Imperial College London

Coordination between local and national energy objectives

Marko Aunedi, Hossein Ameli,
Xi Zhang, Danny Pudjianto and Goran Strbac

EERA workshop on Energy Systems Integration
3 November 2016

Imperial College London

Outline

- Challenges associated with integrating RES and decarbonising heat and transport
- Time and location effects when studying RES integration
- Conflicts and synergies between national and local objectives
- Role of flexibility in delivering cost-efficient low-carbon mix
- Including other energy vectors in portfolio of flexible solutions

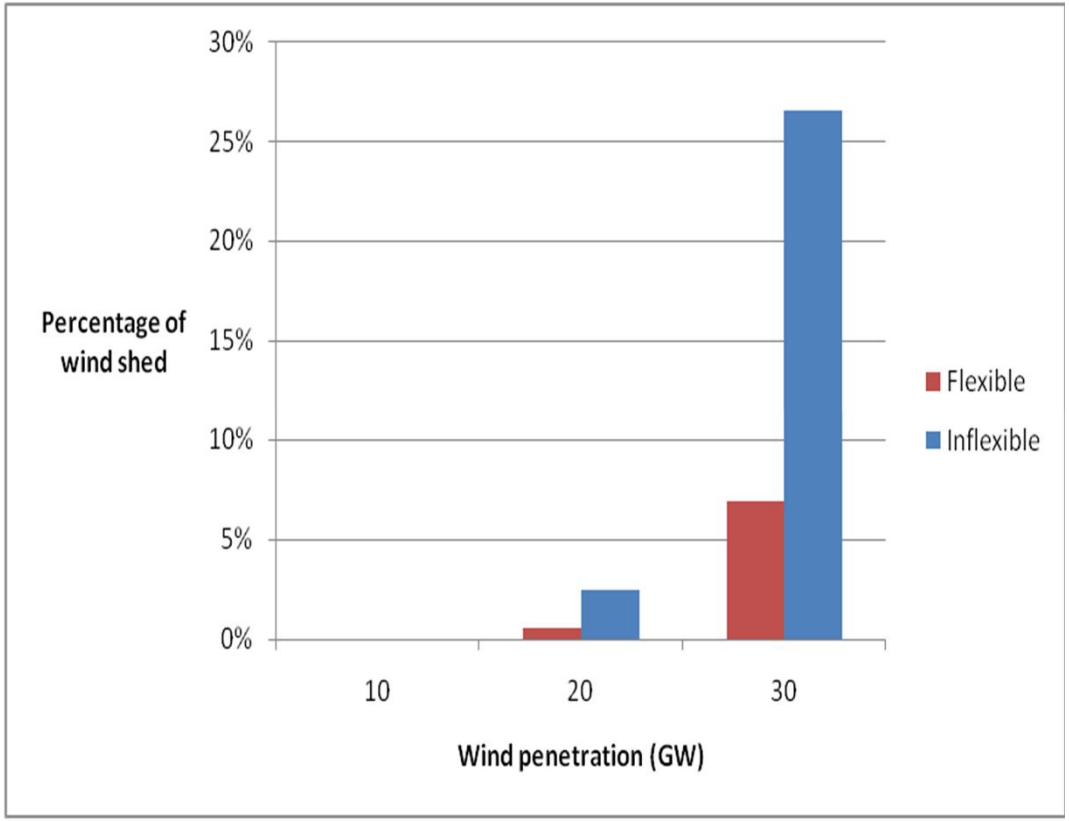
Imperial College London

System integration challenges

