Modelling and controlling the risks in future energy systems

Risk and Resilience Day , 8th March 2023

Head of Energy Engineering, BEIS (soon DESNZ)

Department for Business, Energy & Industrial Strategy

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- Risks of renewable generation
- Ways of dealing with non-dispatchability
- Modelling risk of imbalance
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- Future Work

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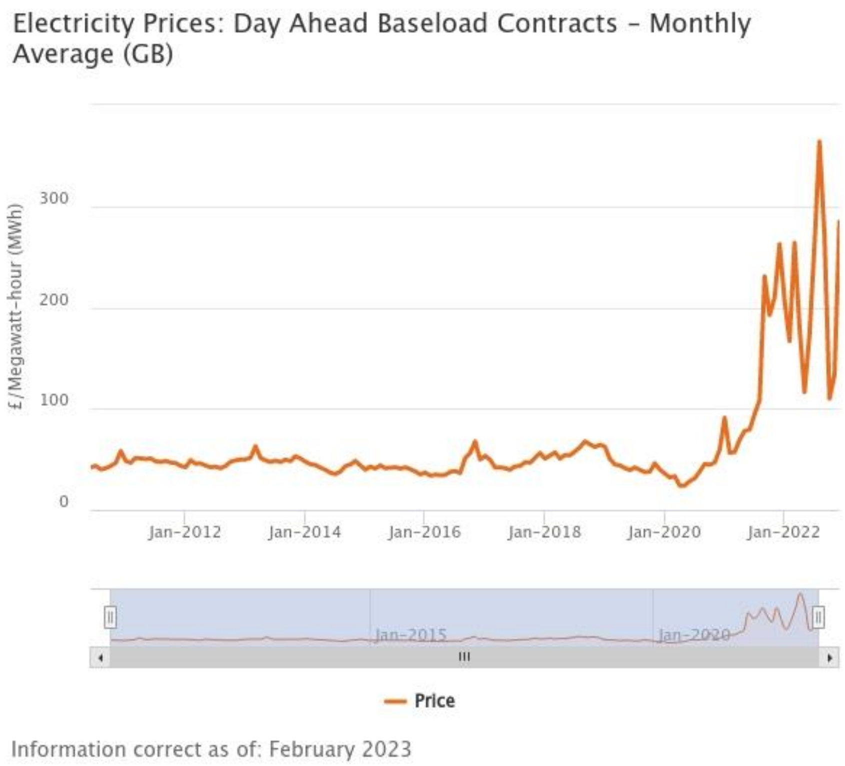
The Good and the Bad of Renewables

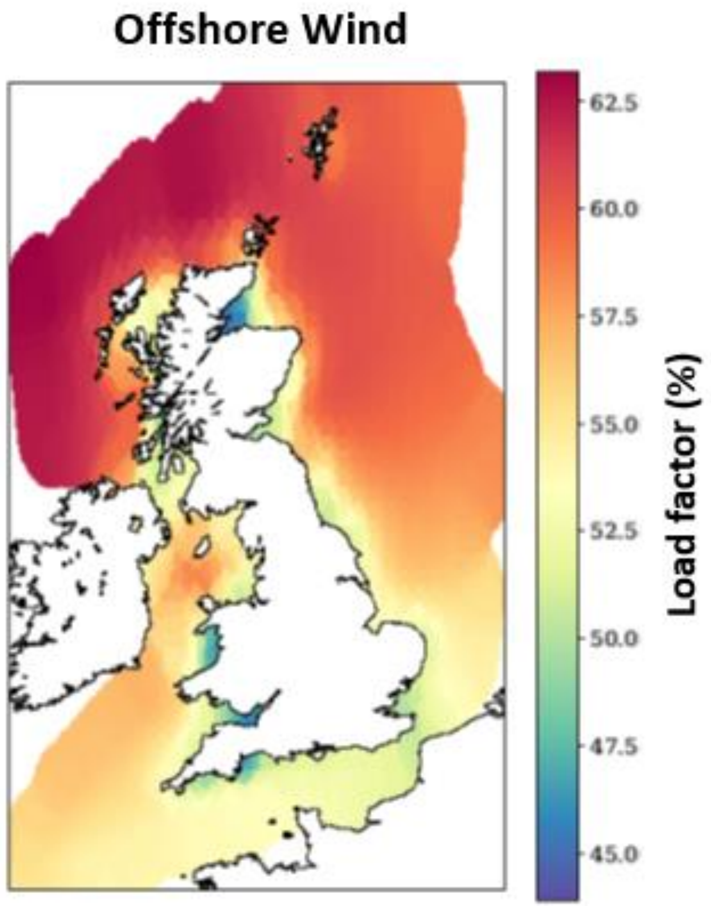
Renewable Generation (2012 Prices)

- Per MWh of electricity produced, renewable generation is now the cheapest source of power on the network:
  - Contracts for Difference Allocation Round 4 strike prices:
    - Pot 1 Onshore wind for delivery FY24/25 - £42.47
    - Pot 1 Solar PV for delivery FY24/25 - £45.99
    - Pot 2 Remote Island Wind for delivery FY26/27 - £46.39
    - Pot 3 Offshore Wind for delivery FY26/27 - £37.35
  - New renewable technologies are rapidly decreasing in price
    - Pot 2 Floating Offshore Wind for delivery FY26/27 - £87.30
    - Pot 2 Tidal Stream for delivery FY26/27 - £178.54
  - Rough Comparison: CCGT Class H for delivery in 2030 has a central LCOE of £99/MWh



Renewables Properties

- Renewables are:
  - Predictable
  - Reliable
  - Improving in performance
  - Largely immune from external factors in market
  - Can provide in combination diversity
  - Low carbon – total lifetime emissions <12g/kWh
  - Low cost
- Renewables are not:
  - Easily dispatchable to follow load



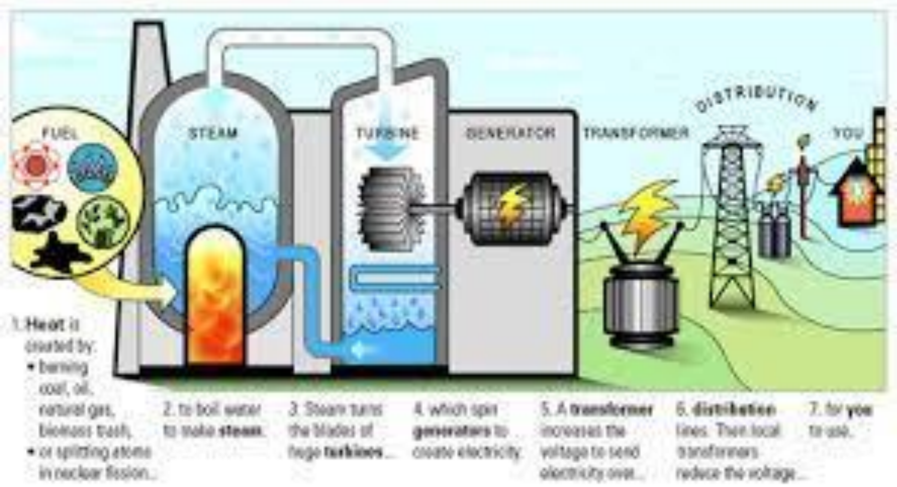
There is therefore a risk that in a system dominated by renewable generation, demand will at times exceed load

