Imperial College London

wholeSEM

Modelling of Smart Low-Carbon Electricity Systems

Goran Strbac, Maysam Quadrdan, Dimitrios Papadaskalopoulos, Rodrigo Moreno, Ioannis Konstantelos, Predrag Djapic, Fei Teng, Marko Aunedi, Danny Pudjianto

March 2014

Models

1. Whole electricity System Investment Model (***WeSIM***)

2. Stochastic Unit Commitment model (***SUC***)

3. Dynamic Transmission Investment Model (***DTIM***)

4. Distribution Network Planning Model (***DistPlan***)

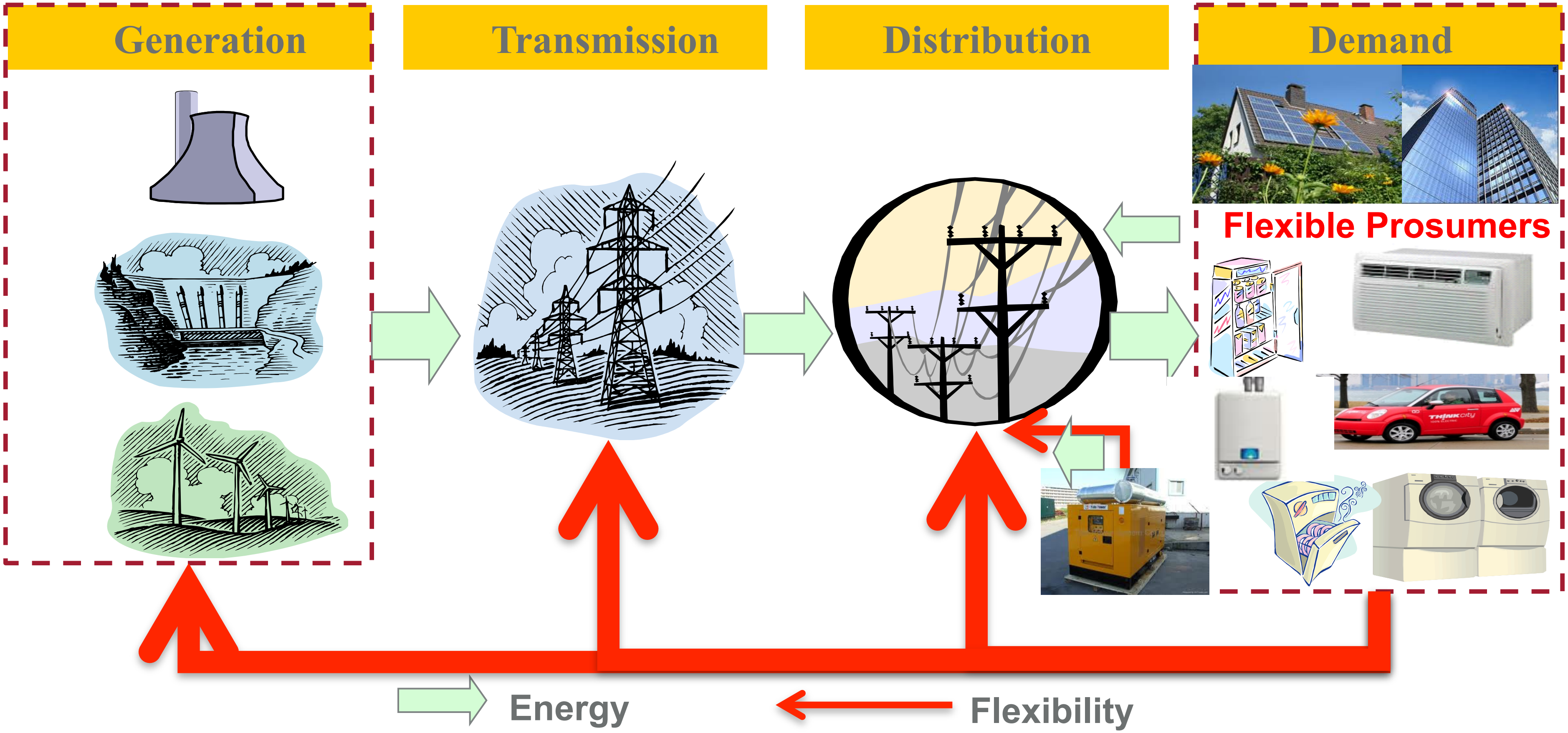
5. Combined Gas and Electricity Model (***CGEN***)

1. Whole electricity System Investment Model - *WeSIM*

Imperial College London

Energy: From the Grid to Consumers

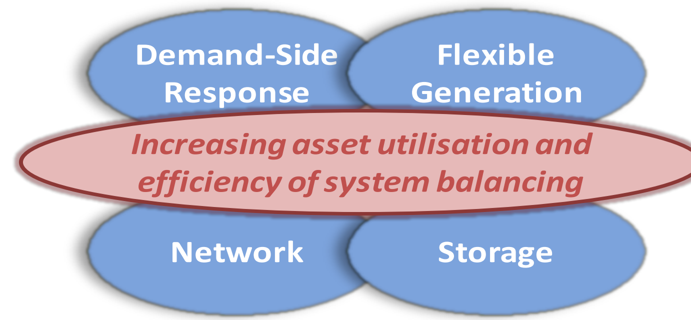
Flexibility: From Consumers to the Grid



WeSIM –quantifying the value of DSR & storage – informing policy, regulation & business models

Valuing Flexible Technologies
Whole Systems Approach

Generation, Transmission & Distribution Planning	Long-term Generation and Storage Scheduling	Day-ahead Generation, Storage & DSR Scheduling	System Balancing
Years before delivery	Months to days before delivery	One day to one hour before delivery	Actual delivery: physical generation & consumption
Adequacy		Arbitrage	Reserve & Response



Whole-system modelling critical for capturing Time and Location interactions

(1) cost and performance targets
(2) competitiveness and synergies of alternative technologies

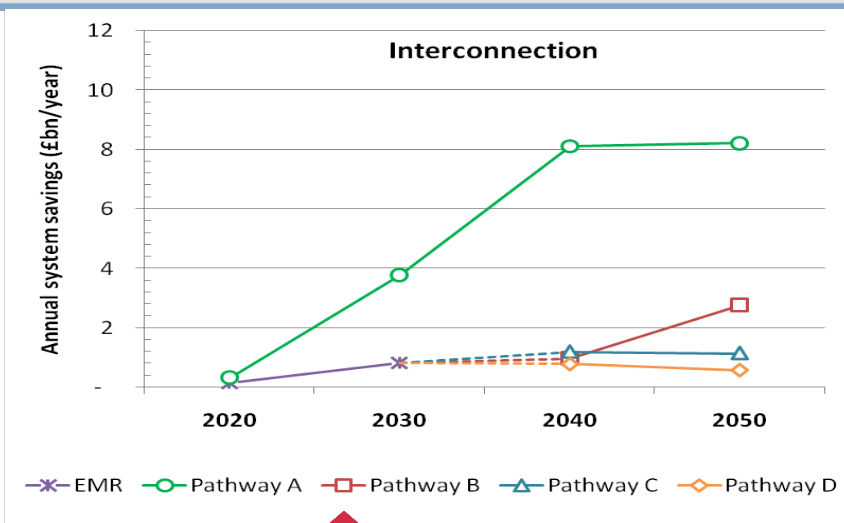
Volume of the market for flexible balancing technologies >£60b

