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Distributed optimisation and game-theoretic approaches for market-based coordination of operation and planning decisions

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Motivation

- **Smart Grid concept**:
  - Integration of vast number of small-scale flexible demand and energy storage technologies in system operation and planning
  - Cannot be addressed through traditional centralised control approaches, due to scalability and privacy limitations
  - Need for distributed coordination approaches

- **Deregulation of energy sector**:
  - Moving away from models optimizing system-wide objectives (e.g. maximization of social welfare)…
  - …to models optimizing individual market players' objectives (e.g. maximization of individual profit)
  - Need for game-theoretic modeling approaches

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DISTRIBUTED COORDINATION OF FLEXIBLE LOADS

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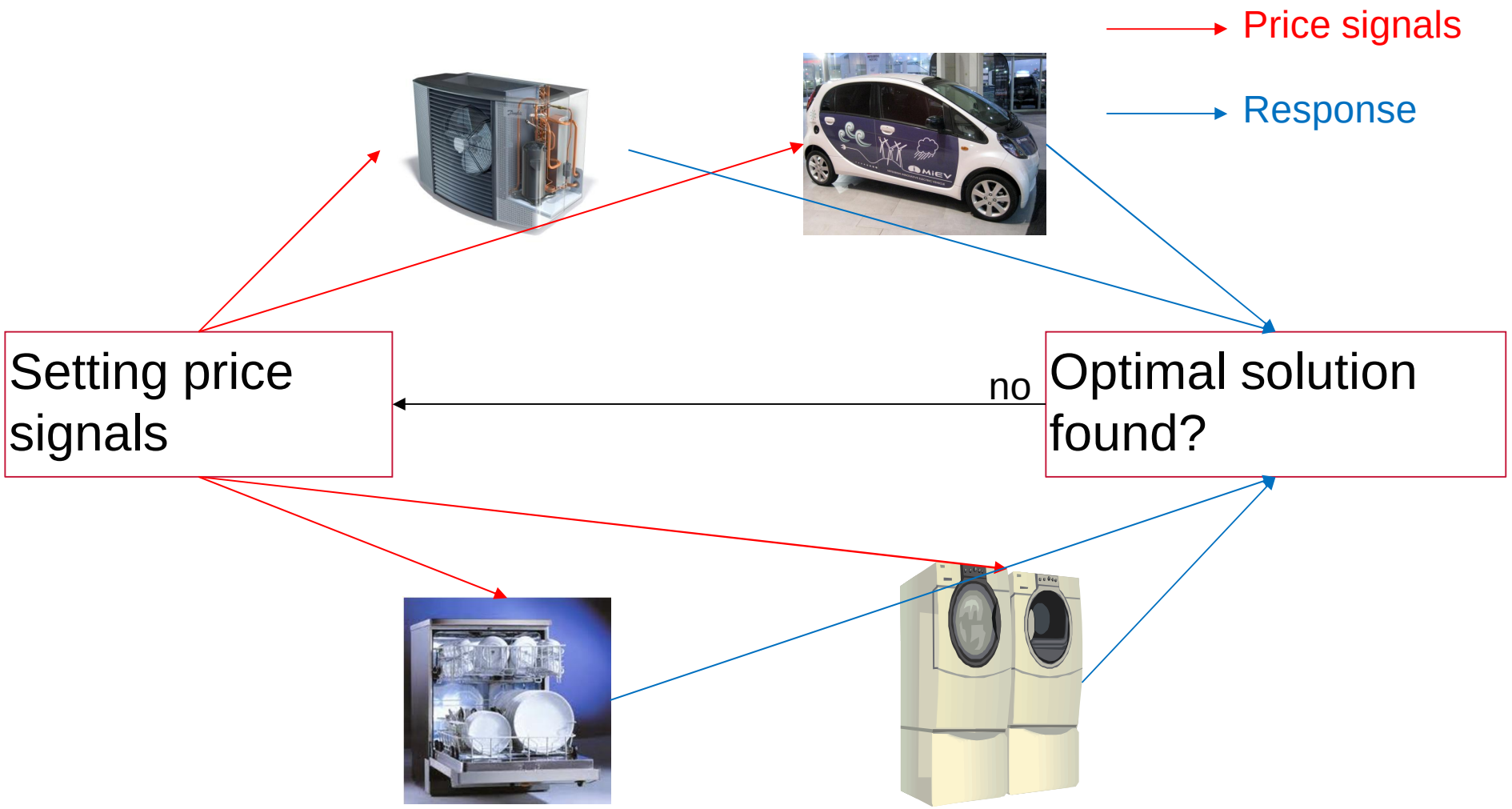
Distributed, price-based coordination approach