Degradation in infrastructure utilisation

Year	Utilisation
2015	55%
2025	35%
2030+	<25%

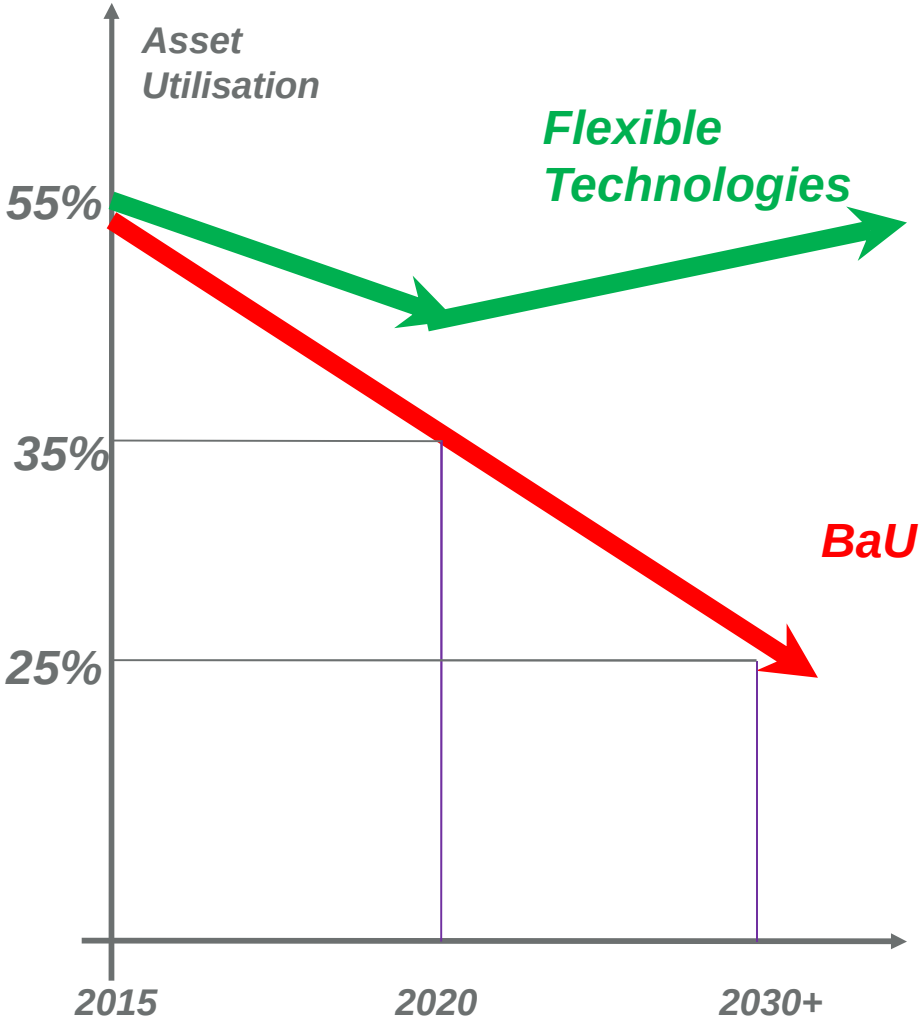
Balancing and need for flexibility

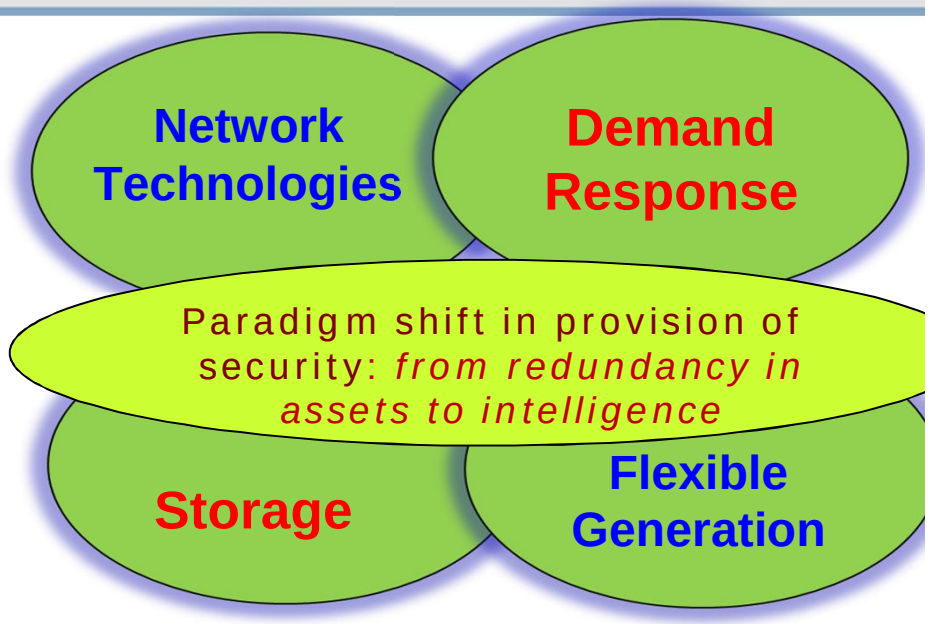


Significant opportunity for flexible technologies

Imperial College London

Low carbon electricity system: degradation in asset utilisation



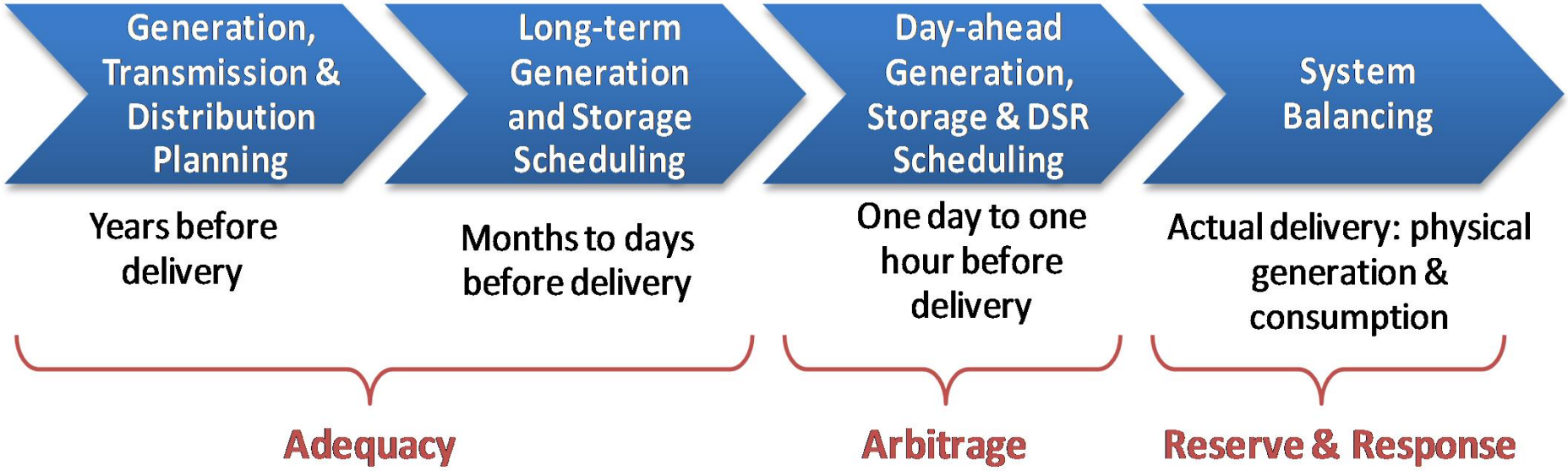


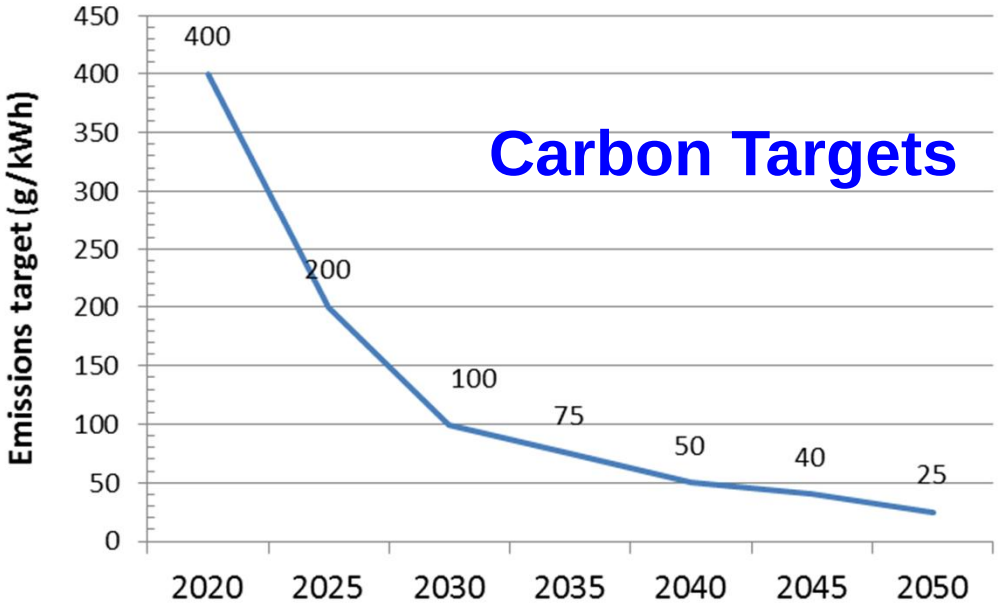
Volume of the market for flexible technologies >£60b

EU>€500bn

Imperial College London

Time and Location effects /1





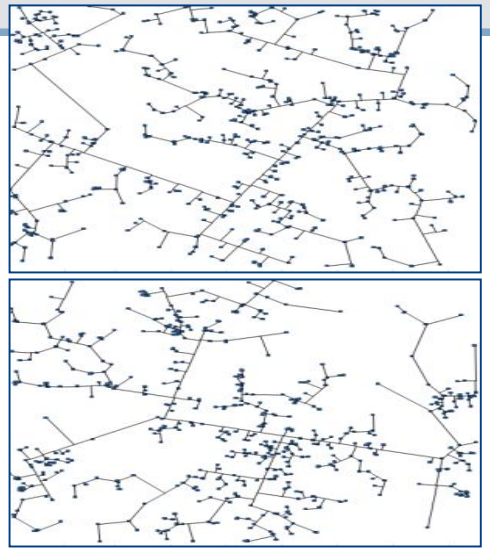
Carbon Targets

Whole-system modelling critical for capturing Time and Location interactions in *low carbon systems*

