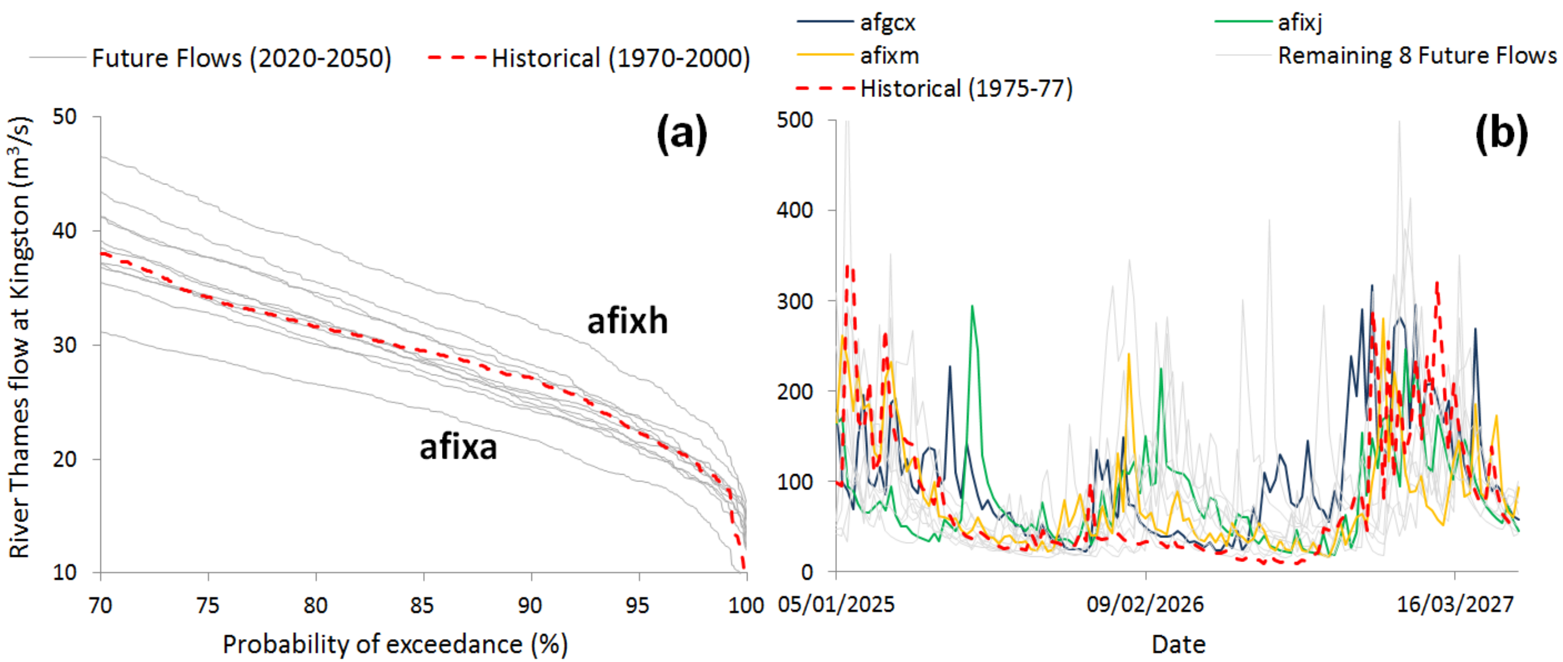
Robust optimisation works nicely, but can we give recommendations about when to put assets in?

- Time horizon of 50 years (2020 – 2070) with transient demand and energy price
- Supply uncertainty – Future Flows scenarios
- Interventions introduced in 5 year planning periods (2020, 2025, 2030, …)
- Construction lead times considered
- Interventions are “turned off” after they reach design life

Future Flows scenarios (Prudhomme et al., 2013)