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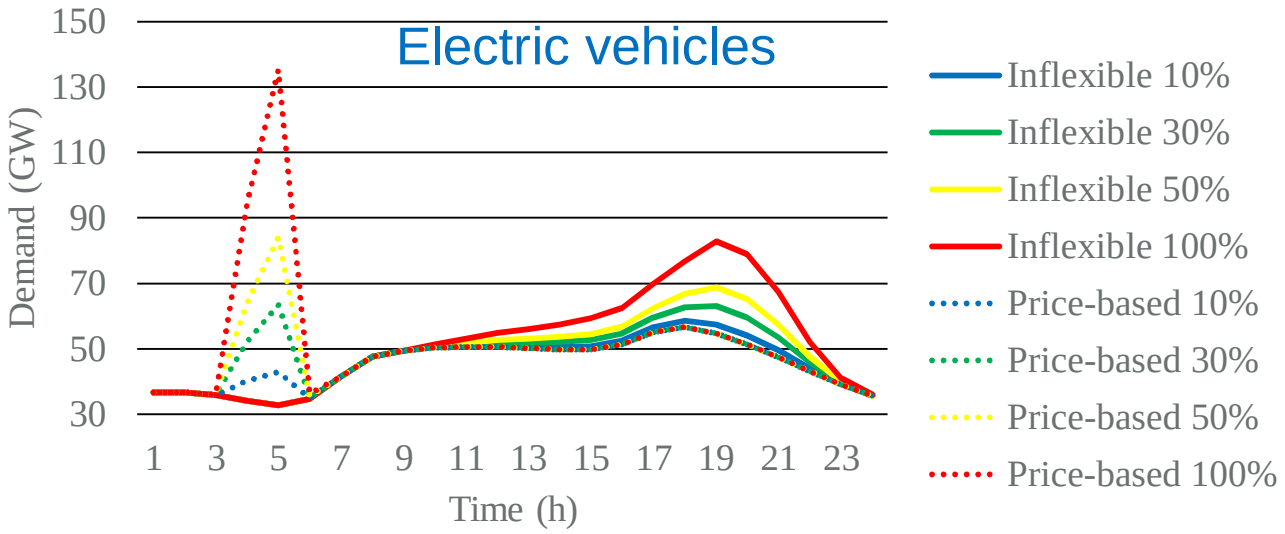
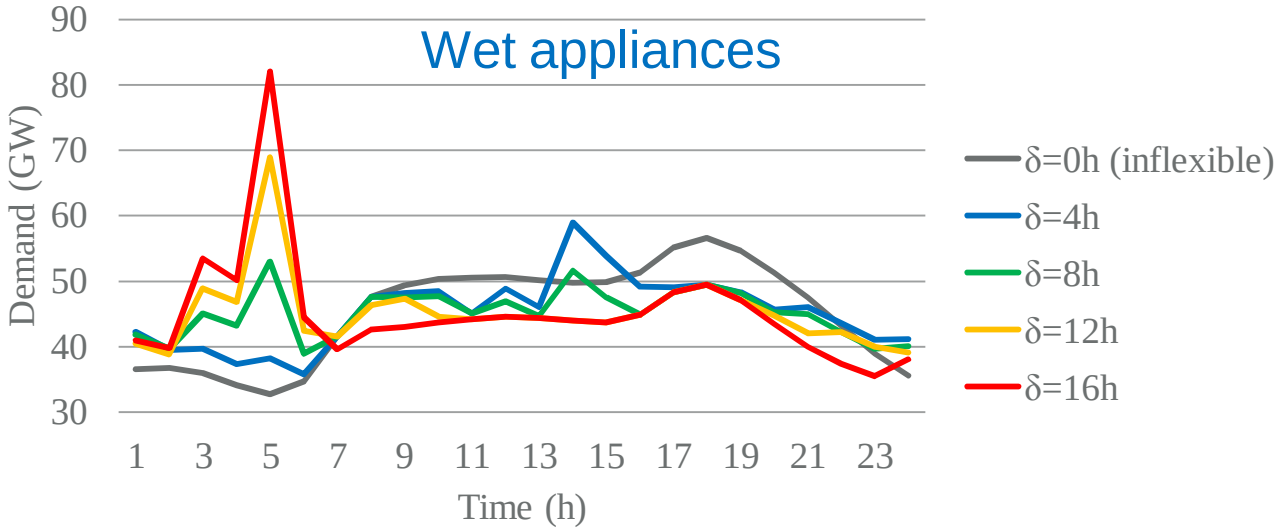
Demand response concentration effect

- Flexible loads' response is concentrated at the lowest-priced periods
  - ➢ New demand peaks, higher costs, higher network losses
  - ➢ Concentration effect enhanced with higher number, higher flexibility and lower diversity of flexible loads





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Measures against demand response concentration