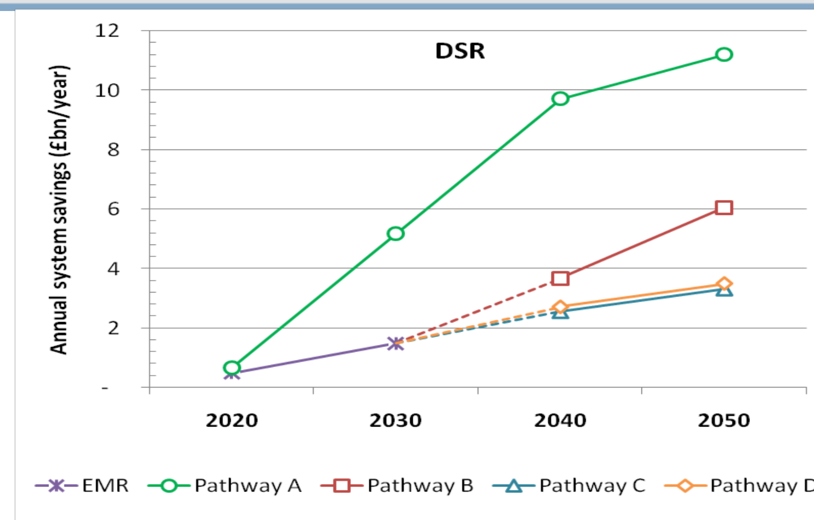
System integration costs of low carbon European system >€500b

Imperial College London

Applications of *WeSIM* in the UK – informing policy

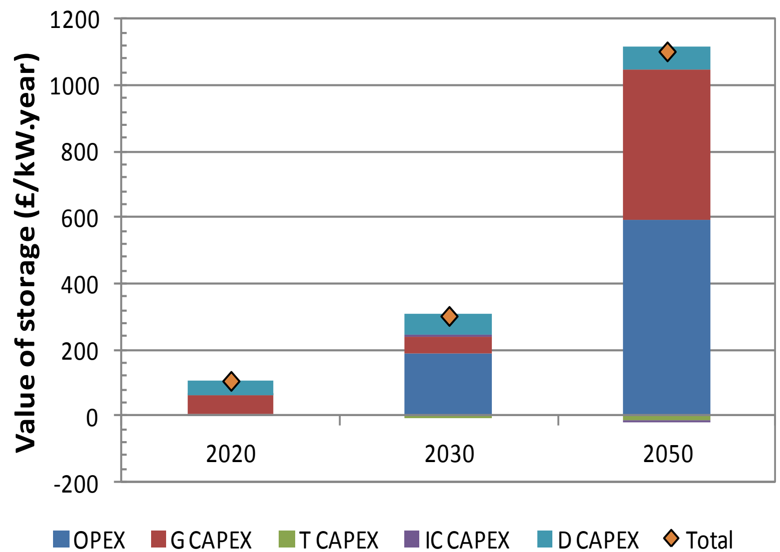
wholeSEM





(1) Understanding the balancing challenge

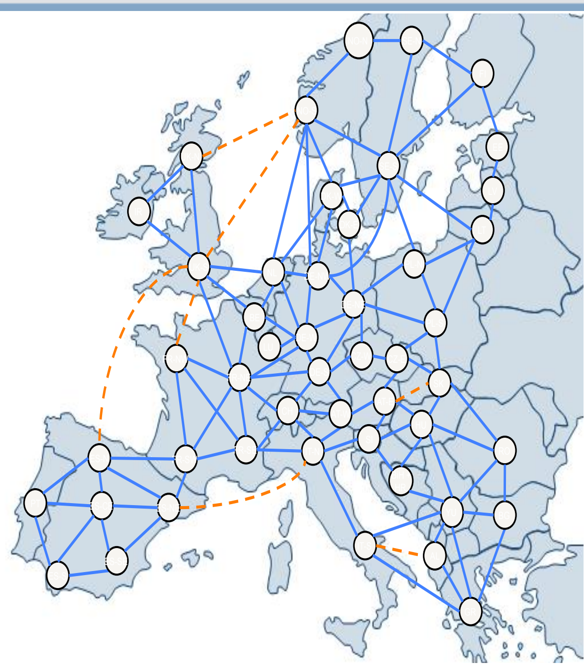
(2) Strategic value of Storage



WeSIM – Informing EU electricity market integration :
Member State-centric or EU wide approach?

1. Infrastructure development?
2. RES deployment?
3. Adequacy?
4. Balancing?

EU-wide capacity mechanism can save 100-160 GW of peaking plant!



**Can you really trust ……..
when it comes to security of supply?**

Benefits of whole electricity systems approach at the EU level

In €bn/year (rounded)	By 2030
Integrated energy market	9.5 to 32.0
Extra for integrated capacity market	3.0 to 7.5
Extra for shared balancing	0.5 to 2
Extra for Demand Side Response	3.0 – 5.0
Extra for Coordinated RES investment	15.6 - 30

Can we afford member state-centric approach to electricity supply?

Scope for further application and for enhancing WeSIM

- *Quantifying whole electricity system integration costs of different low carbon generation technologies*
- Coordinated development of different industry sectors with energy sector (e.g. strategic water sector infrastructure development to support integration of renewable generation)
- Incorporation of resource constraints associated with different generation and energy storage
- Including other energy vectors, such as hydrogen