Ways around lack of dispatchability

- Gas turbine backup
  - Not completely green and limits grid carbon intensity to around 50g/kWh
- Gas turbine backup with CCS
  - Greener- CCS is typically 80-90% efficient
  - But expensive to build and operate
  - Need a secure carbon dioxide store
  - Still not completely zero carbon

Ways around lack of dispatchability

- Biomass to electricity to provide back-up to renewables
  - Limited amount of biomass available
  - Risk of indirect land use change if we grow more biomass
  - Lots of difficult to decarbonise areas where biomass could be more effectively used (e.g. making sustainable synthetic aviation fuels)



Ways around lack of dispatchability

- Storage of electricity generated
  - Very short term, short term and long term storage solutions
  - Options for short-term (diurnal) storage:
    - Batteries- getting cheaper and more reliable
    - Compressed air
    - Liquid air
    - Gravitational systems (including pumped hydro)
  - Fewer, but possible, options for long-duration (inter-seasonal) storage:
    - Heat stores, both latent and sensible heat systems possible
    - Power to Gas to Power systems could store TWh of electricity as hydrogen
    - Systems are scalable, low cost per MWh scored but have much lower round trip efficiencies than storage systems designed for short-term

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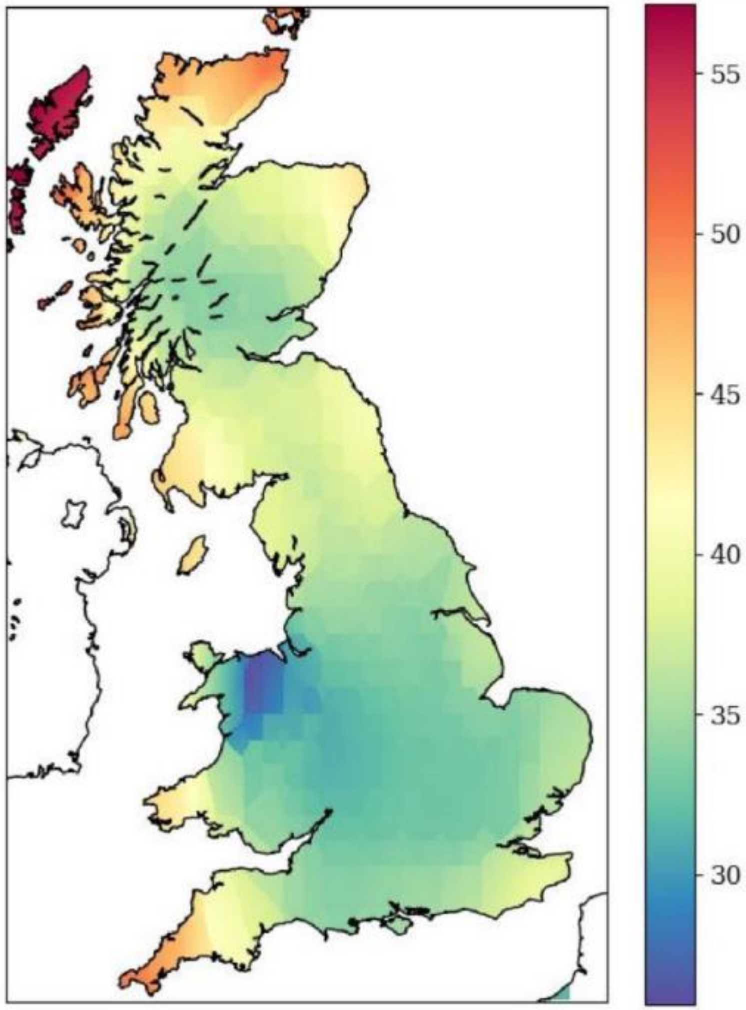
Modelling of risk of imbalance

SCORES Model

Storage and **C**ost **O**ptimisation of **R**enewable **E**lectricity **S**ystems

- In-house model for modelling non-dispatchable renewable electricity generation with storage
- Based on high-resolution weather data
- Used for analysis including:
  - Load factor calculations to inform future Contract for Difference rounds
  - Impact of changing planning restrictions with respect to solar PV farms
  - Potential for onshore wind in England, with various turbine specifications and locations
  - Potential for rooftop solar at farms, for Defra’s Farming Investment Fund
  - Assessment of UK tidal generation potential
- Ongoing development to answer longer-term research questions:
  - Implications of different generation technologies on future electricity system
  - Role of different storage and flexibility technologies