- Impose relative flexibility restriction ω
  - Loads with continuously adjustable power: *maximum power restriction*
  - Loads with deferrable cycles: *maximum cycle delay restriction*
- Apply non-linear / flexibility price α
  - Loads with continuously adjustable power: *penalize square of power*
  - Loads with deferrable cycles: *penalize duration of cycle delay*
- Apply differentiated price signals to different loads
  - Randomise prices following normal distribution (with standard deviation σ)

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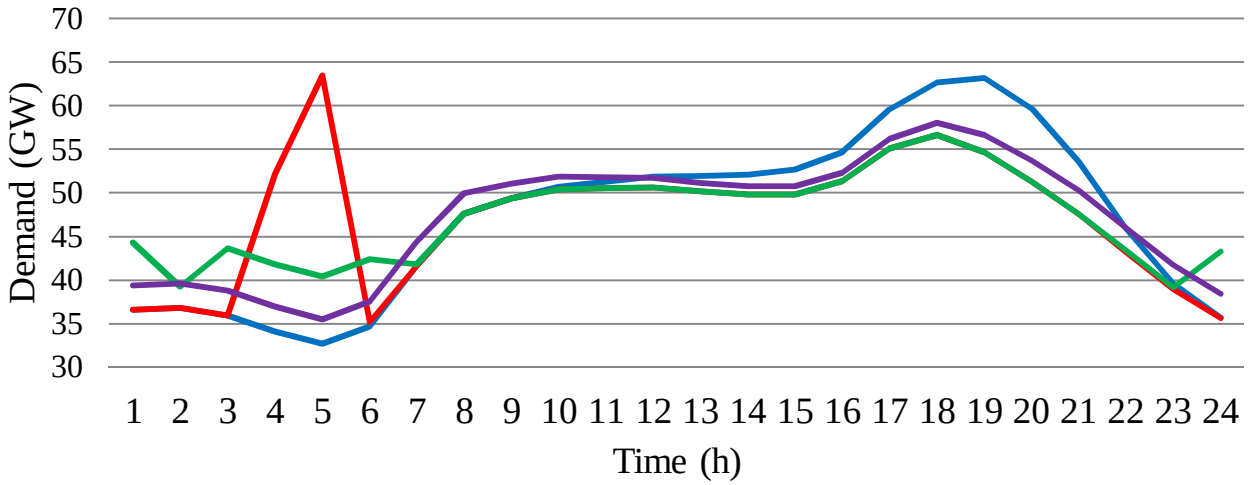
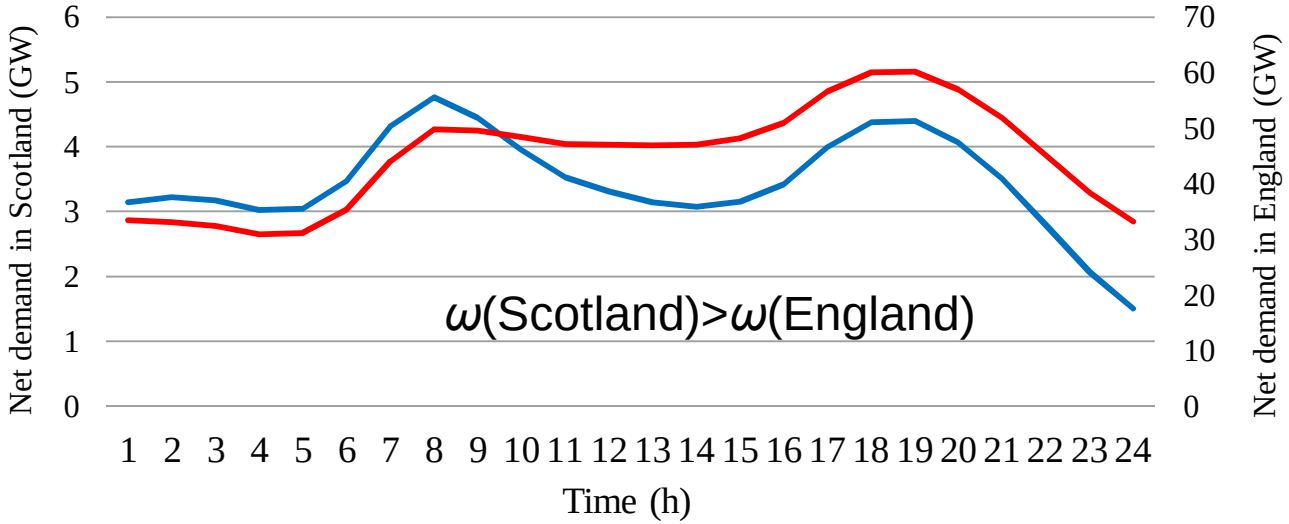
Tuning measures' parameters

- Trade-off between:
  - ➢Avoiding demand response concentration
  - ➢Filling the off-peak valleys



- Network congestion and losses…> location-specific tuning?



