DIGEST

Optimal allocation of energy storage in the GB grid for renewable curtailment reduction through open-source software development

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CIGRE-UK Knowledge Sharing Event
Imperial College London
14th Oct 2025

Brunel University of London

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- Open-source modelling
- GB grid implementation in PyPSA
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DIGEST

Key objectives

- Explore how placing energy storage in the network could enable better integration of renewables in the short- to medium-term
- Improve geographical resolution of available optimisation models to adequately address the locational benefits of energy storage
- Implement optimisation model in an open-source framework

Why Python?

Open source

Wide availability of libraries

Research community increasingly adopting Python / open-source

Can be linked with machine learning libraries

Available Python libraries for power system analysis

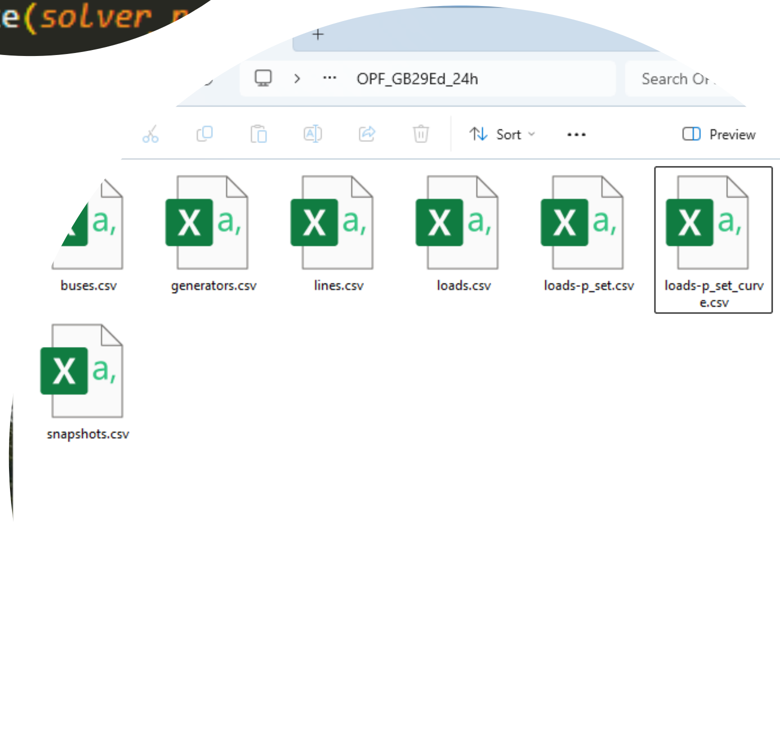
- PyPSA
- Pandapower
- PYPOWER

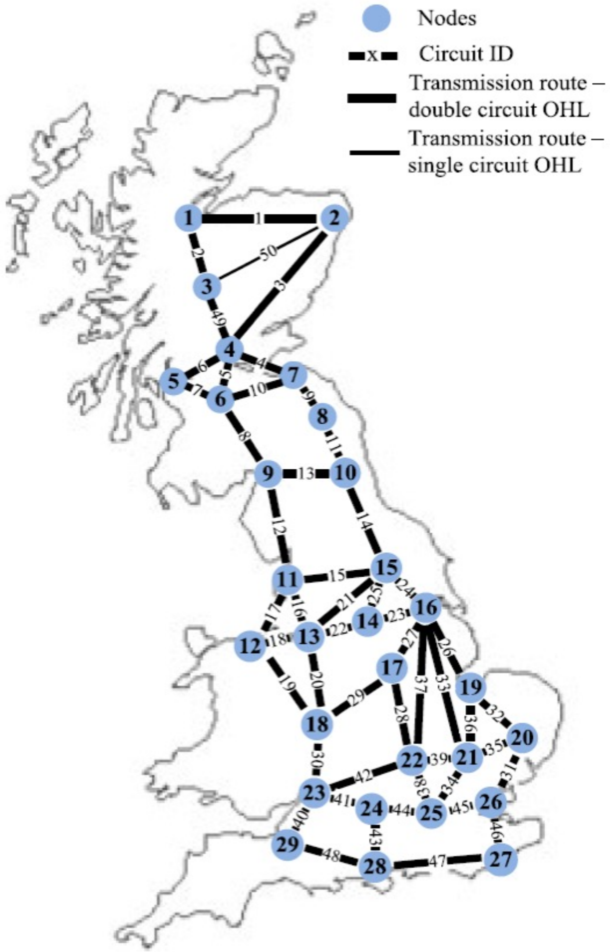
PyPSA is used extensively in Europe by researchers and regulators (ACER / FNA).