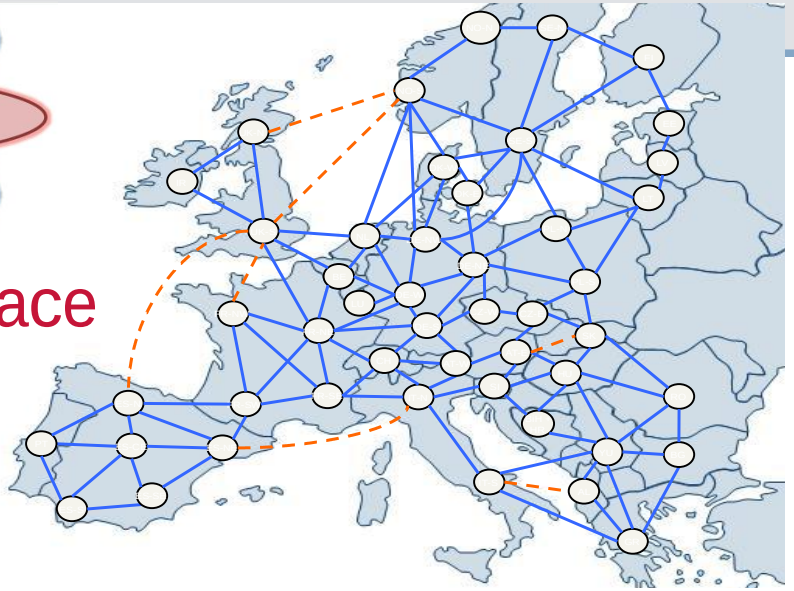
Imperial College London

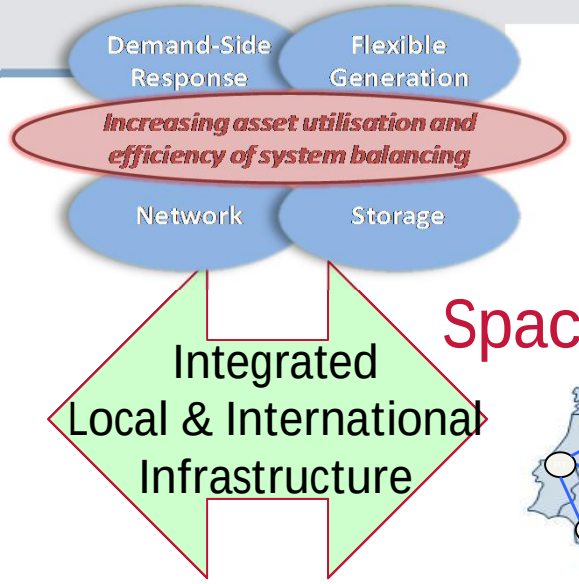
Time and Location effects /2

Local district level

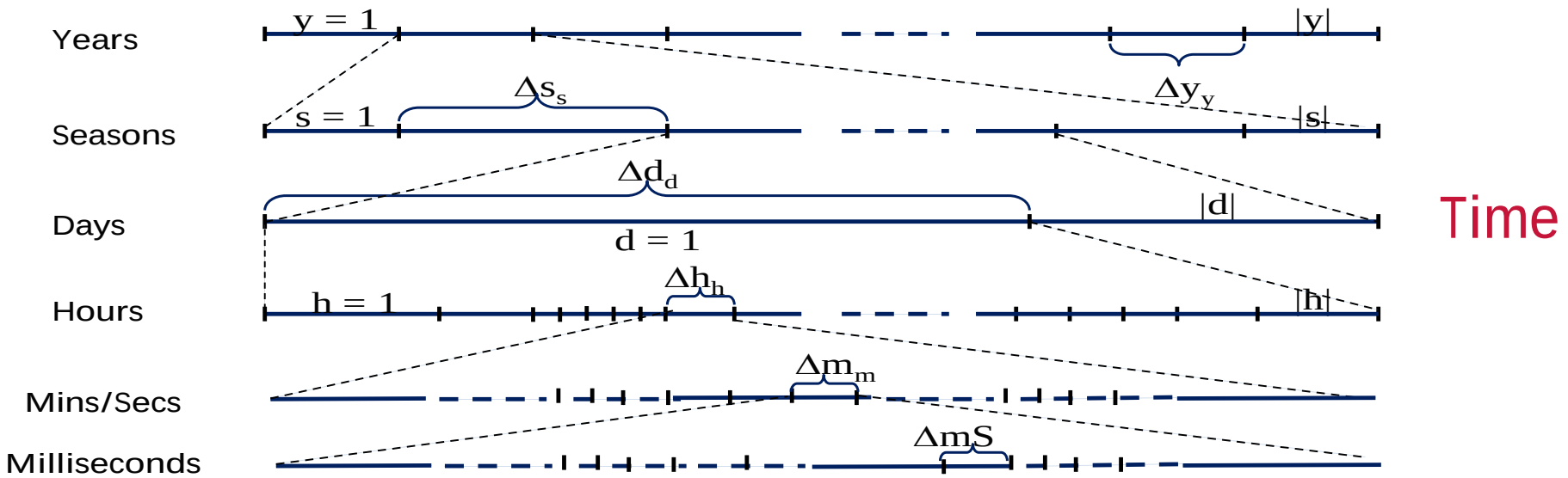


National and EU system level





Space

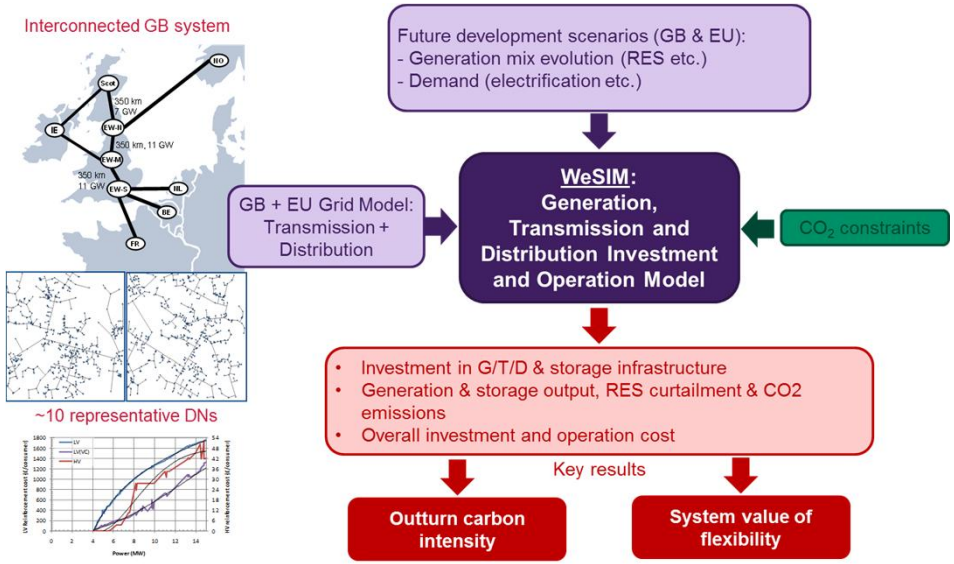


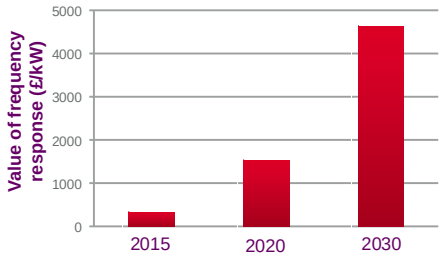
Time

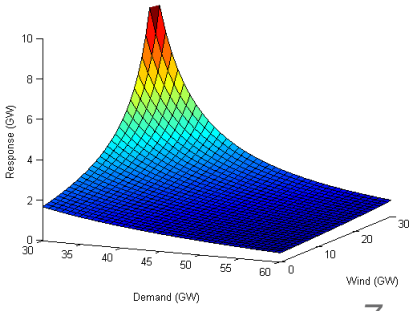
Imperial College London

Whole – electricity System Model (WeSIM)

- Makes optimal investment and operational decisions that minimise total system cost:
  - Generation CAPEX
  - Transmission CAPEX
  - Distribution CAPEX (RNs)
  - OPEX
- High temporal and spatial resolution
- Quantifies cost implications across different segments of electricity system
- Simultaneously & endogenously ensures least-cost solution whilst ensuring that system-level CO_2 constraint is met
- Advanced treatment of system inertia and frequency regulation requirements
- Highly suitable for evaluating flexible options (storage, DSR, interconnection, flex. generation…)



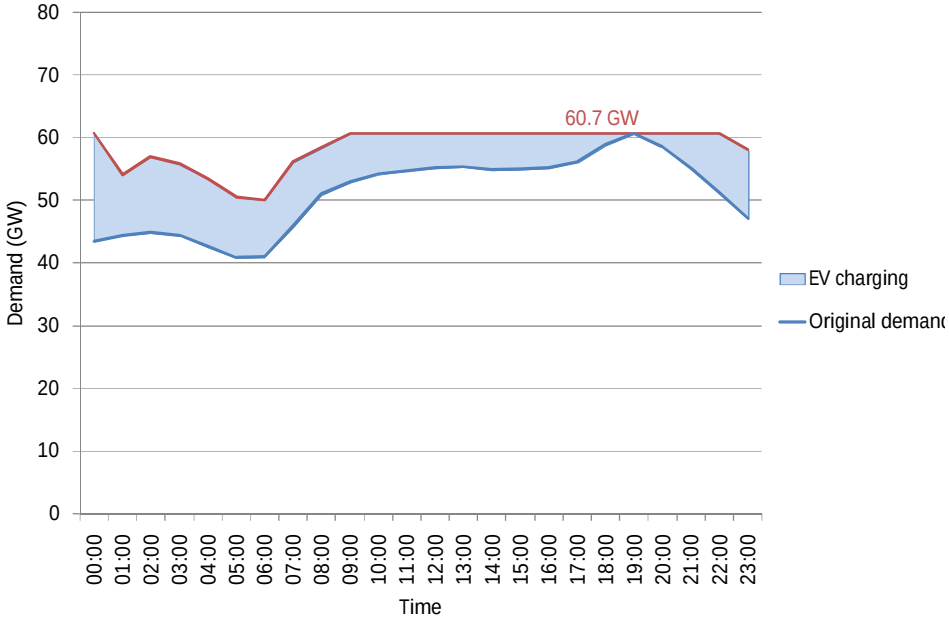




Imperial College London

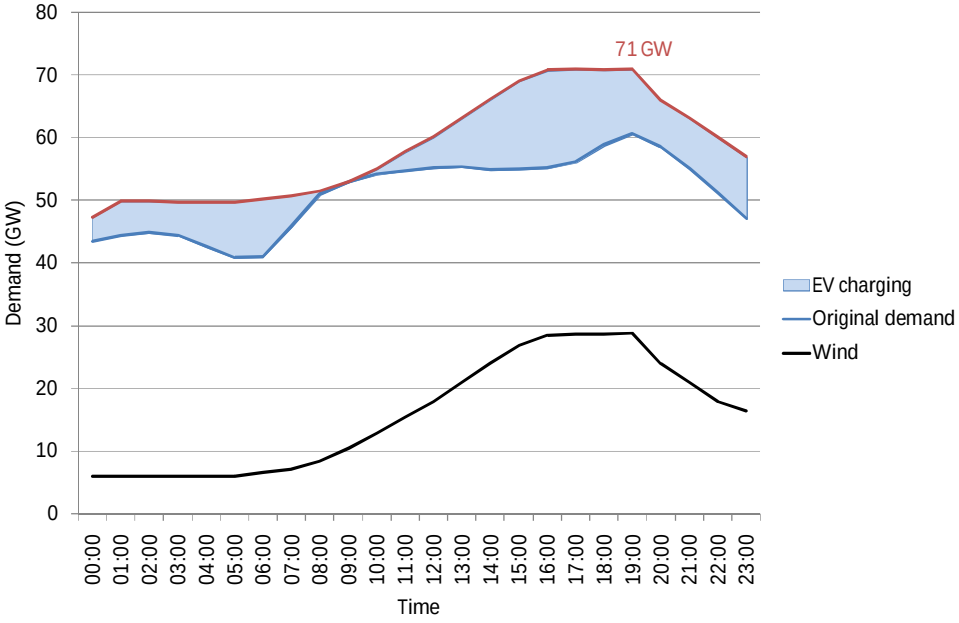
Conflict between peak-driven and supply-driven demand response

Min peak-driven EV charging



EV charging distributed throughout the day to reduce system peak.

