Capacity expansion optimisation for water supply investment decisions in England -

Limitations and extensions of current approaches

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Planning decisions in supply-demand systems

- Supply-demand (S-D) systems – network of supply and demand nodes

- *Problem: how to do capacity expansion – a classical engineering problem:*
  WHAT to build, WHEN, HOW BIG?

Since a decade, ‘Economics of Balancing Supply and Demand’ (EBSD) planning method is used by water companies in England for supply-demand planning.

EBSD model formulation

Minimise discounted sum of capital, operating, environmental and social costs of future capacity expansions

Subject to:

- MASS BALANCE CONSTRAINT

  Firm yield (‘deployable output’) per region ≥ Dry year average demand+ ‘headroom’ (safety factor).

- MAXIMUM CAPACITY CONSTRAINT AT NODES AND LINKS

- FIRST YEAR IMPLEMENTATION CONSTRAINTS

- INTERDEPENDENCES AMONG OPTIONS (*Mutually exclusive, Prerequisite, Dependent*)

Solving the supply demand planning problem

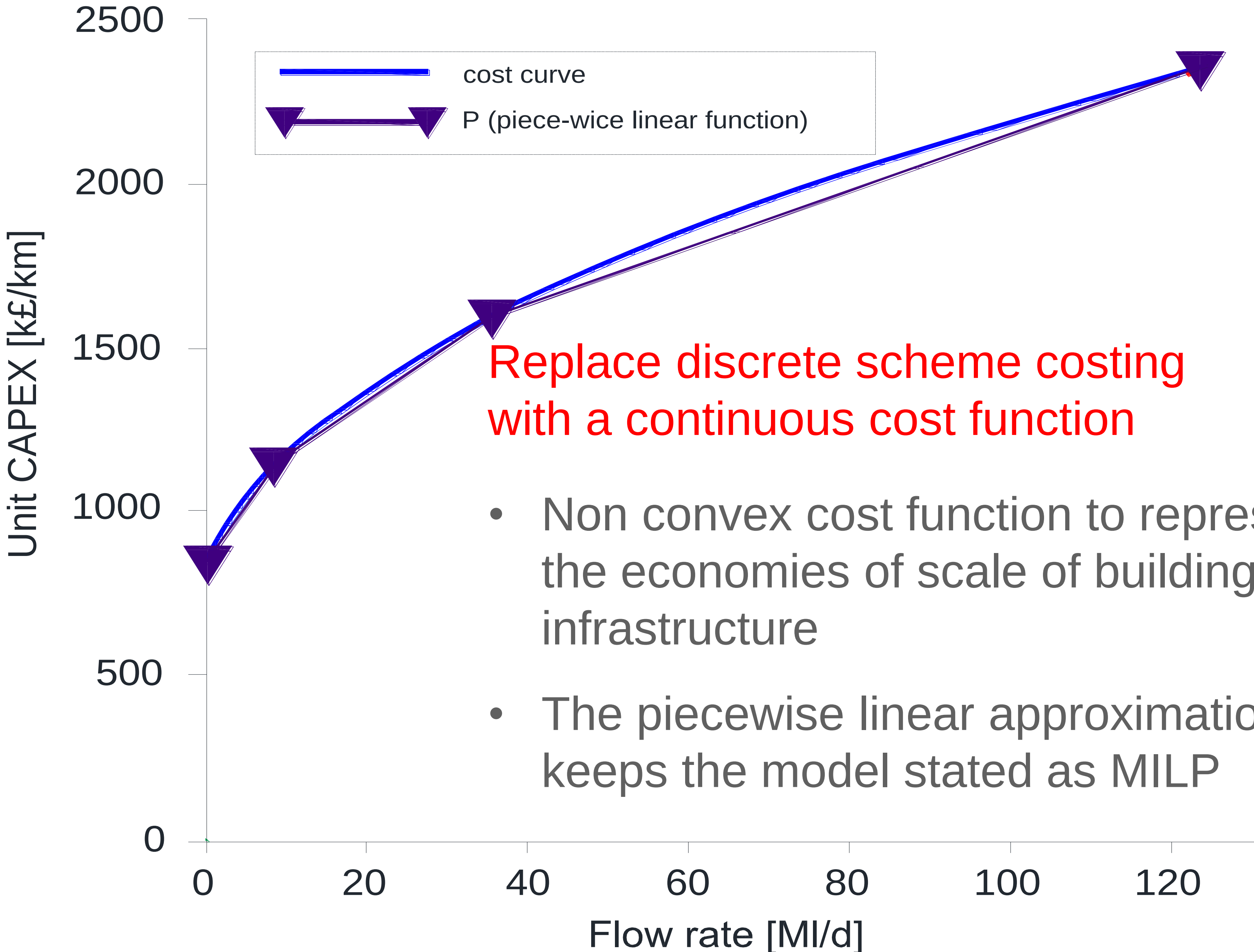
Frequently solved using mixed integer linear programs (MILP) with binary variables to represent build yes/no decisions on optional sources (new supplies or demand management programs) and links (transfers)