	PyPSA	pandapower	PYPOWER
Purpose	**Power system simulation and optimization**	**Power flow and grid analysis**	**Power flow and optimal power flow**
Power Flow Analysis	Yes	Yes	Yes
Optimal Power Flow (OPF)	Yes	Yes	Yes
Multi-Period Optimization	Yes	No	No
AC/DC Network Support	Yes	AC only	AC only
Large Scale Analysis	Yes	No	No
Renewable Energy Modeling	Yes	Limited	Limited
Documentation and examples	Very limited	Limited	N/A

Optimal Power Flow in PyPSA – CSV Files

- Model takes inputs in the form of CSV files for various aspects of the power system (generators, demand, lines, etc.)
- For running the optimal power flow, the main CSV files are *snapshots.csv* and *generators.csv*
- Optimal power flow is executed by the optimize function in PyPSA
- Possibility to use different solver packages





GB Reduced Network

- This system is adopted from the data from Edinburgh University, available here:

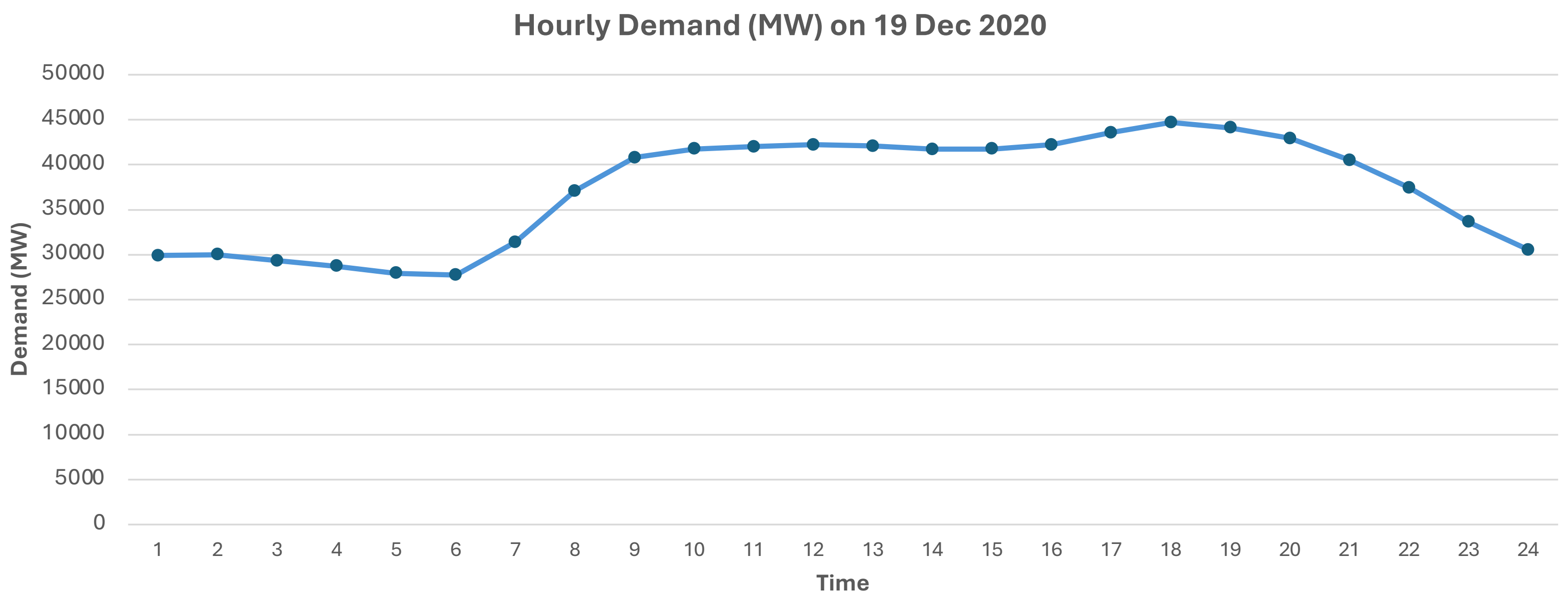
https://www.maths.ed.ac.uk/OptEnergy/NetworkData/reducedGB/

- It has 29 buses, 66 generators, and 99 transmission lines
- Originally implemented in MatPower, and we transferred it to PyPSA
- Also added interconnectors and HVDC “bootstraps” (not shown in map)

