Modelling long- term energy pathways with high shares of variable renewable energy sources

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Motivation

- Variable renewable energy technologies (VRE) and demand vary in time and space
- How do we integrate high shares of VRE into the GB power system?
- Need a model to complement long time horizon energy system models such as UKTM:
  - Runs from 2010 to 2050
  - Each years is represented as 16 time slices: 4 seasons and 4 intraday (day, evening, late evening, night)
  - One region representing the whole of the UK

Research questions

Design a power system with high shares of VRE that is cost- effective, flexible and robust to the diversity of the weather:

→What are the robust locations for VRE?

→Which are the robust integration options (storage, flexible generation, transmission line extension) and their locations?

highRES

High spatial and temporal resolution electricity system model highRES:

→ Complements UKTM to find cost-effective, flexible and robust low carbon electricity pathways

→ Integration options are network reinforcement (spatial diversification), energy storage, flexible generation

→ Objective: minimise power system costs to meet hourly demand subject to constraints
- Technical constraints: ramping, minimum & maximum generation
- Storage constraints
- Transmission constraints

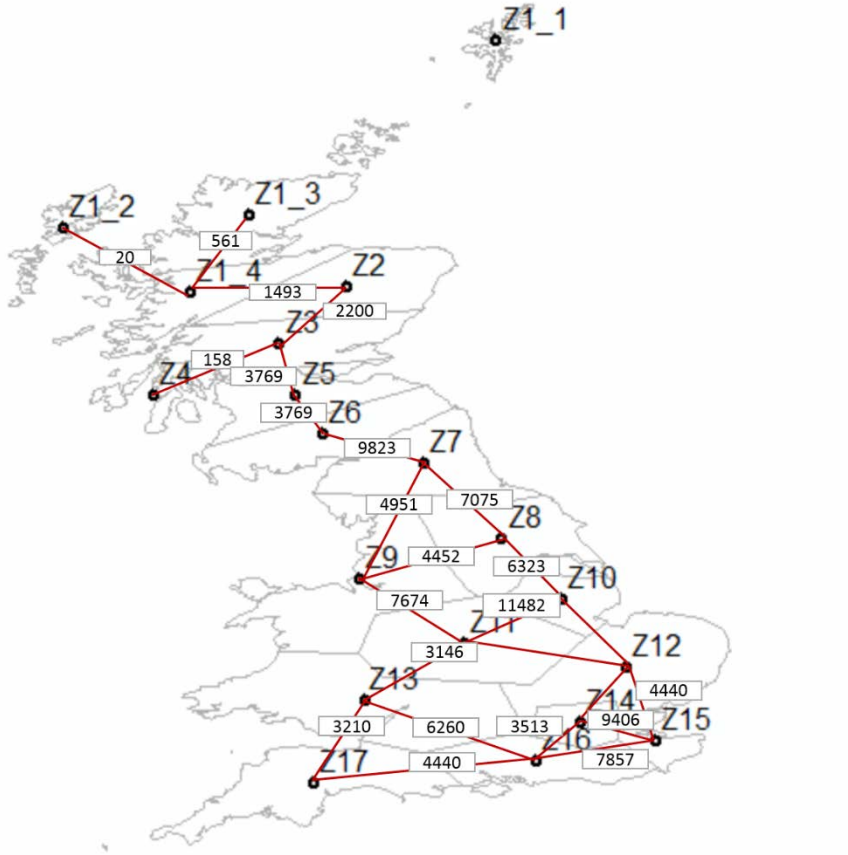
→ Output: Total system costs, electricity price, power plants usage rates, emissions, renewable curtailment, location of generation and integration options

→ Strong point: good representation of VRE

Demand- Supply Balancing

Demand Supply Matching at Zonal Level

- Zones and demand shares based on National Grid
- Simplified grid connecting the zones and enabling demand-supply balancing between zones