Imperial College London

wholeSEM

2. Modelling of real time balancing of supply and demand

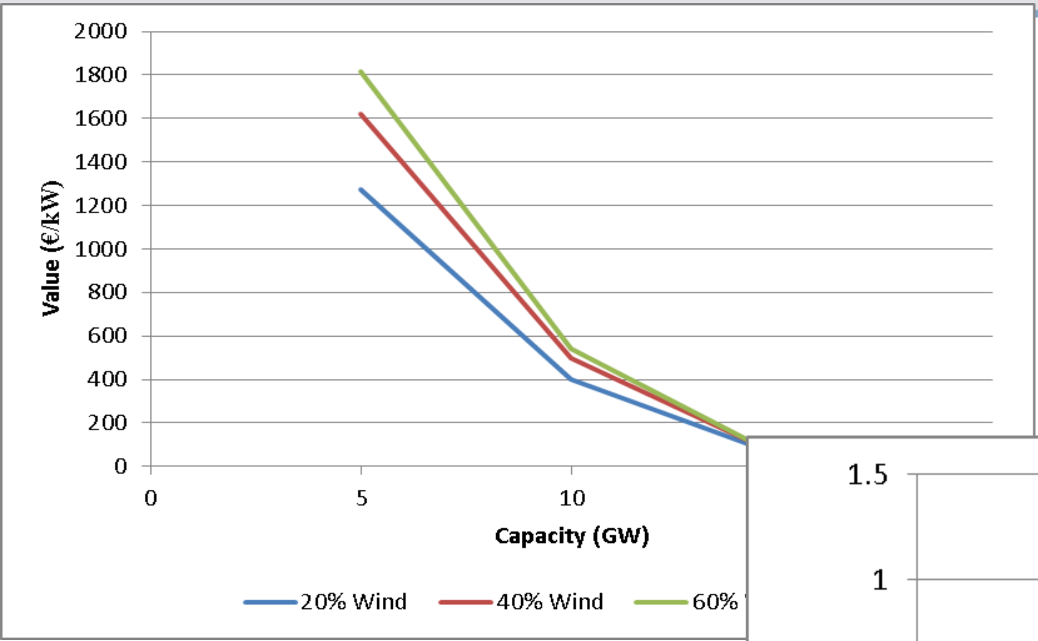
Stochastic Unit Commitment - SUC

Stochastic Unit Commitment (SUC) – key features

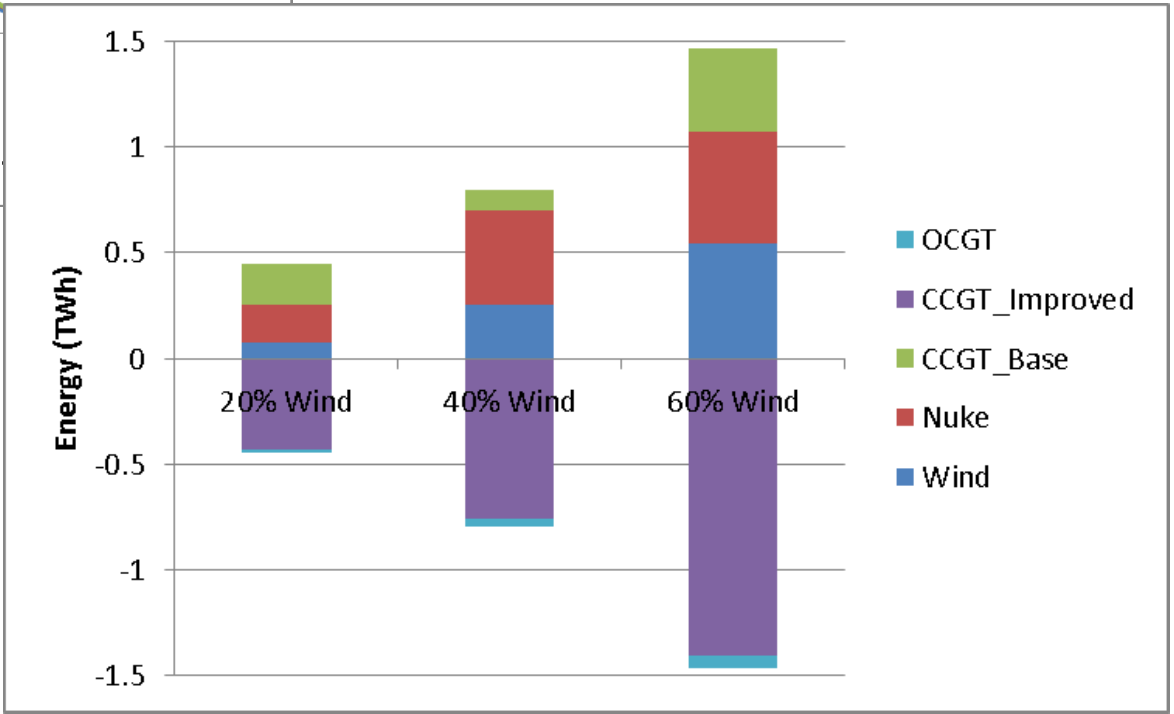
- SUC quantifies operational costs associated with balancing demand and supply in real time in systems with significant contribution of renewable generation
- Through time-domain generation scheduling SUC captures complex inter-temporal constraints that limit the balancing actions of the thermal plant, storage, and demand-side measures
- *SUC schedules optimally / dynamically (1) reserves including both spinning and standing and (2) response services both primary and secondary reserves, considering wind and demand* ***uncertainties*** *and generation outage uncertainty* (this is critical for allocating storage or DSR resource between energy arbitrage and the provision of various ancillary services).
- *SUC quantifies the value of various emerging technologies that offer different types of flexibility*

Imperial College London

Flexibility of generation, not only capacity and energy provision will be critical

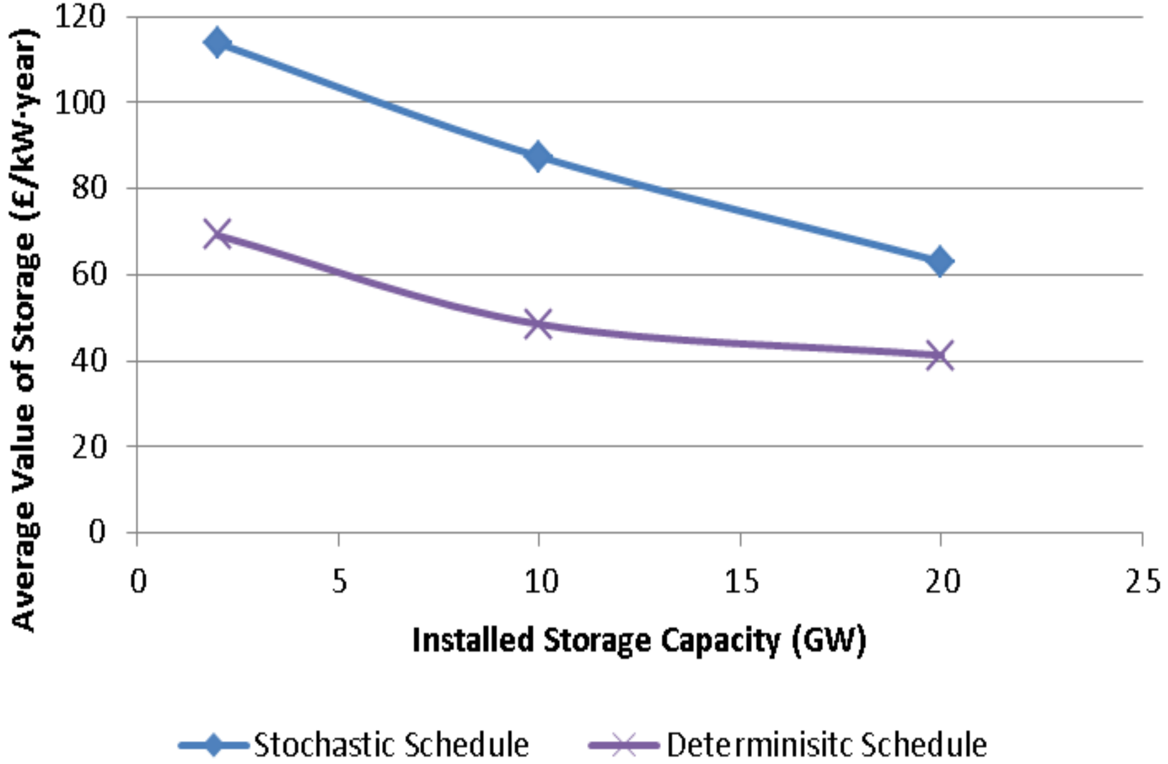


Significant value in enhancing flexibility of conventional gas plant



Will future market adequately reward flexibility?

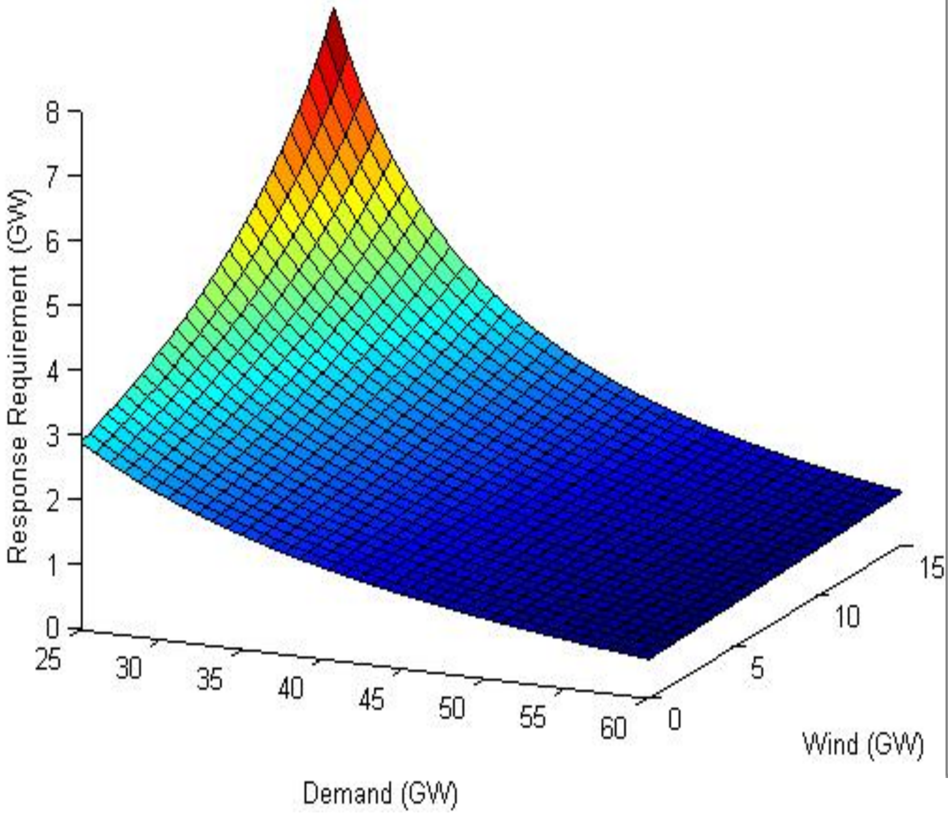
Valuing storage: deterministic v stochastic