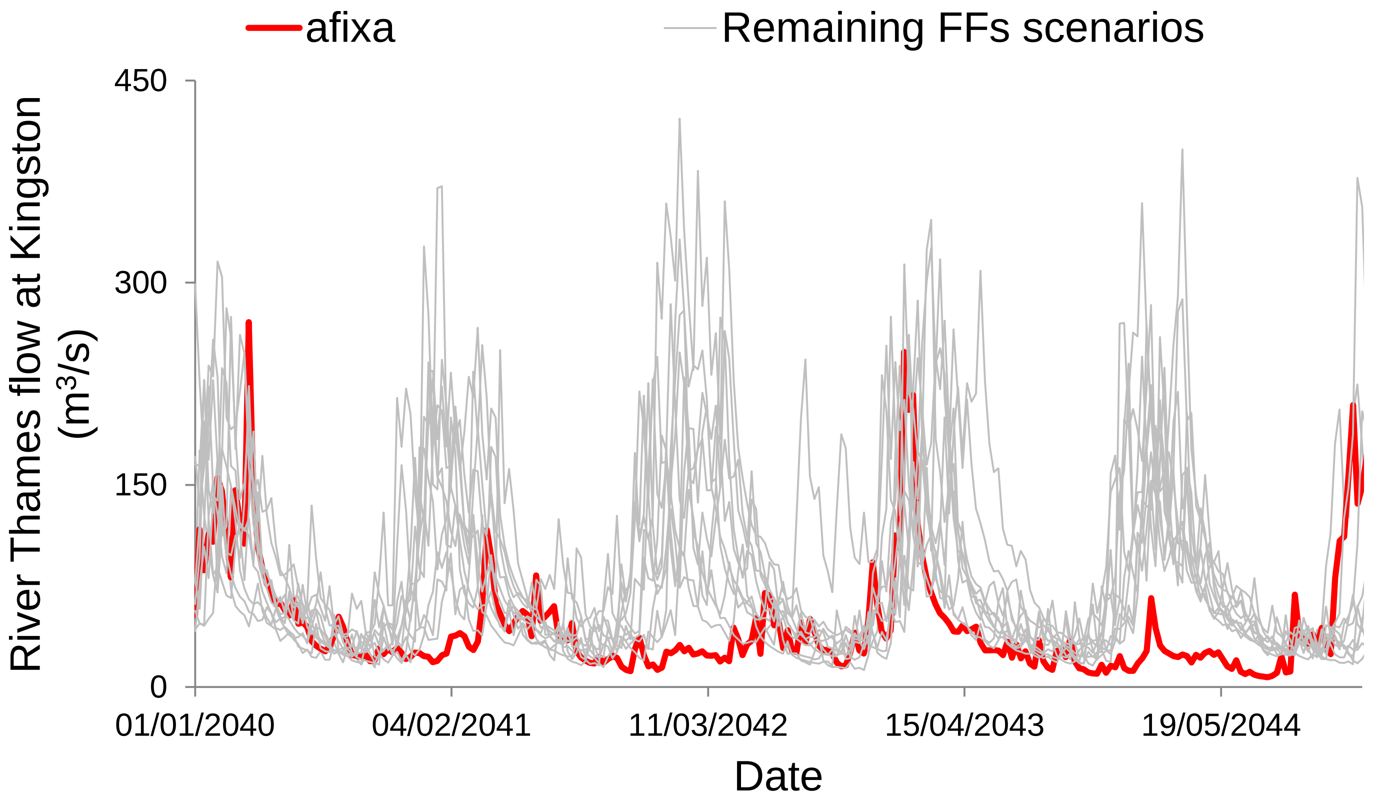
11 scenarios of transient hydrological river flows for the UK

- Derived from transient climate projections from the Met Office Hadley Centre Regional Climate Model (HadRM3-PPE-UK)
- Scenarios vary in magnitude of flows, and duration and timing of extreme events



Worst drought – afixa scenario

The most extreme event in the scenario ensemble occurs during 2040-2045 in afixa scenario



Challenges

- The major drought influences the scheduling
  - Random resampling of the original time series in 5 year blocks (Local Block Bootstrap)
  - Ensure even distribution of drought within time horizon
  - Generated 4 ensembles of 110 future hydrology scenarios from the original 11 Future Flows scenarios and performed search with each
- Problem formulation influences the scheduling
  - Average
    - Similar sets of results across ensembles but investments in majority of plans delayed (“do nothing” in first 10 years)
  - Worst
    - Different sets of results across ensembles
  - Discounted performance (worst 5 year performance)
    - Similar sets of results across ensembles and majority of plans implement demand management interventions within the first 10 years

Discounting

- Discount non-financial performance (resilience and eco-deficit)
  - Discount rate 4.5% (as for cost metrics)
  - 4 week long failure within next 10 years higher priority than 7 week failure occurring in 25 years time (new information, technology, etc. may become available)
- Take the worst 5 year performance value

	5 years	10 years	15 years	20 years	25 years
Undiscounted	0	4	1	0	7
Discounted	0	3.4	0.7	0	3

