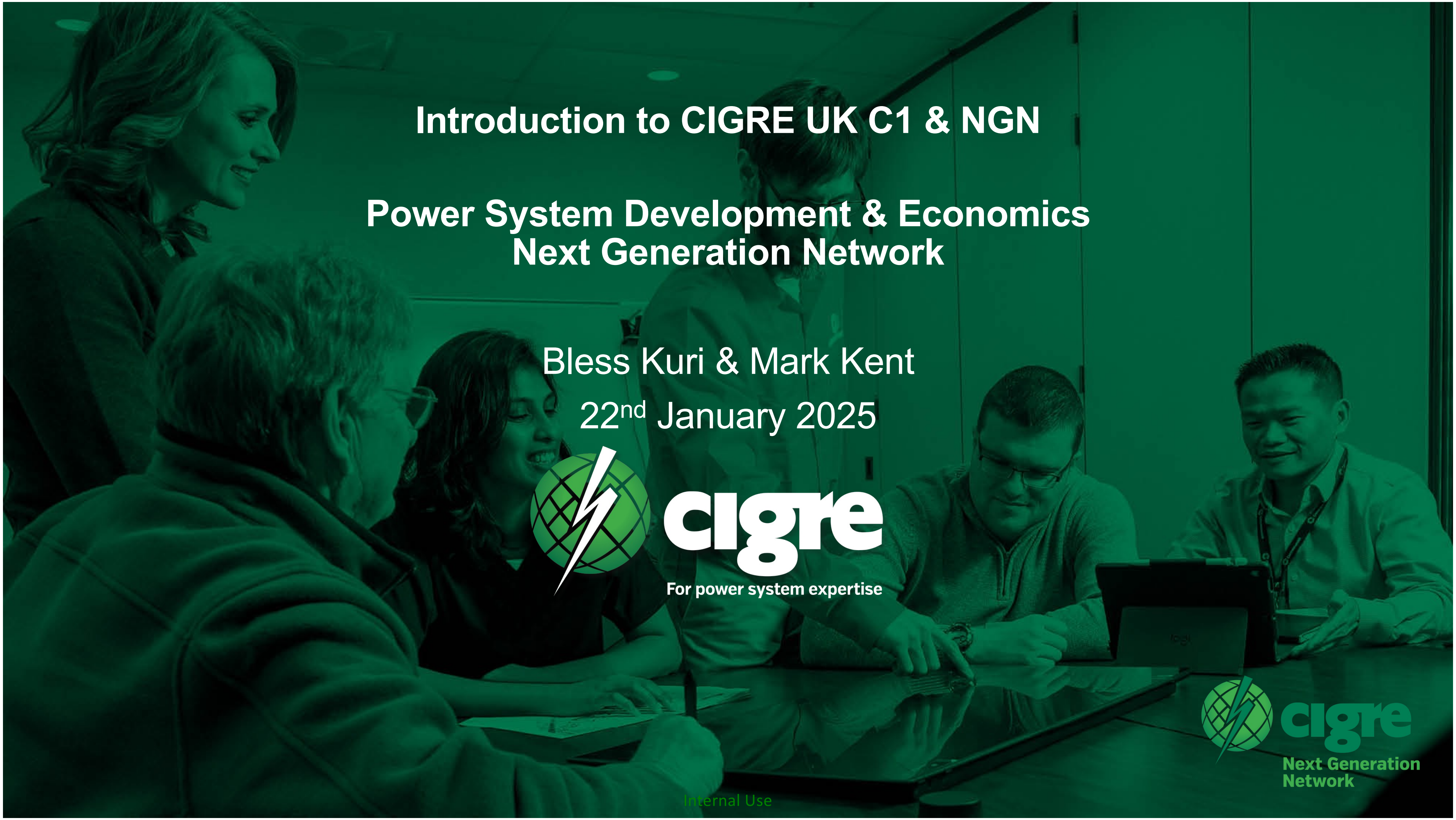

Introduction to CIGRE UK C1 & NGN

Power System Development & Economics
Next Generation Network

Bless Kuri & Mark Kent

22nd January 2025

For power system expertise

Next Generation Network

About the

CIGRE UK
Next Generation Network (NGN)

Who are we?

- A professional network for students & young engineers in the power industry
- To engage with CIGRE's activities ("The Gateway to CIGRE")
- To develop knowledge, skills and contacts within the power industry.

How can I get involved?

- Become a CIGRE UK NGN member (Send an email to chair@cigre-ngn-uk.org or follow the instructions at https://cigre.org.uk/ngn/join-ngn/)
  - Free for students & first 3 years for young professionals
- Participate in NGN events (Technical webinars, site visits, educational events)
- Get involved in CIGRE activities (Join international Working Groups, Attend CIGRE conferences)
- Become a CIGRE UK NGN committee member

cigre
For power system expertise

THE PLACE OF USEFUL LEARNING www.strath.ac.uk/engineering

How far does the power need to go?

GB transmission network development to accommodate renewables

Keith Bell
Holder of the ScottishPower Chair in Future Power Systems
at the *University of Strathclyde*
and a co-Director of the *UK Energy Research Centre*
http://www.strath.ac.uk/staff/bellkeithprof/

Simon Gill
Founder and owner of *The Energy Landscape*
and an associate of *Regen*

CIGRE UK webinar, January 22nd 2025

Acknowledgements

- This project was conducted by Simon Gill of *The Energy Landscape* and Keith Bell of *University of Strathclyde* in early 2024 on behalf of the *Offshore Renewable Energy Catapult* which funded the work.
  - Many thanks to Paul McKeever*, Andrew Jamieson*, Chong Ng, Dai Lewis and Michael Smailes for their support
- Many thanks to *CIGRE UK* for the opportunity to present the work.
- Many thanks to Shanay Skellern and Callum MacIver at *University of Strathclyde* for their help with scenario construction.
- Full report available: https://pureportal.strath.ac.uk/en/publications/how-far-does-the-power-need-to-go-the-impact-of-gb-wide-transmiss

CATAPULT Offshore Renewable Energy

cigre United Kingdom | National Committee of the United Kingdom

* Paul McKeever and Andrew Jamieson are ex-ORE Catapult

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Transmission planning in GB today: a fog of complexity?

ofgem
Making a positive difference
for energy consumers

Decision on accelerating onshore electricity transmission investment

Publication date:	15 December 2022
Contact:	RIIO team
Team:	Networks
Telephone:	020 7901 7000
Email:	RIIOElectricityTransmission@ofgem.gov.uk

July 2024
Future Energy Scenarios:
ESO Pathways to Net Zero
ESO

July 2022
Pathway to 2030
A holistic network design to support offshore wind deployment for net zero

March 2024
Beyond 2030
A national blueprint for a decarbonised electricity system in Great Britain
ESO

Department for Energy Security & Net Zero
Strategic Spatial Energy Plan
Commission to the National Energy System Operator
October 2024

Clean Power 2030
Advice on achieving clean power for Great Britain by 2030
NESO National Energy System Operator

Figure A4: GB Existing Transmission System

Supply & demand modelling and planning

- Credible future energy scenarios
- Strategic Spatial Energy Plan: “**will determine the optimal mix, scale and location of generation infrastructure to transition to homegrown energy**”

Identify system need

- Identify developments needed to comply with the Security and Quality of Supply Standard (SQSS)

Identify options

- “FSO, TOs and third parties identify a range of options to address network needs
- “Includes network, non-network solutions, or wider strategic energy system solutions”

Cost-benefit analysis

- “FSO carries out an appraisal of the technical, economic, social and environmental aspects of each option to form a strategic plan to 2050”

Develop a CSNP

- economic, efficient, deliverable, and operable
- compliant with the SQSS
- has acceptable impacts, on environment and communities
- facilitates decarbonisation

Handover to delivery body

- The delivery body may be the TOs or third parties
- Provide advice and guidance on strategic energy system solutions to government and Ofgem

https://www.ofgem.gov.uk/publications/decision-framework-future-system-operators-centralised-strategic-network-plan

Think, Plan, Design, Deliver

Similarities between today and the early 1960s

- A strategic energy system challenge
- An abundance of options
- Strong spatial dependencies
- The need to explore a wide range of options quickly
- Value in understanding national trends at a high level before diving into the detail
- The need to explain and draw in a wider range of stakeholders

By the time these children are ten years older, Britain's power demands will have doubled. But the number of transmission towers will *not* have doubled. On the contrary—because the Central Electricity Generating Board is adopting 400,000 volt transmission, fewer new towers will be needed. The new power system will use some existing towers, suitably reinforced, and a limited number of new, slightly taller ones. By Act of Parliament, the C.E.G.B. must provide an efficient, economical electricity supply, while preserving visual amenity as far as possible.

who make and supply electricity to
12 Area Electricity Boards in England and Wales
(which re-sell to consumers) and British Railways.

621.311.1

The Institution of Electrical Engineers
Paper No. 3883 S
Mar. 1962
©

THE 400kV GRID SYSTEM FOR ENGLAND AND WALES

By E. S. BOOTH, M.Eng., M.I.Mech.E., Member, D. CLARK, B.Sc.(Eng.), Associate Member,
J. L. EGGINTON, B.Sc., Member, and J. S. FORREST, M.A., D.Sc., Member.