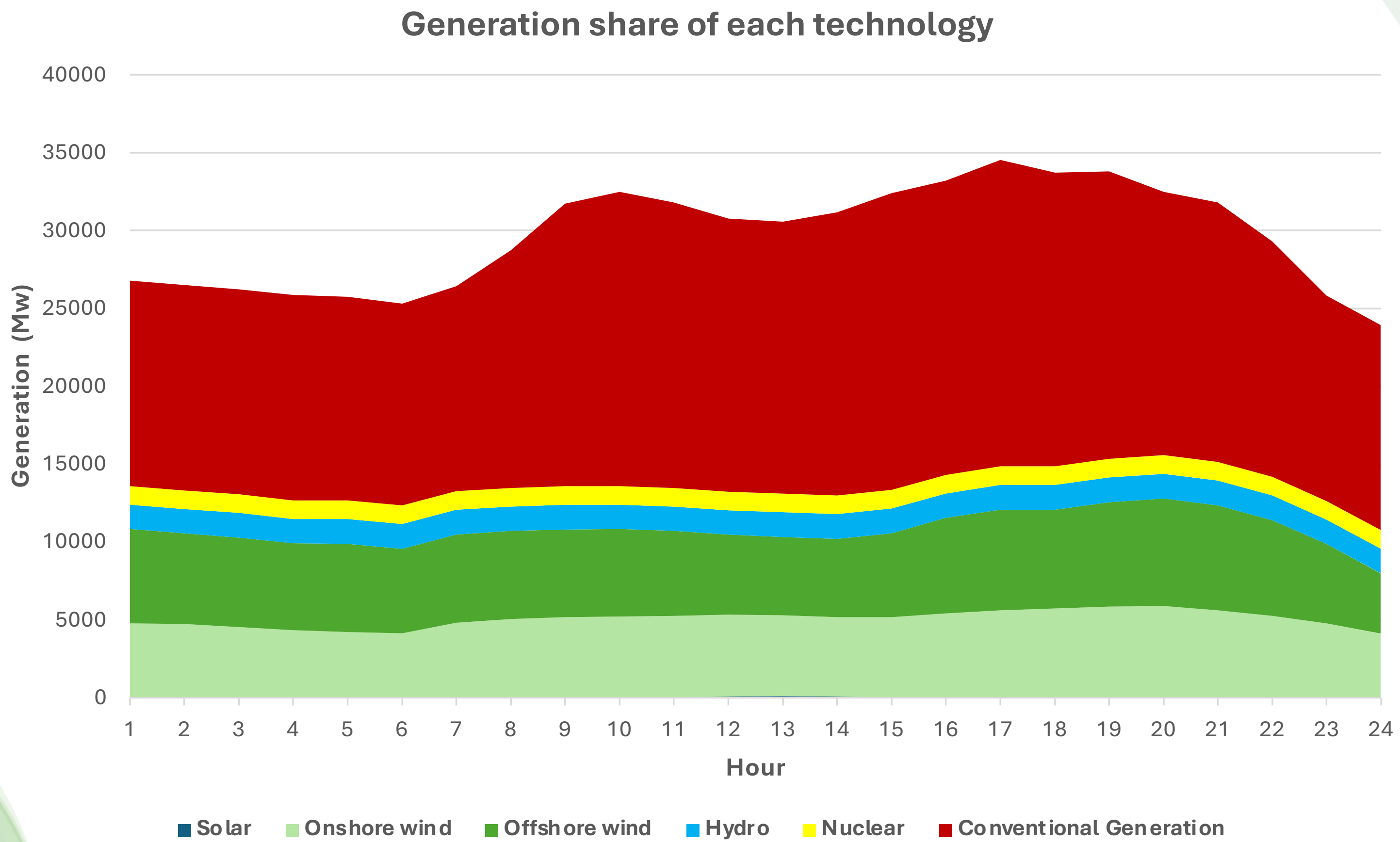
Approach for 2020 and 2040

- System details (lines, buses, links, and conventional generators) haven't changed compared to the Edinburgh model
- The demand for a winter day in 2020 has been calculated based on Elexon raw data
- Renewable and conventional generation details are adopted from DUKES
- Gurobi optimizer has been used for the OPF
- Model outputs include generation and storage dispatch, line utilisation, RES curtailment and total operation cost
- Weather data has been adopted from Renewables.ninja