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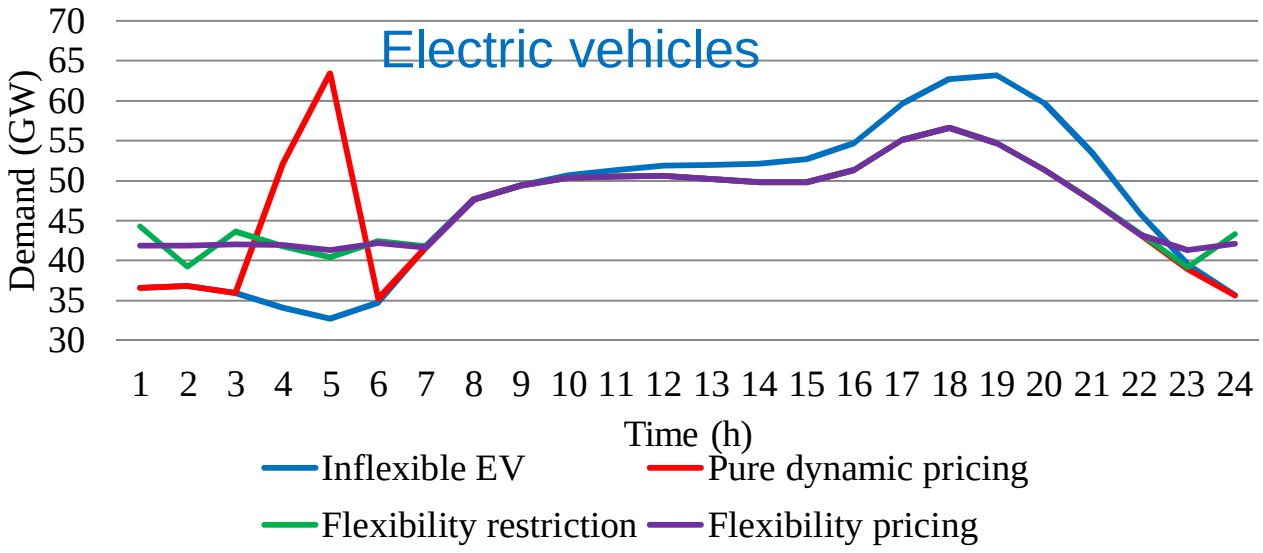
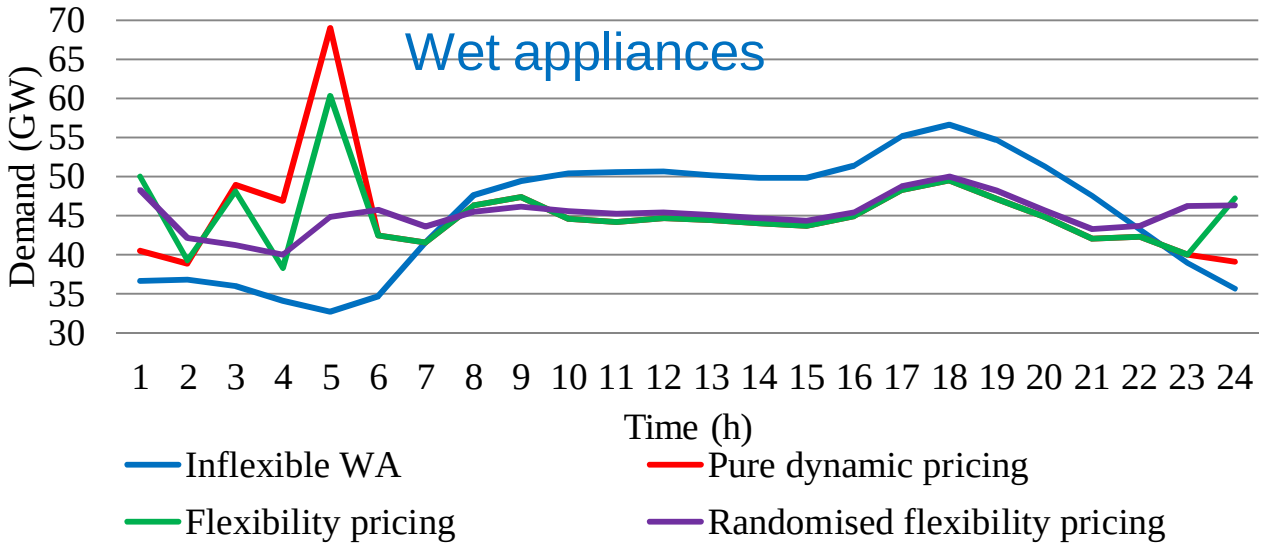
Performance of different measures depends on flexible loads' operational properties

- Flexibility pricing slightly outperforms flexibility restriction
- Randomised pricing does not bring additional benefits



- Flexibility restriction and flexibility pricing have similar performance
- Randomised pricing brings significant additional benefits