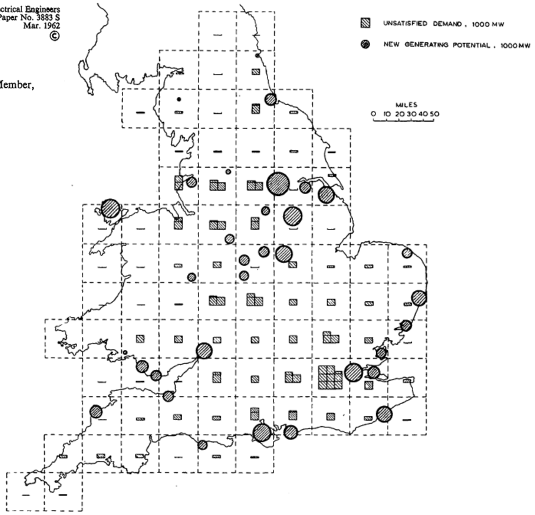


Fig. 1.—Pattern of unsatisfied demand and new generating potential.

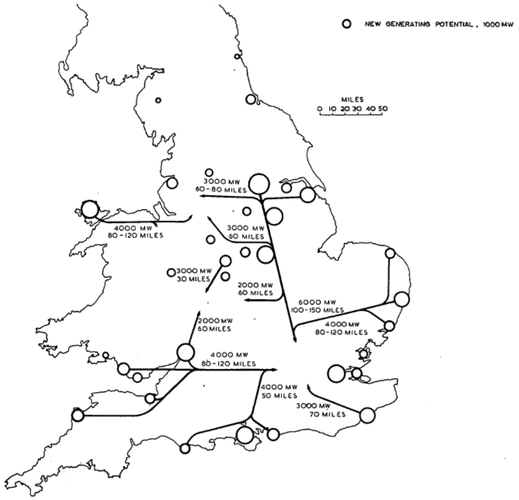


Fig. 2.—Principal power flows.

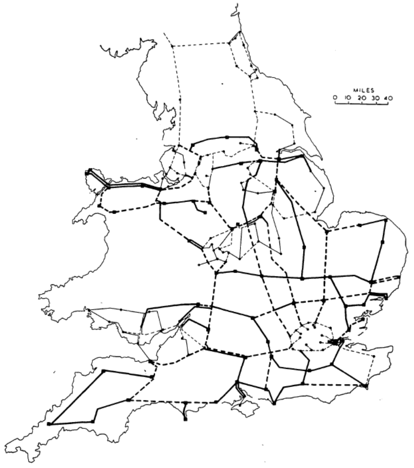
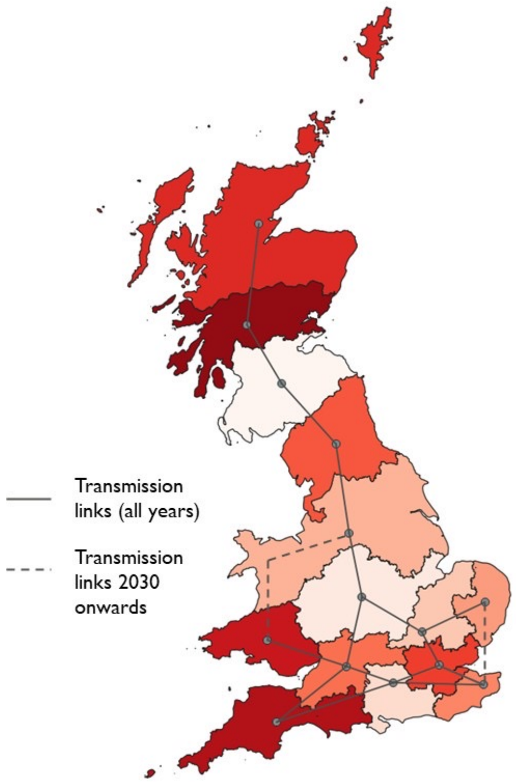


Fig. 4.—Geographical layout of 400kV network.

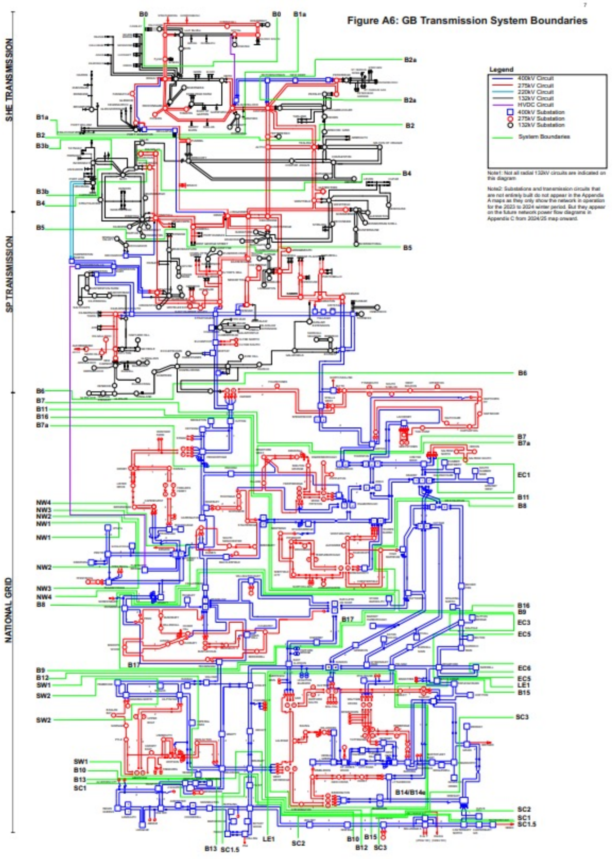
275kV	400kV	
- - - -		Existing and planned for 1964.
	▪ ▪ ▪ ▪	Converted.
——	━━	New.
●	■	Switching stations.

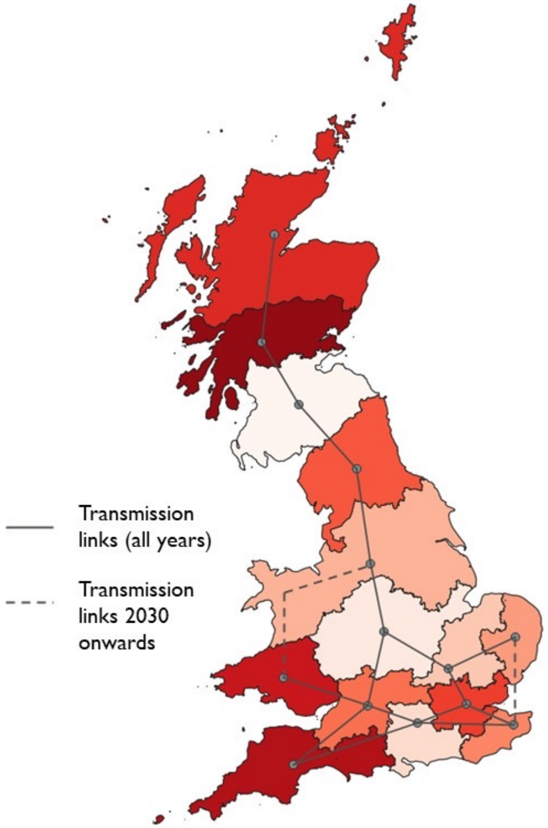
The model

- For this project, GB system split into 14 zones connected by 16 transmission links (18 from 2030) each representing inter-area transfers on the main interconnected transmission system (MITS)
- Within each zone there are a number of resources:
  - Fixed demand (hourly time series)
  - Schedulable generation, some of which is inflexible
  - Variable renewable generation (spatially and temporally correlated hourly availability time series for: onshore wind, offshore wind and solar)
  - Interconnection (capacity, country of connection)
  - Electrolysis demand (capacity connected)
  - Energy storage and flexible demand (considered but off model)
- Uses a cost minimisation to mimic the operation of a centralised zonal wholesale market
  - meet fixed demand subject to: energy balance, power flow limits, maximum generation (or flexible demand limits), interconnection max / min.
- The model is run for each of the 8760 hours of a year.
- Branches: represent inter-area transfers.
  - Branch limits chosen to match broad secure boundary ‘capability’.
  - Pseudo impedances used to give a realistic share of power between parallel network connections



What is the network’s capacity to transfer power?



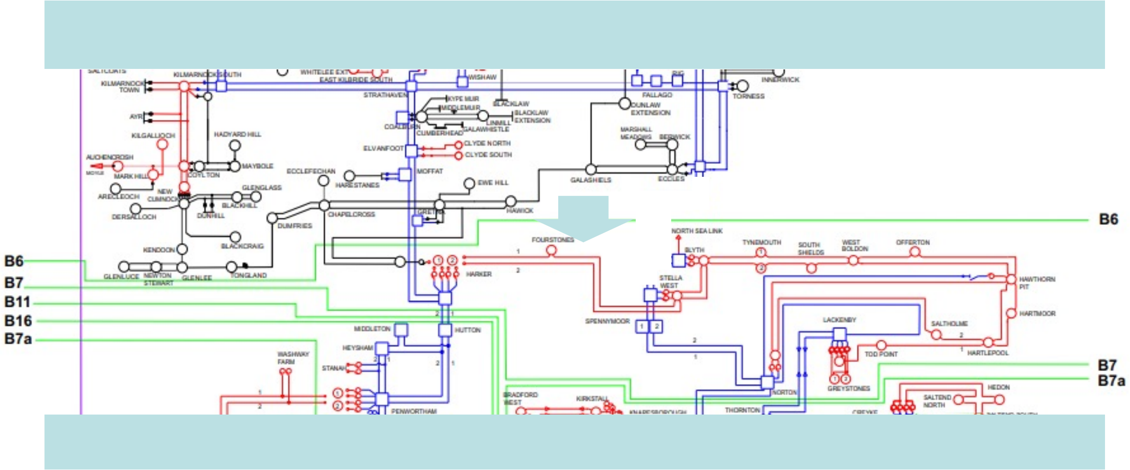


- Zones defined to delineate the main boundaries of the Main Interconnected Transmission System (MITS)
- ‘Bulk’ power transfers on the MITS treated as flowing between the geographical centres of zones
- Branches
  - Placed where there are connections between zones
  - Branch capacities equal to secure boundary transfer capabilities

Network schematic: NESO, Electricity Ten Year Statement 2023, https://www.neso.energy/document/294511/download

What is the network’s capacity to transfer power?