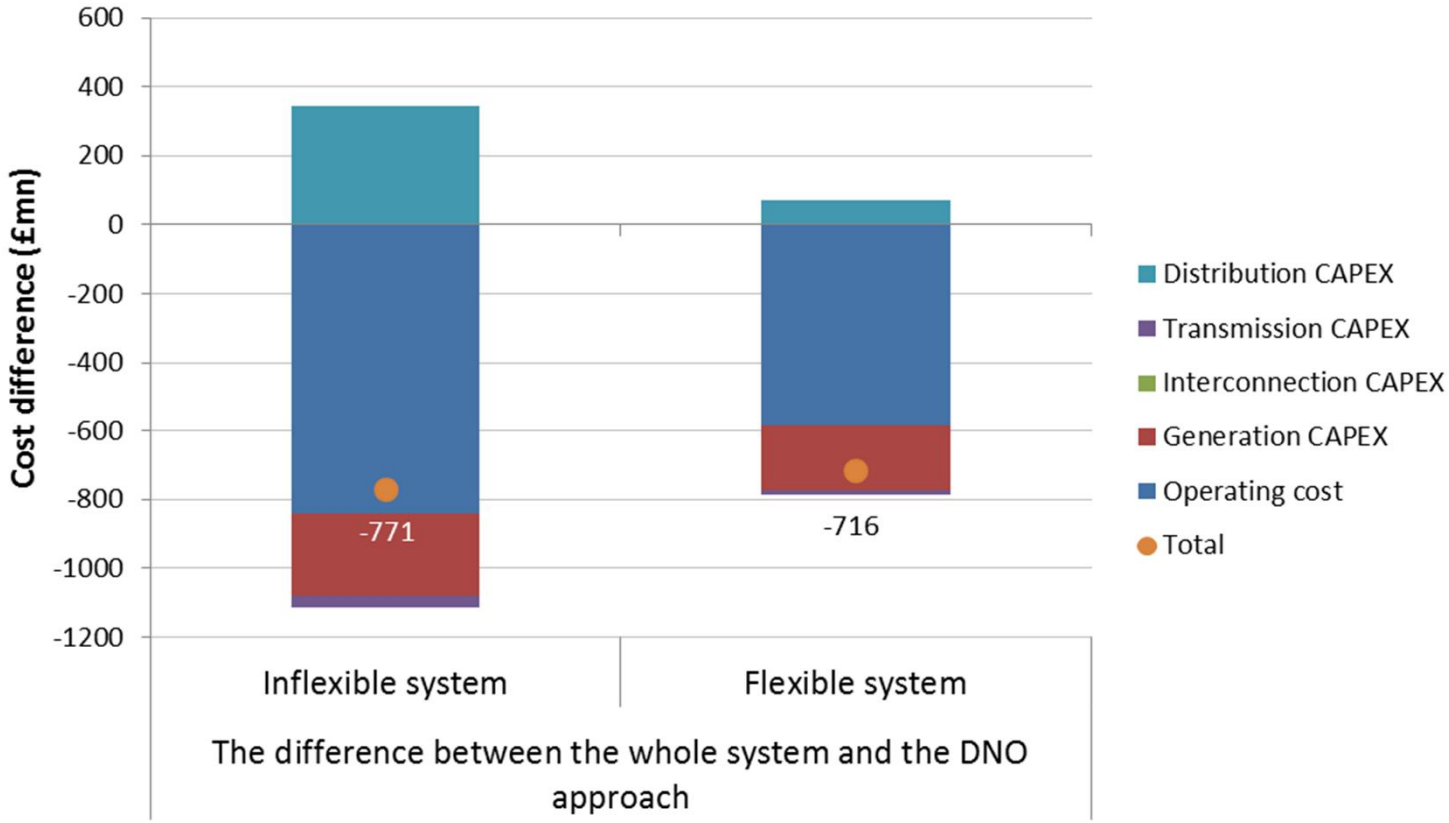
Supply-driven EV charging



A sharp increase in wind output during system peak –> EV charging moved to peak time to utilise wind.