Discussion…

EBSD simplifies the S-D problem: uses discrete schemes with fixed costs and max capacities rather than continuous cost functions

Sub-optimal results: the truly optimal level of option implementation is unlikely to be present in the pre-specified set of discrete options.

Proposed extension …



Replace discrete scheme costing with a continuous cost function

- Non convex cost function to represent the economies of scale of building large infrastructure
- The piecewise linear approximation keeps the model stated as MILP

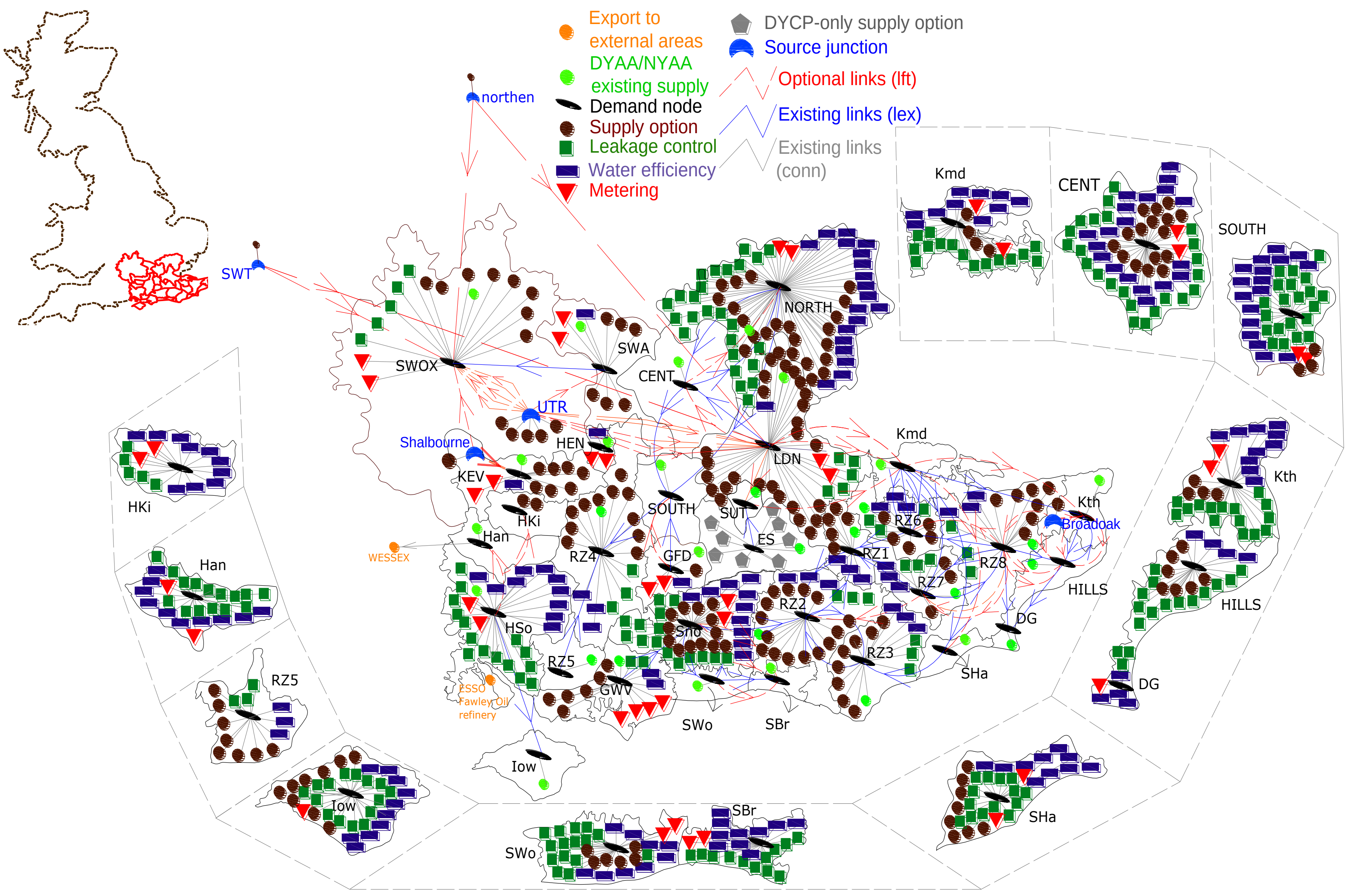
Study goal

Run 2 models applied to the WRSE area:

- water company proposed discrete options only
- water company proposed options + the 19 additional interconnections (cost function)

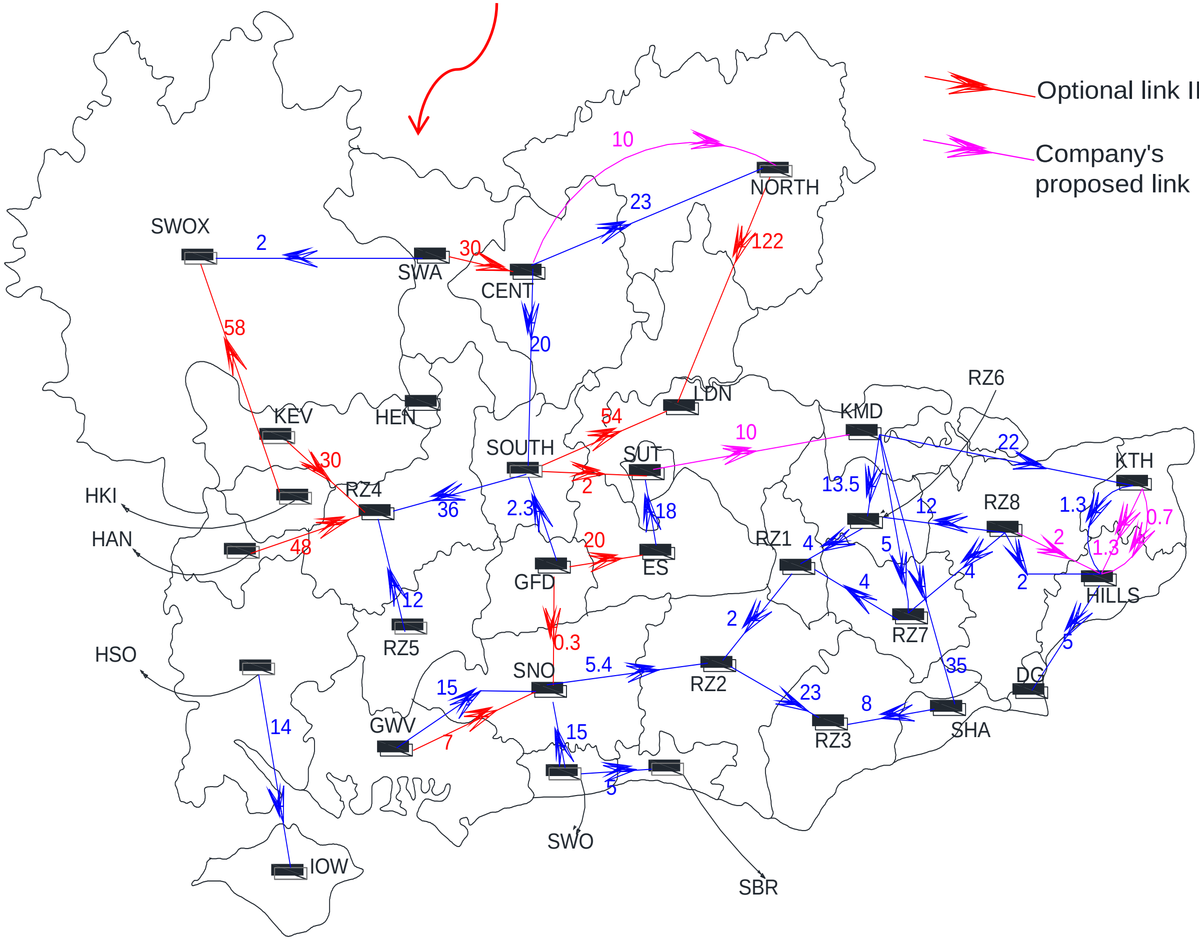
Compare the model solutions (supply-demand schedules)