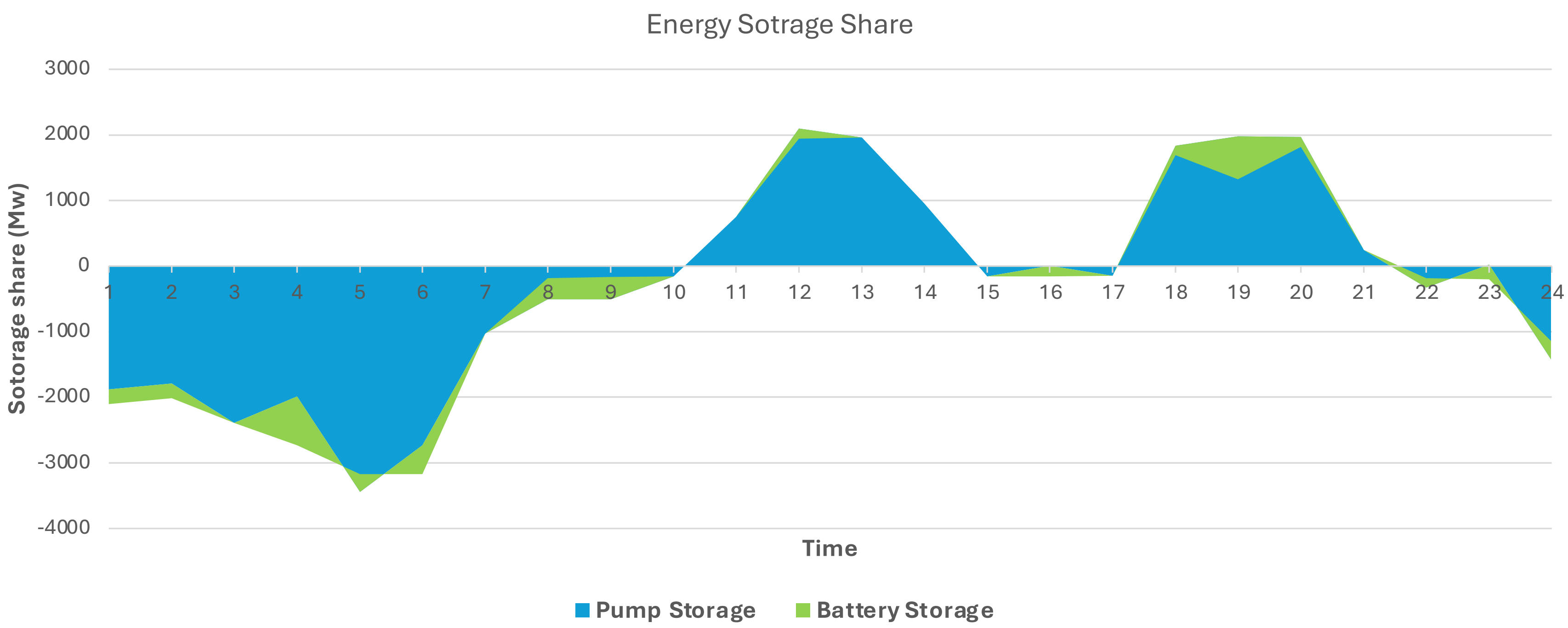
Hourly Demand

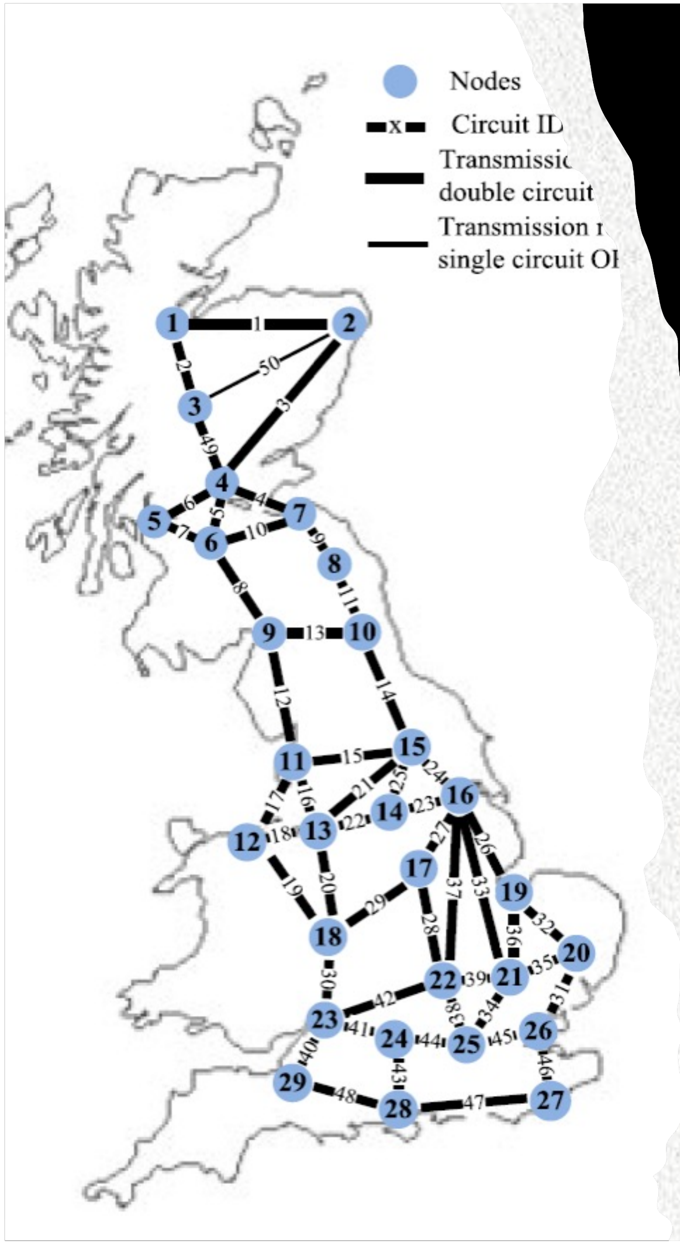


Generation output

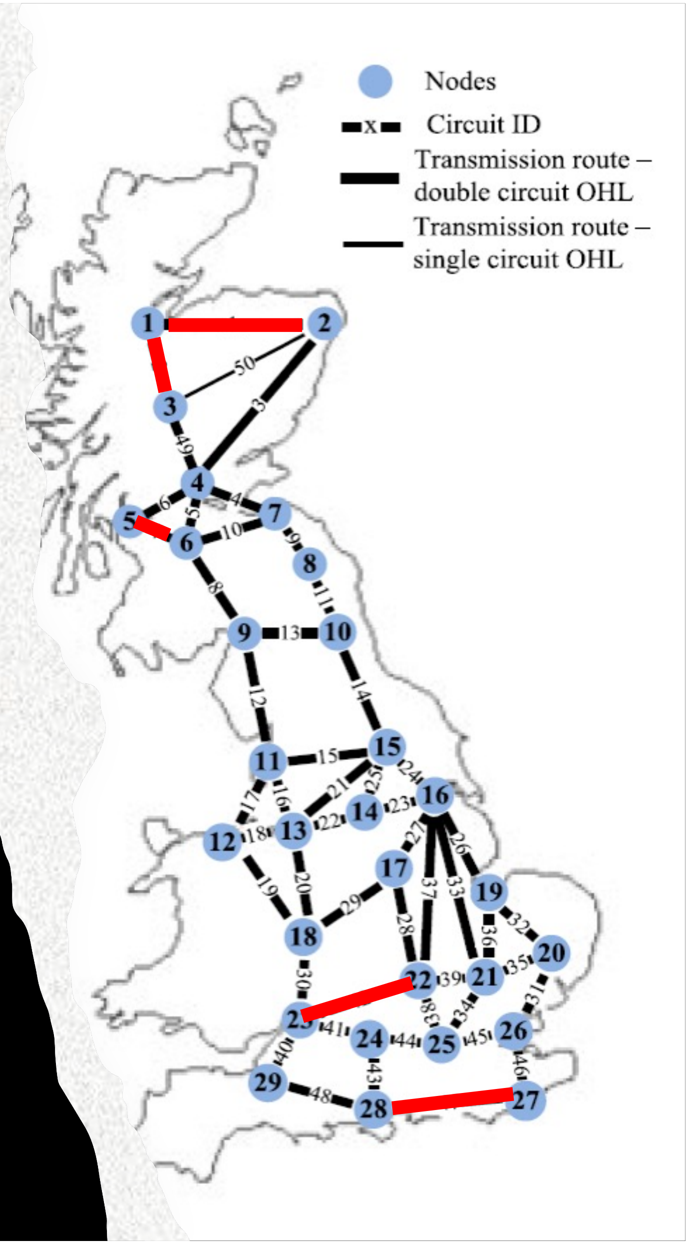


Energy Storage operation





Congested Lines