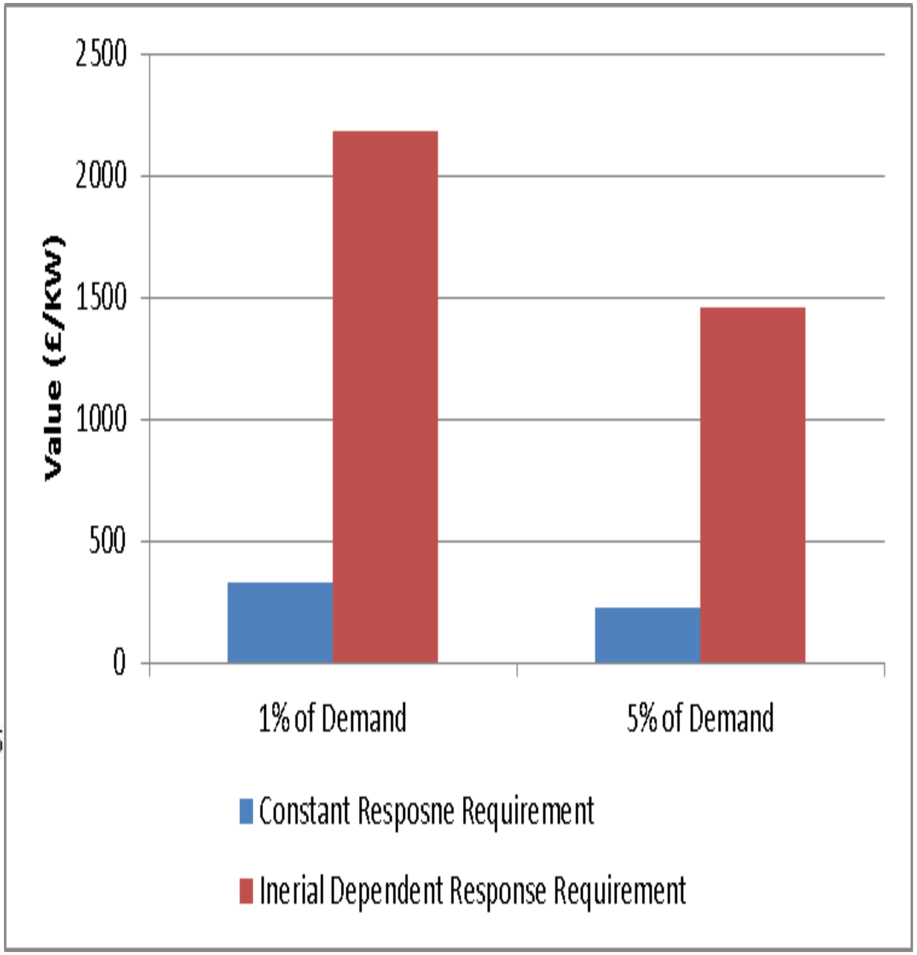


Imperial College London

Reduction in GB system inertia: value of frequency regulation

wholeSEM





SUC informing policy

- There is a significant interest in further developments of market arrangements beyond energy and capacity to include various **reserve** and **response** services.
  - ❖SUC could be applied to assess needs for different flexibility products and provide quantitative evidence to industry, government and regulators regarding the development of incentives / market to facilitate investment in flexibility

Imperial College London

wholeSEM

3. Dynamic Transmission Investment Model – DTIM

Imperial College London

wholeSEM

DTIM: Future investment in Transmission

- *Unprecedented scale* of expected investment in on- and offshore transmission and interconnection
- *Significant uncertainty* in level, location and timing of connection of new generation

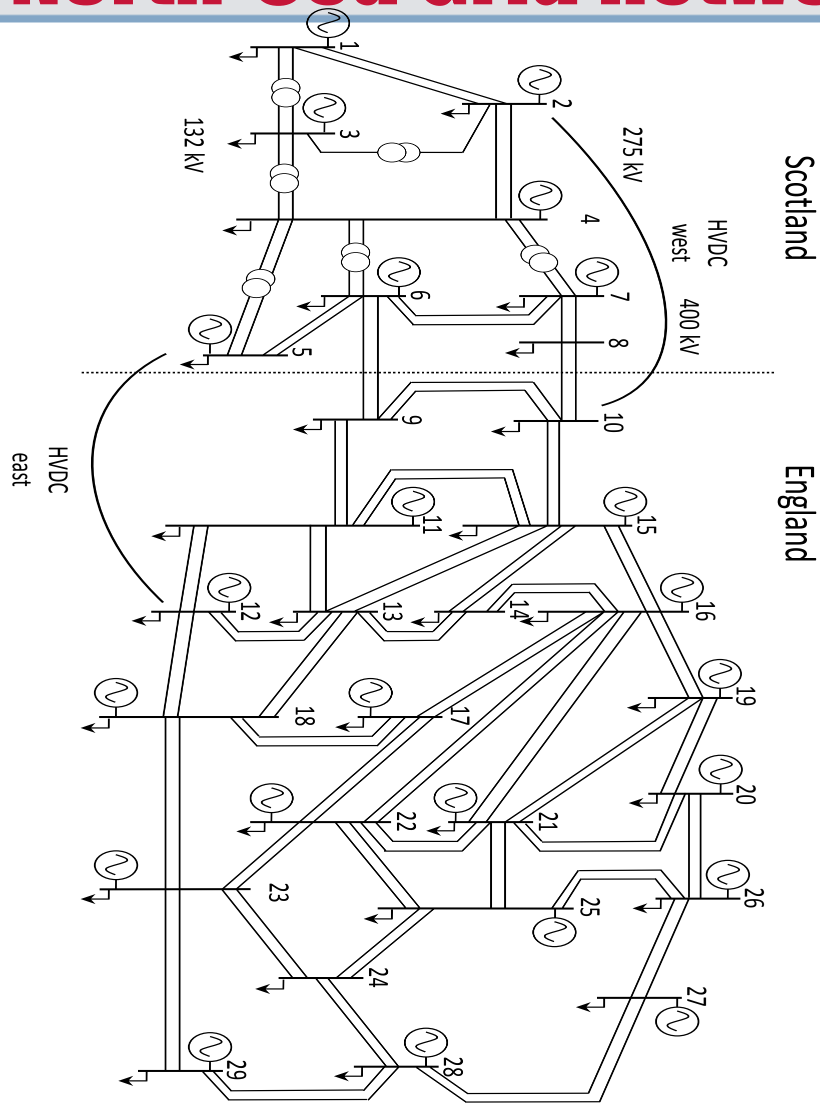
	Current value (£bn)	Expected Investment (£bn)
Onshore	8.4	6.2 – 12.4
Offshore	2.5	8 - 20
Interconnection	2	8 - 20