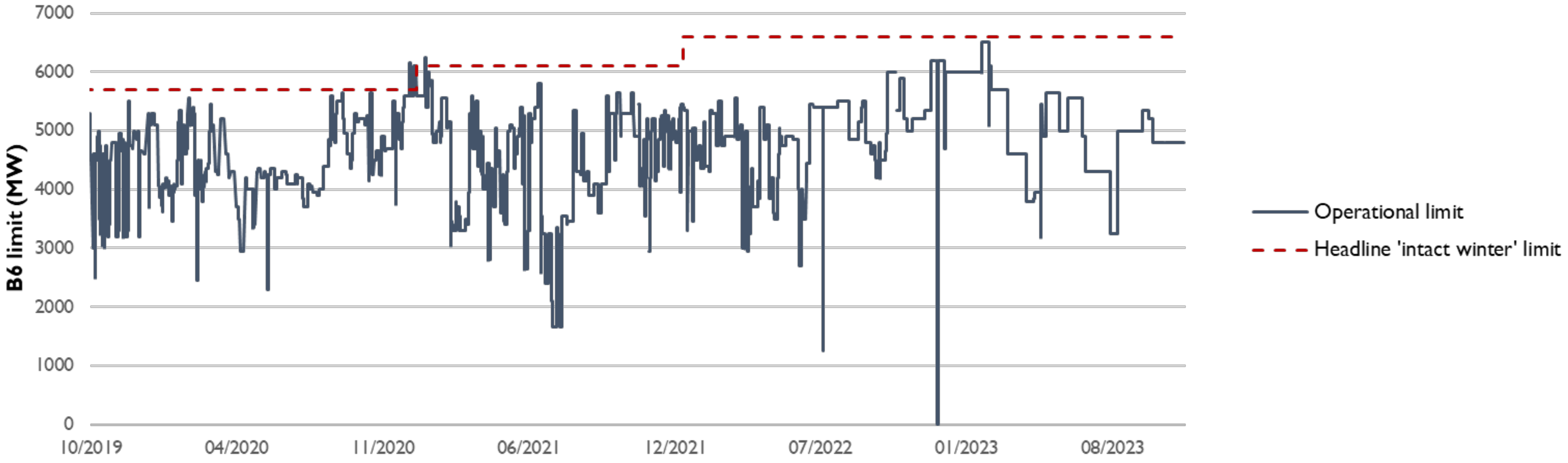
- A ‘secure’ transfer is one where there are no breaches of operational limits even after a ‘secured event’
  - fault outage of a single circuit, double circuit, bus section, generating unit, interconnector, reactive compensator
- Must be true for prevailing conditions regardless of which ‘secured event’
  - Different permitted outcomes depending on the secured event
- A secure boundary transfer capability is the total power that can flow across a boundary while being secure.
- The System Operator may to have change the pre-fault conditions in order for the system to be secure.
- Various NESO documents quote a “secure transfer capability” for key network boundaries, e.g. Electricity Ten Year Statement (ETYS)



- e.g. B6 and the fault outage of the Eccles-Blyth-Stella West circuit: post-fault, the pre-fault power transfer can only flow over the remaining circuits.
  - How much power could flow pre-fault while complying with limits post-fault?
  - Test this for every possible secured event (‘contingency’)
- The secure B6 transfer capability is the maximum pre-fault flow across the boundary among all the secured events

Network schematic: NESO, Electricity Ten Year Statement 2023, https://www.neso.energy/document/294511/download

Beware: the network’s capacity isn’t always what it could be

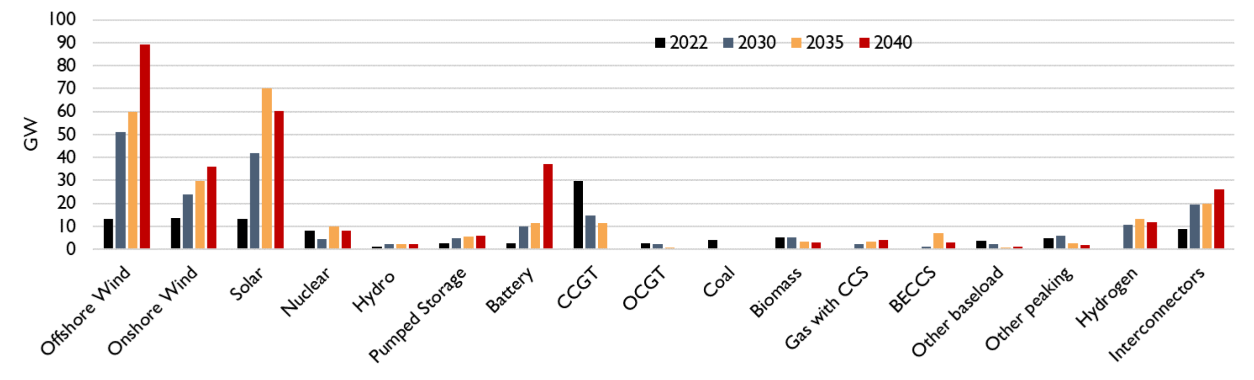


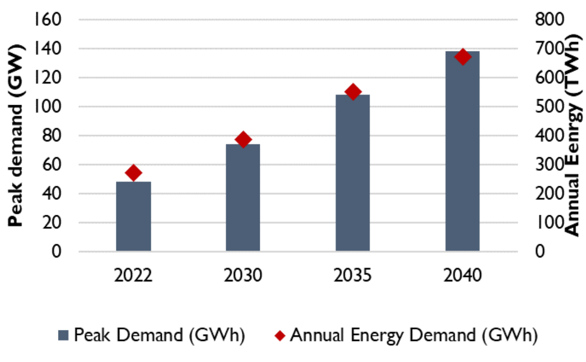
Comparison of the nominal capability of the transmission network to transfer power from Scotland to England across boundary ‘B6’ with the capability actually available on each day in recent years.

(Data from the ESO Electricity Ten Year Statement and ESO data on day ahead constraint flows and limits)

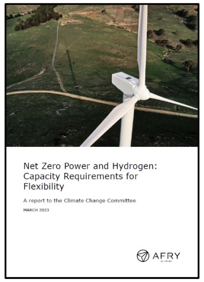
Scenarios for a net zero electricity system

Core Scenarios

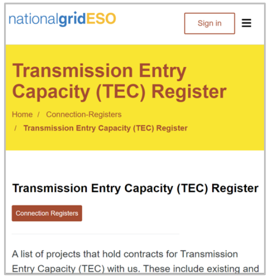




July 2022
Future Energy Scenarios



Net Zero Power and Hydrogen: Capacity Requirements for Flexibility
A report to the Climate Change Committee
MARCH 2023
AFRY



nationalgridESO

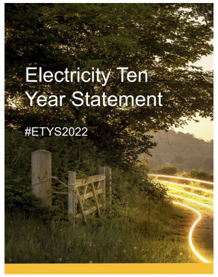
Transmission Entry Capacity (TEC) Register

Home / Connection-Registers / Transmission Entry Capacity (TEC) Register

Transmission Entry Capacity (TEC) Register

Connection Registers

A list of projects that hold contracts for Transmission Entry Capacity (TEC) with us. These include existing and