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GAME-THEORETIC MODELLING OF OPERATION AND PLANNING

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Game theoretic modelling: Equilibrium programming

Bi-level problem:

Upper Level (UL) problem:
Profit maximization of strategic player

Max Profit of strategic player
subject to:
- Strategic player's constraints

Prices/dispatch ↑ ↓ Strategic action

Lower Level (LL) problem:
Market clearing process

Max Social welfare
subject to:
- System constraints
- Individual players' constraints

MPEC problem:
Profit maximization of strategic player

Max Profit of strategic player
subject to:
- Strategic player's constraints
- **LL-equivalent KKT optimality conditions**

↑

Lower Level (LL) problem:
Market clearing process

Max Social welfare
subject to:
- System constraints
- Individual players' constraints

MPEC is highly non-linear > need for suitable linearization techniques

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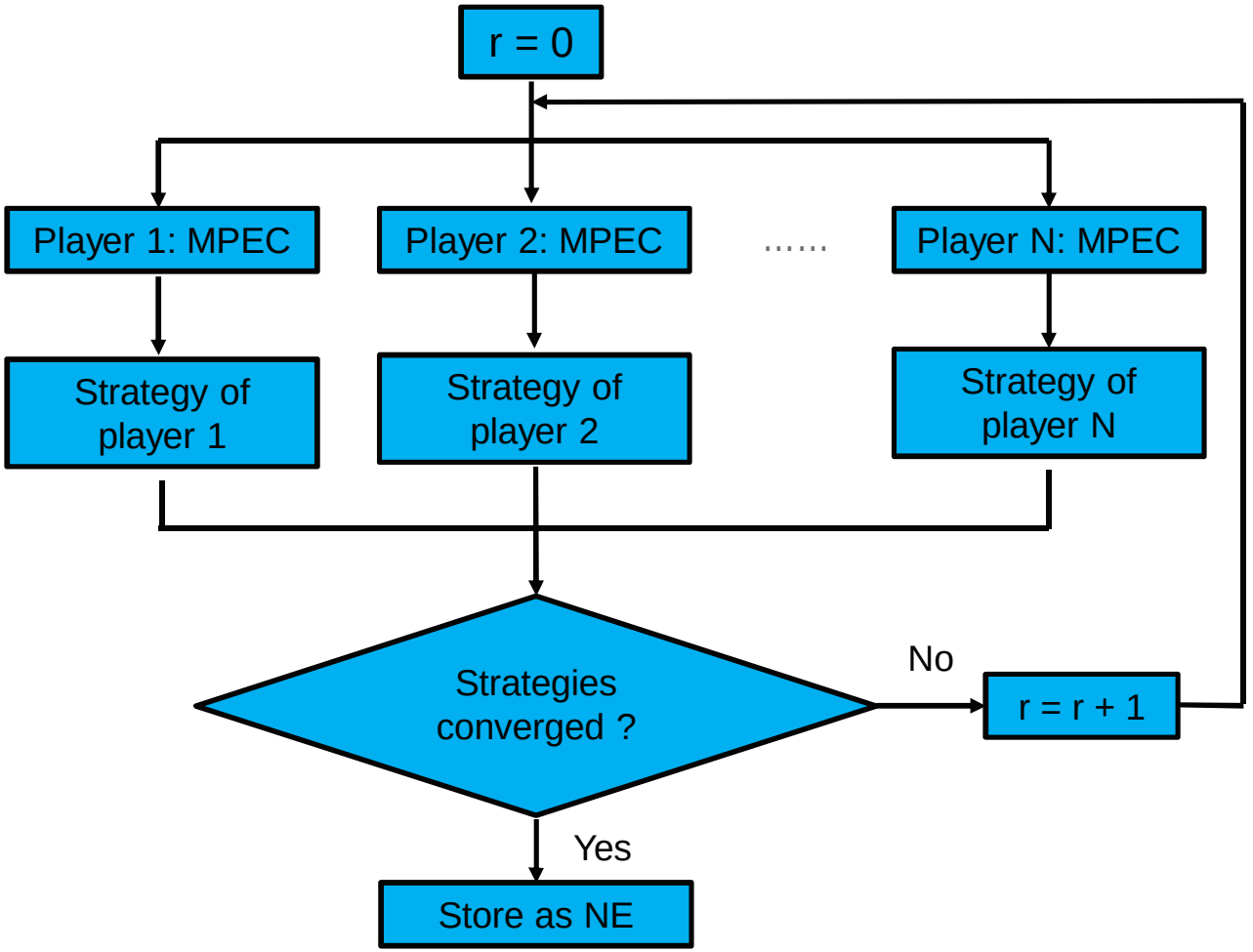
Interaction among multiple players: Finding Nash Equilibria (NE)