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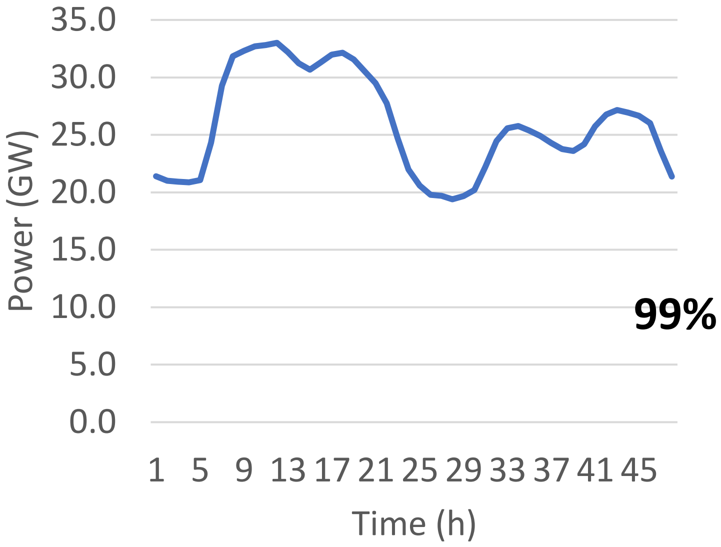
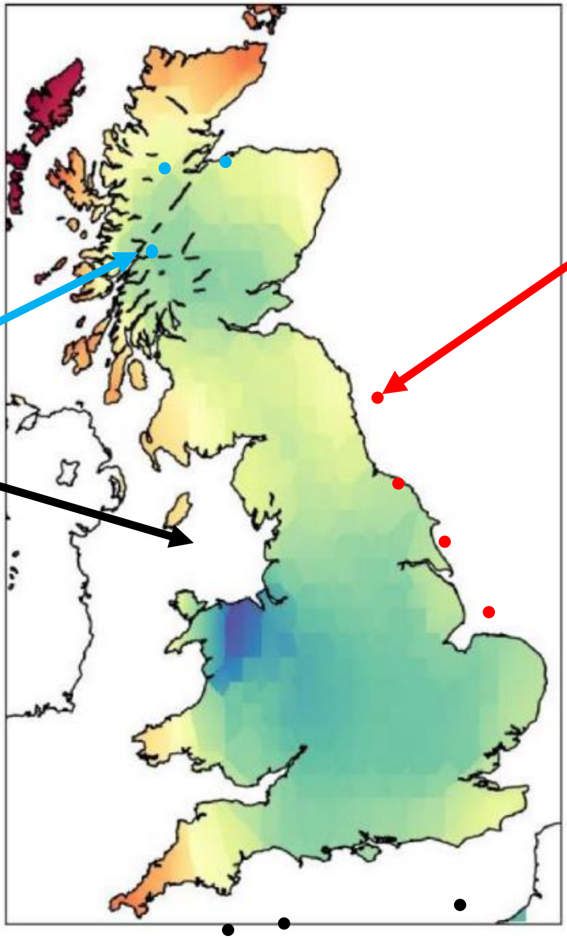
SCORES Model - Optimization

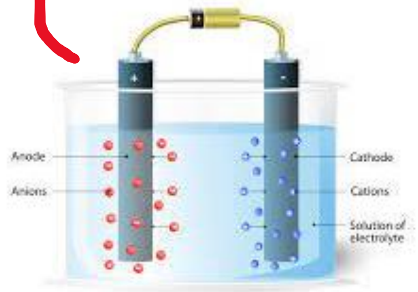


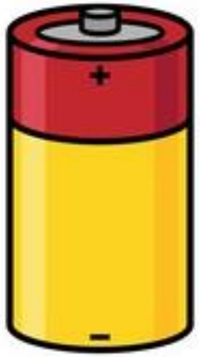
3. Demand



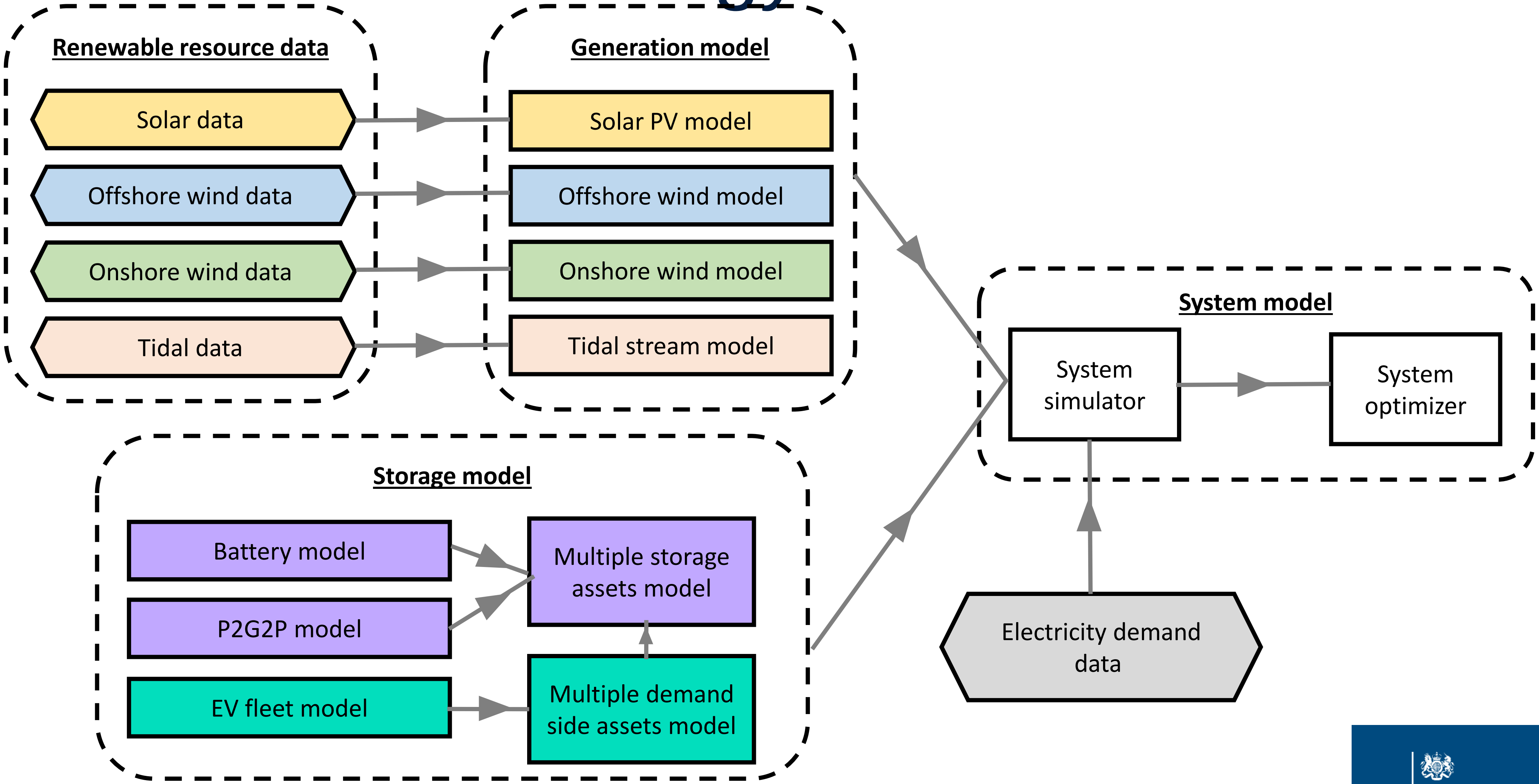
1. Generation

What is the lowest cost combination?