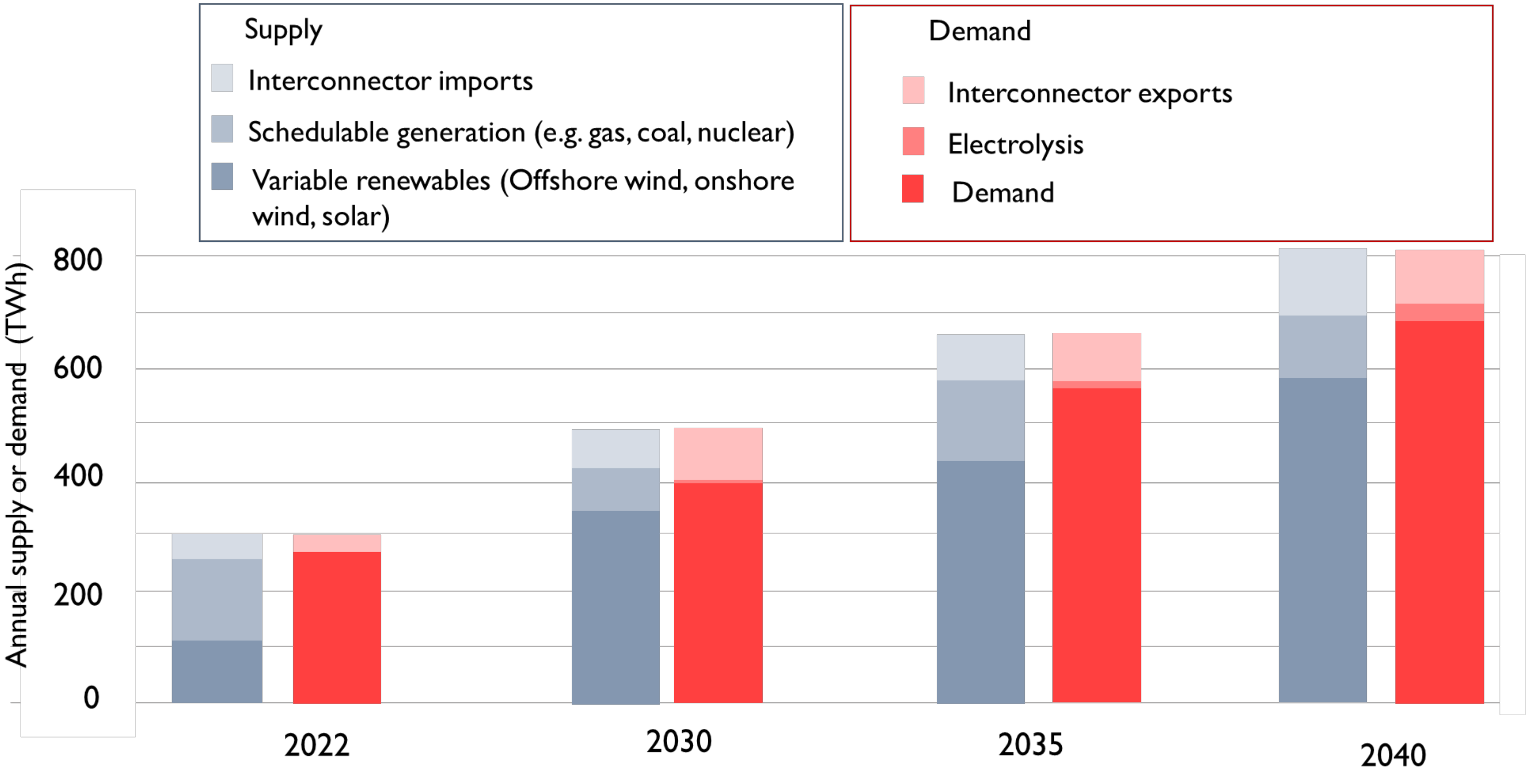
Electricity Ten Year Statement
#ETYS2022

- Total national generation capacities and demand are taken from AFRY work for the CCC, used to inform the CCC's 2035 net zero power system work.
- The scenario falls between NGESO's 'Leading the Way' and 'Consumer Transformation' scenarios. Meets the 2030 50 GW offshore wind target.
- Geographic distribution of generation and demand informed by NGESO FES and the Transmission Entry Capacity Register.
- Base network capacities taken from the Electricity Ten Year Statement.

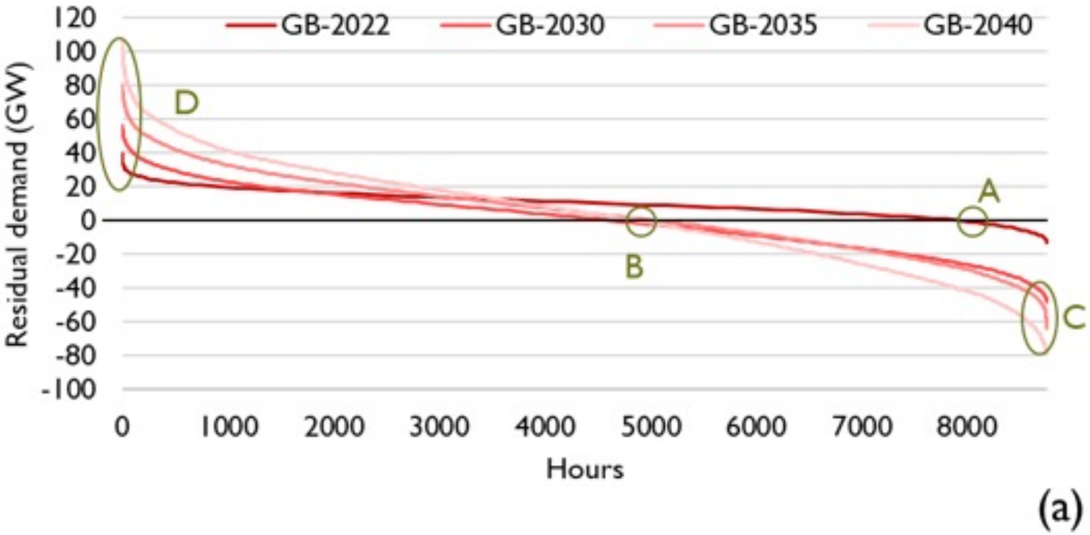
Sensitivities:

- Slower roll out of renewables
- Variation on geographical location (e.g. more offshore wind in the south)
- Impact of interconnection and hydrogen electrolysis demand
- Impact of reduced network capacity (modelling delays and outages)
- "Let the model build transmission" studies
- Impact of storage and demand flexibility

Supply and demand in the scenarios we modelled



Demand, inflexible generation, renewables & residual demand: GB



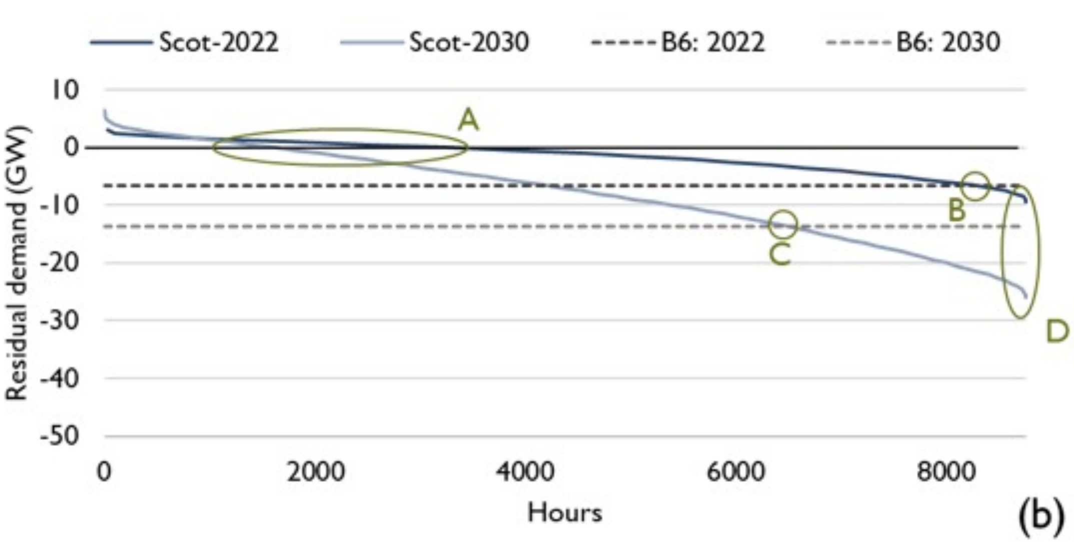
A: In 2022, GB residual demand is positive for 7,966 hours or 91% of the year.

B: By 2030, GB residual demand is positive for 4651 hours, or 53% of the year. This value stays in the range 50% - 60% for the rest of the decade.

C: In 2022, Residual GB demand never falls below -13 GW. In 2030 this becomes more negative, with the minimum value falling to -48 GW. By 2040 it has fallen to -78 GW.

D: In 2022 the maximum residual demand is 34 GW, in 2030 this rises to 57 GW and 106 GW by 2040.

Demand, inflexible generation, renewables & residual demand: Scotland



A: In 2022, Scottish residual demand is positive for 3257 hours or 37% of the year. This falls to 18% in 2030.