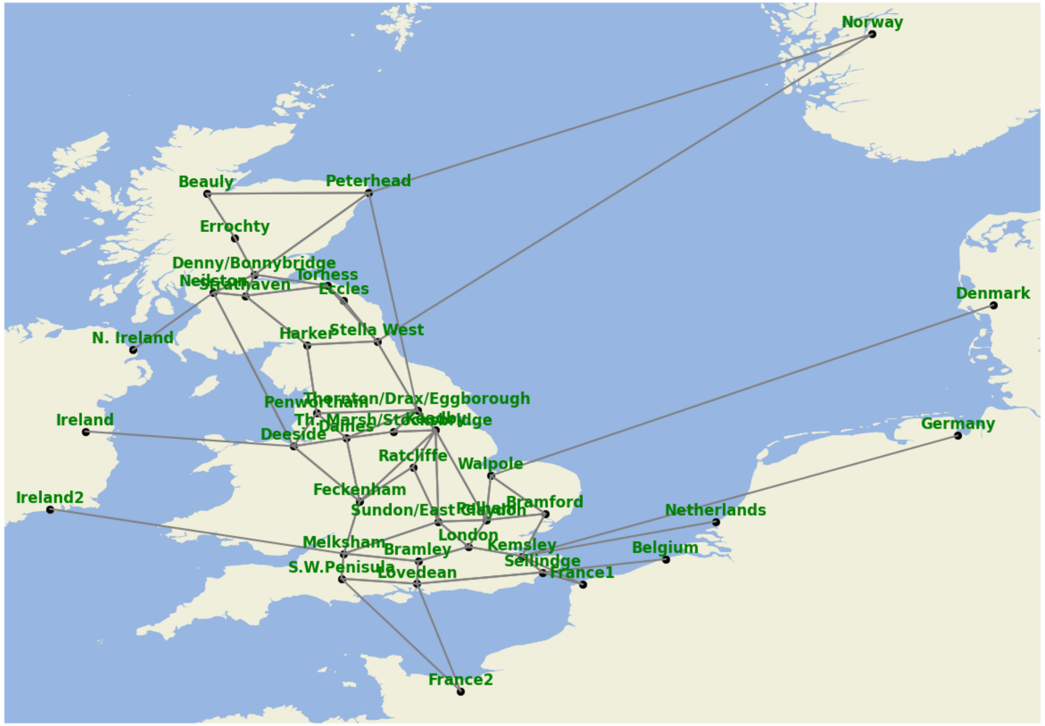
Technology	Curtailment (MWh)
Battery Storage	71,995
Pumped Storage	121,886
Conventional generation	666,746
Wind Offshore	**15,622**
Wind Onshore	**52,727**