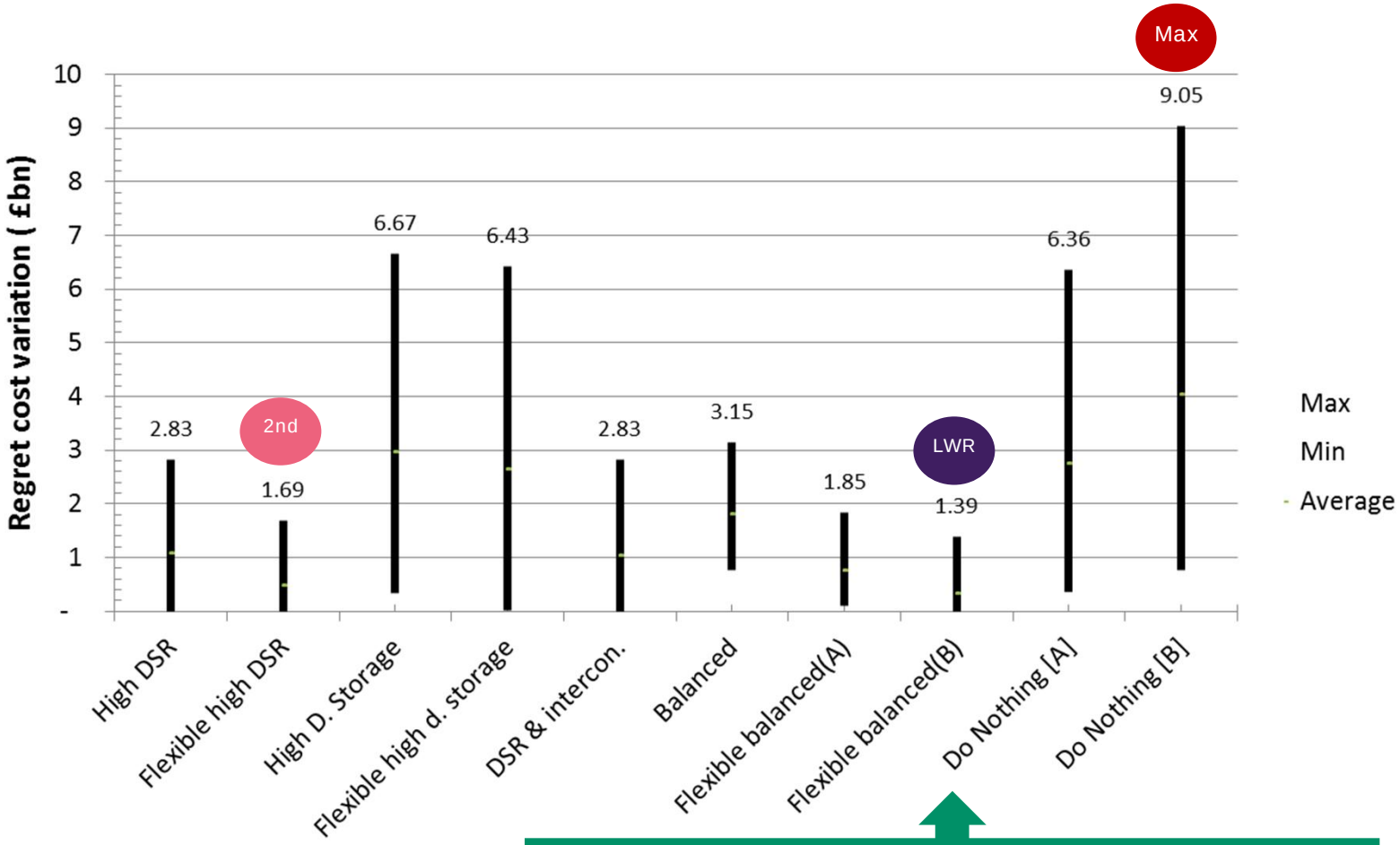
Imperial College London

Conflicts and synergies between local and national objectives – use of DSR



Imperial College London

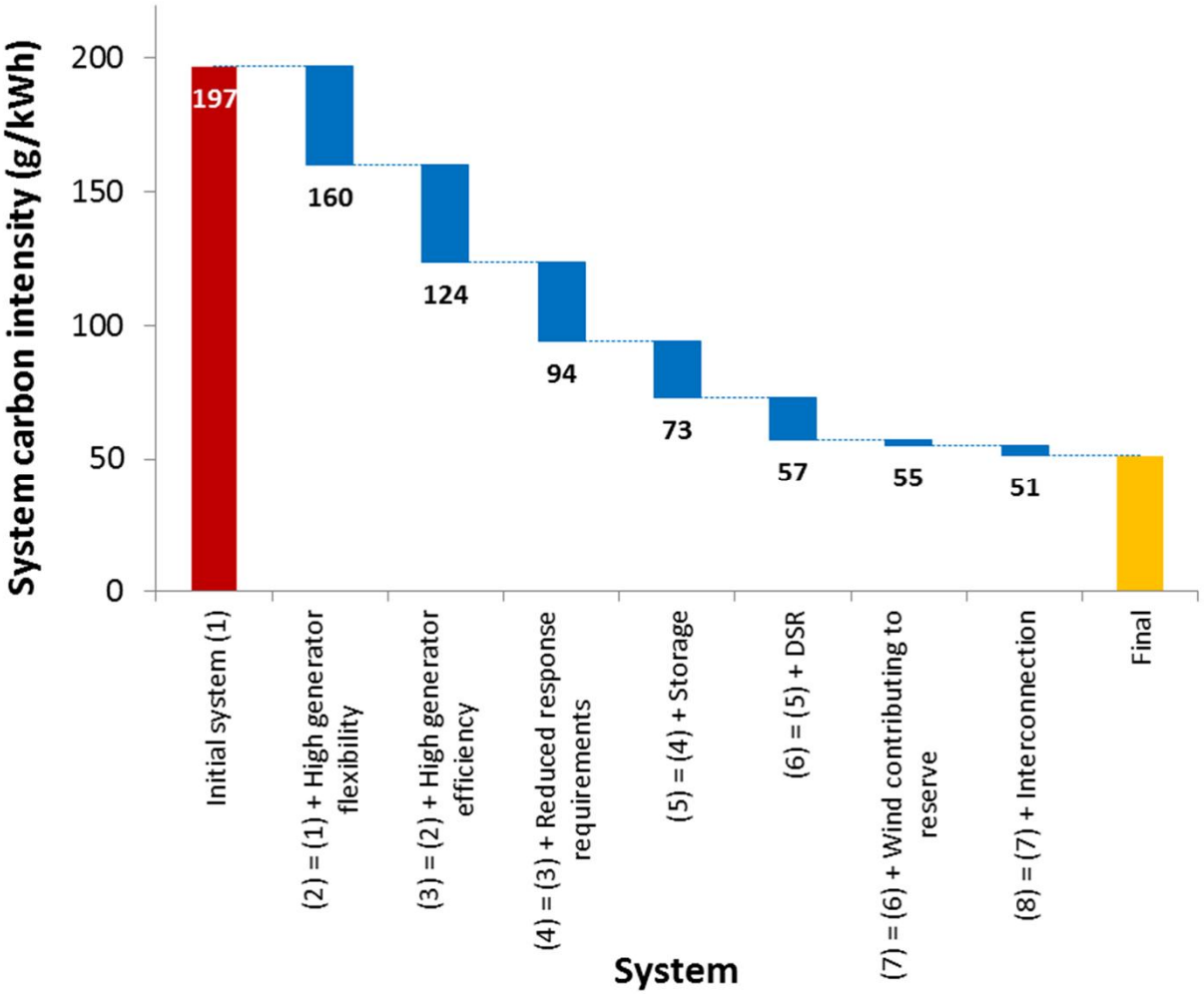
Informing policy under uncertainty – Least-Worst Regret approach



Flexible balanced deployment (with residential DSR switched to I&C when the residential DSR's cost is high).