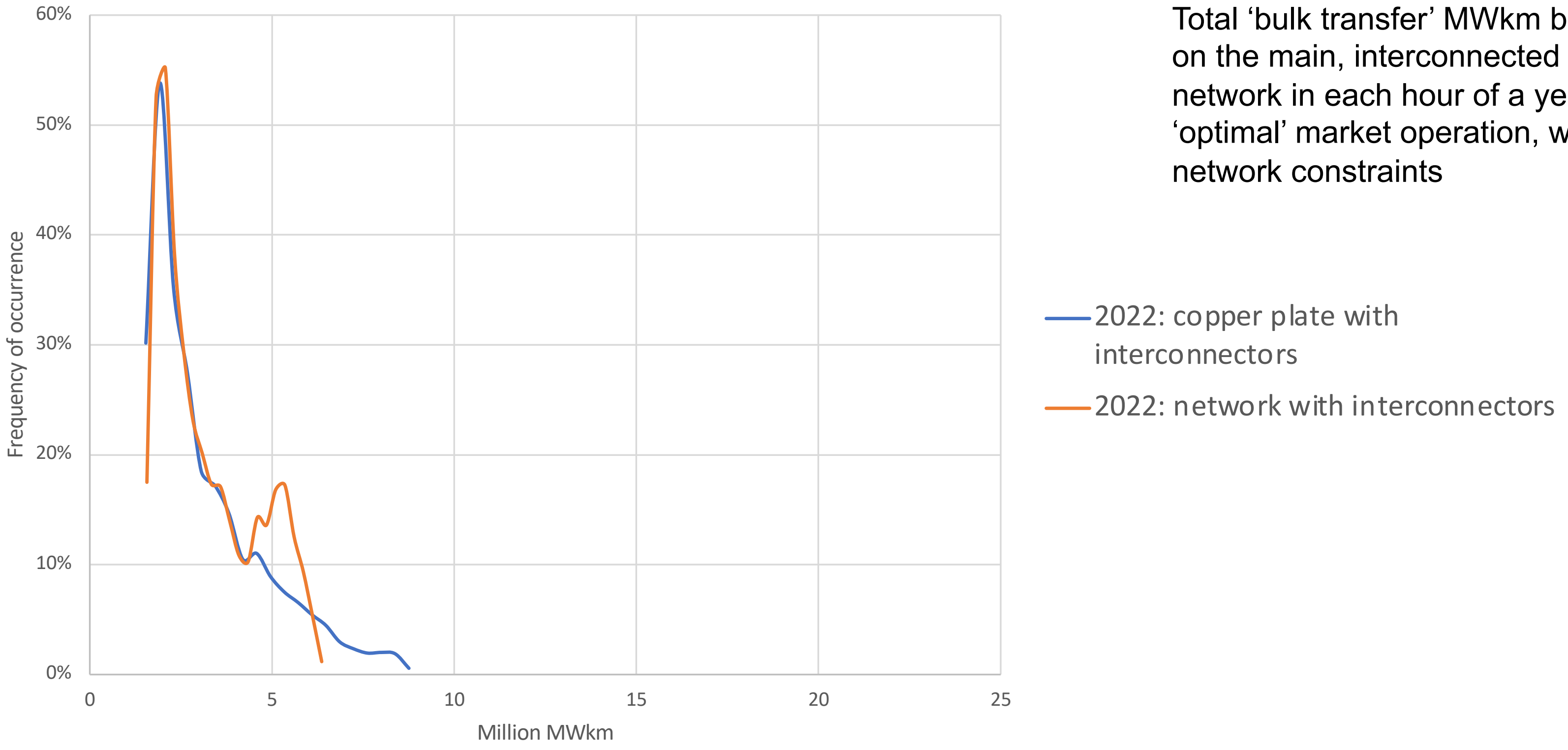
B: In 2022, Scottish residual demand falls below -6.6 GW, the secure transfer capacity of the network to export power, for just over 700 hours, or 8% of the year. The majority of this 'excess' negative residual demand can be managed through flexibility.

C: By 2030, Scottish negative residual demand exceeds the secure transfer capacity during 26% of the year despite the secure boundary capability increasing from 6.6 to13.2 GW.

D: The absolute difference between the minimum residual demand and the secure boundary capability also increases from 3 GW in 2022 to 13 GW in 2030.

Need for the transmission network: how far does how much power travel?

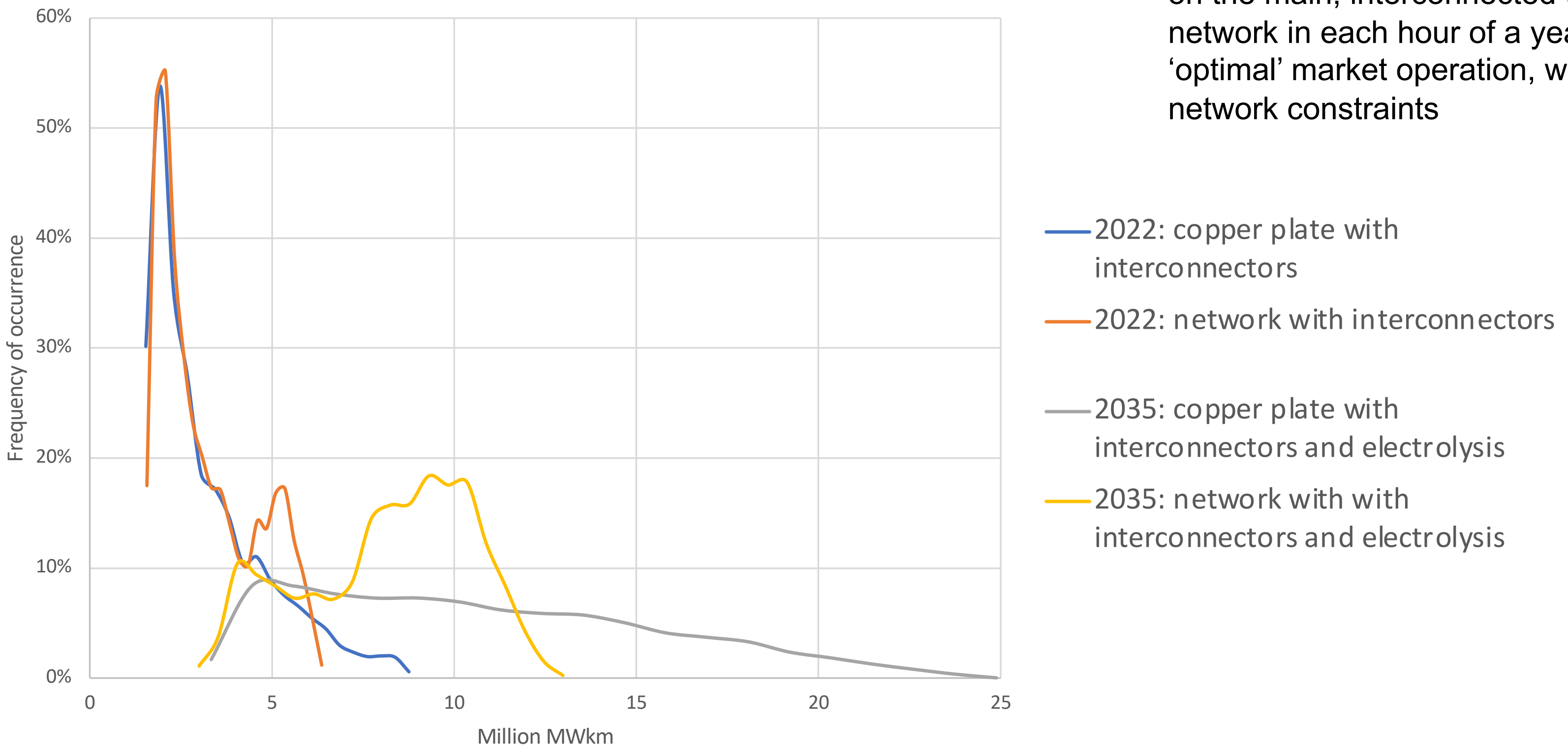
1 MWkm is 1 megawatt of power transferred over a distance of 1 kilometre



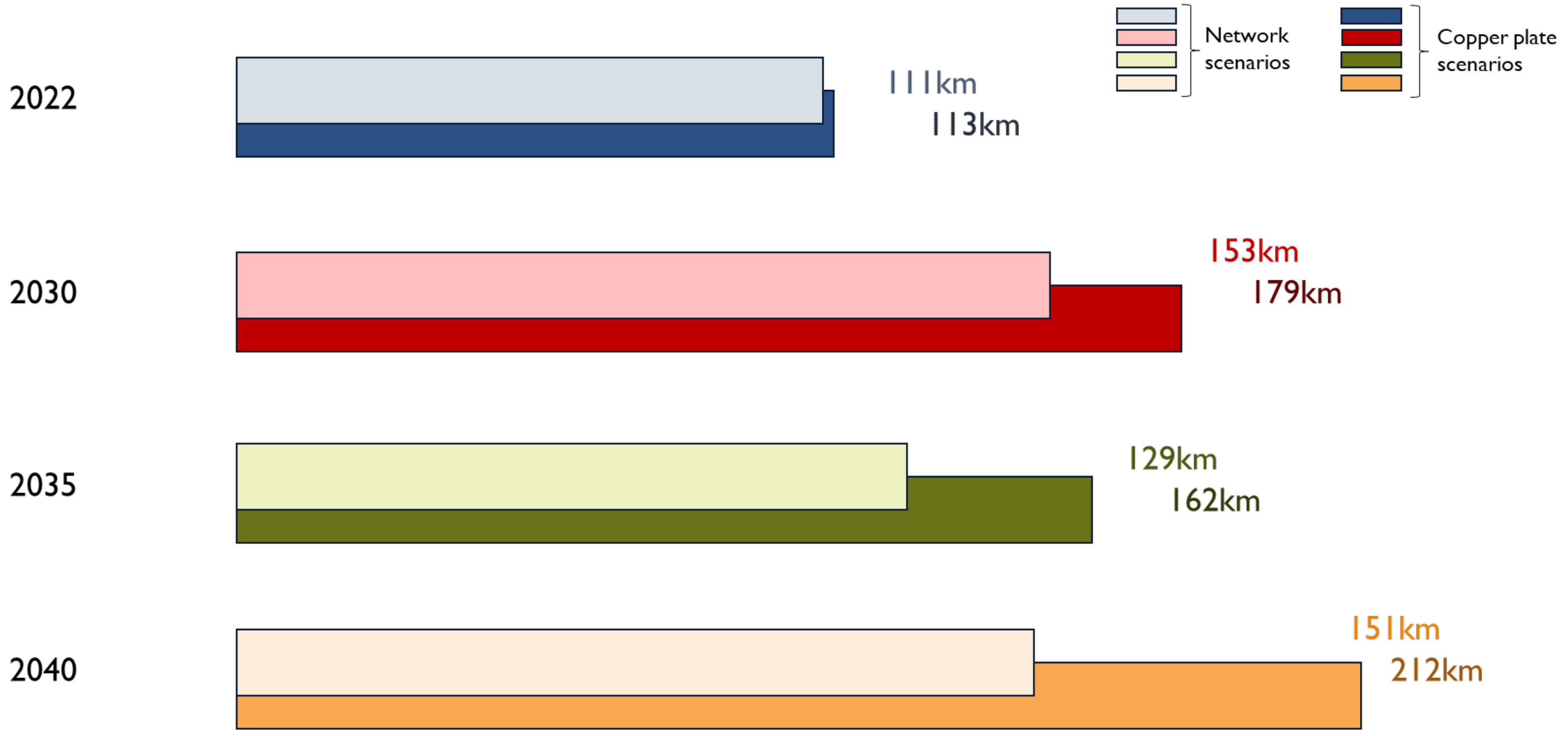
Total ‘bulk transfer’ MWkm between zones on the main, interconnected transmission network in each hour of a year of simulated ‘optimal’ market operation, with and without network constraints

Need for the transmission network: how far does how much power travel?