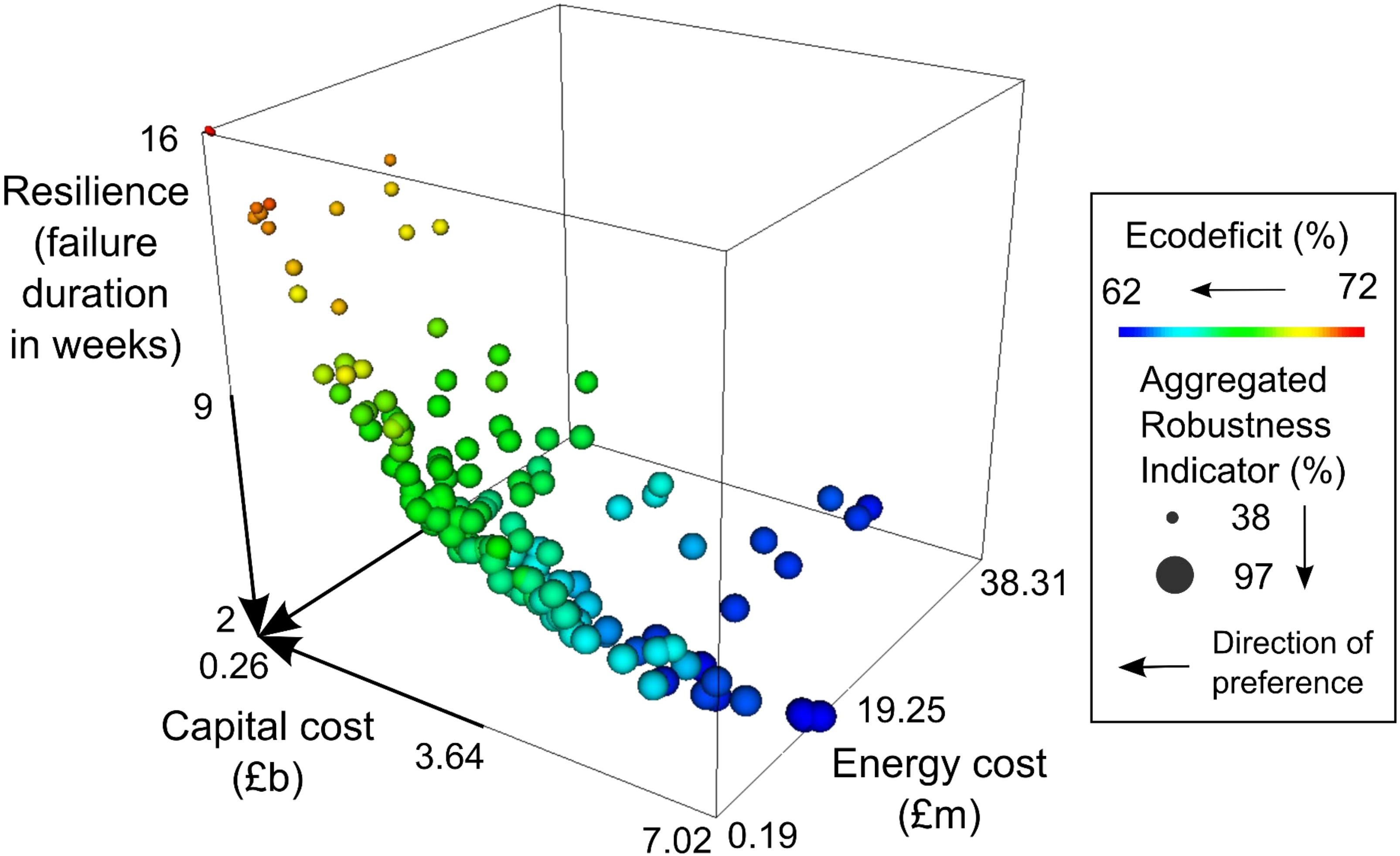
Final problem formulation

- 12 possible supply and 5 demand management schemes
- 6 objectives
  - Total discounted capital cost
  - Total discounted energy cost
  - Discounted engineering resilience (maximum duration of failure – imposing temporary use restrictions)
  - Discounted environmental eco-deficit – difference between natural and simulated low flows
  - Robustness Indicator LoS3: percentage of scenarios maintaining allowed frequency of imposing temporary use restrictions (Level of Service 3)
  - Robustness Indicator LoS4: percentage of scenarios maintaining allowed frequency of imposing standpipes (Level of Service 4)
- Constraints – mutual exclusivity of some supplies