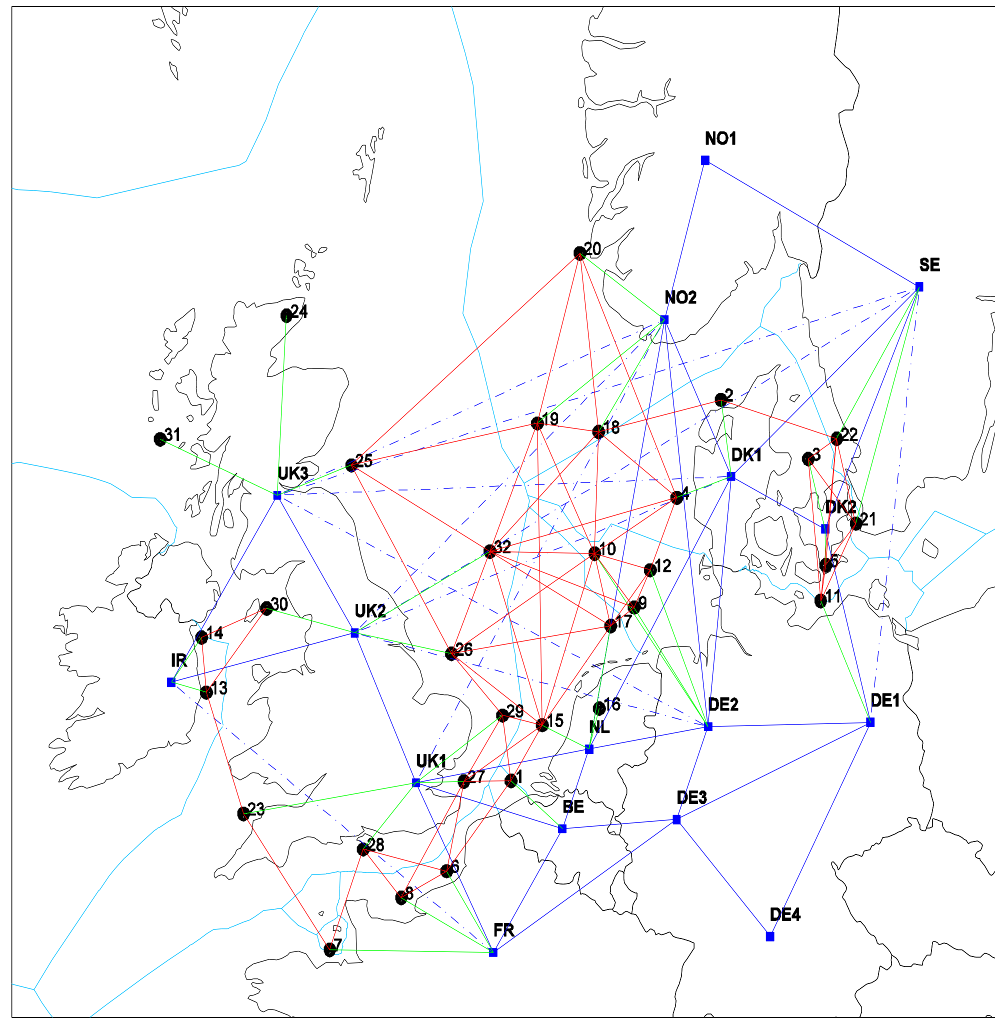
Informing policy and regulation

- Alternative approaches to developing GB transmission system and North Sea Grid infrastructure:
  - ***Incremental or Strategic***
  - ***Proactive or reactive***
  - ***Asset heavy or Smart***
- Dealing with uncertainty:
  - ***Benefits of a minimum regret approach***

Imperial College London

DTIM – GB transmission system and North-Sea Grid network





Example application: *does the network deliver good value for money to network users?*

- *How much network capacity is released to network users?*
- *What VoLL justifies the existing network security standards?*

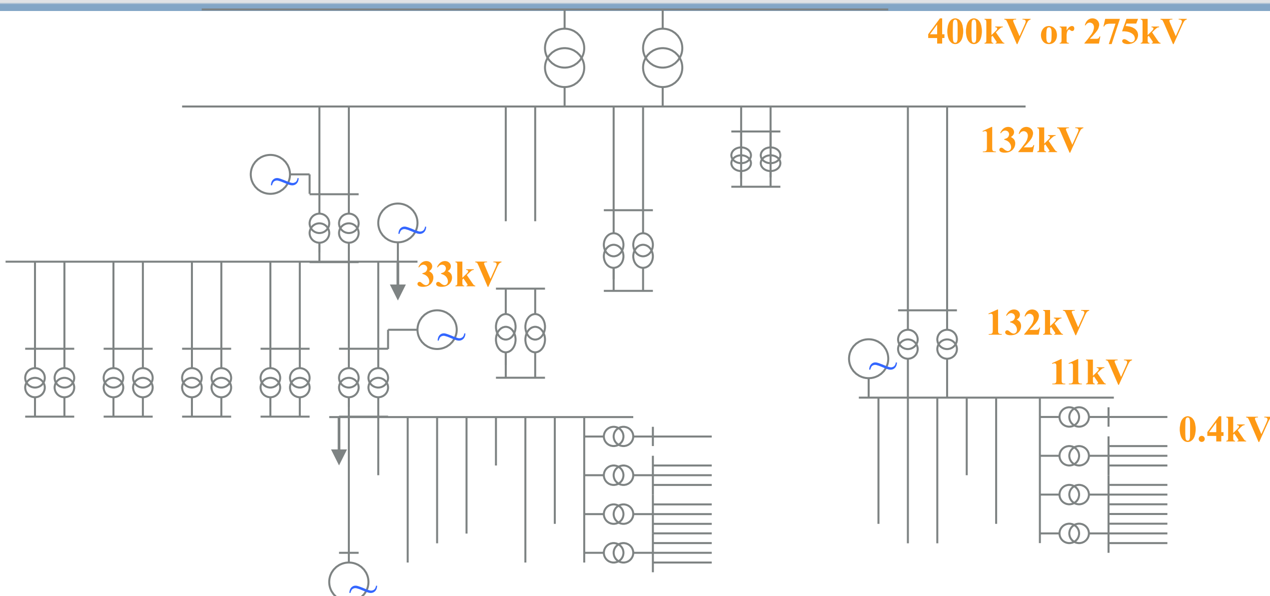
Wind output	Fair Weather Condition	Adverse Weather Condition
5.5 GW	3,000,000 £/MWh	100,000 £/MWh
>7.5 GW	27,000,000 £/MWh	810,000 £/MWh