Existence, uniqueness and convergence to NE are not generally guaranteed ! > need for heuristics

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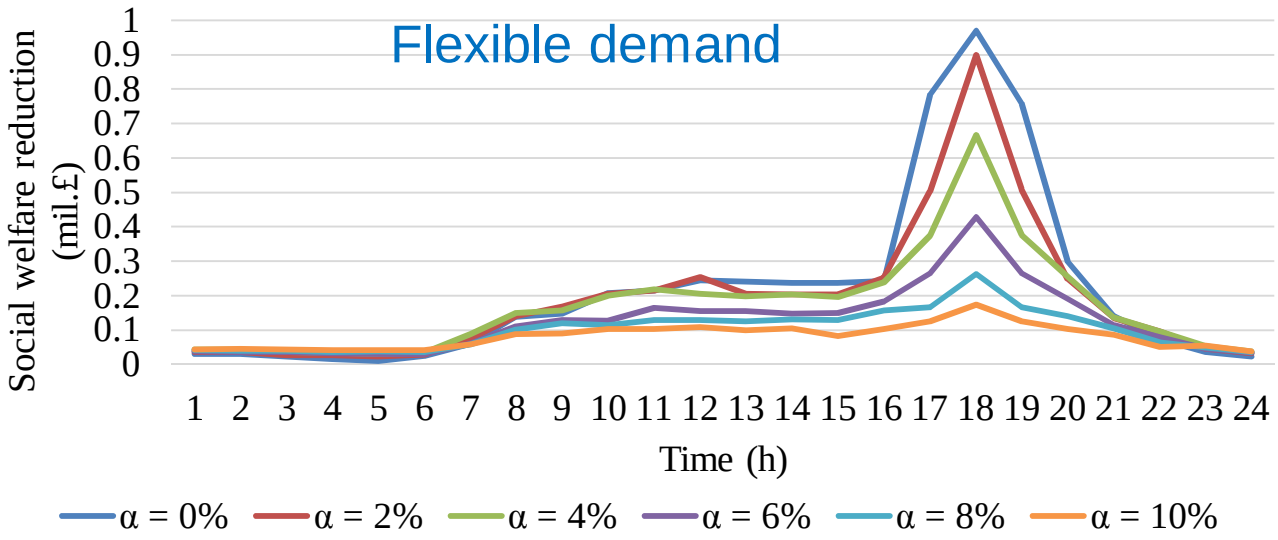
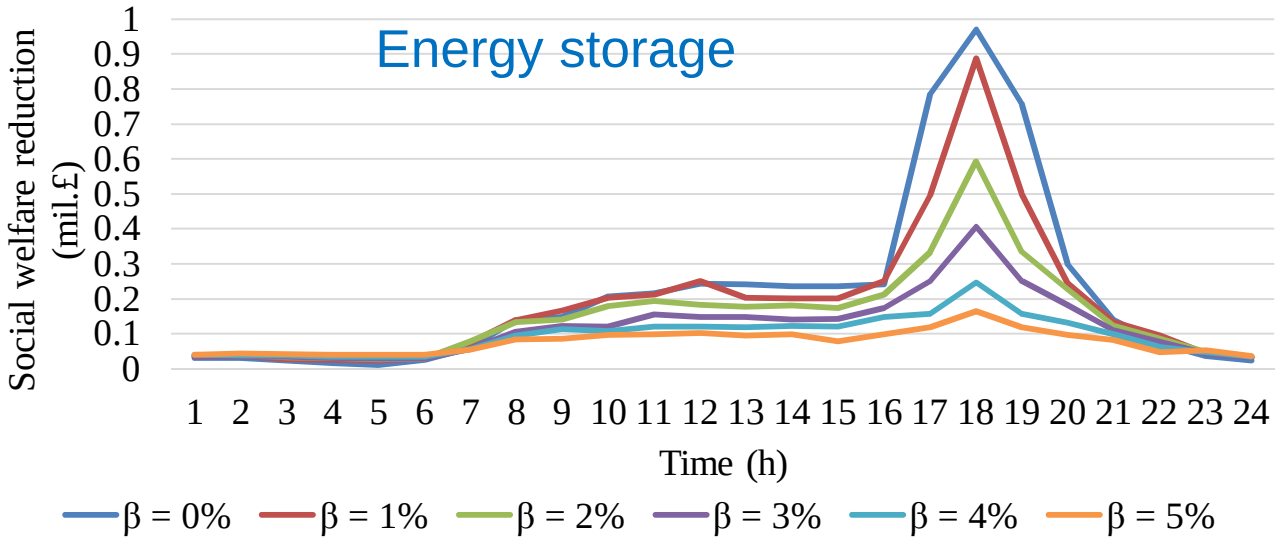
Impact of demand flexibility and energy storage on generators' market power