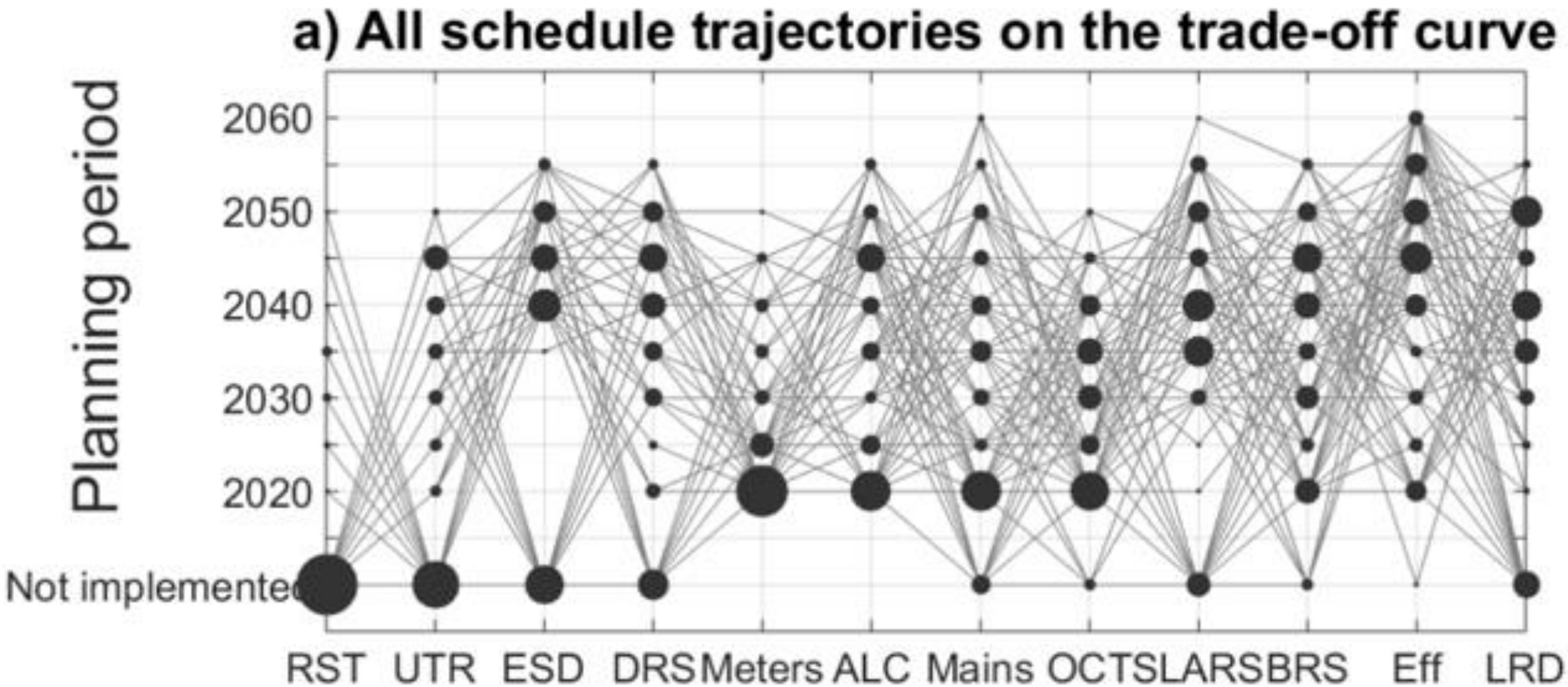
Final approach

- 4 ensembles of 110 future hydrology scenarios (generated from the original 11 Future Flows scenarios)
  - Investigation of bigger scenario ensemble size (220 scenario and 330 scenario ensembles) showed no further improvement in the similarity between the 4 sets of plans
- Many-objective search with each ensemble and discounted performance – 4 sets of Pareto-optimal plans
- Combined the 4 sets into a single final recommended set
  - Simulation of the 4 sets of plans against 4*110 scenarios (combined 4 ensembles) and non-dominated sorting