Application to the south East of England- WRSE network



Model results

Selected transfer options



	Cost [k£]	
	WC	WC+INT
Supply	714	485
TR	858	476
DM	618	146
INT	/	100
Total	**2,190**	**1,207**

WC= company proposed schemes
INT=additional interconnection

With 19 additional transfers, the total cost of future capacity expansions decreases by almost 1 million pounds (in net present value), than if water company schemes only were considered

Discussion…

Computational burden:

the algorithm converges to a 28% relative gap

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	Run time (DELL Precision 7500 machine, 24 GB of RAM)
WC	3 minutes, 4% RGAP
WC+INT	1 hr, 28% RGAP. After 1 hr the convergence does not improve. Model stopped after 12 days

This means that the proposed extension cannot be used to replace water company proposed discrete scheme costings with continuous cost functions using EBSD

The regulatory context

EBSD is applied in a regulatory context:

‘socially-efficient and least-cost’ plans (UKWIR, 2002) are the ‘best case’ scenario of the cost efficiencies that can be achieved under the regulatory regime (price-cap regulation)

If, however, the regulatory incentives are not well designed, companies may not minimise costs but rather invest to increase their profit.

A ‘capital bias’ has been recorded in the English water system (Ofwat, 2011, Severn Trent Water, 2010).

Study objectives

How does regulation influence water company investment decisions?

- Run 2 supply-demand planning models from:
  - Social perspective (min cost) – EBSD model
  - Private firm perspective (‘max profit’)

    ‘max profit’ selects S-D schemes that meet forecast demands and maximise company profit under the price-cap regulatory constraints

- Compare suggested supply-demand schemes

Water company objective function

$$\pi = \boxed{\sum_{t=1}^{T}\left(ic_t - i_t\right) * RCV_t} + \boxed{\left(opexc_t - \sum_s \sum_t opex_{s,t}\right)} + \boxed{\sum_{pr} CIS_{pr}} + \boxed{IAJ_t}$$

A company can make profit (π):