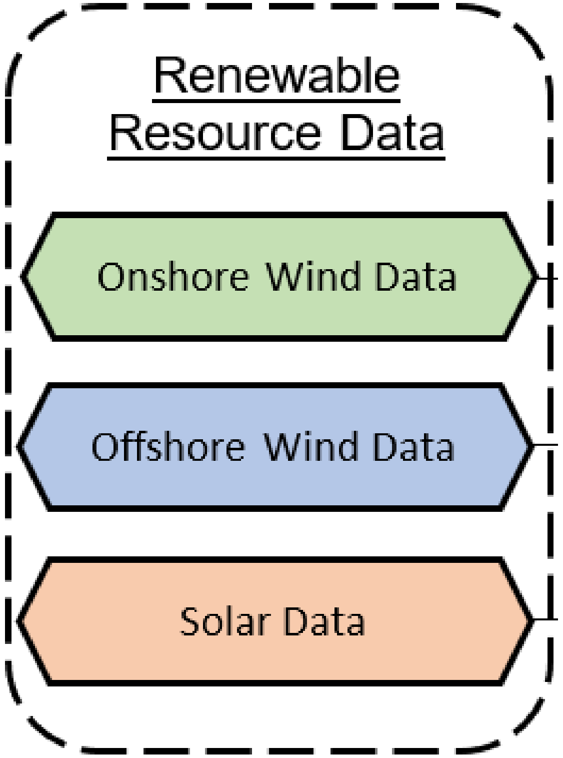




SCORES Methodology

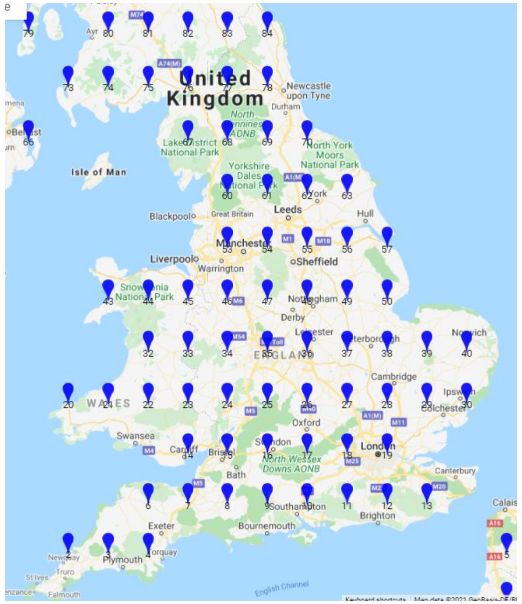


SCORES Methodology – Resource Data



- Hourly locational weather data:
  - Offshore Wind – hourly wind speed (m/s) @ 150m height (MET Office)
  - Onshore Wind – hourly wind speed (m/s) @ 50m height (NASA Merra2)
  - Solar – hourly net surface longwave radiation (kJ/m^2) (NASA Merra2)
  - Tidal – hourly tidal flow data (Admiralty)

Grid of SCORES input onshore wind data

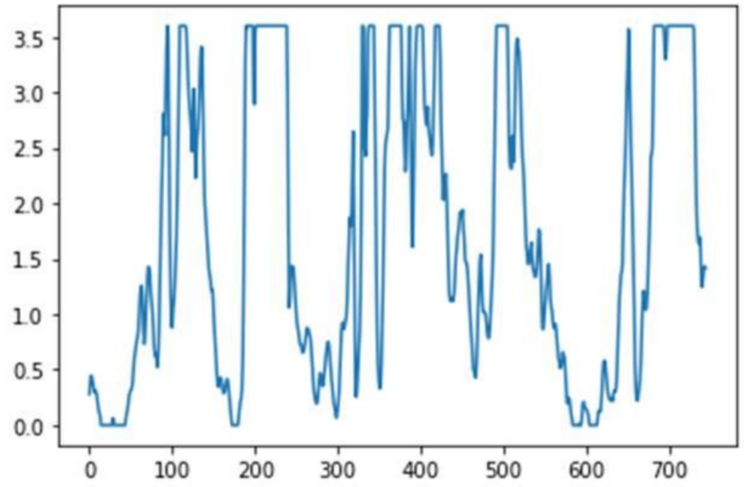


SCORES Methodology – Renewables Model

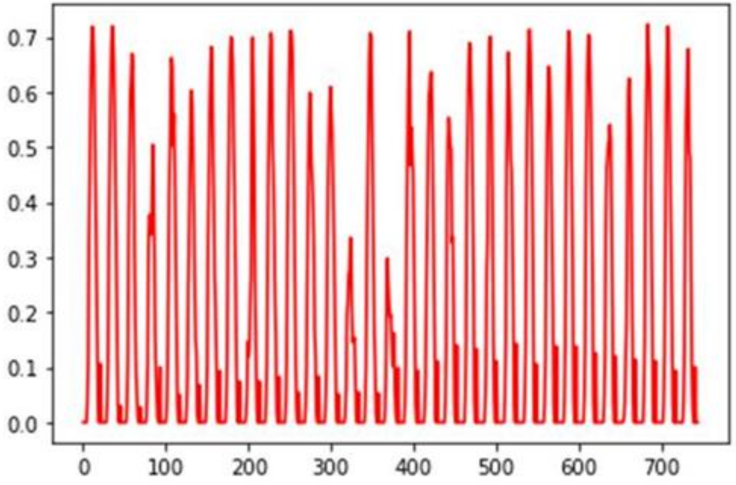
Generation model

- Solar PV model
- Offshore wind model
- Onshore wind model
- Tidal stream model

- Converts hourly renewable resource data into hourly power output (MW)