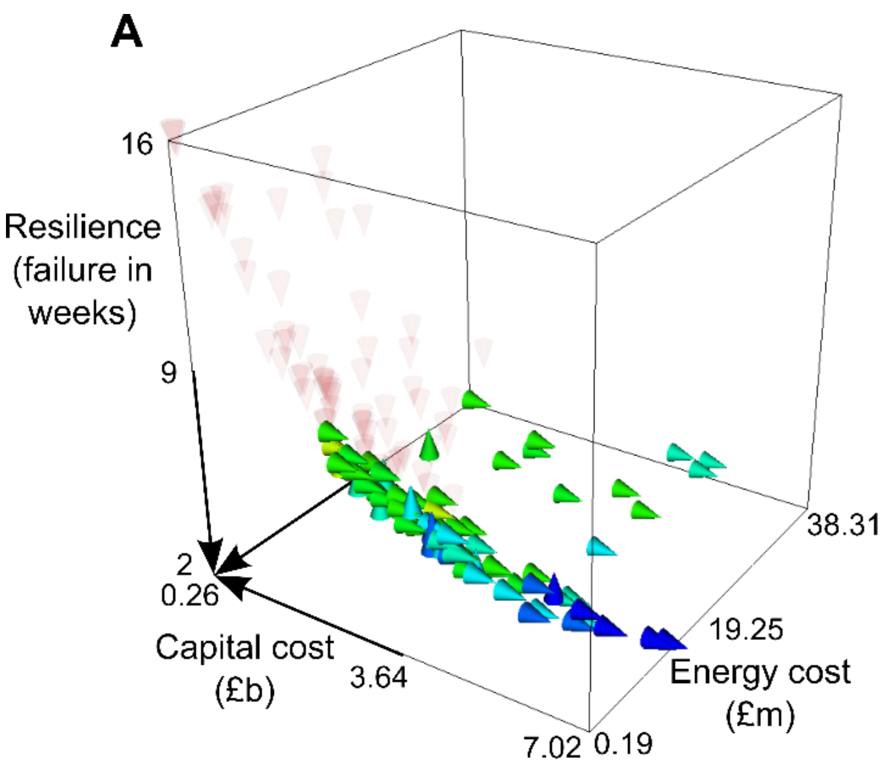
Final recommended set



Schedule trajectories

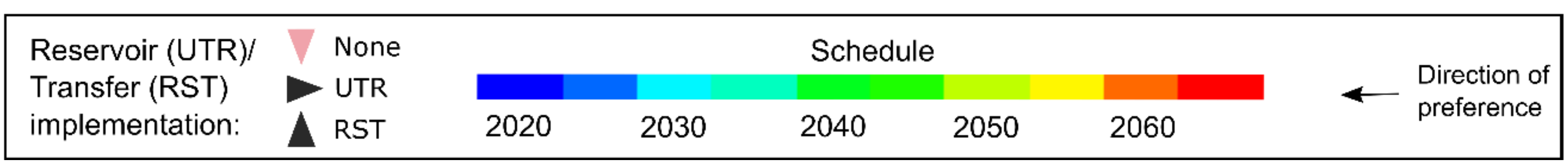


Deliberation of preferred plan

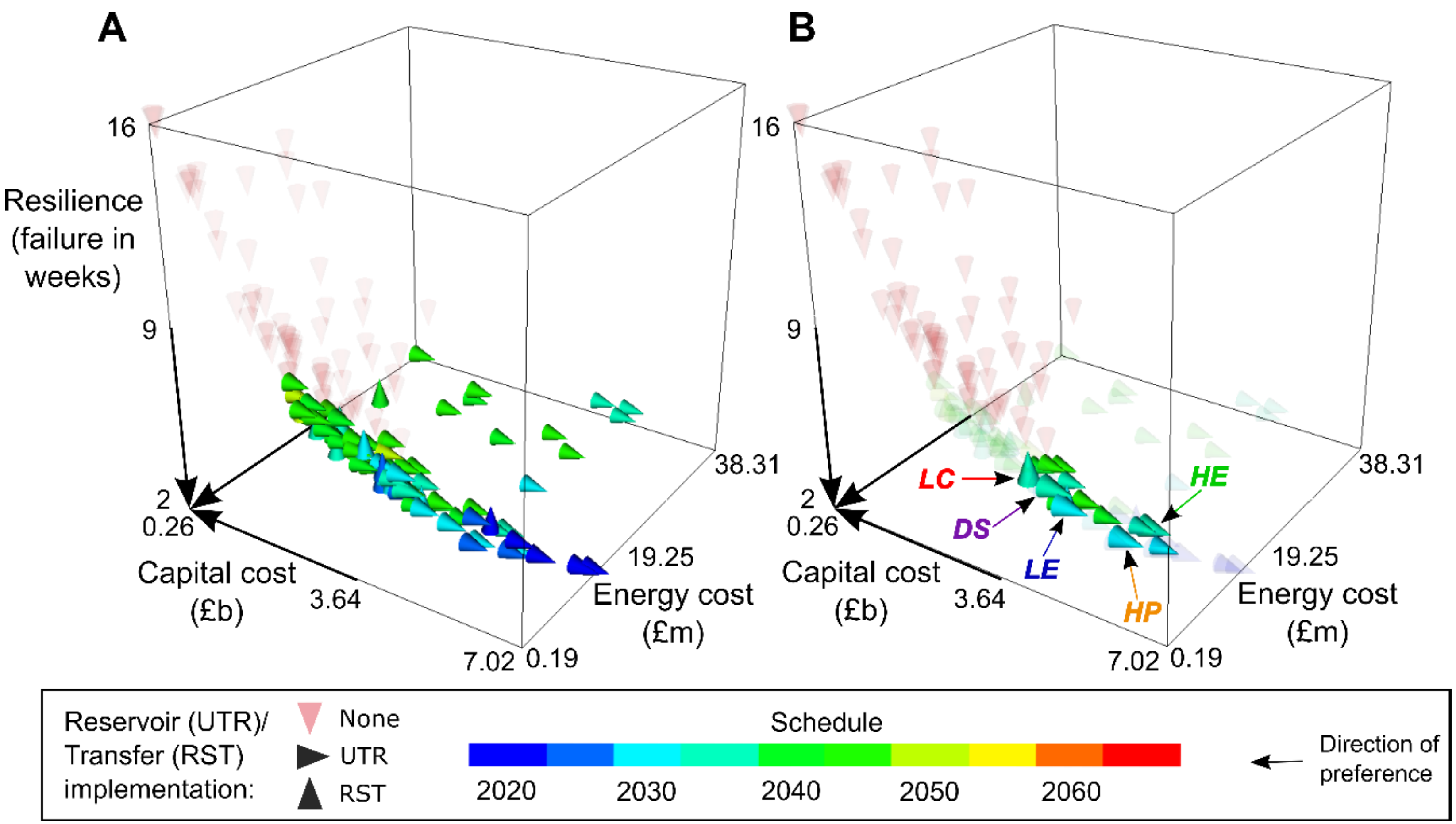