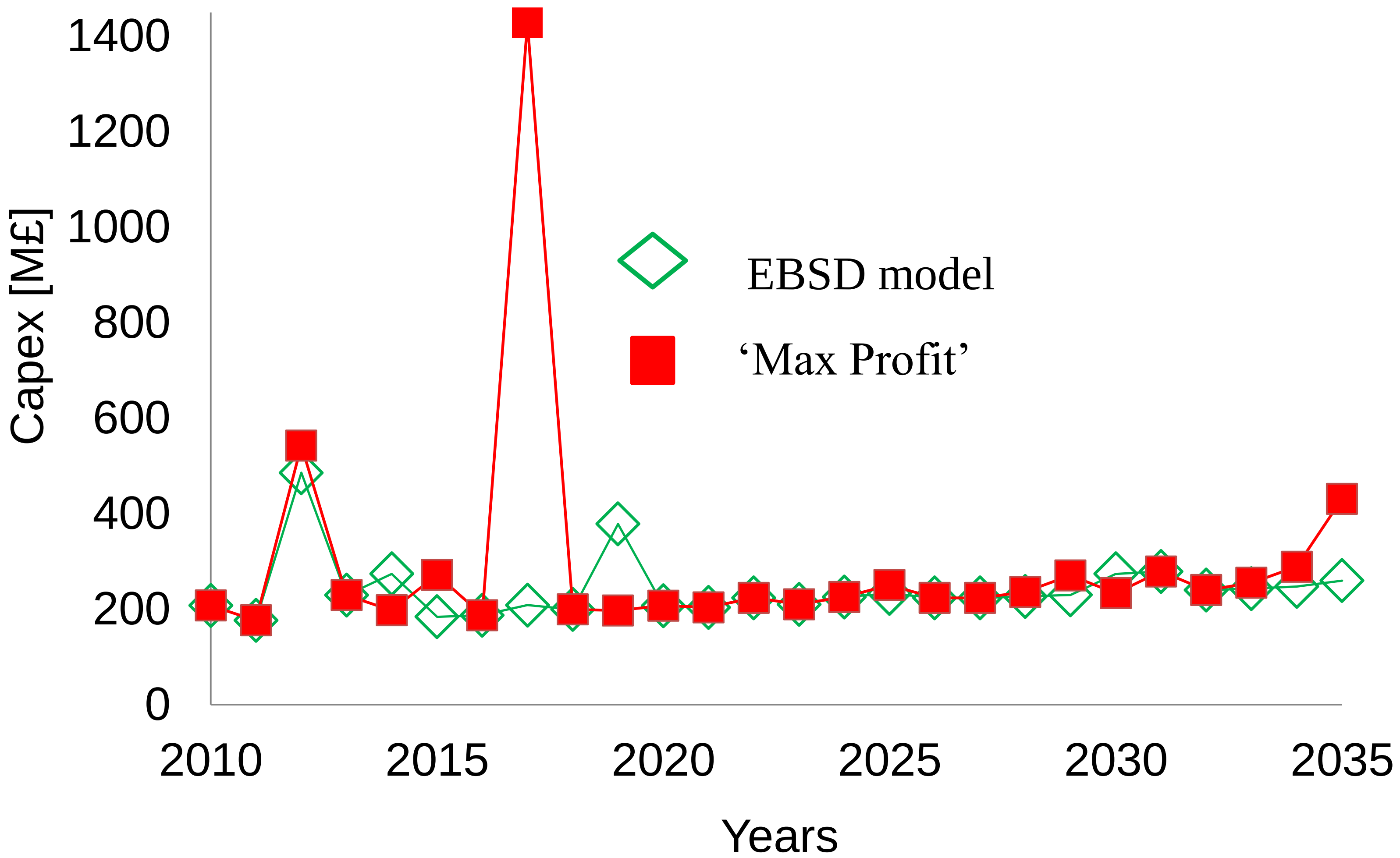
If the allowed rate of return is greater than the market cost of capital. π increases with the regulatory capital value (RCV_t).

By outperforming the OPEX allowance

'CIS' rewards (penalties) apply if companies under- (over-) spends the regulatory assumptions on CAPEX