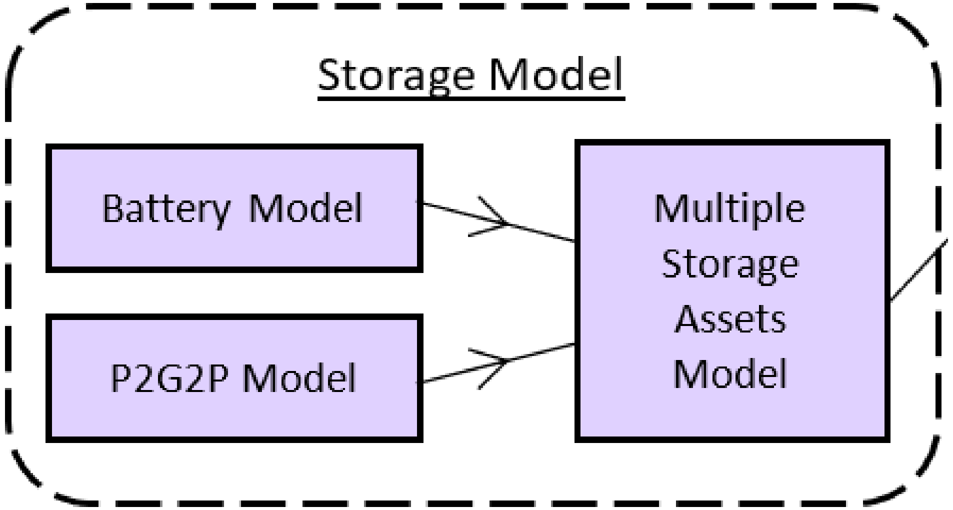


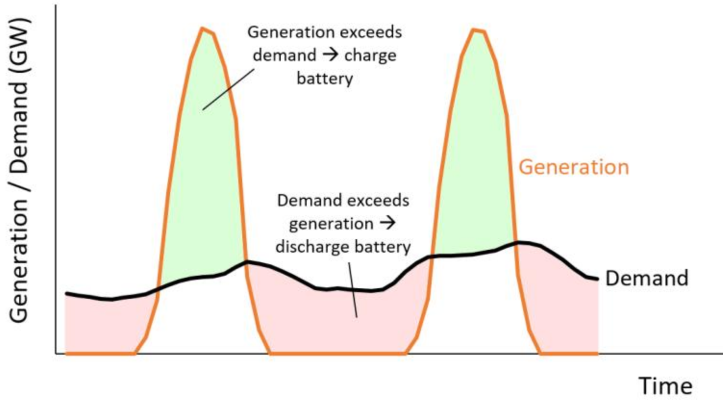
3.6 MW Wind Turbine Output, Example Site, August 2019



1 MW Solar PV Output, Example Site, August 2019

SCORES Methodology – Storage Model





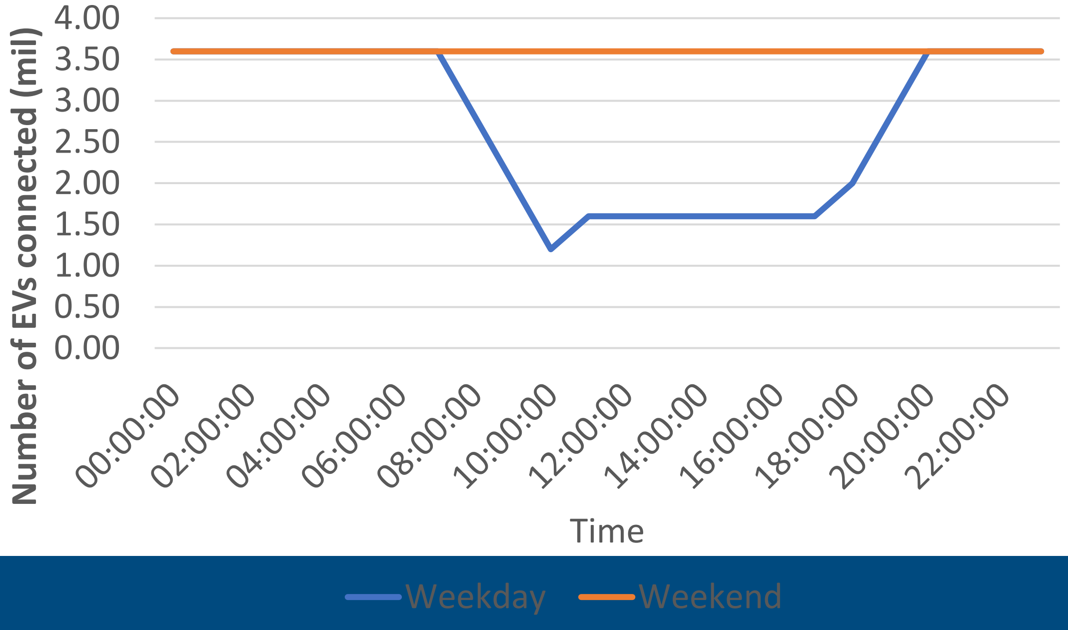
- Model one or more storage technologies
- Important parameters:
  - Storage capacity
  - Charging & discharging rates (power capacity)
  - Efficiency
  - Self-discharge
- “Multiple Storage Assets” specifies priority order between technologies

SCORES Methodology – Demand Model

- Models several likely scenarios up to 2050: e.g.-
  - No EVs, no HPs
  - ICEs no longer sold after 2030
  - All heating is moved to electric by 2050
- Possible to model with or without V2G
- You can model increasing appliance efficiency improvements or assume no future efficiency improvements

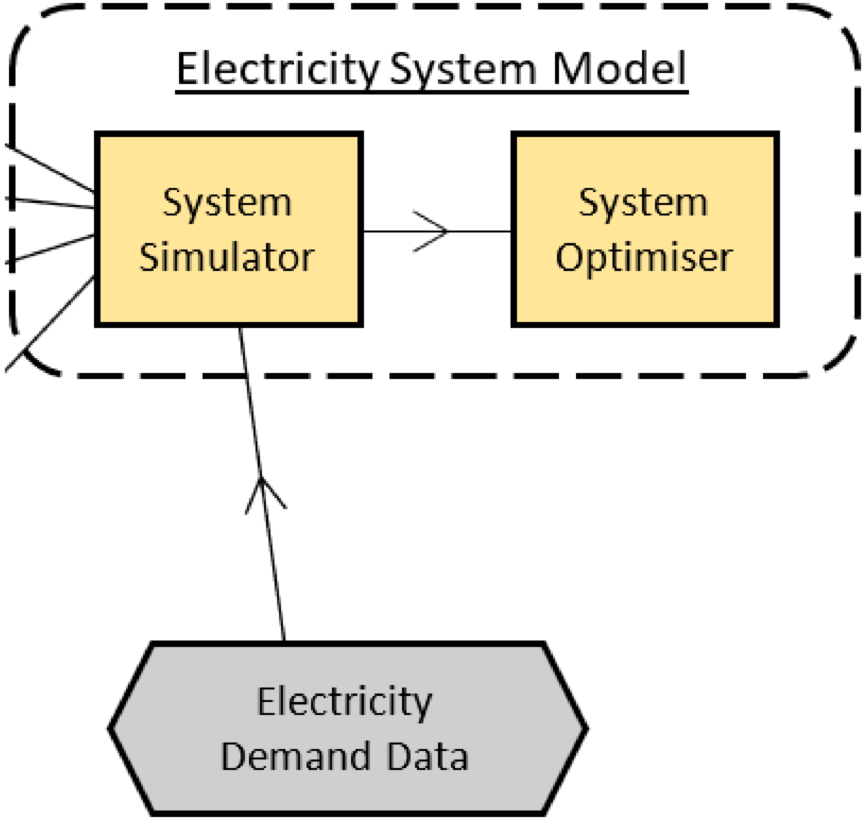
SCORES Methodology – EV Model

- Light Fleet
  - 4 million
  - 10kw
  - V2G: £2000, Smart: £800
  - Plug out charge: 100%
  - Plug in charge: 50%