Scope for further application and enhancement of DTIM

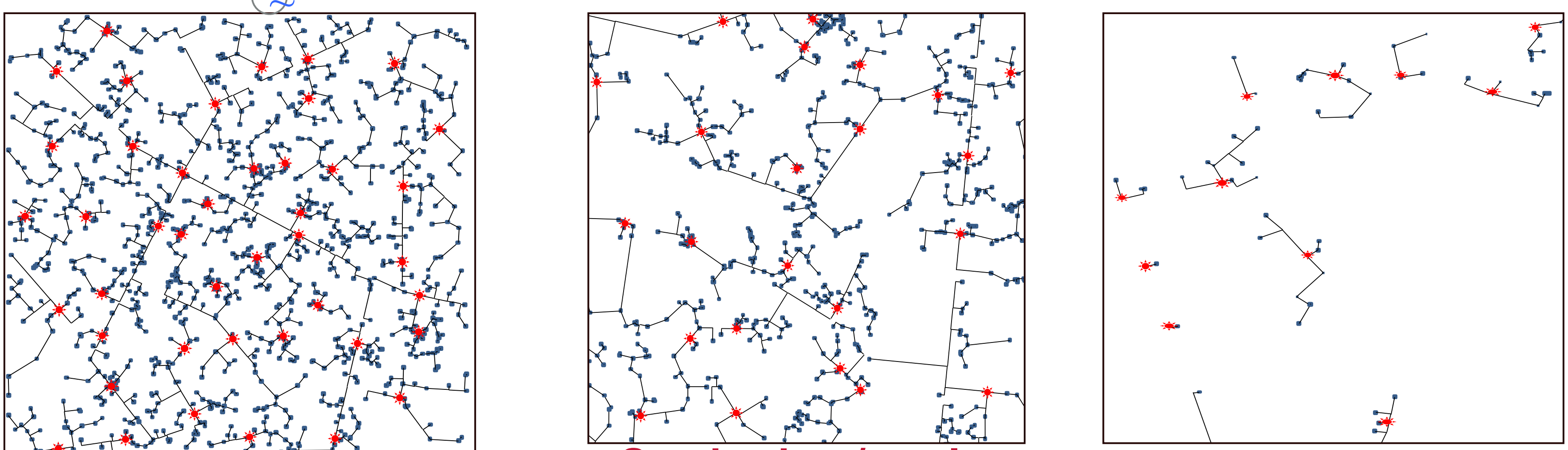
- Cost of the present silo approach?
- Incorporating flexible grid technologies such as FACTS and HVDC combined with DSR
- Allocation of of various reserve services across interconnected transmission – *evidence for benefits of developing cross-border reserve market*
- *Strategic development of North Sea Grid and Interconnection*
- Coordinated planning of electricity, gas and hydrogen infrastructures.

4. Distribution Network Planning Model - *DistPlan*

Distribution Network Planning model (DistPlan)

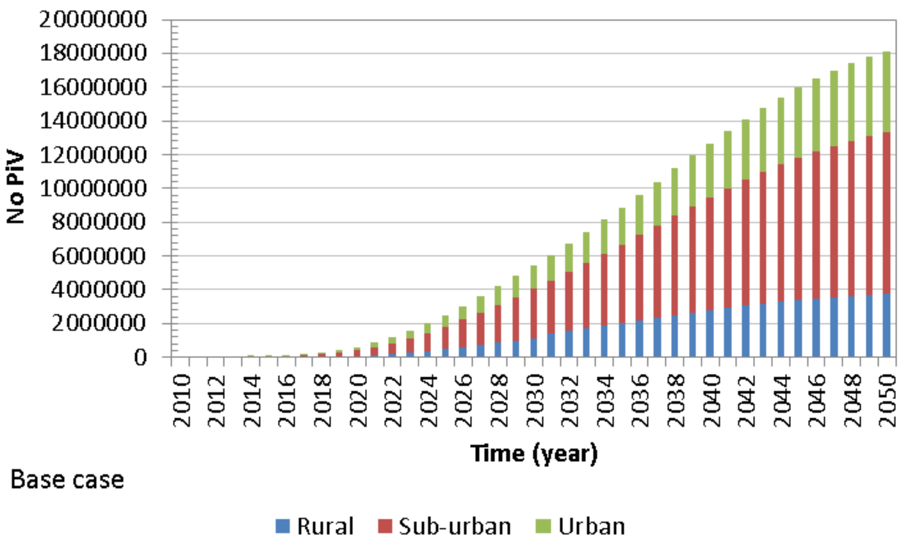


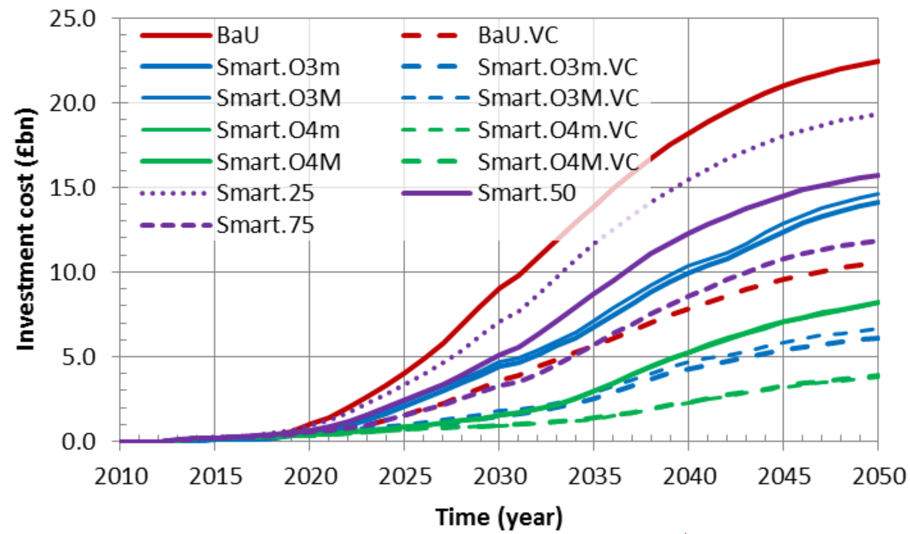
DistPlan representative distribution network models are used to assess the cost and benefits of alternative network operation and reinforcement strategies



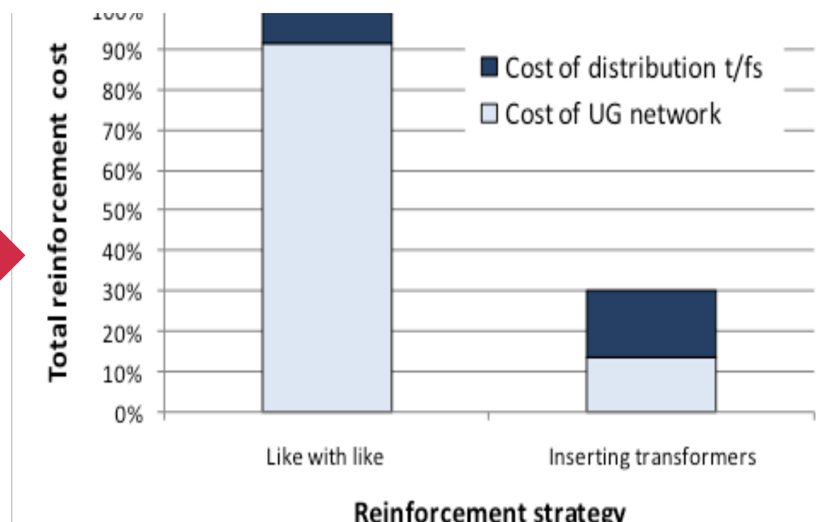
Imperial College London

Example applications-impact of heat and transport sector electrification





Strategic or incremental



Smart or asset heavy

Enhancing DistPlan

- Update of distribution network planning standard to incorporate smart grid technologies
- *Strong interest in combined heat, gas and electricity network planning* reinforced by various emerging energy conversion and storage technologies to support national energy objectives