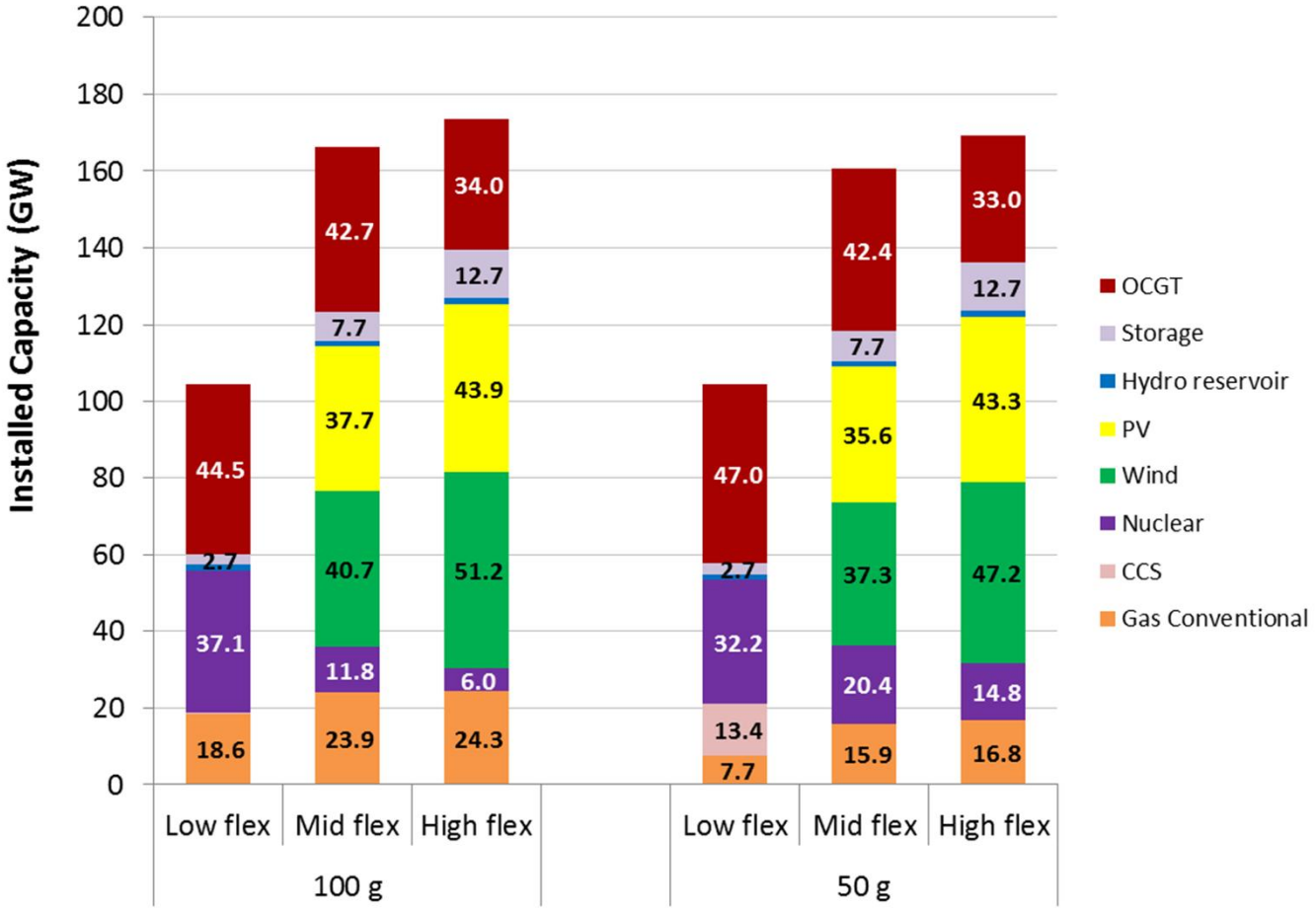
Imperial College
London

Effect of flexibility on system carbon performance



Imperial College London

Impact of flexibility on least-cost low-carbon generation mix in the UK



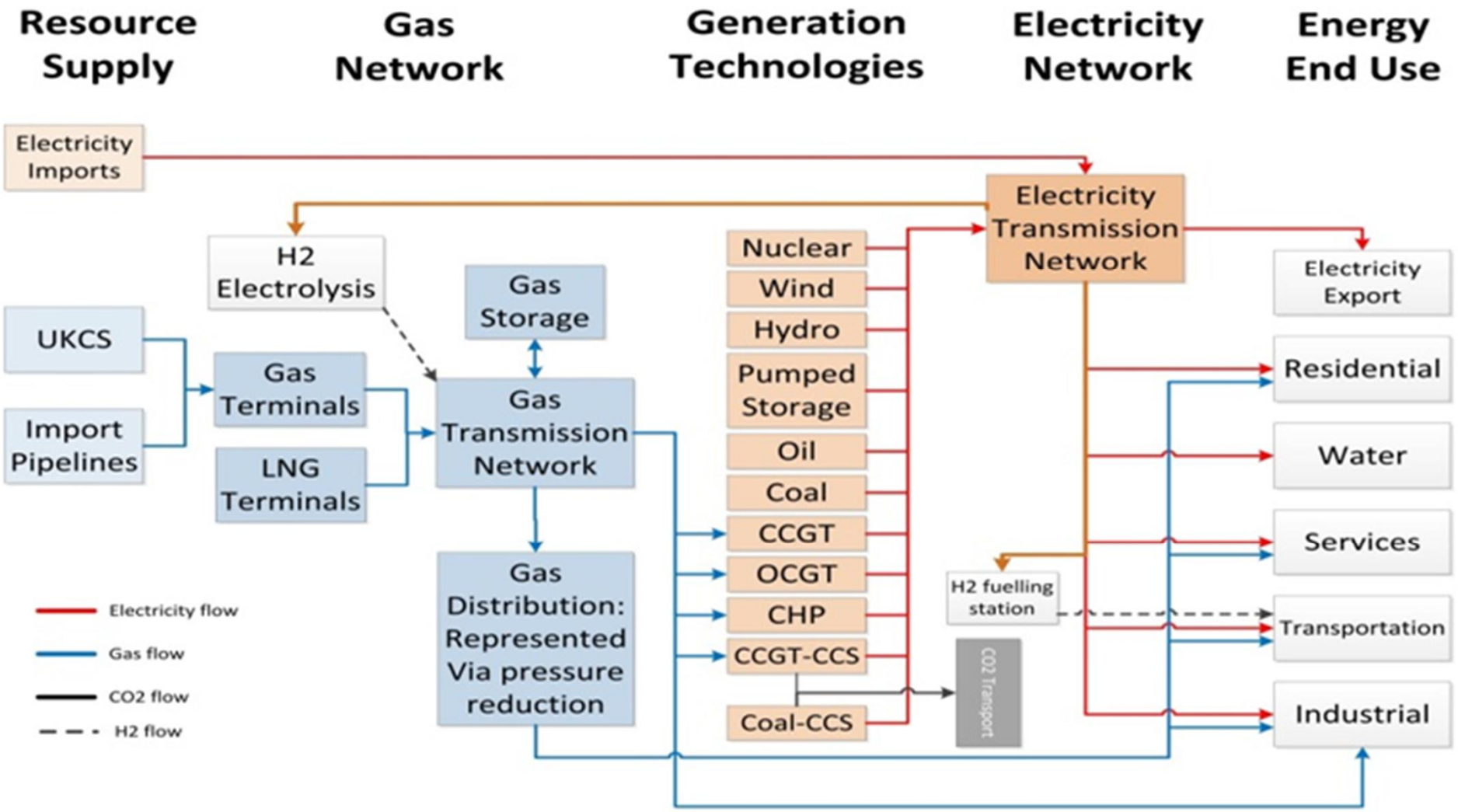
Flexibility* is a core enabler of cost-effective decarbonisation

Can we use flexibility from other vectors?

Flexibility = high deployment of storage, DSR and interconnectors

Imperial College London

Combined Gas & Electricity Model (CGEN)



Imperial College London

Structure of CGEN model

Inputs

Regional and temporal demand data

Capacity/location/type of the existing infrastructure

Operating costs of infrastructure

Fuel prices

Infrastructure's operating limits

CGEN model

(Mixed Integer Non Linear Programming)

- Objective function:

$$\min Z = \sum_{t=1}^{Horizon} \left(\underbrace{Cost\ of\ electricity\ generation} + \underbrace{Cost\ of\ gas\ supply} + \underbrace{Cost\ of\ unserved\ energy} + \underbrace{Cost\ of\ CO2} \right)$$

- Constraints
  - Maximum limit for gas supply from terminals and storage facilities
  - Min and max pressure limits at gas nodes (35 to 85 bar)
  - Maximum generation capacity
  - Power generation ramp up/down limit
  - Power and gas transmission capacity
  - Meeting gas and electricity demand (otherwise high shedding cost is incurred)
  - Conservation of energy and mass
  - Provision of reserve (predetermined)