- Heavy Fleet
  - 4 million
  - 10kw
  - V2G: £2000, Smart: £800
  - Plug out charge: 100%
  - Plug in charge: 25%

SCORES Methodology – System Model



- Models an overall generation + storage “system”, e.g.:
  - Combination of renewable technologies
  - Combination of storage/DSR technologies
- Compare generation with demand, utilise storage to fill gaps where possible
- System optimiser can seek “optimal” overall system, accounting for cost of each generation and storage technology
- BUT limitation- assumes network constraints not an issue

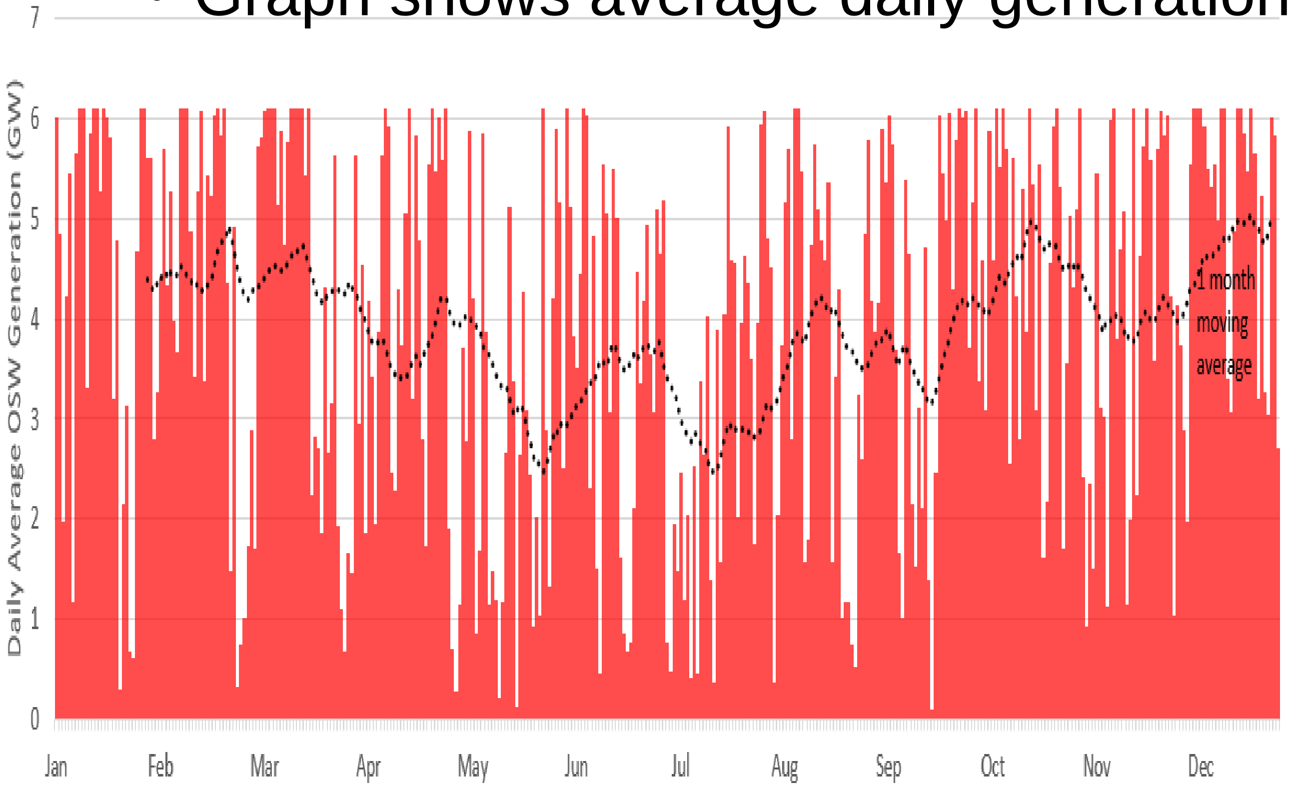
Case Study

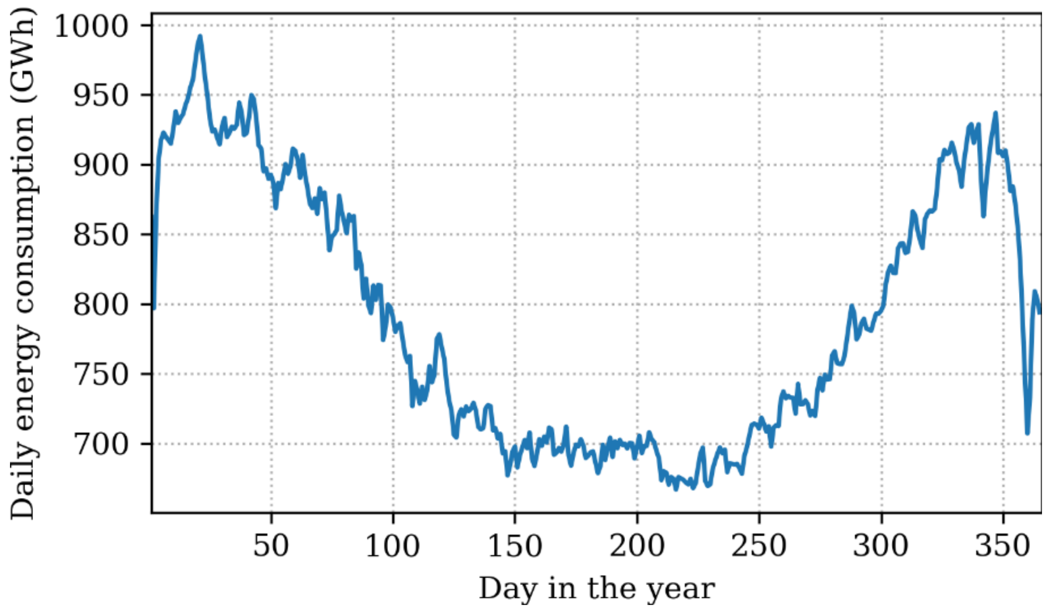
Qu: What mixture renewables and how much storage do we need for a certain reliability?