Example identification of preferred plans:

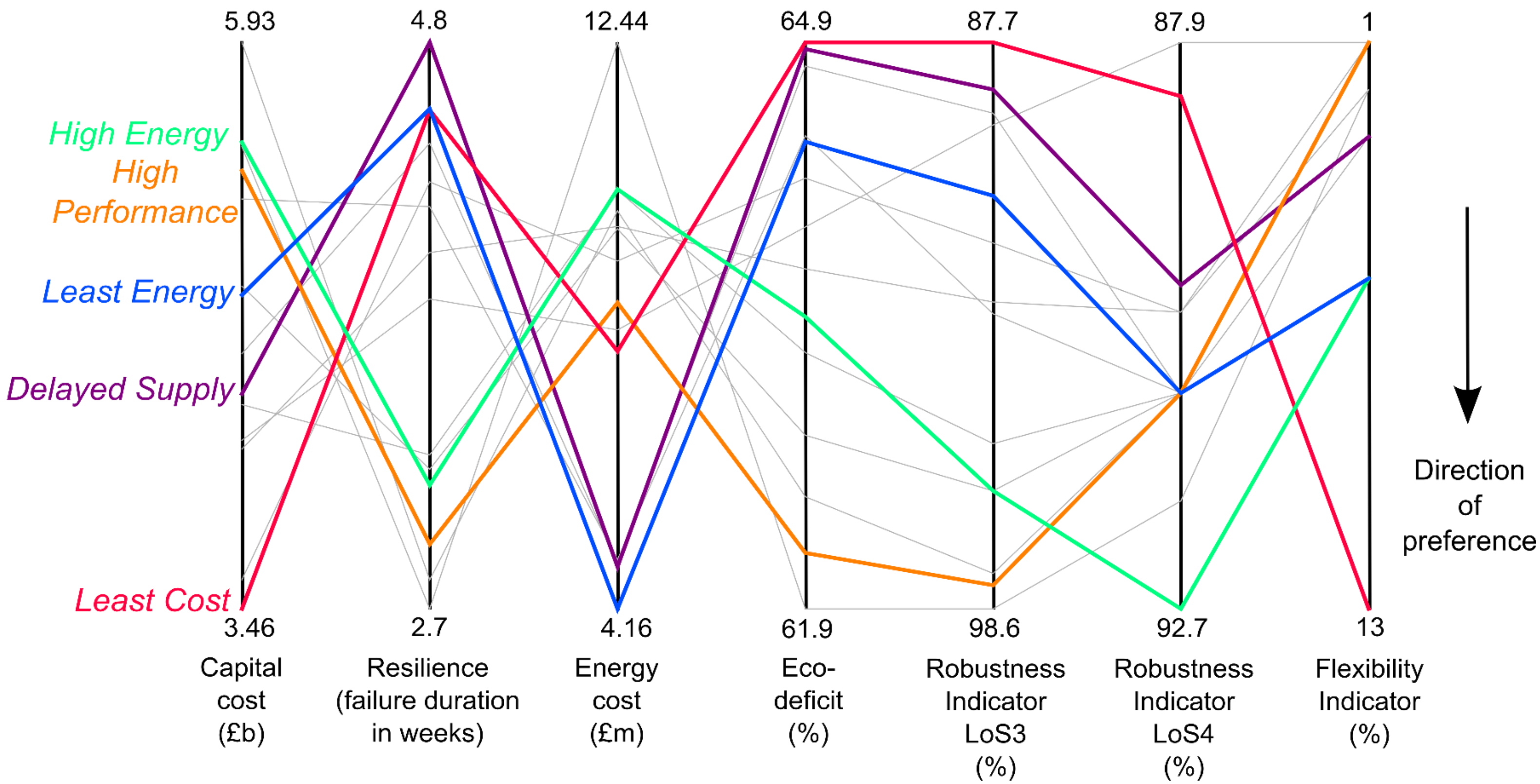
- *Delay building Reservoir/Transfer till 2030*
- *Maximum energy cost of £12m*
- *Maximum eco-deficit of 65%*