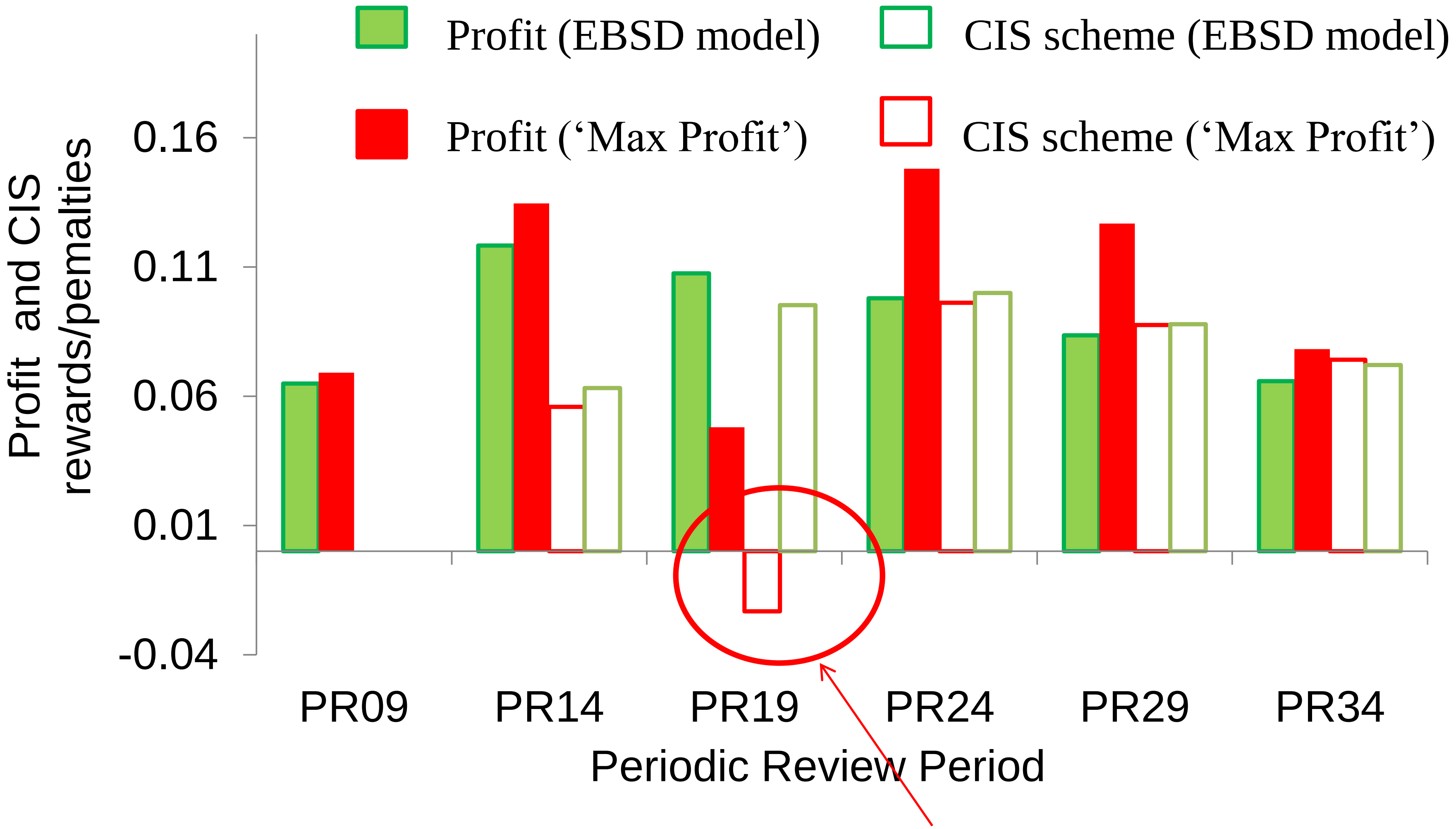
The benefits of spending less OPEX than the regulatory allowance can be retained for 6 years