Imperial College London

wholeSEM

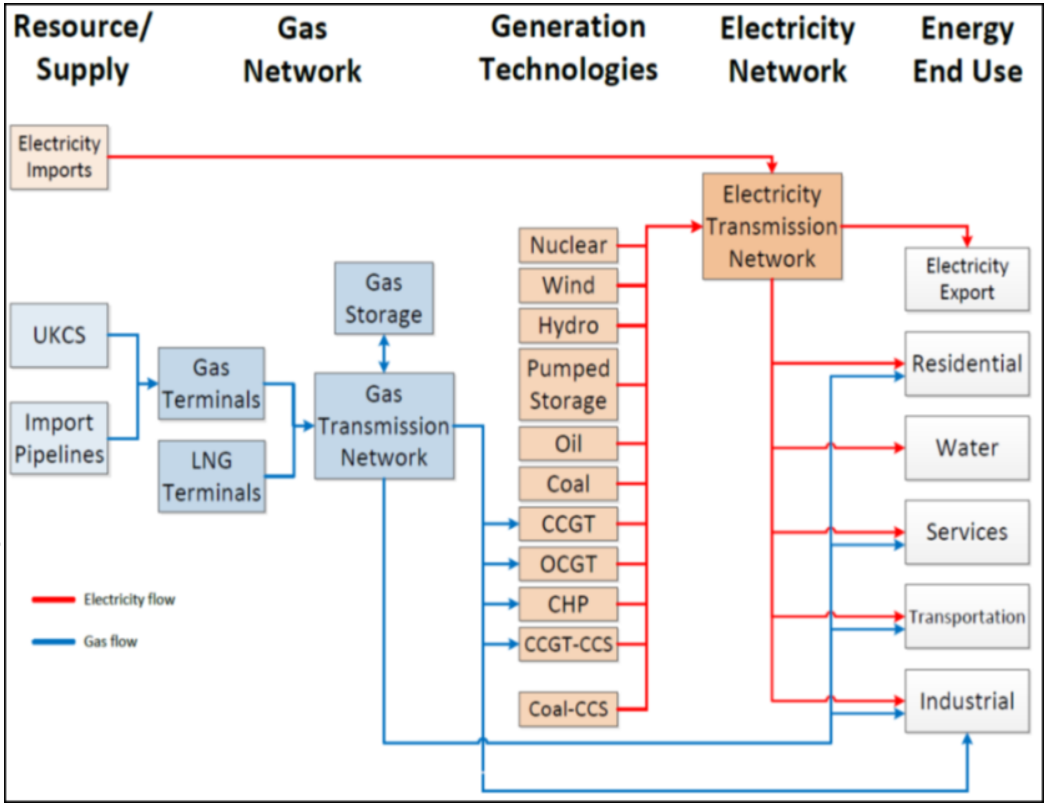
5. Combined Gas and Electricity Network model – *CGEN*

Imperial College London

wholeSEM

Objectives and Scope of CGEN

- Determines where, when, what type and how much capacity need to be built, subject to: meeting energy demand, CO2 target (if set) and any other constraints
- Investigates impacts of a particular strategy on both networks (e.g. impact of GB shale gas exploitation on the gas import and generation mix)