Applying the thresholds and identifying 5 plans with similar schedules in the first decade

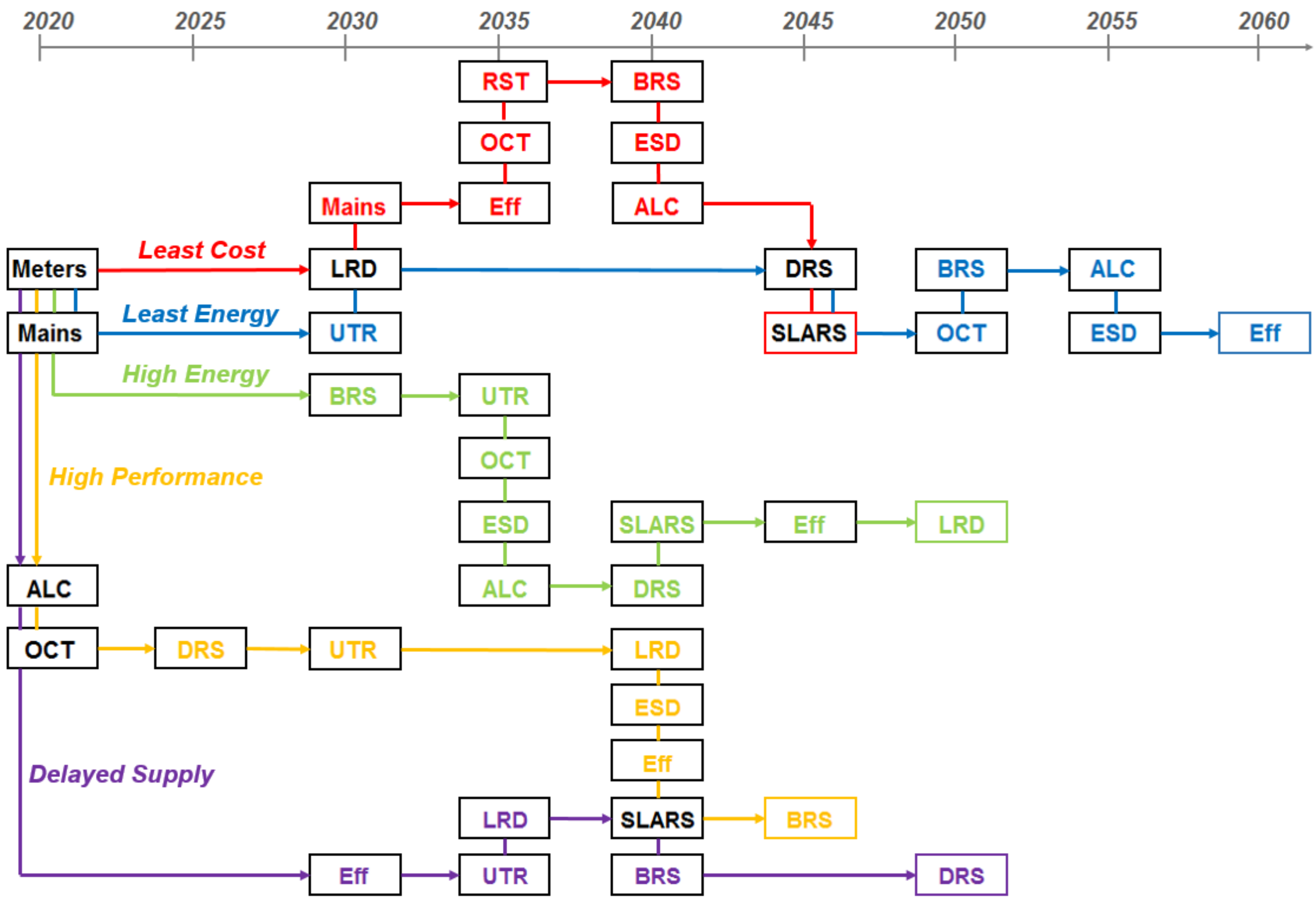


Performance comparison of the 5 plans



Least Cost	3.46	4.5	7.92	64.9	87.7	88.4	13
Demand Mng.	4.40	4.8	4.77	64.8	8.6	90.0	3
Least Energy	4.83	4.5	4.16	64.4	90.7	90.9	6
High Perform.	5.37	2.9	8.63	62.2	98.2	90.9	1
High Energy	5.49	3.1	10.3	63.4	96.3	92.7	6