Application to a water company



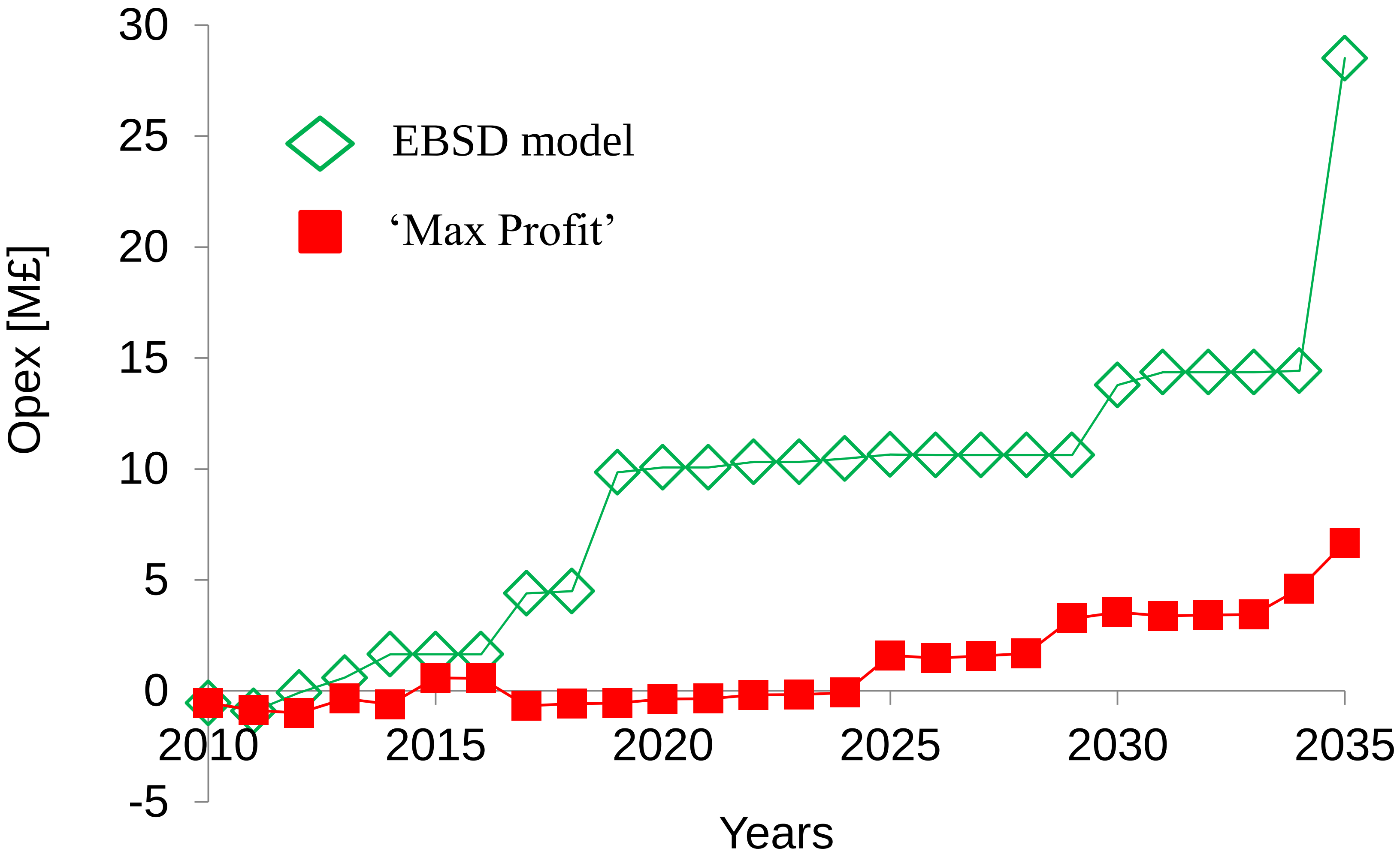
CAPEX increases under 'Max profit' model compared to the least-cost solution (EBSD model), mainly due to the activation of reservoir options in year 2017, in place of transfers schemes selected by the EBSD model

Application to a water company



The CAPEX increase generates a CIS penalty at PR19. The CIS penalty does not prevent the model from increasing the total profit!

Application to a water company



Companies accrue 100% of any under-performance on OPEX. This may induce them to reduce OPEX below the least-cost solution and consequently increase CAPEX

Discussion…

The least-cost solution is given by a determined ratio of capital and operating costs

Having separate incentives on the two cost types can generate a ‘capital bias’ depending on the relative strength of the incentives

Exploring near-optimal solutions

Least-cost capacity expansion schedules have multiple near-optimal solutions (Rogers and Fiering, 1986) in addition to the least-cost plan

Multiple solutions allow decision-makers to explore and suggest plans considering criteria not represented in the optimisation model