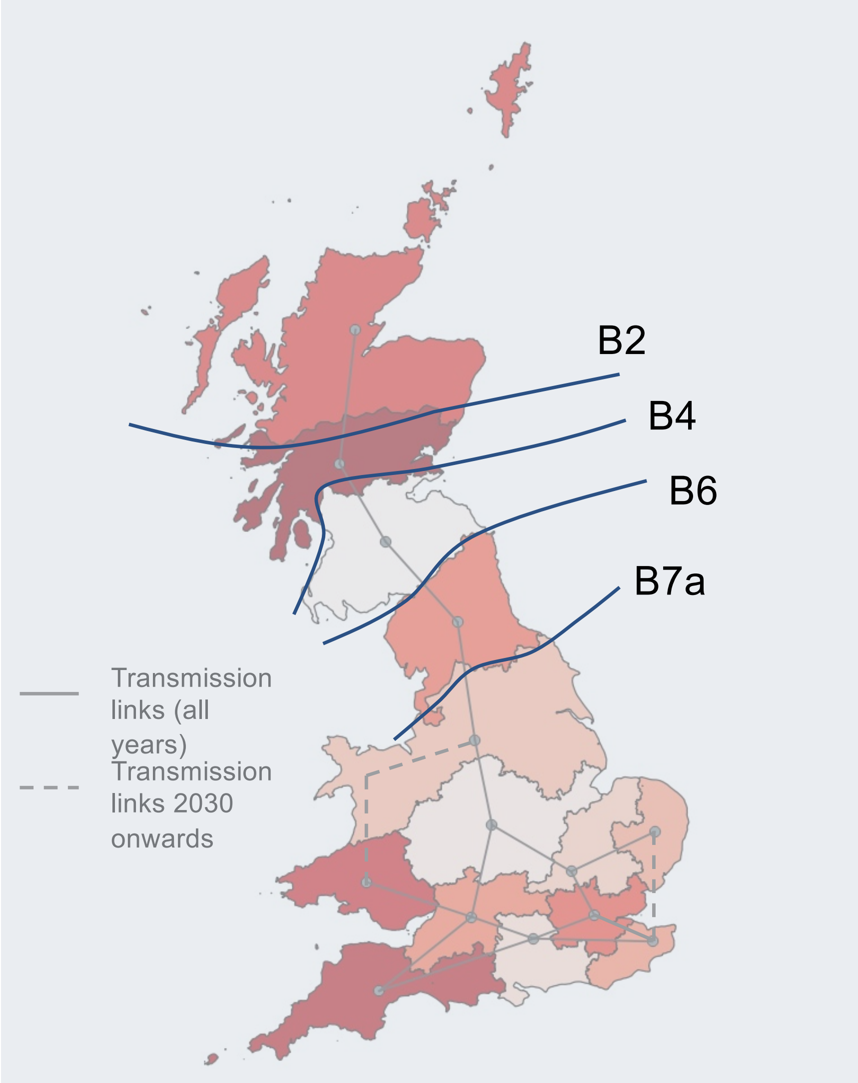
Total ‘bulk transfer’ MWkm between zones on the main, interconnected transmission network in each hour of a year of simulated ‘optimal’ market operation, with and without network constraints



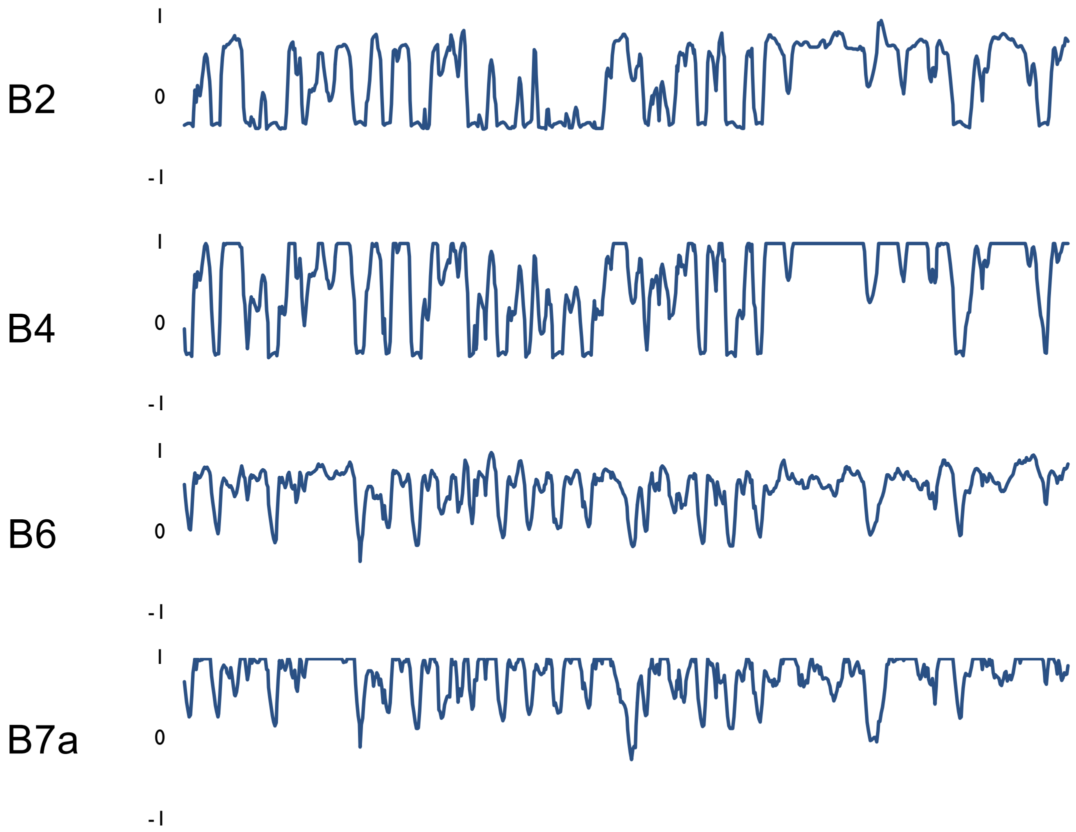
The average distance travelled by each MWh of electrical energy on the ‘bulk’ transmission network



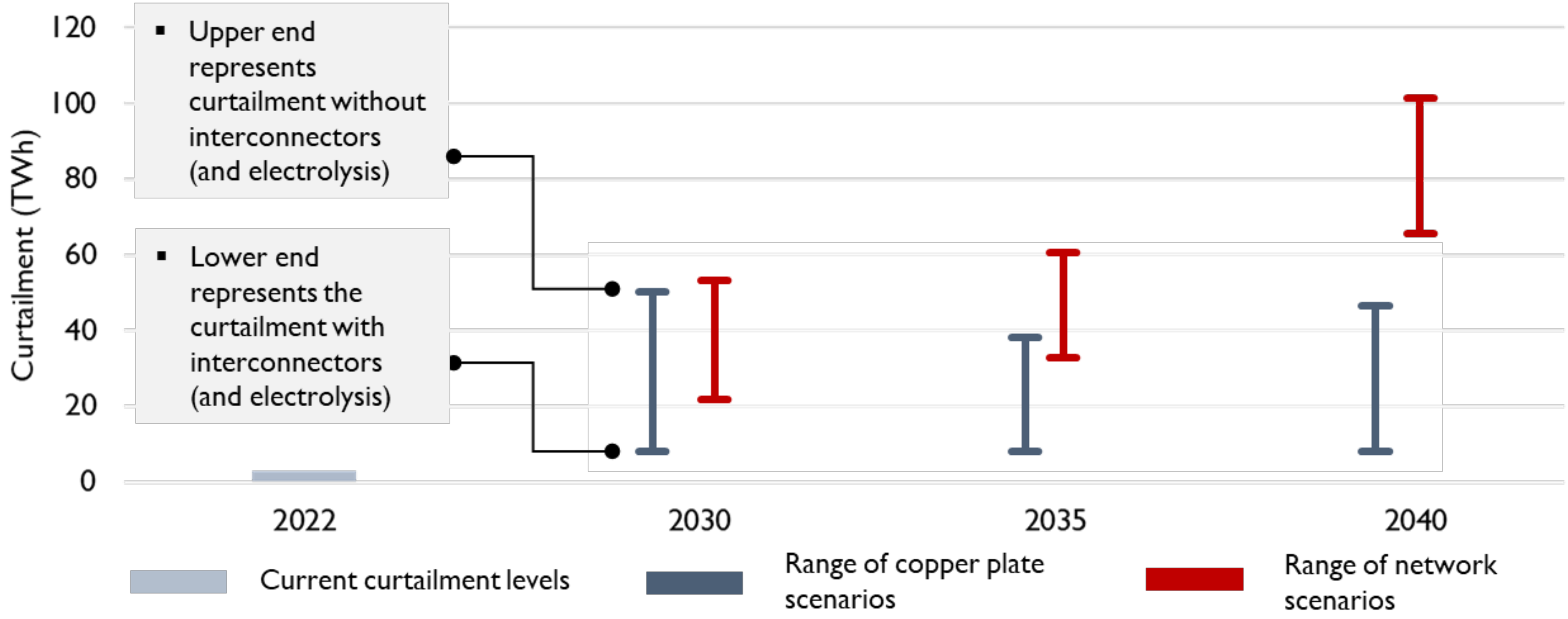
Branch flows during Jan 2030



- Transmission created curtailment is superimposed on top of energy-balancing related curtailment
- Graphs below indicate typical (modelled) branch flows in 2030 (winter month) as a fraction of boundary transfer capability