Total Curtailment

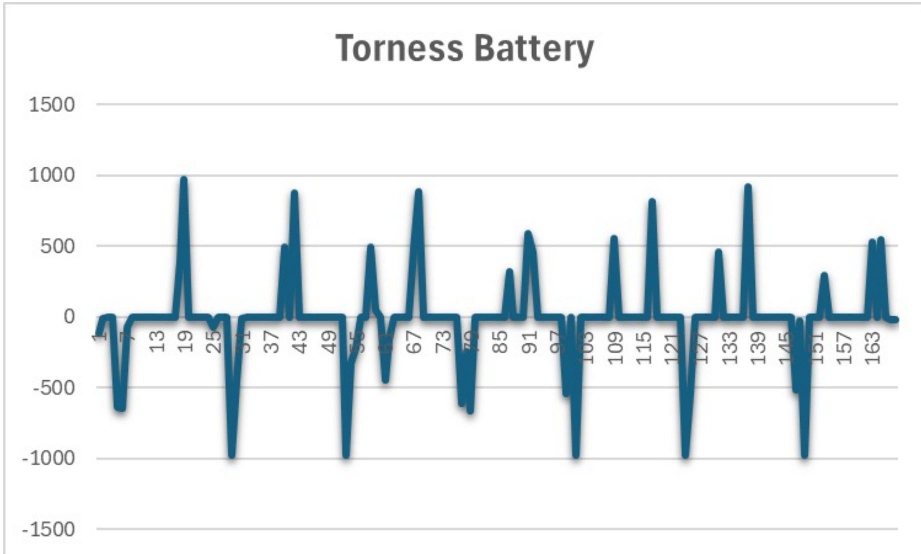
Approach for 2040

- System details (lines, buses, links, and conventional generators) haven't changed compared to the Edinburgh model but all the planned interconnectors are added till 2040
- Simplified modelling of interconnectors using export/import prices
- Electricity demand for a week in December (12-18 Dec) used as input
- Renewable and conventional generation details are adopted from a dataset published in FES 2024
- We consider energy storage installation (batteries) in Scotland

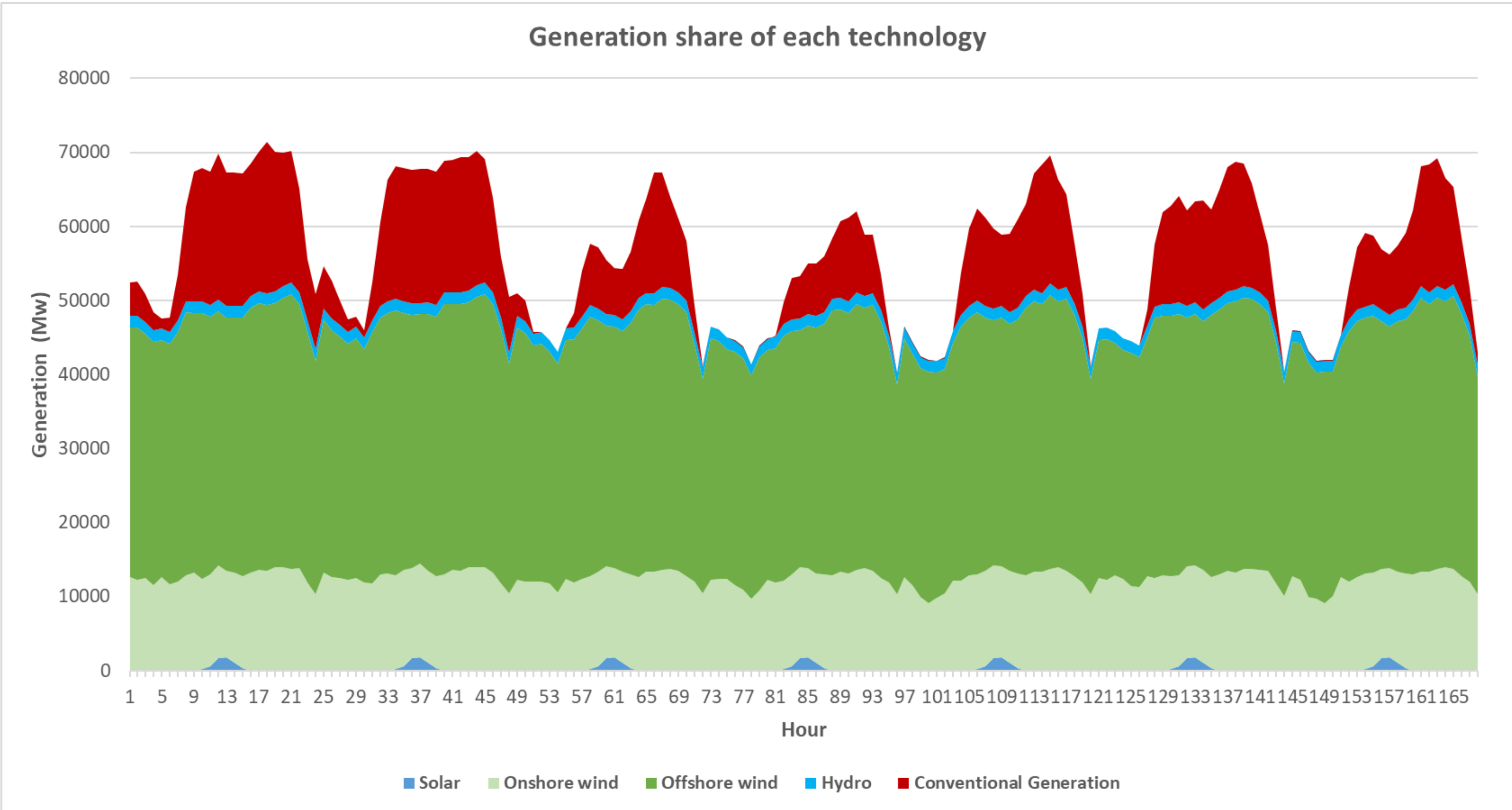
GB 29 Bus Reduced Network with Interconnectors 2040