- Complex problem- depends on:
    - The low-carbon renewables mix installed
    - The correlation of the renewables with demand peaks
    - Round-trip efficiency (RTE) of the storage technologies used
    - The way you charge the storage and in what order
- Diurnal batteries have high cost, low-power density but RTE of >95%
- Inter-seasonal P2G2P has lower cost, high power densities but RTE of 30%
- Still need to understand how markets can deliver this optimum build- currently markets are building short-term battery storage and not inter-seasonal as they can cycle batteries more frequently making more money out or arbitrage and ancillary services

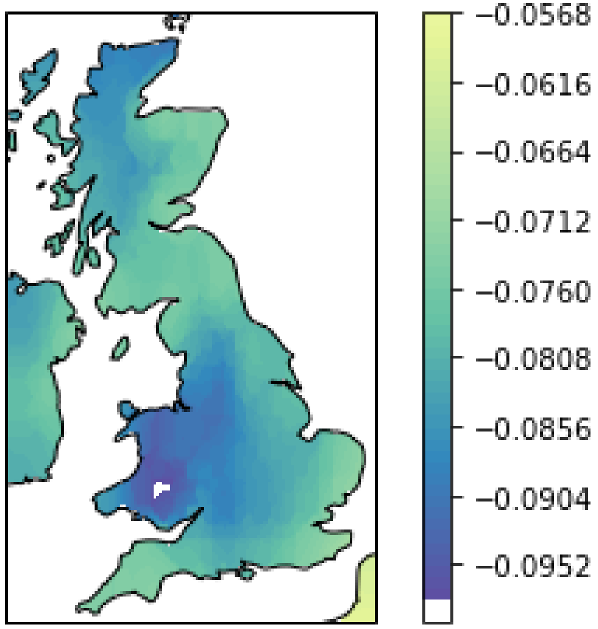
Annual Generation - OSW

- Graph shows average daily generation for 6.1 GW OSW comparator

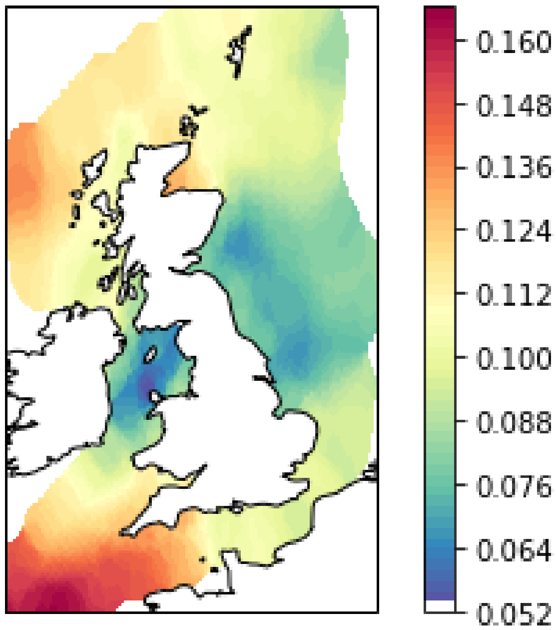




Correlation Renewables with Demand



Correlation of solar generation with demand



Correlation of offshore wind with demand

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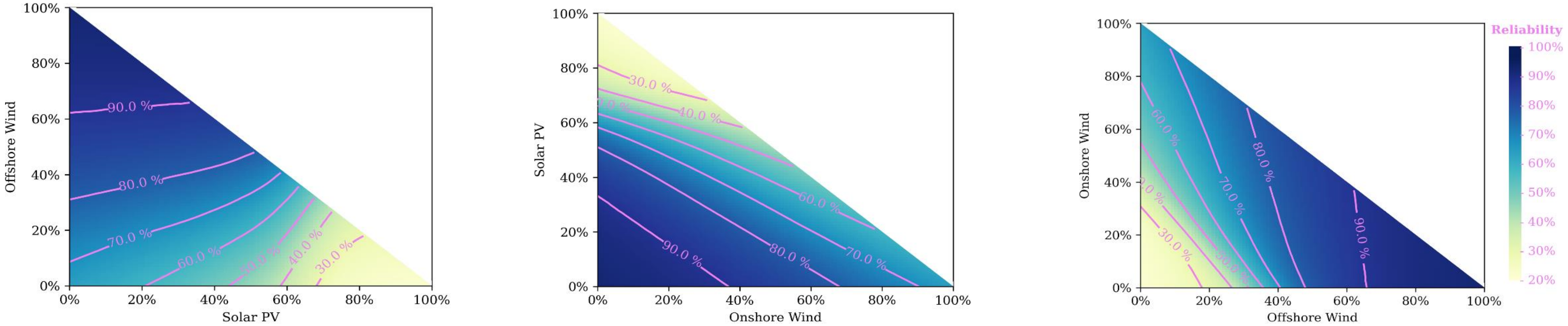
Optimum Mix is Biased Towards OSW



System reliability as a function of renewable capacity generation mix of solar PV, offshore wind and onshore wind with a total installed capacity of 100 GW and a fixed storage installed capacity of 300 GWh.