- Impact of varying degrees of demand flexibility on generators' market power



- Impact of varying sizes of energy storage on generators' market power



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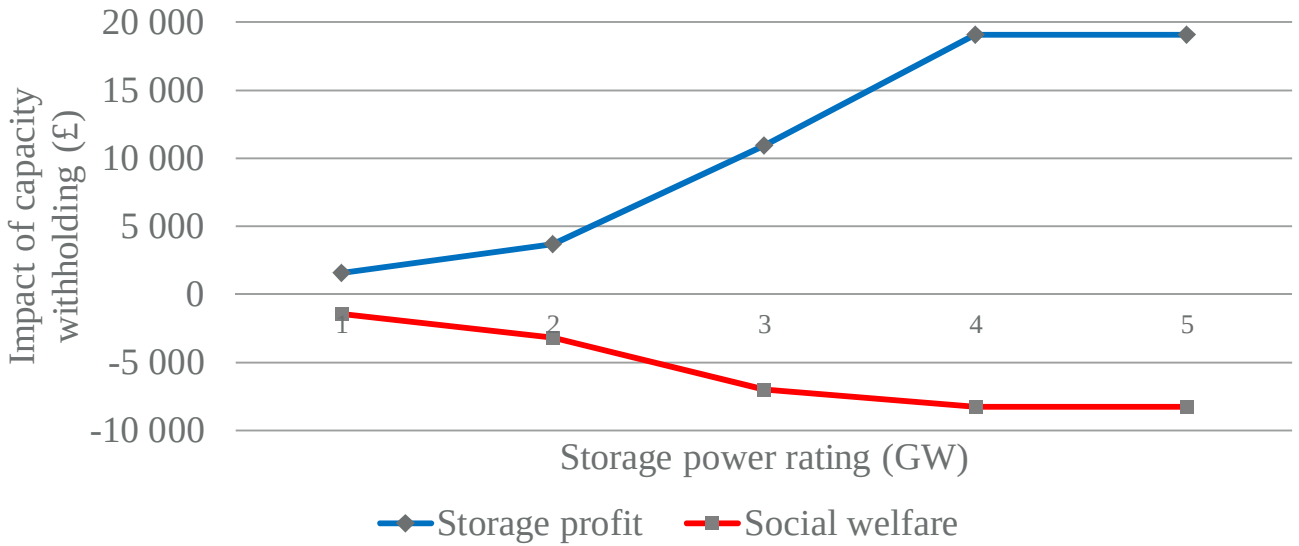
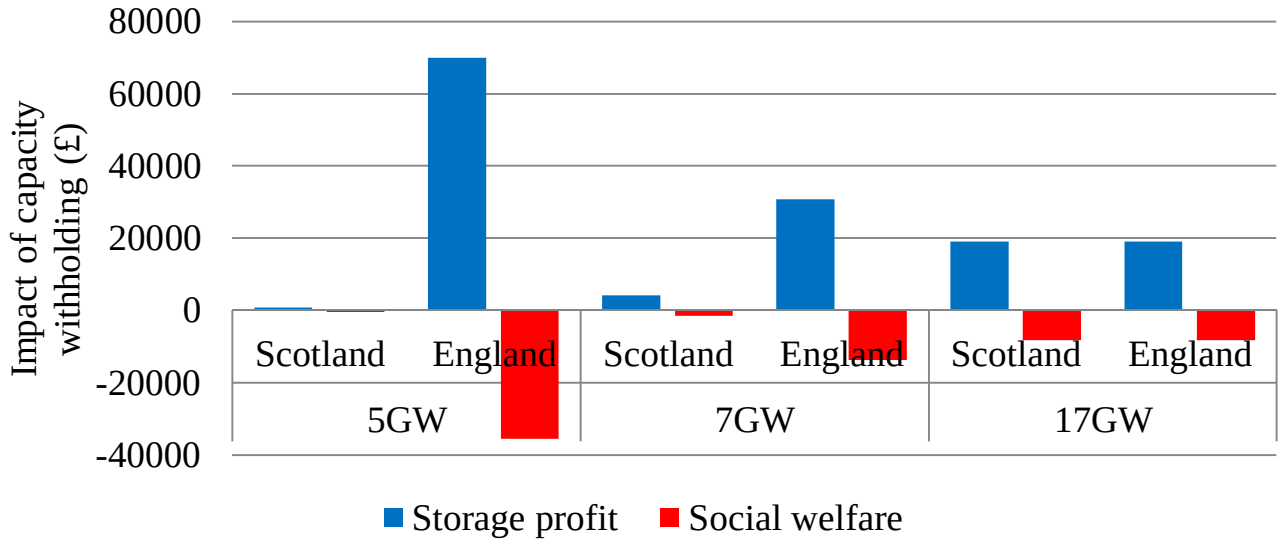
Exercise of market power by strategic storage through capacity withholding