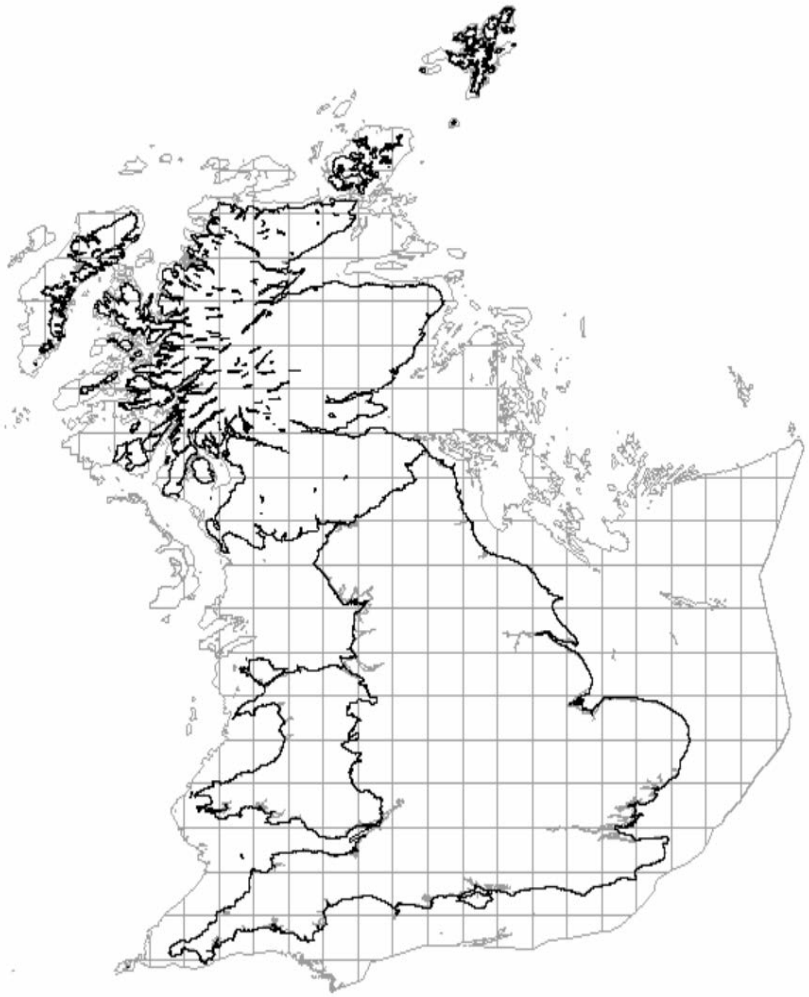
Weather data

- Core focus of highRES is a good representation of renewables -> this means input weather data with sufficient:
  - Temporal coverage (number of years), one single year is not enough.
  - Temporal resolution, as high as possible subject to computational constraints and data availability.
  - Spatial coverage, at least enough to capture whole of GB power system (on and offshore). Ideally uniform.
  - Spatial resolution, fine enough to represent simplified implementation of high voltage transmission system.

- Combined this allows us to begin to capture temporal and spatial variability of VRE generation.

Weather data – On and offshore wind

- For wind use NCEP Climate Forecast System Reanalysis (CFSR):
  - Ingests (assimilates) historical observations (satellites, radiosondes, surface stations, etc) every 6 hours from 1979-2010.
  - Produces a consistent representation of the state of the global atmosphere and ocean on a 3D grid.
- CFSR gives us:
  - 2m and 10m instantaneous wind speeds every hour.
  - Data available both on and offshore on a uniform grid at 0.5°x0.5° (35km x 50km) resolution.
  - Adopt this as our reference grid for the model.