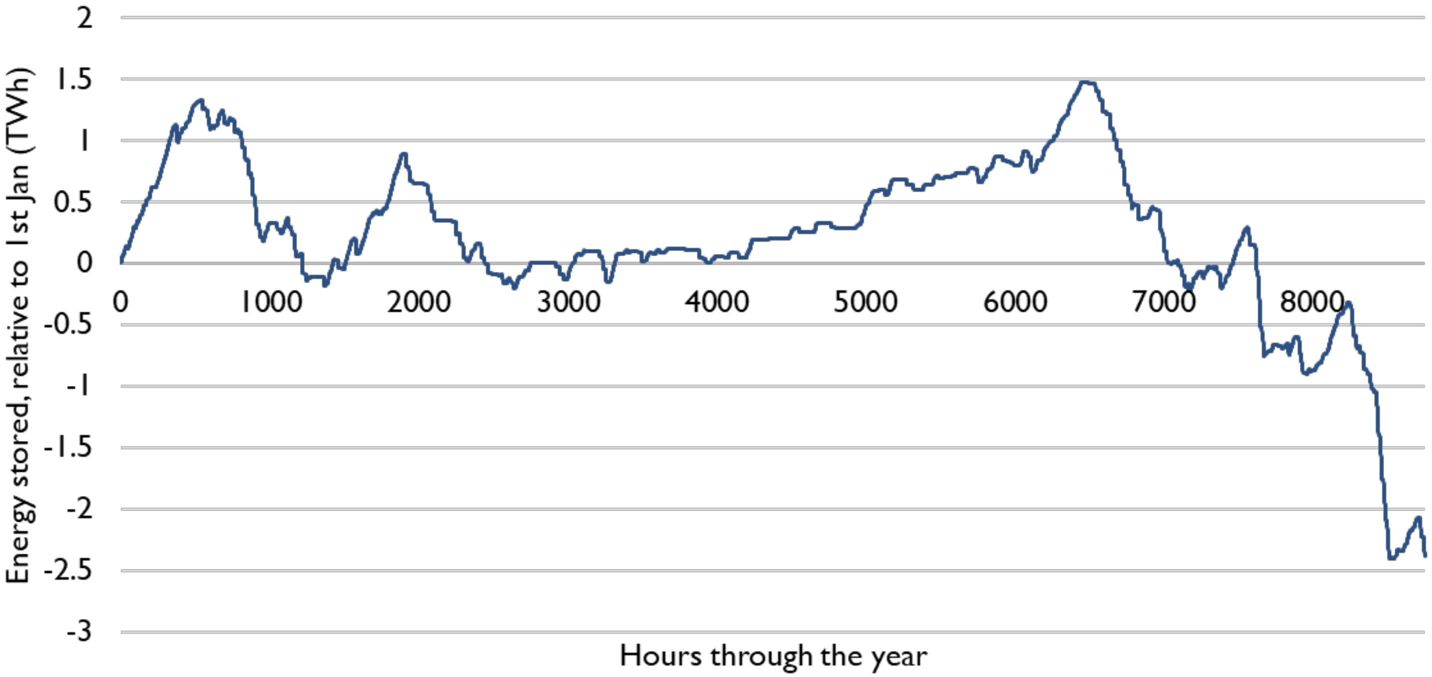
Curtailment, network capacity, interconnection and electrolysis



- Upper end represents curtailment without interconnectors (and electrolysis)

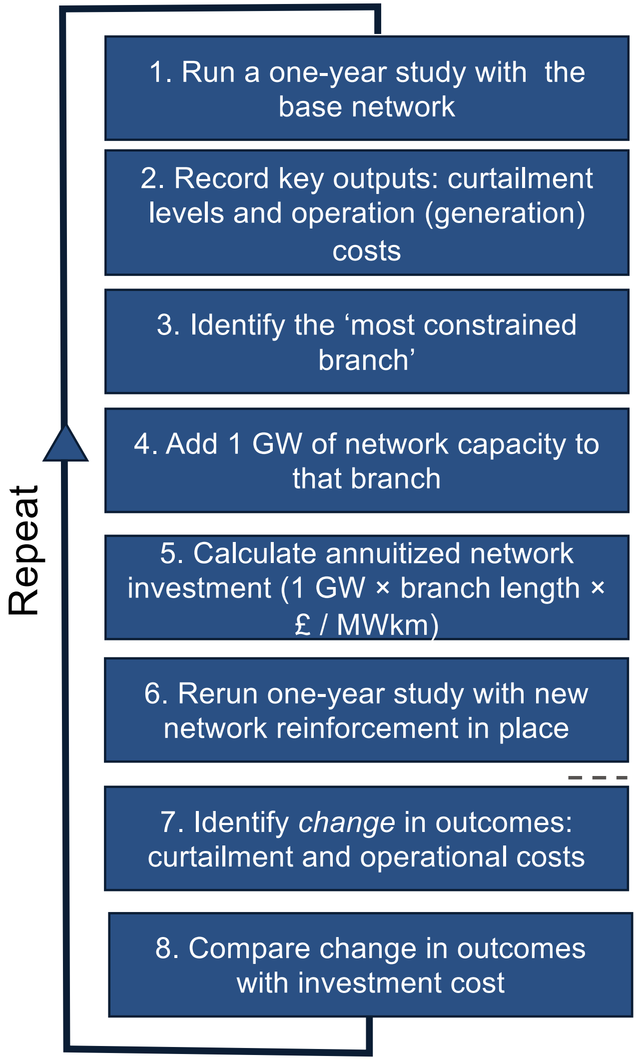
- Lower end represents the curtailment with interconnectors (and electrolysis)

Surpluses and deficits of energy: charging and discharging a large store

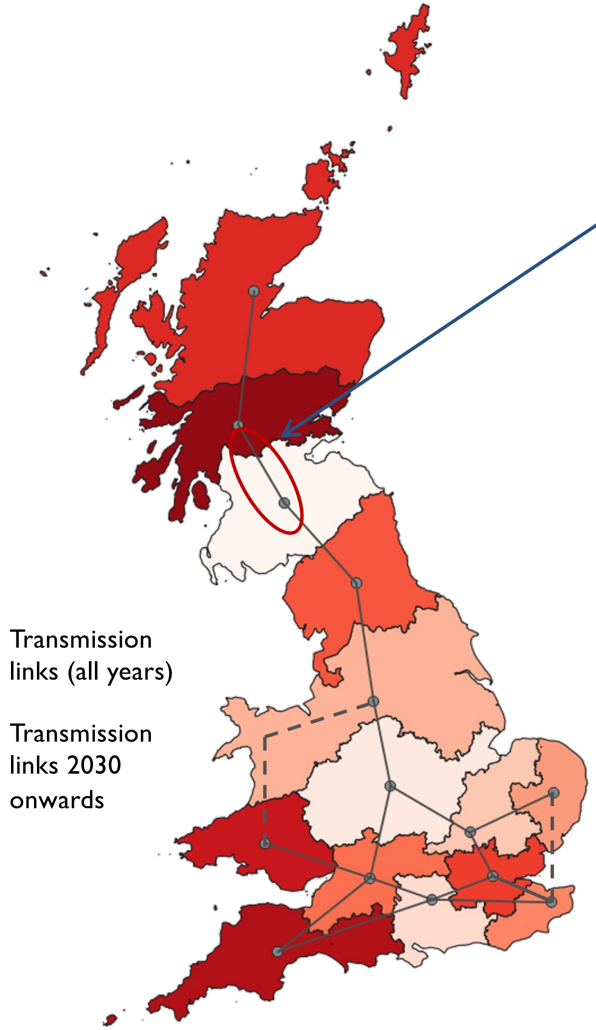


Energy stored and used in 2035 (for a single ‘weather year’) as a result of surpluses and deficits of available zero marginal cost low carbon generation relative to demand

Might we need new network capacity? Where might we need it?