- Impact of storage size on its market power potential



- Impact of storage location on its market power potential



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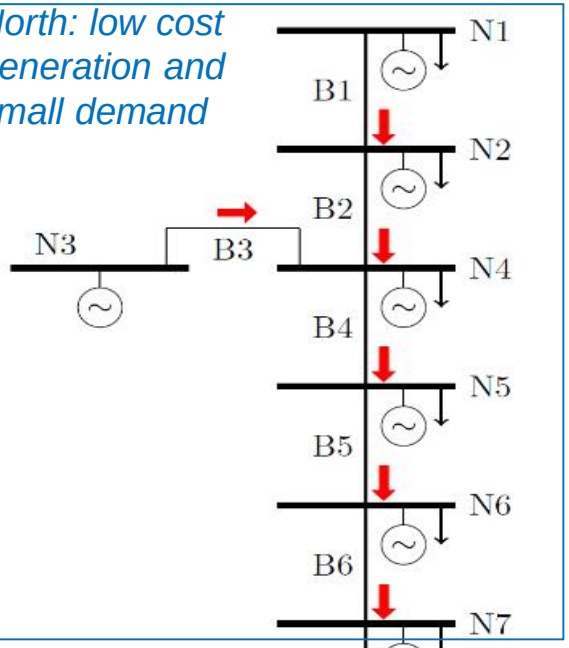
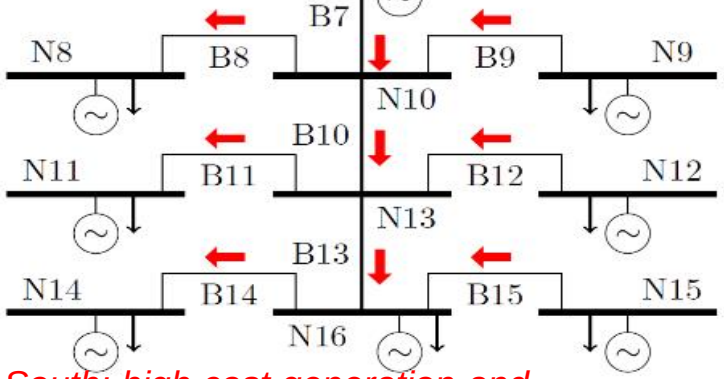
Game-theoretic modelling of decentralised network planning

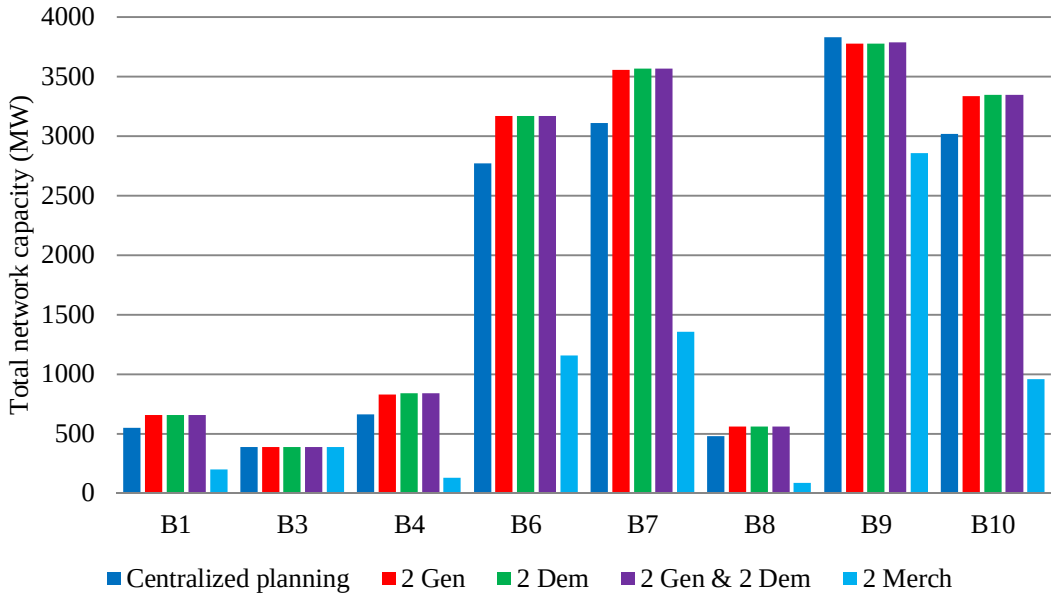
North: low cost generation and small demand





South: high cost generation and large demand

Player	Players' capacity contribution per branch (MW)							
	B1	B3	B4	B6	B7	B8	B9	B10
Scot. G	220	70	830	2020	2670	420	0	270
Eng. G	0	0	0	0	0	0	0	0
Scot. D	0	0	0	0	0	0	0	0
Eng. D	440	320	10	1150	900	140	3790	3080



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