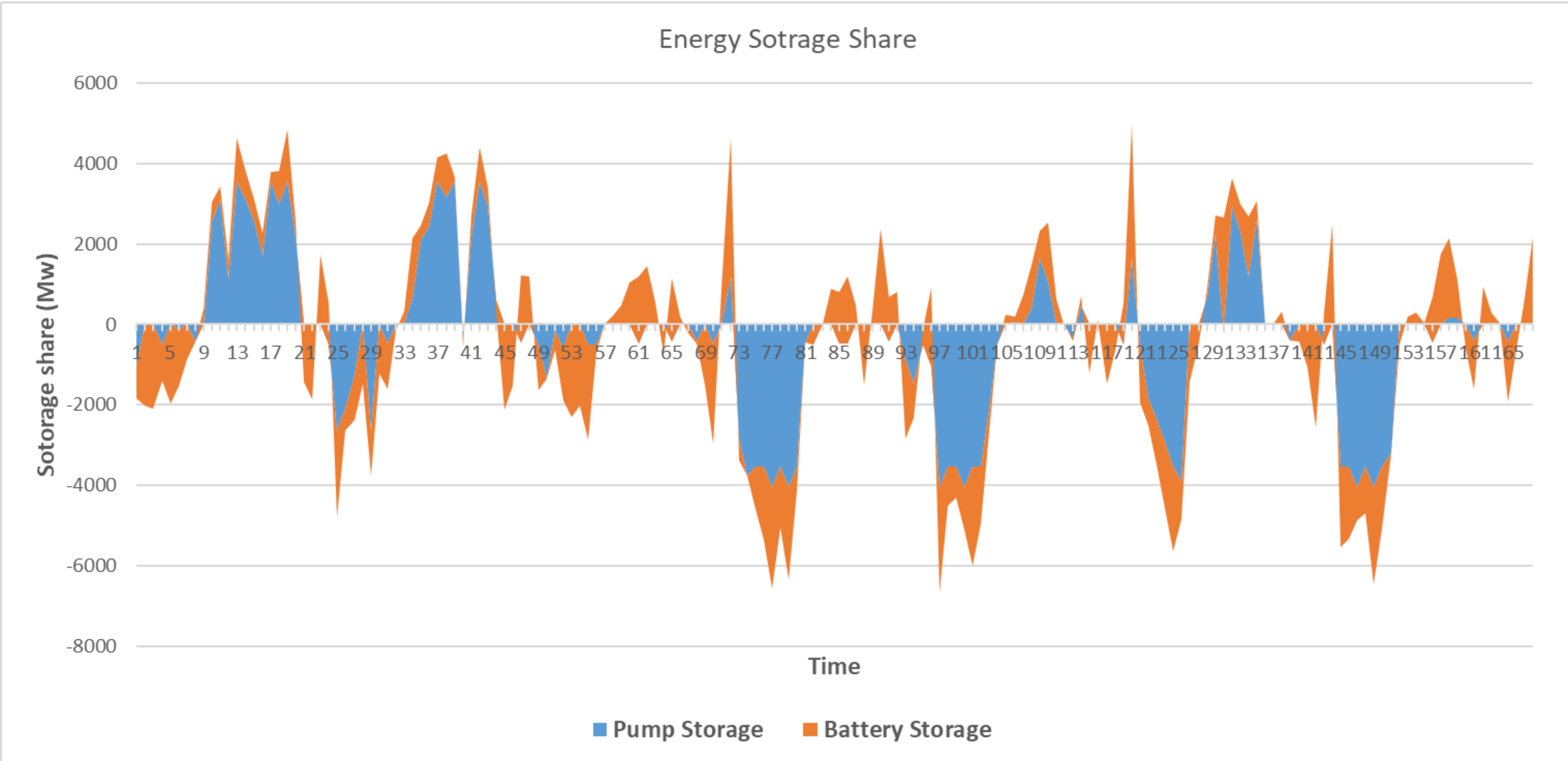

```
INFO:gurobipy:
Solved in 1529 iterations and 0.68 seconds (0.32 work units)
INFO:gurobipy:Solved in 1529 iterations and 0.68 seconds (0.32 work units)
Optimal objective  4.977565185e+07
INFO:gurobipy:Optimal objective  4.977565185e+07
INFO:linopy.constants: Optimization successful:
Status: ok
Termination condition: optimal
Solution: 44627 primals, 110086 duals
Objective: 4.98e+07
Solver model: available
Solver message: 2
```