1. Run a one-year study with the base network
2. Record key outputs: curtailment levels and operation (generation) costs
3. Identify the ‘most constrained branch’
4. Add 1 GW of network capacity to that branch
5. Calculate annuitized network investment (1 GW × branch length × £ / MWkm)
6. Rerun one-year study with new network reinforcement in place
7. Identify *change* in outcomes: curtailment and operational costs
8. Compare change in outcomes with investment cost



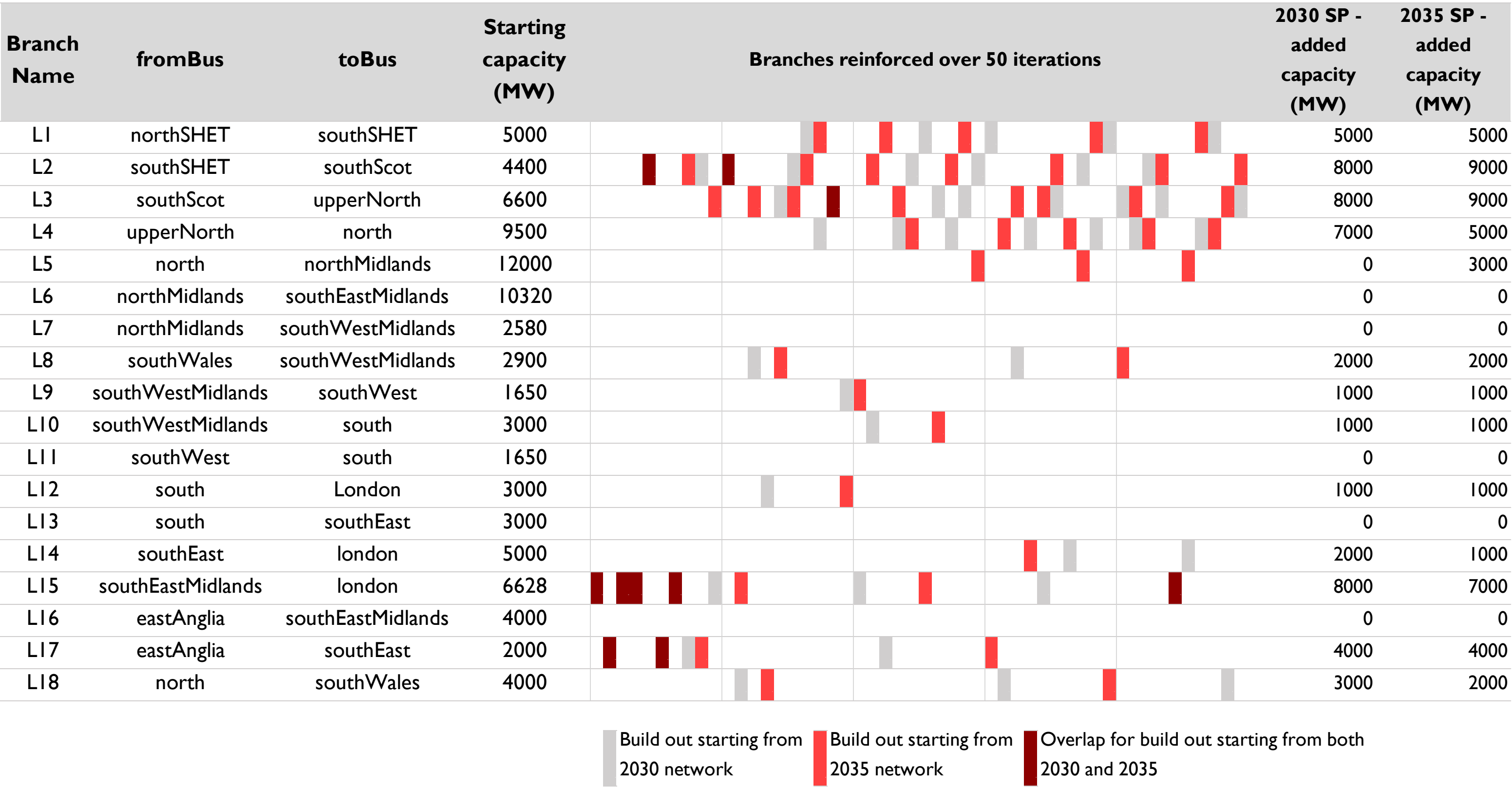
Most constrained branch

Branch	Seetlment Periods	%
01_northSHET - 02_southSHET	0	0.0%
02_southSHET - 03_southScot	1967	22.5%
03_southScot - 04_upperNorth	2	0.0%
04_upperNorth - 05_north	847	9.7%
05_north - 06_northMidlands	0	0.0%
06_northMidlands - 07_southEastMidlands	0	0.0%
06_northMidlands - 08_southWestMidlands	0	0.0%
09_southWales - 08_southWestMidlands	0	0.0%
08_southWestMidlands - 10_southWest	83	0.9%
08_southWestMidlands - 11_south	0	0.0%
10_southWest - 11_south	0	0.0%
11_south - 14_london	1856	21.2%
11_south - 12_southEast	0	0.0%
12_southEast - 14_london	36	0.4%
07_southEastMidlands - 14_london	911	10.4%
13_eastAnglia - 07_southEastMidlands	0	0.0%
13_eastAnglia - 12_southEast	0	0.0%
05_north - 09_southWales	0	0.0%

Might we need new network capacity? Where might we need it?

- The build out studies use a ‘directed search’ approach to choosing where to apply network investment
- In 2035, initial investments focused on the South of England
- Subsequent iterations proposed investment in the north of GB with occasional investment in the south.
- In 2030 and 2035, significant network investment, beyond current plans (as reported in ETYS 2023 for 2035), show positive Return on Investments and significant impact on curtailment

2035 with interconnectors and electrolysis



Branch Name	fromBus	toBus	Starting capacity (MW)	Branches reinforced over 50 iterations	2030 SP - added capacity (MW)	2035 SP - added capacity (MW)
L1	northSHET	southSHET	5000		5000	5000
L2	southSHET	southScot	4400		8000	9000
L3	southScot	upperNorth	6600		8000	9000
L4	upperNorth	north	9500		7000	5000
L5	north	northMidlands	12000		0	3000
L6	northMidlands	southEastMidlands	10320		0	0
L7	northMidlands	southWestMidlands	2580		0	0
L8	southWales	southWestMidlands	2900		2000	2000
L9	southWestMidlands	southWest	1650		1000	1000
L10	southWestMidlands	south	3000		1000	1000
L11	southWest	south	1650		0	0
L12	south	London	3000		1000	1000
L13	south	southEast	3000		0	0
L14	southEast	london	5000		2000	1000
L15	southEastMidlands	london	6628		8000	7000
L16	eastAnglia	southEastMidlands	4000		0	0
L17	eastAnglia	southEast	2000		4000	4000
L18	north	southWales	4000		3000	2000

Build out starting from 2030 network

Build out starting from 2035 network

Overlap for build out starting from both 2030 and 2035

Improvements and extensions

Improve and refine the electricity MWkm model

- Calibrate and refine the representation of the bulk transmission network
- Improve modelling of energy storage and demand flexibility
- Move from a ‘directed search approach’ to an ‘integrated optimisation’ for build out studies
- Model the ‘collection’ networks onshore and offshore

Explore additional questions with the electricity MWkm model

- Explore interconnectors in more depth
- Work to improve understanding of network constraints across GB, including in the south
- Explore the trade-off between storage, demand response and networks

Expand to other energy vectors

- Connect electrolysers, hydrogen stores and hydrogen offtakers including power systems in a hydrogen system
- Consider expansions to include natural gas, petroleum and CO_2 systems using the same high-level, agile approach

Key messages (1/2)

1. The ‘right’ amount of transmission network capacity hits the sweet spot between the cost of network infrastructure and the impact of lack of transmission on what energy sources need to be used and what they cost.
    - In a worst case, lack of transmission also impacts adversely on security of supply.
2. A simple – but not too simple – model of Britain’s electricity transmission system can allow good estimates to be derived quickly and conveniently for the impacts of different amounts of transmission capacity under different scenarios.
    - The same kind of approach also has the potential to be useful in integrated energy system modelling that includes multiple infrastructures.
3. The need for transmission can be summed up in terms of how far each unit of power flows, something that can be expressed via the number of MWkm, either for a snapshot in time or summed over each hour of the year.
4. The average distance electricity will travel between generation and end use is likely to increase significantly over the next few years.
5. Absolute peak MWkm flows, unconstrained by network limits, could increase by a factor of more than three by 2035 but building transmission to facilitate full unconstrained MWkm flows would be impractical and economically inefficient.

Key messages (2/2)

6. Curtailment of renewables, including offshore wind, is likely to grow significantly by the 2030s even with planned transmission network reinforcements.
   - Network limits will continue to drive much of that curtailment, but we will also see a rise in curtailment caused by ‘energy balance’ constraints.
7. Operational network power transfer capacity is rarely as high as the headline figures published in annual studies.
8. Planned investment in the bulk-transportation element of the transmission network will more than double its physical capability by 2040 taking it from 9.0 million MWkm in 2022 to 21.9 million MWkm in 2040.
9. For the generation background (and wholesale market structure) modelled, our results suggest further expansion of the transmission network beyond current plans may be justified.
10. Interconnectors and hydrogen electrolysis can make a big difference to the management of curtailment; short or medium duration electricity system storage such as batteries will likely be much less important.
11. Reduction of electricity system greenhouse gas emissions on the way to ‘clean power’ by 2030 is only the first stage of the electricity system’s transformation. The second stage is its massive growth.
   - In the course of that growth, the development of different parts of the system – generation, interconnector, storage and network capacity, and demand – need to be well synchronised.
   - We also need to retain a sense of perspective about curtailment of renewables and the costs of different aspects of the system.