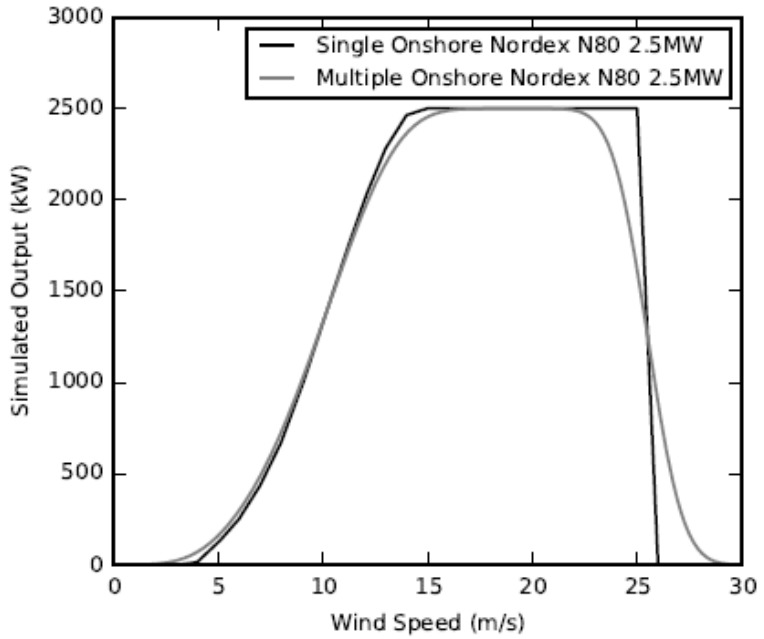


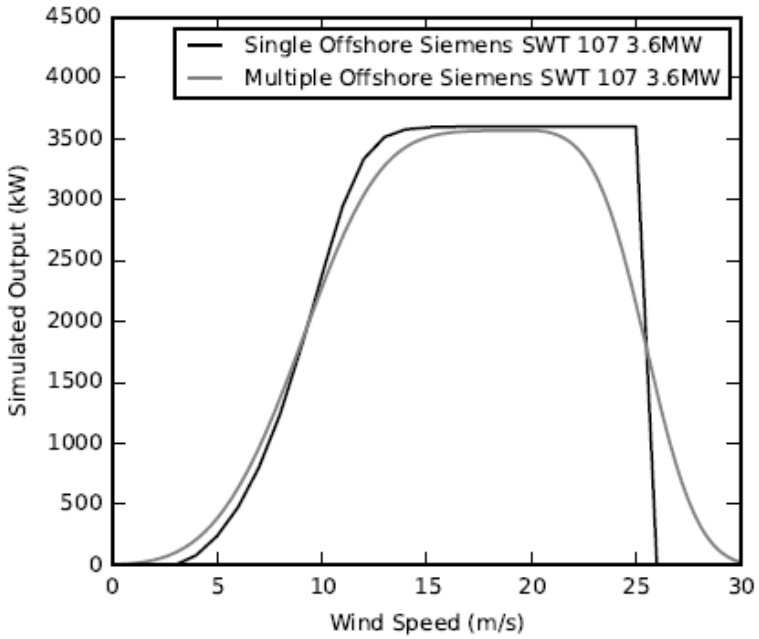
Weather data – On and offshore wind

- Hourly 10m wind speed extrapolated to turbine hub height (80m) using*:

$$u(z_2) = u(z_1)\left(\frac{z_2}{z_1}\right)^H$$

- Then converted to turbine power assuming*:

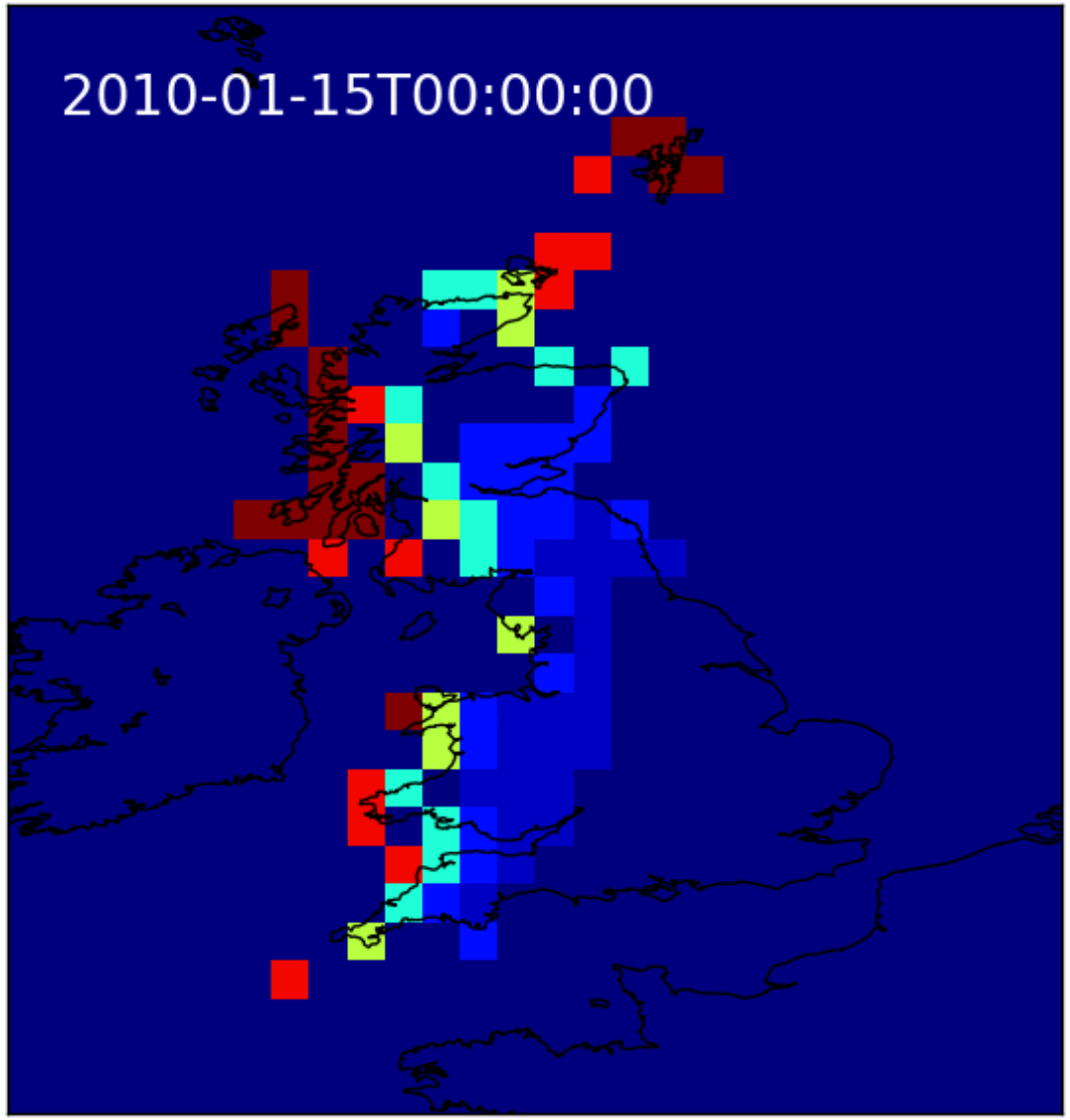




- Then adjusted using a correction factor based on calibration to hourly Elexon data*.

*For details see Sharpe, 2015 – UCL PhD thesis with a focus on GB wind modelling.