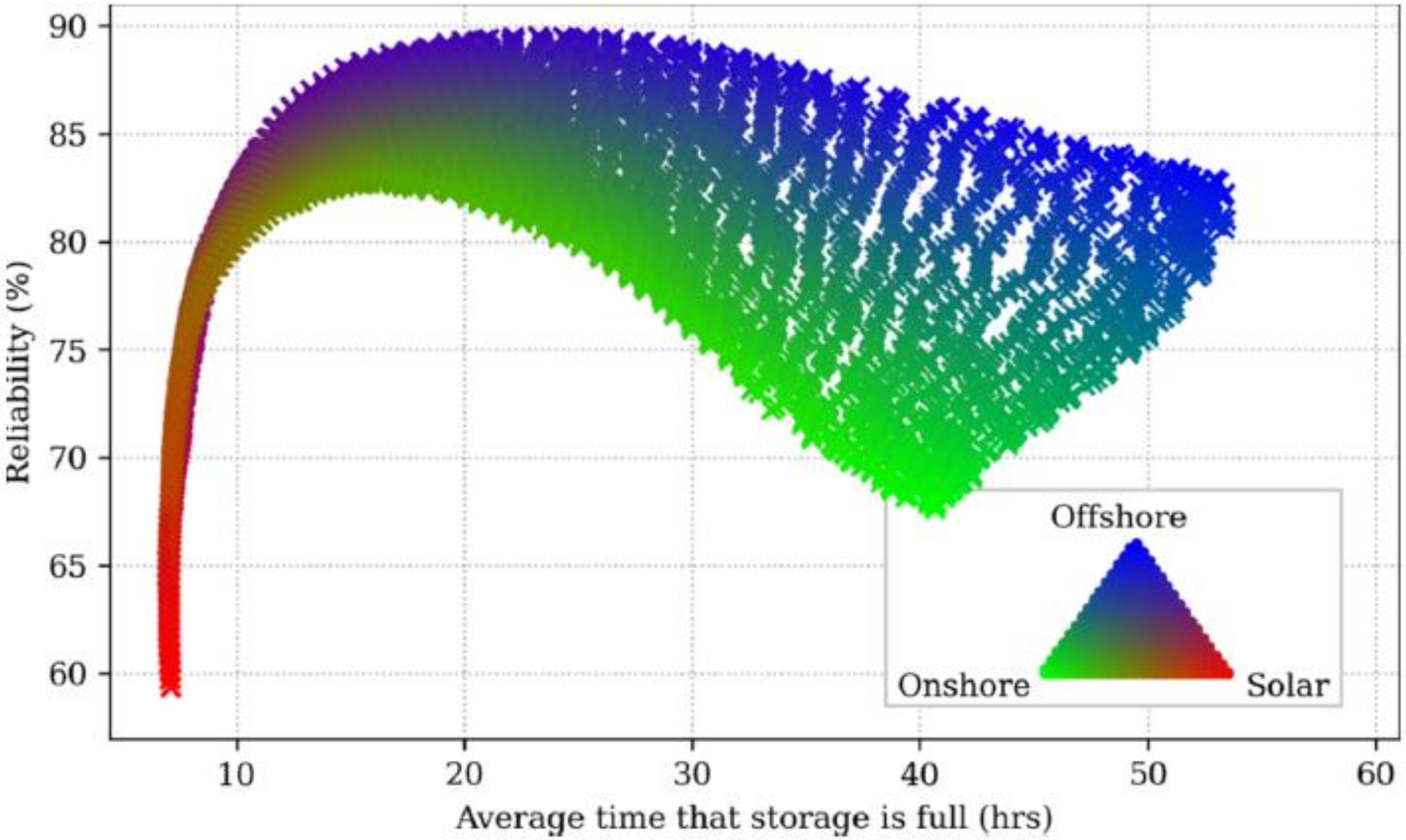
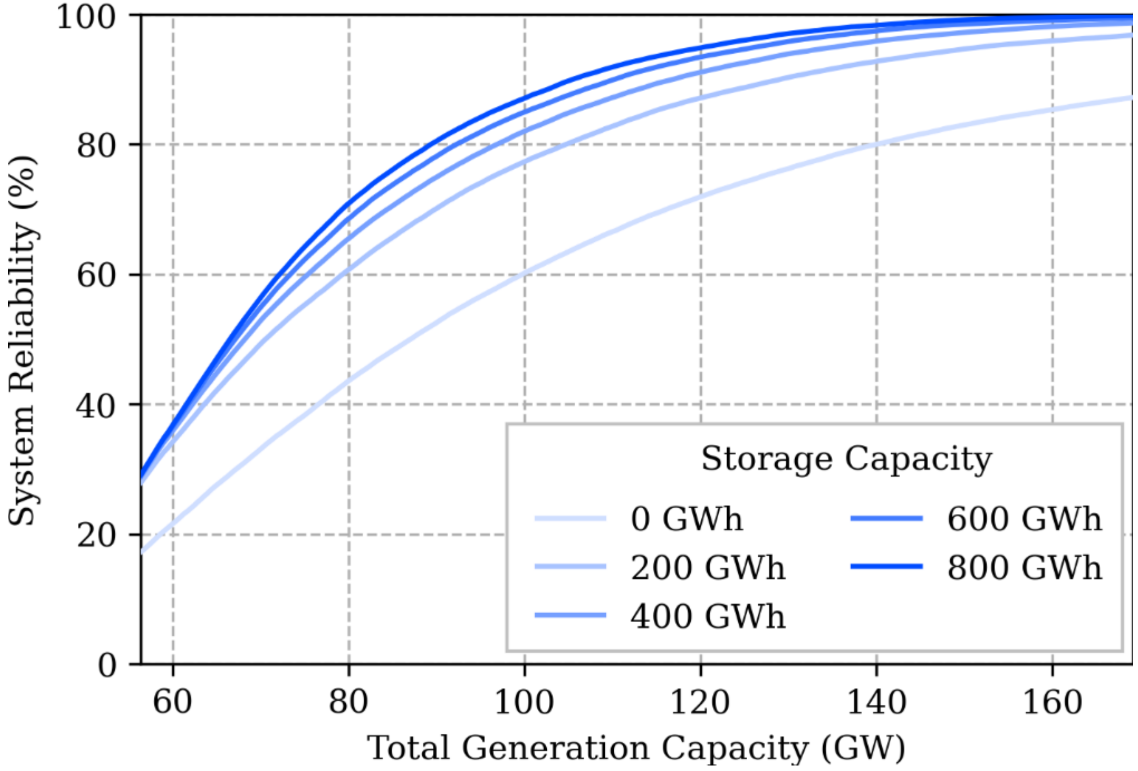


Figure 6. A scatter plot showing the reliability of different system designs against the average number of consecutive hours for which the energy storage was fully charged. Each system design has an annual generation of 350 TWh/y and 300 GWh of storage. The colour of the markers indicates relative contribution of each generation technology to the total annual energy generation.

Can you achieve high reliability with renewables + storage?



System reliability for a range of total system generation and storage capacities. Renewables mix is made up of 40% offshore wind, 30% onshore wind and 30% solar PV in this example. The model uses historical demand data- a peak demand of 58GW. Optimum has batteries around 10% of total storage.

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Conclusions to date

- You can build a reliable generation system from renewables (>99%) if you have both an optimum mixture of renewables plus both short-term and long-term storage
- But affordability of this decreases as you require reliabilities above 95%
- This points to a role for dispatchable generation using CCS
- But grid carbon intensities below 15g/kWh are possible even assuming CCS is only 90% efficient

Future work

Future Work

- Model upgrades:
  - New generation technologies
    - SMR Nuclear
  - Improved cost optimisation
- Applying the model to policy questions:
  - Role and value of alternative flexibility options (storage, DSR, etc.)
  - Diversity of GB renewables capacity, and value of floating offshore wind
  - Effect of “wind droughts” on optimum system

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Further information

- Model is open source and is published on GitHub
- Assumptions and model parameters
  - Published here: Crozier, C.; Quarton, C.; Mansor, N.; Pagnano, D.; Llewellyn, I. Modelling of the Ability of a Mixed Renewable Generation Electricity System with Storage to Meet Consumer Demand. *Electricity* **2022**, *3*
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