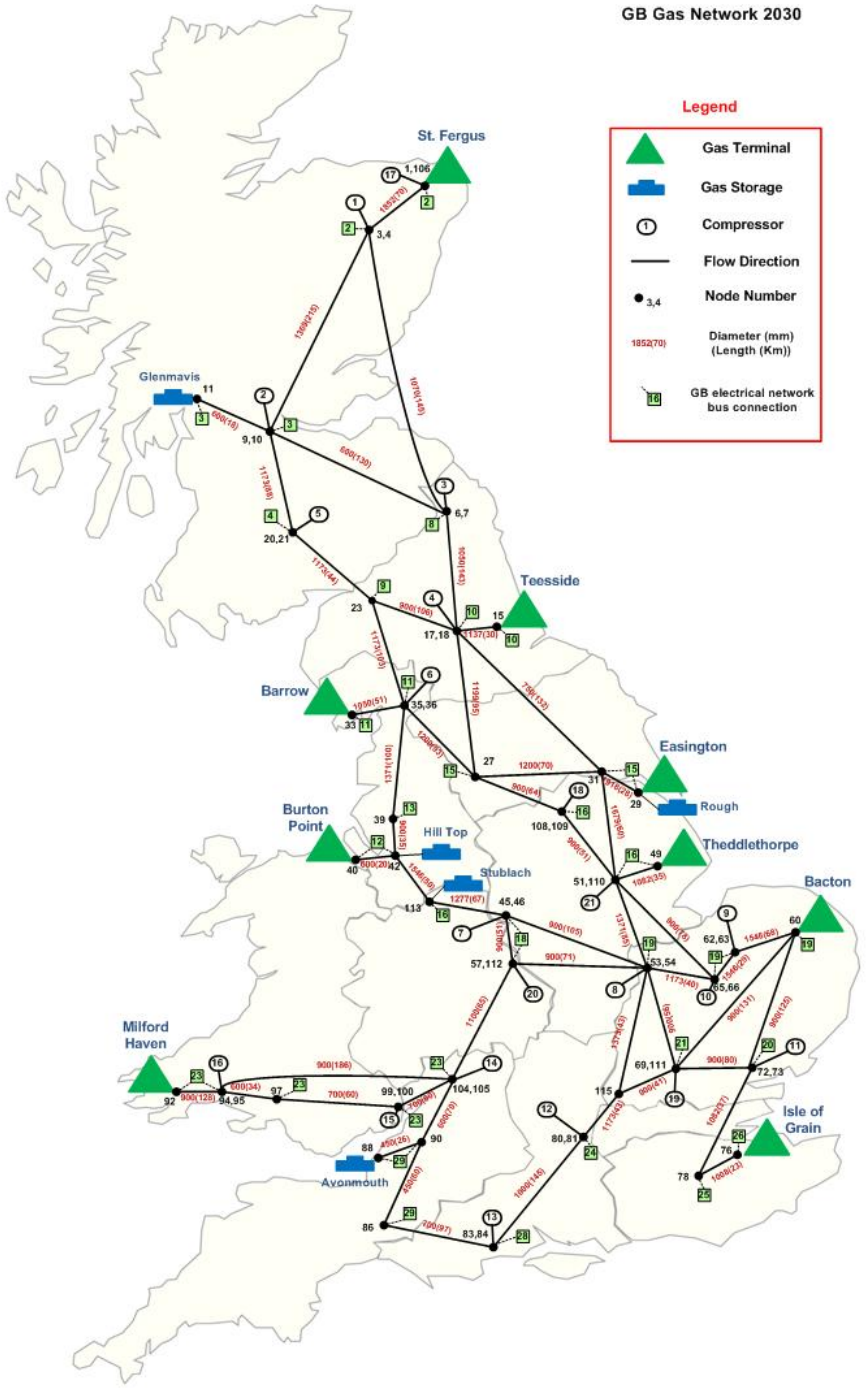
Outputs

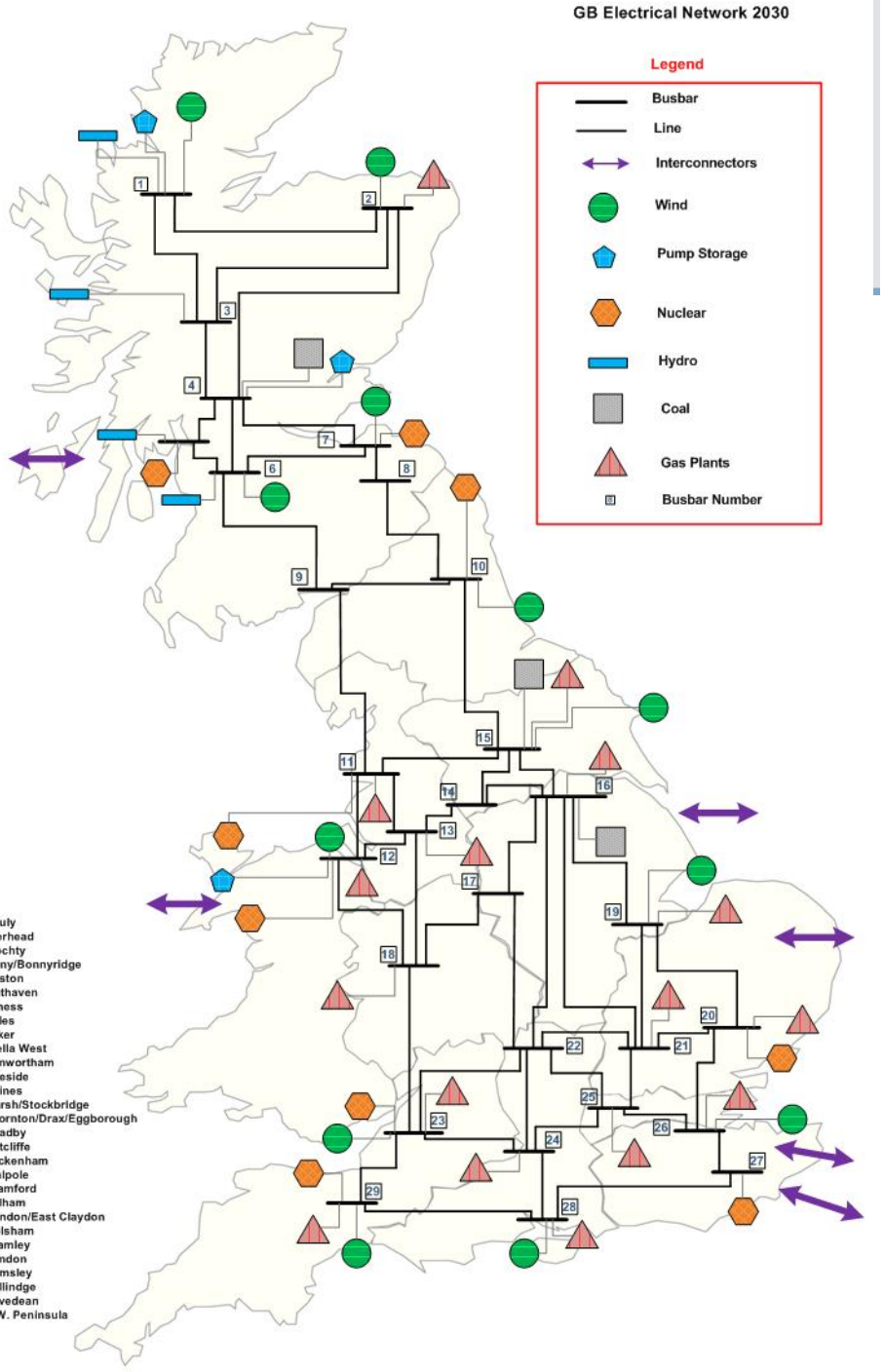
Optimal cost of operation for gas and electricity networks

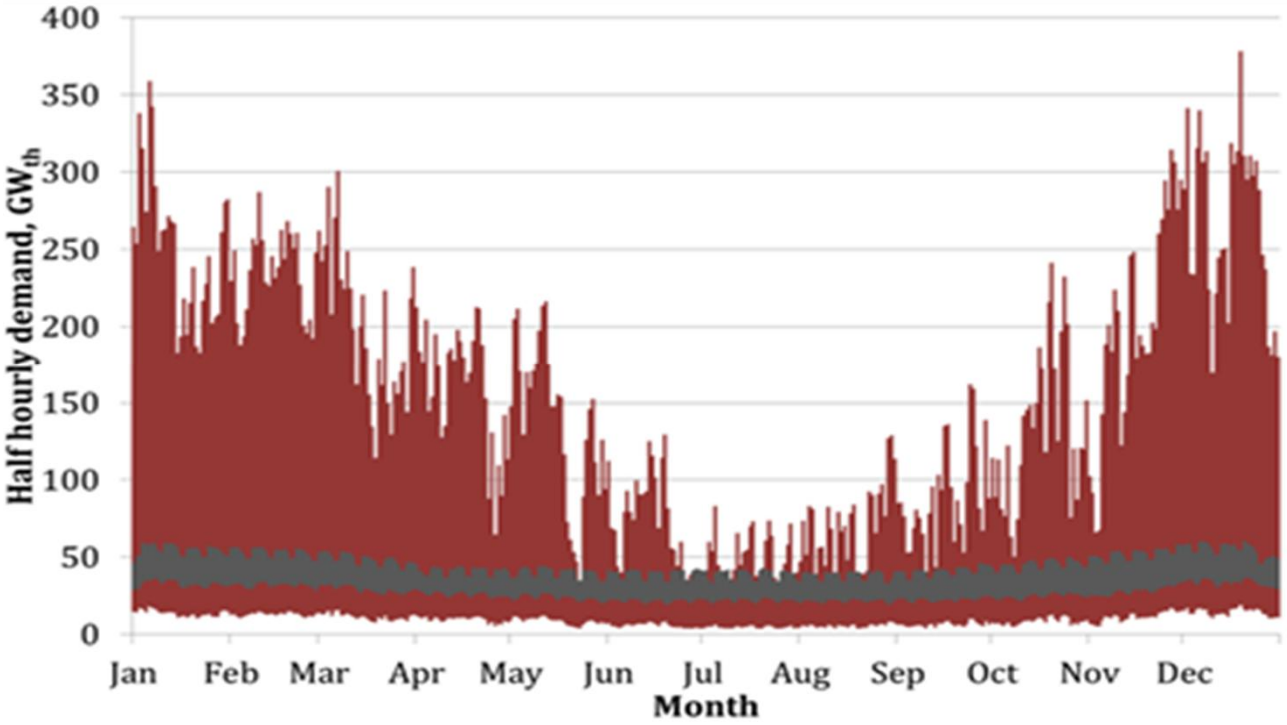
Optimal power generation by each technology at each time step