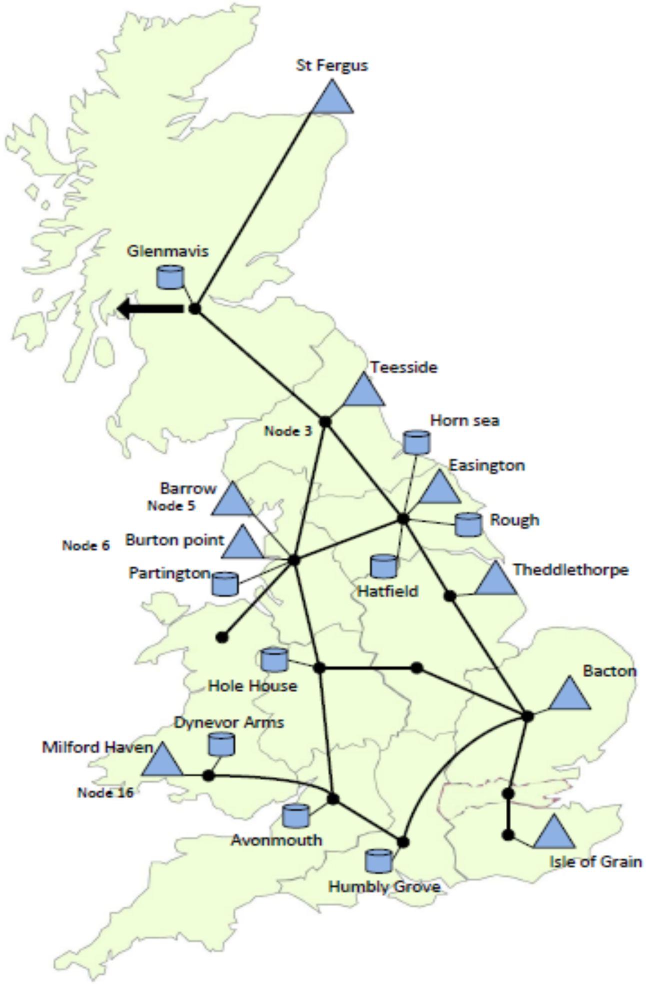


Imperial College London

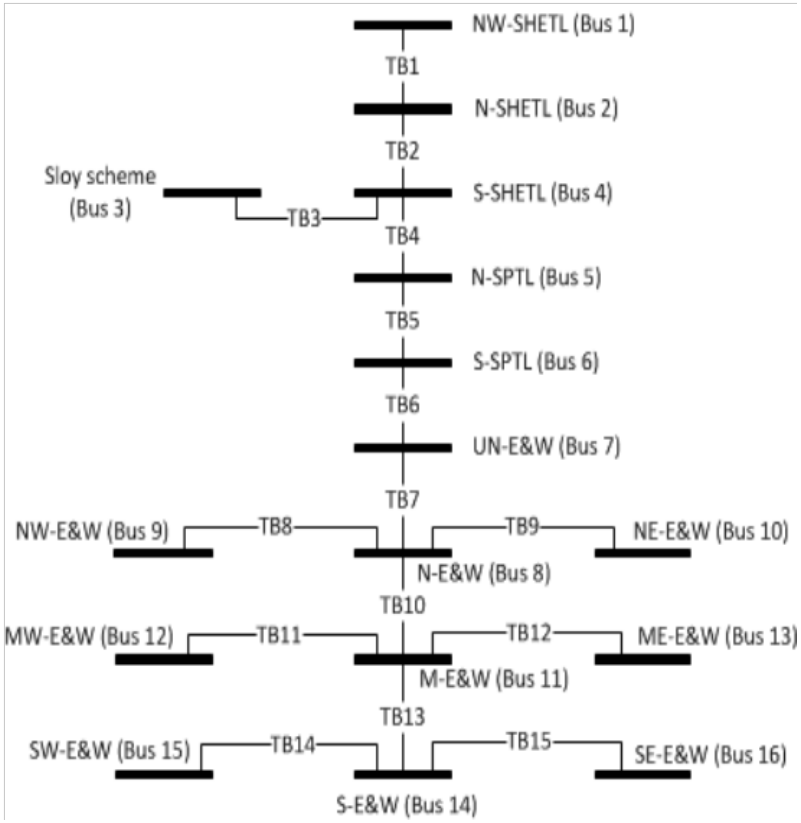
CGEN: GB gas and electricity networks

wholeSEM

Simplified GB gas network

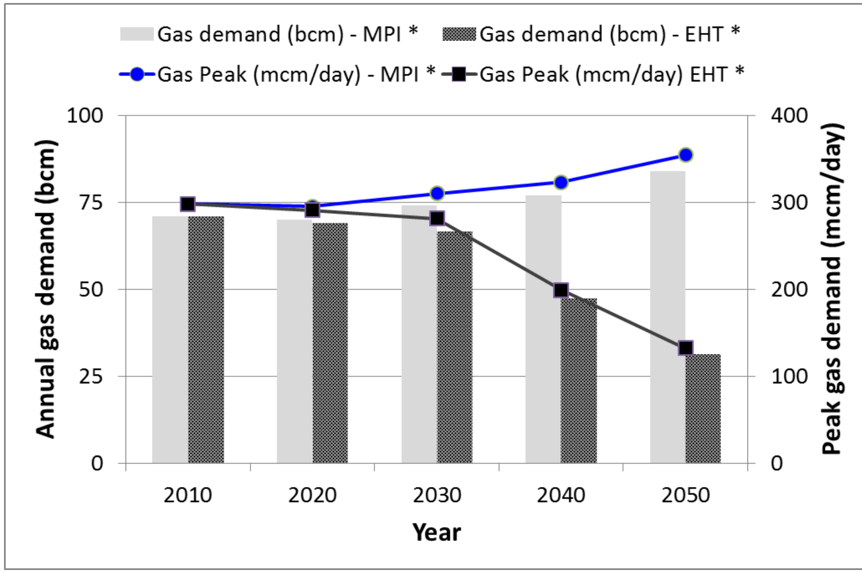


Simplified GB electricity network



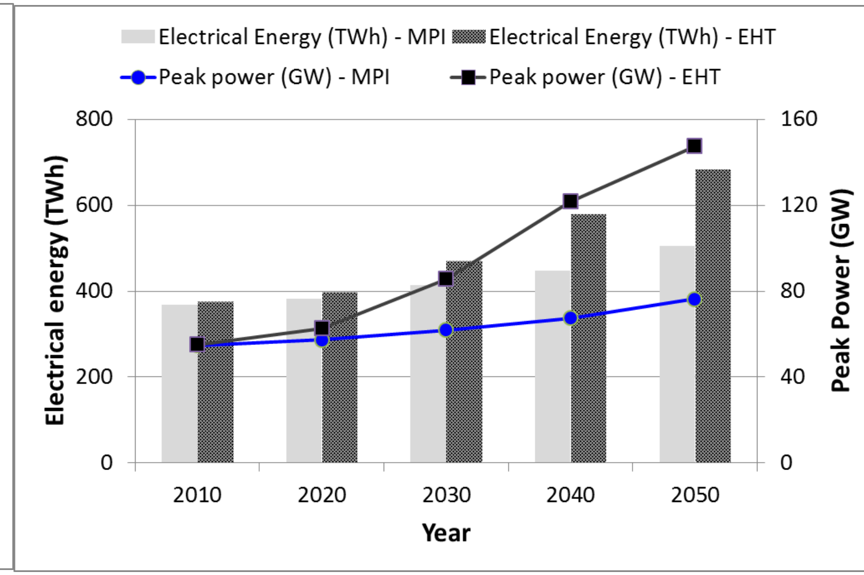
Energy and peak demand for gas and electricity

Annual and peak gas demand



- Electrification of heat sector significantly reduces the gas demand

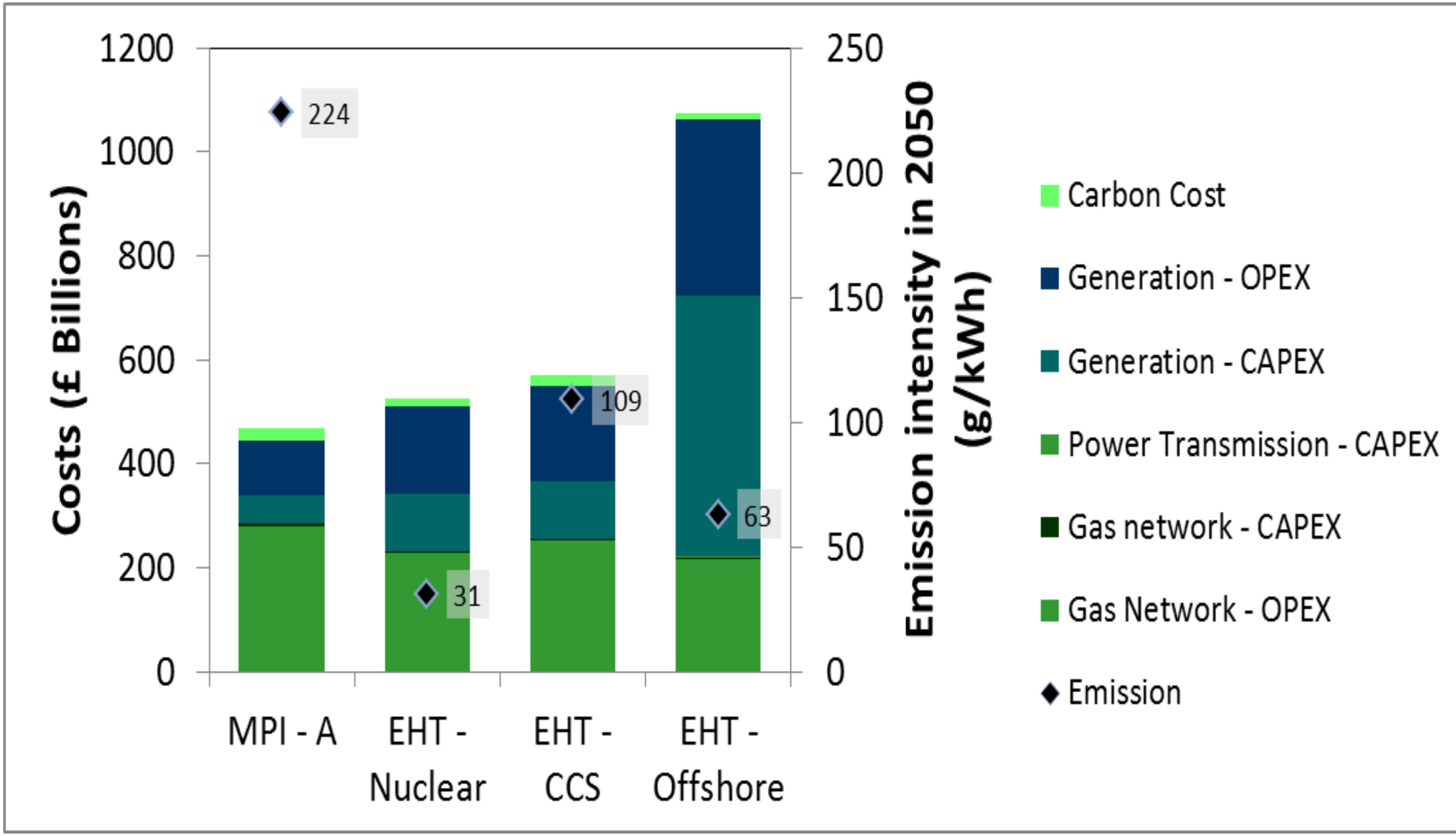
Annual and peak electricity demand



- Electrification of heat and transport sectors doubles the peak electricity demand

Imperial College London

Cost and CO2 intensity



Imperial College London

Areas for further development

- Planning under energy demand and fuel price uncertainties
- Exploring power-to-gas systems (e.g. H2 electrolysers) to CGEN+ to investigate the possibility of using the GB gas network to mitigate impact of intermittency of wind generation

Imperial College London

wholeSEM

Modelling of Smart Low-carbon Electricity Systems

Goran Strbac, Rodrigo Moreno, Maysam Quadrdan,
Dimitrios Papadaskalopoulos, Ioannis Konstantelos,
Predrag Djapic, Fei Teng, Marko Aunedi, Danny Pudjianto

March 2014