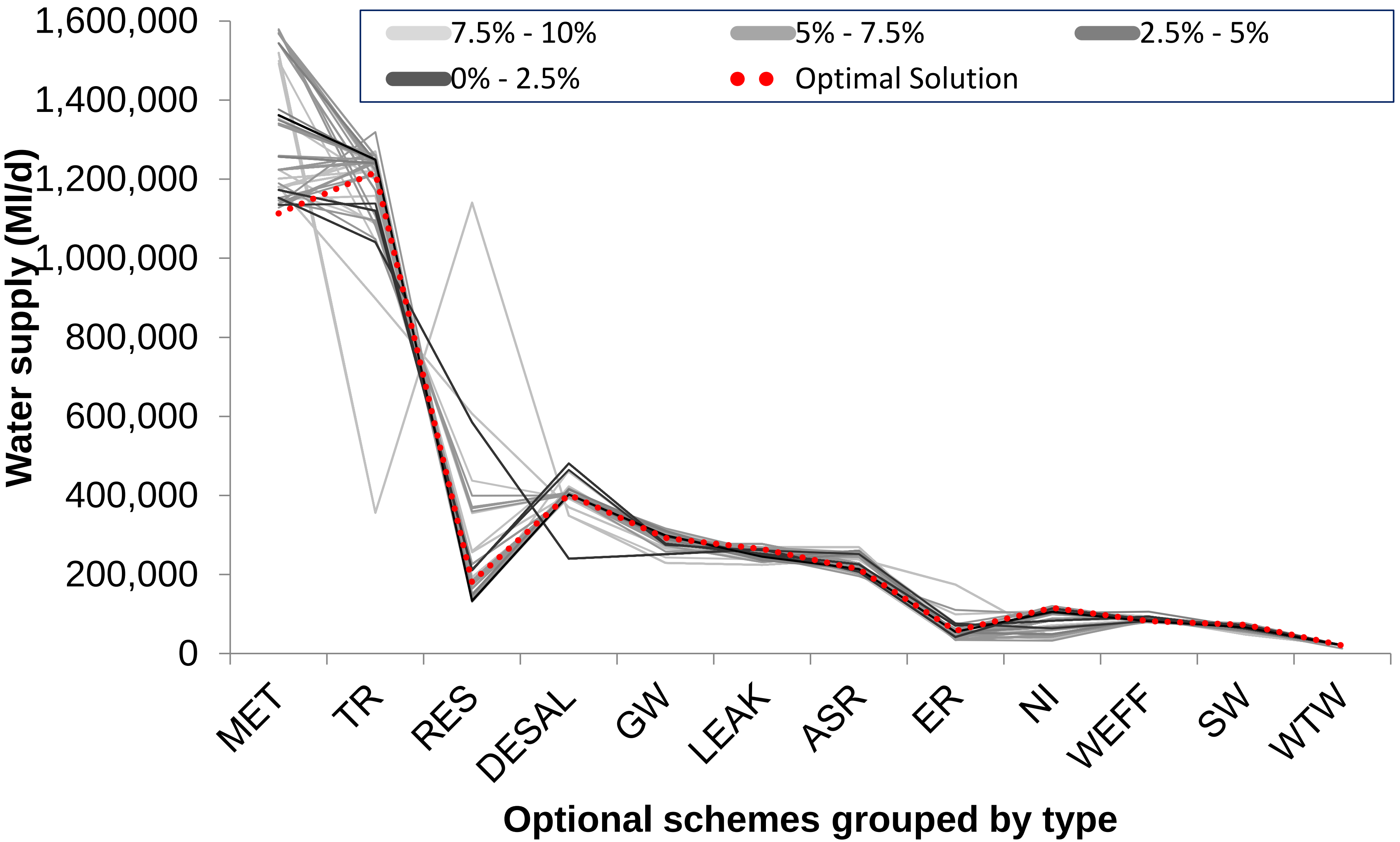
Modelling to generate alternatives (MGA) is an optimization technique that allows generating multiple near-optimal solutions (Brill, 1979)

Application to the WRSE network

We use the CPLEX MILP solver *solution pool* feature to generate nearly-optimal solutions (MGA) for the WRSE problem

Near-optimal solutions

240 near-optimal solutions within 10% of the least-cost plan



Discussion…

- This work showed allowing small economic deviations from least-cost capacity expansion plans can lead to substantially different plans

- Reporting only a single optimal solution provides incomplete picture of the options available to both regulators and company decision-makers.

Conclusion

- The MGA analysis can be viewed as a transition point to more complex planning systems (e.g. RDM, info gap, real options, robust optimization) where multiple aspects of performance are considered given different plausible futures.
- Ideally England will transition to a multi-criteria planning framework where other objectives can be quantified and optimized for.

Thank you

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