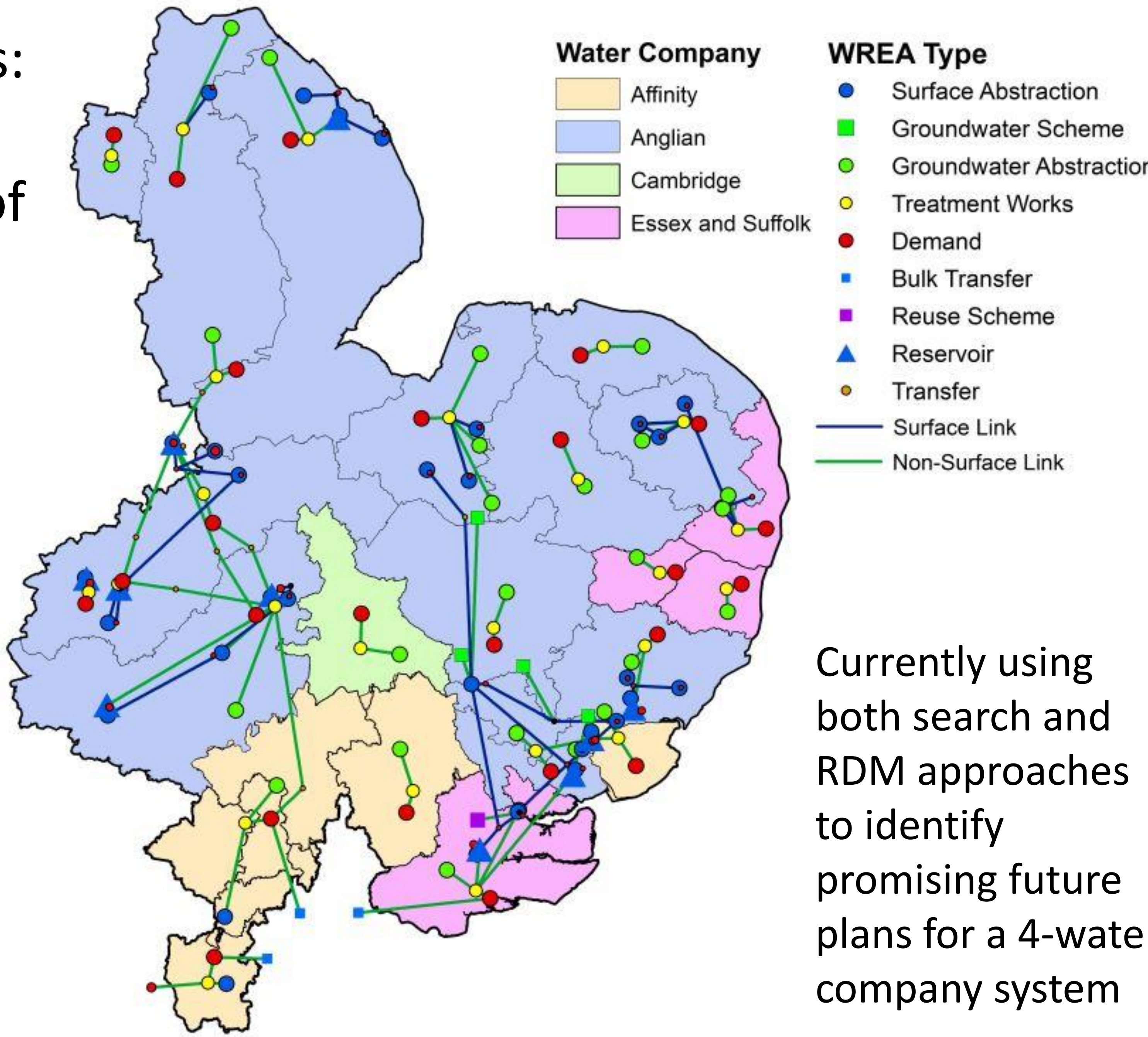
Combining the 5 plan schedules into a single coherent plan



Thames System Findings

- Based on preliminary results (these may change as system simulation model improves and/or different improved performance metrics are considered)
- Reservoir and Pipe repair campaign are likely low-regret options – *(provide benefits even in the absence of climate change scarcity)*
- All demand management options in London WRZ are selected by search in all Pareto optimal sets (multi-scenario case)

Other applications: Water Resources of East Anglia (WRE)



Currently using both search and RDM approaches to identify promising future plans for a 4-water company system

Robust Search: Discussion, Future work

Benefits

- Suggest alternative plans which are equally ‘optimal’, identifies trade-offs between them
- Identifies robust plans (assets, policies) given many plausible futures
- RDM can be used to further stress test robustness of chosen plans over a wider set of futures

Limitations

- Computational burden limits number of scenarios considered in robust search

Future work

- Adaptive options *(options are adaptive trajectories over the time horizon)*

Thank you,

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