Optimal real power and gas flow

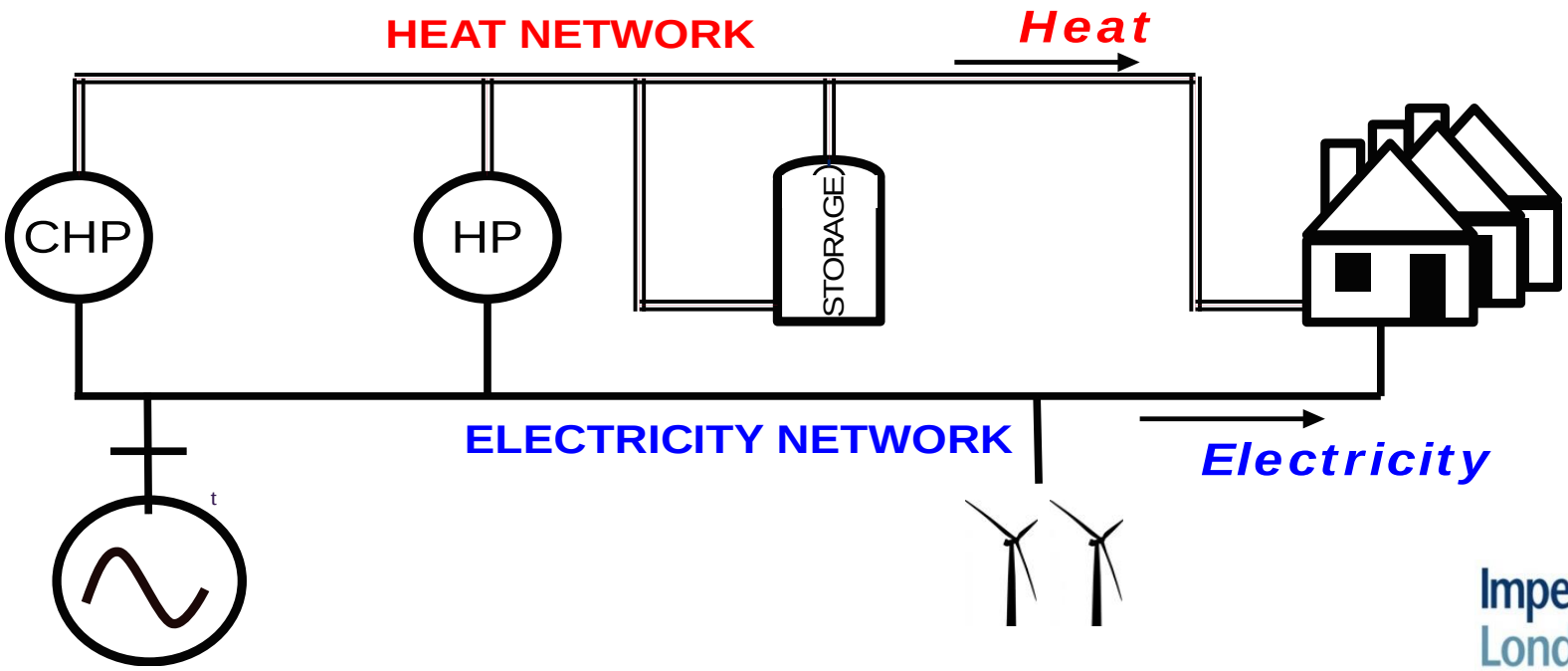
Gas pressure at each node and gas linepack within each pipe


GB Gas Network 2030
Legend
Gas Terminal
Gas Storage
Compressor
Flow Direction
Node Number
Diameter (mm) (Length (Km))
GB electrical network bus connection
St. Fergus
Glenmavis
Teesside
Barrow
Easington
Rough
Burton Point
Hill Top
Theddlethorpe
Stublach
Bacton
Milford Haven
Ayonmouth
Isle of Grain


GB Electrical Network 2030
Legend
Busbar
Line
Interconnectors
Wind
Pump Storage
Nuclear
Hydro
Coal
Gas Plants
Busbar Number
1 Beauly
2 Peterhead
3 Errochty
4 Denny/Bonnyridge
5 Neilston
6 Strathaven
7 Torness
8 Eccles
9 Harker
10 Stella West
11 Penwortham
12 Deeside
13 Daines
14 Marsh/Stockbridge
15 Thornton/Drax/Eggborough
16 Keadby
17 Ratcliffe
18 Feckenham
19 Walpole
20 Bramford
21 Pelham
22 Sundon/East Claydon
23 Melsham
24 Bramley
25 London
26 Kemsley
27 Sellindge
28 Lovedean
29 S.W. Peninsula



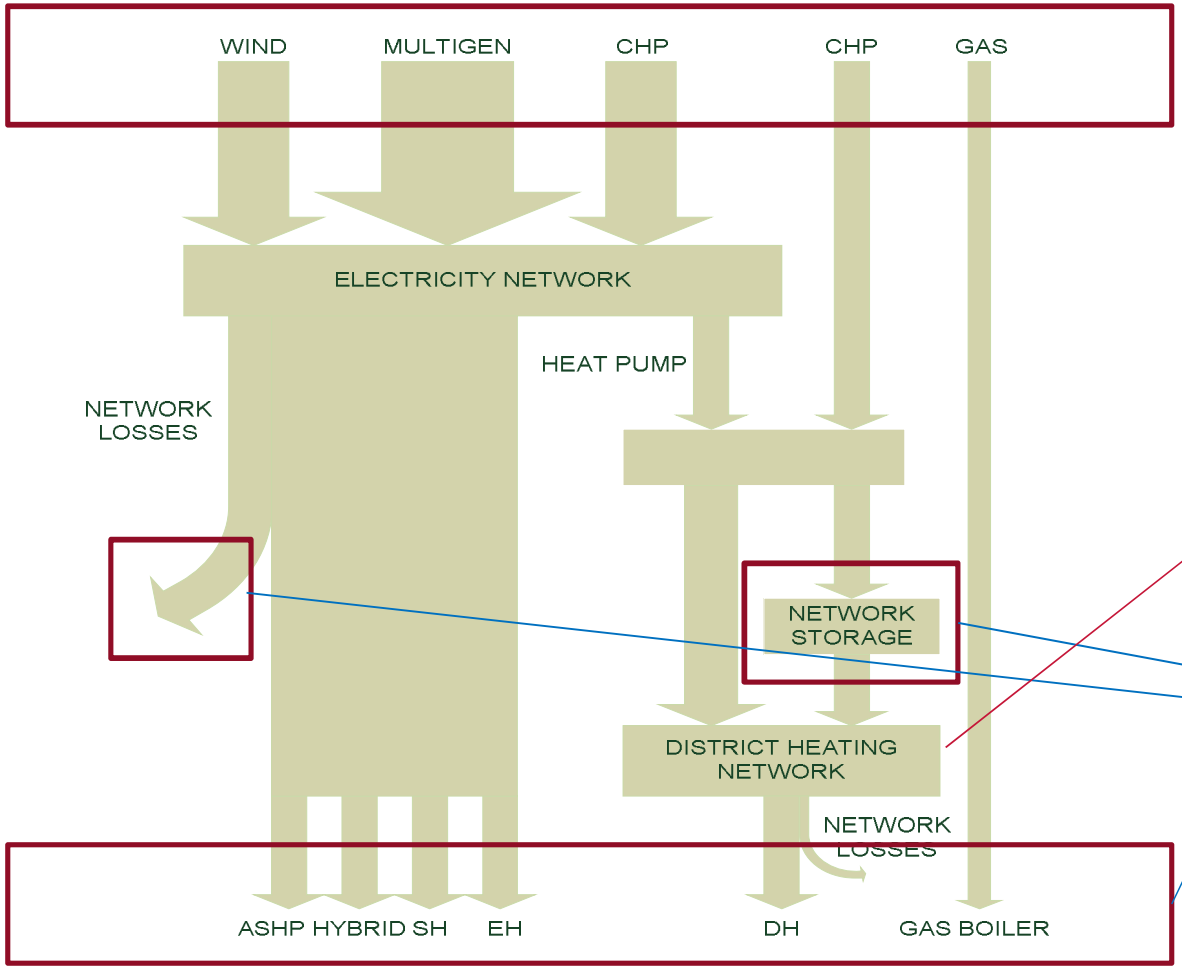
Integrated heat and electricity model



Imperial College London

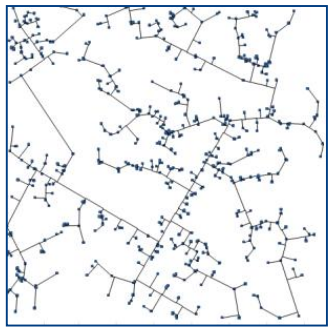
Imperial College London

Electricity and heat network operation and investment model



Production

Fractal network models



Consumption

Perform **cost-benefit analysis** of investment into heat networks vs. other heat supply options (HPs, H_2, gas…)

Imperial College London

Conclusions

- **Flexibility is critical** for cost-efficient decarbonisation of electricity supply (energy storage, DSR, interconnectors…)
- Need to expand high temporal and spatial resolution models to capture interactions between **gas, heat and hydrogen** and electricity system
  - Operation of and investment in integrated electricity and heat distribution networks
  - Impact of linking technologies (CHP, HP, heat storage) on investment in electricity and heat networks
  - Cost-benefit analysis of investment into heat networks vs. other heat supply options (HPs, H_2, gas…)
- Challenge of linking local and national perspectives
  - Capturing trade-offs between additional investment at local level and benefits at whole-system level → increasing complexity

Imperial College London

Coordination between local and national energy objectives

Marko Aunedi, Hossein Ameli,
Xi Zhang, Danny Pudjianto and Goran Strbac

EERA workshop on Energy Systems Integration
3 November 2016