Generation output



Energy Storage operation



Congested Lines

snapshot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
12/12/2040 0:00	-0.52146	1	-0.52146	1	0.57653	0.57653	0.12064	0.12064	1	0.56894	0.76197	1	1	1	-0.63311	-0.41252	1
12/12/2040 1:00	-1	1	-1	1	0.67844	0.67844	0.12101	0.12101	1	0.56984	0.76318	1	1	1	-0.6286	-0.40959	1
12/12/2040 2:00	-1	1	-1	1	0.68041	0.68041	0.12468	0.12468	1	0.56615	0.75824	1	1	1	-0.64704	-0.4216	1
12/12/2040 3:00	-0.98681	1	-0.98681	1	0.67971	0.67971	0.12858	0.12858	1	0.58553	0.78419	1	1	1	-0.55022	-0.35852	1
12/12/2040 4:00	-1	1	-1	1	0.68412	0.68412	0.13156	0.13156	1	0.61094	0.81823	1	1	1	-0.42324	-0.27577	1
12/12/2040 5:00	-0.4973	1	-0.4973	1	0.57666	0.57666	0.13043	0.13043	1	0.61991	0.83023	1	1	1	-0.37845	-0.24659	1
12/12/2040 6:00	-0.53211	1	-0.53211	1	0.57647	0.57647	0.11633	0.11633	1	0.56978	0.7631	1	1	1	-0.62888	-0.40977	1
12/12/2040 7:00	-1	1	-1	1	0.6648	0.6648	0.09565	0.09565	1	0.59602	0.79825	1	1	1	-0.49778	-0.32434	1
12/12/2040 8:00	-0.61272	1	-0.61272	1	0.57604	0.57604	0.08367	0.08367	1	0.60229	0.80664	1	1	1	-0.46646	-0.30394	1
12/12/2040 9:00	-1	1	-1	1	0.65468	0.65468	0.07684	0.07684	1	0.6137	0.82192	1	1	1	-0.40946	-0.2668	1
12/12/2040 10:00	-0.62903	1	-0.62903	1	0.57596	0.57596	0.07707	0.07707	1	0.61383	0.82209	1	1	1	-0.40883	-0.26639	1
12/12/2040 11:00	-1	1	-1	1	0.65403	0.65403	0.07563	0.07563	1	0.6214	0.83223	1	1	1	-0.37098	-0.24173	1
12/12/2040 12:00	-0.6352	1	-0.6352	1	0.57593	0.57593	0.07457	0.07457	1	0.60752	0.81364	1	1	1	-0.44034	-0.28692	1
12/12/2040 13:00	-1	1	-1	1	0.65435	0.65435	0.07622	0.07622	1	0.59703	0.79959	1	1	1	-0.49276	-0.32108	1
12/12/2040 14:00	-0.62615	1	-0.62615	1	0.57597	0.57597	0.07823	0.07823	1	0.61259	0.82043	1	1	1	-0.41503	-0.27043	1
12/12/2040 15:00	-1	1	-1	1	0.65478	0.65478	0.07702	0.07702	1	0.60898	0.8156	1	1	1	-0.43306	-0.28217	1
12/12/2040 16:00	-0.64532	1	-0.64532	1	0.57587	0.57587	0.07047	0.07047	1	0.57736	0.77325	1	1	1	-0.59105	-0.38511	1
12/12/2040 17:00	-1	1	-1	1	0.64973	0.64973	0.06762	0.06762	1	0.61975	0.83002	1	1	1	-0.37924	-0.2471	1
12/12/2040 18:00	-0.65093	1	-0.65093	1	0.57584	0.57584	0.0682	0.0682	1	0.60038	0.80407	1	1	1	-0.47604	-0.31018	1
12/12/2040 19:00	-1	1	-1	1	0.65284	0.65284	0.07341	0.07341	1	0.61732	0.82676	1	1	1	-0.39139	-0.25503	1
12/12/2040 20:00	-0.61803	1	-0.61803	1	0.57602	0.57602	0.08152	0.08152	1	0.59634	0.79867	1	1	1	-0.4962	-0.32331	1
12/12/2040 21:00	-1	1	-1	1	0.66359	0.66359	0.0934	0.0934	1	0.59078	0.79123	1	1	1	-0.52396	-0.34141	1
12/12/2040 22:00	-1	1	-1	1	0.6704	0.6704	0.10607	0.10607	1	0.5986	0.8017	1	1	1	-0.48491	-0.31596	1
12/12/2040 23:00	-1	1	-1	1	0.67735	0.67735	0.11898	0.11898	1	0.57991	0.77667	1	1	1	-0.57829	-0.3768	1
13/12/2040 0:00:0	-0.51736	1	-0.51736	1	0.57655	0.57655	0.1223	0.1223	1	0.57111	0.76488	1	1	1	-0.62227	-0.40546	1
13/12/2040 1:00:0	-1	1	-1	1	0.679	0.679	0.12206	0.12206	1	0.56818	0.76095	1	1	1	-0.63691	-0.415	1
13/12/2040 2:00:0	-0.50515	1	-0.50515	1	0.57662	0.57662	0.12725	0.12725	1	0.61469	0.82324	1	1	1	-0.40454	-0.26359	1
13/12/2040 3:00:0	-1	1	-1	1	0.68363	0.68363	0.13065	0.13065	1	0.56429	0.75575	1	1	1	-0.65632	-0.42765	1

Conclusion

- Open-source PyPSA-based model adopted and adapted for the GB transmission grid (steep learning curve) – to be used in future projects
- Reviewed input data sources (FES, online databases) – some input data issues still to be sorted
- Validated and ran case studies for the GB system for illustrative scenarios
- Energy storage helps with RES integration and carbon reduction, but effect can be limited by transmission constraints – significant reinforcement required
- Working on adapting the model for investment optimisation

Ongoing/future work

- Extend simulation of GB-29 network for whole year
- Implement FES scenarios such as Holistic transition, incl. different scenarios for storage placement
- Co-optimise location-specific storage investment (including both “standard” and heuristic optimisation methods) and transmission expansion
- Consider different storage duration (short-term vs. long-term)
- Assess the impact of battery degradation on investment decisions