Weather data – On shore wind



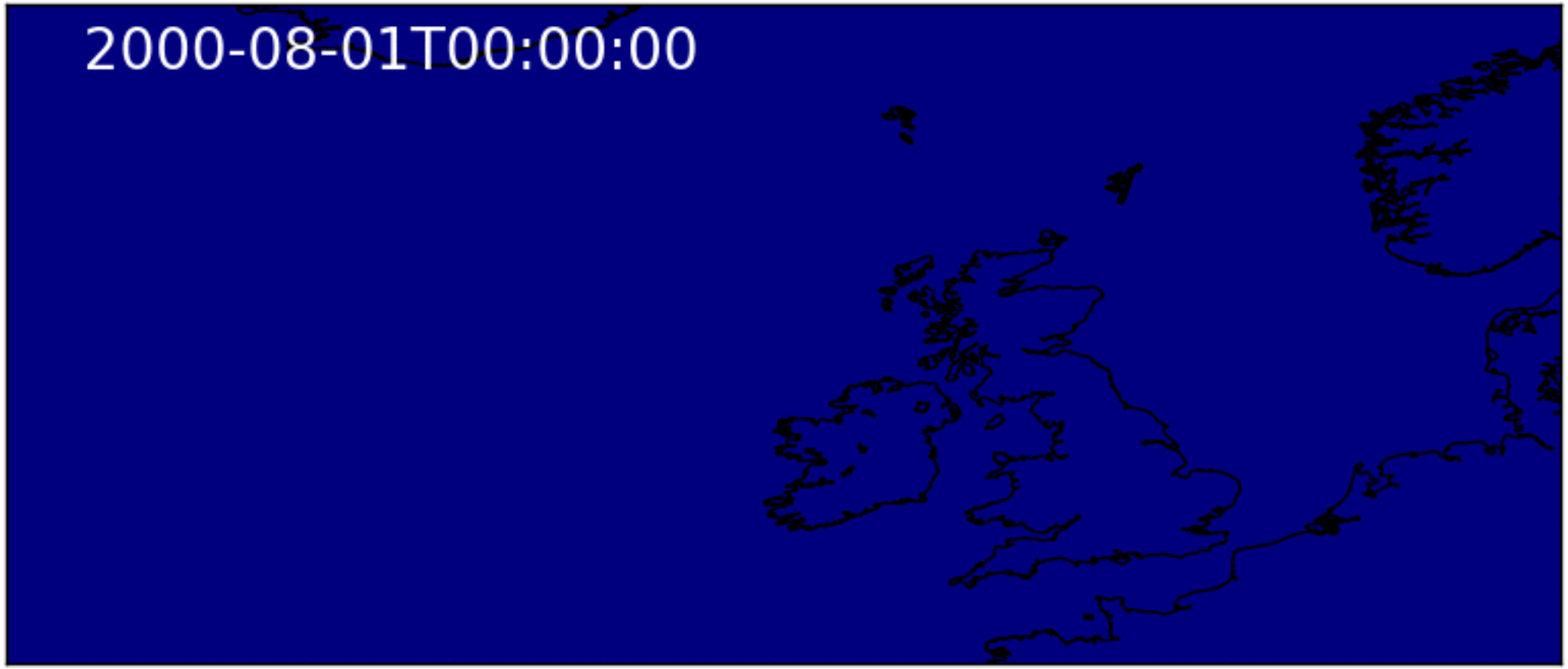
Weather data – Solar PV

- For solar PV (roof and ground mounted) use data from Satellite Application Facility on Climate Monitoring (CMSAF).
  - Based on observations from Meteosat First and Second Generation – geostationary satellites covering Europe and Africa – between 1983-2013.
  - Satellite sees cloud cover which is converted to global horizontal irradiance (GHI) and direct normal irradiance (DNI) by CMSAF*.

- Use physical model (in python) to:
  - Convert GHI and DNI -> on panel irradiance given desired angle of tilt and orientation of module.
  - Power output obtained from simple model that accounts for impact of module temperature on relative efficiency given model type (here crystalline Silicon).

* For details see Meteosat Solar Surface Irradiance and effective Cloud Albedo CDR manual on www.cmsaf.eu

Weather data – Solar PV



Weather data – Wind and Solar

- Currently have 2000-2010 data processed and ready to use in highRES for both wind and solar (version 1).

- Fed into the model as hourly capacity factors, i.e. the model decides how much capacity is built in a grid cell and that capacity is multiplied by CF to get generation.

- Model can run in two modes, either at full grid cell resolution or with the cells aggregated to zones prior to execution, i.e. each zone has an average wind and solar CF per hour.

Resource assessment

Where can VRE be placed?

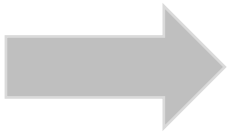
→Technical constraints
→ Socio- political constraints

- Literature review to define constraints
- GIS analysis to exclude areas

Resource assessment:
Ground- mounted PV buildable area

Low quality agricultural land

Excluding protected areas and areas steeper than 15 degrees



Resource assessment: Onshore wind buildable area

Exclusion areas:

protected areas

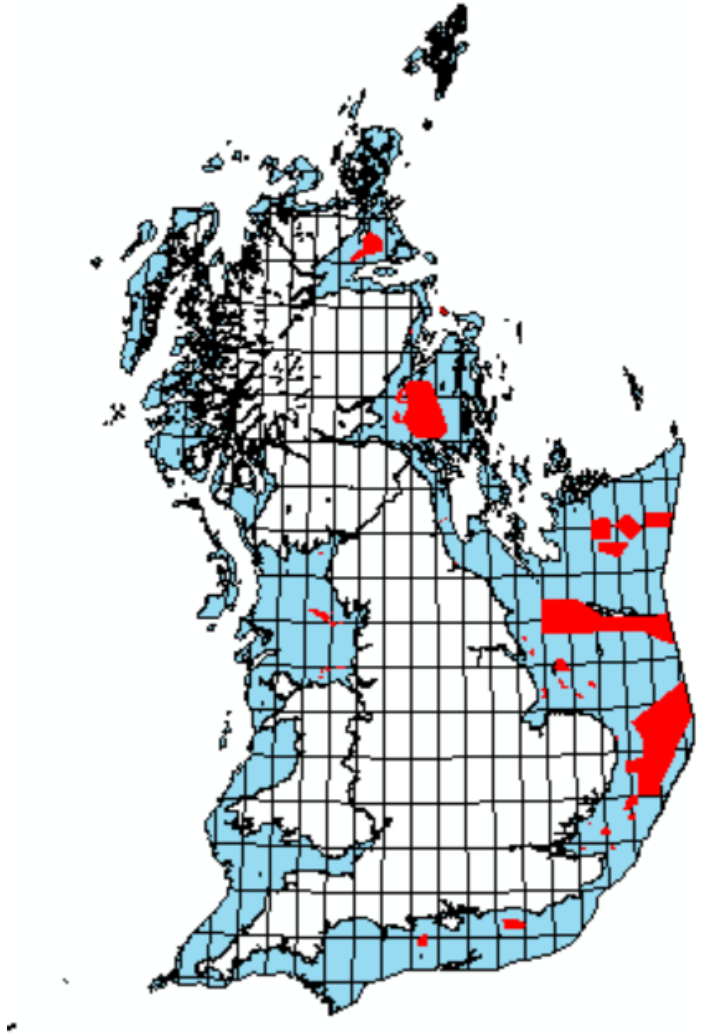
buildings

infrastructure

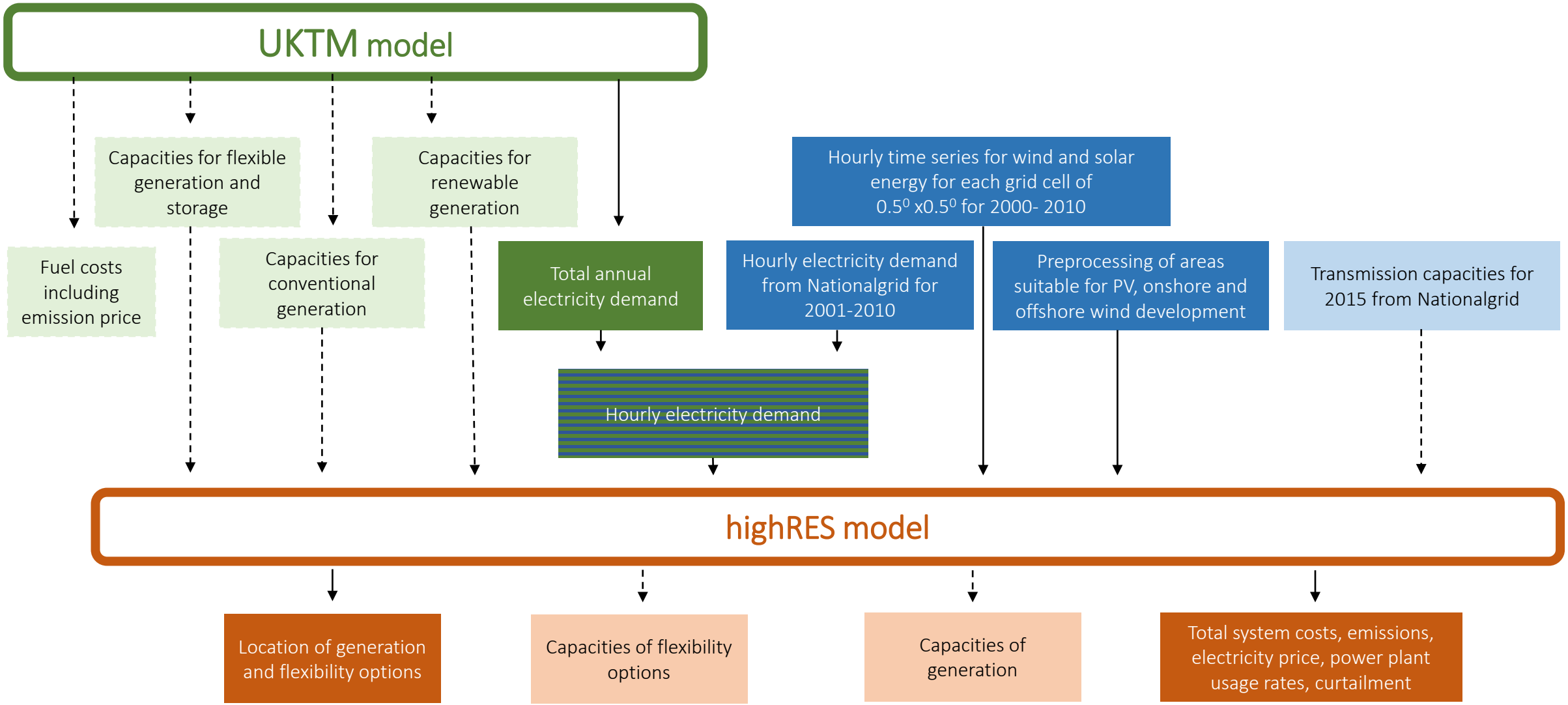
slope

Resource assessment: Offshore wind buildable area

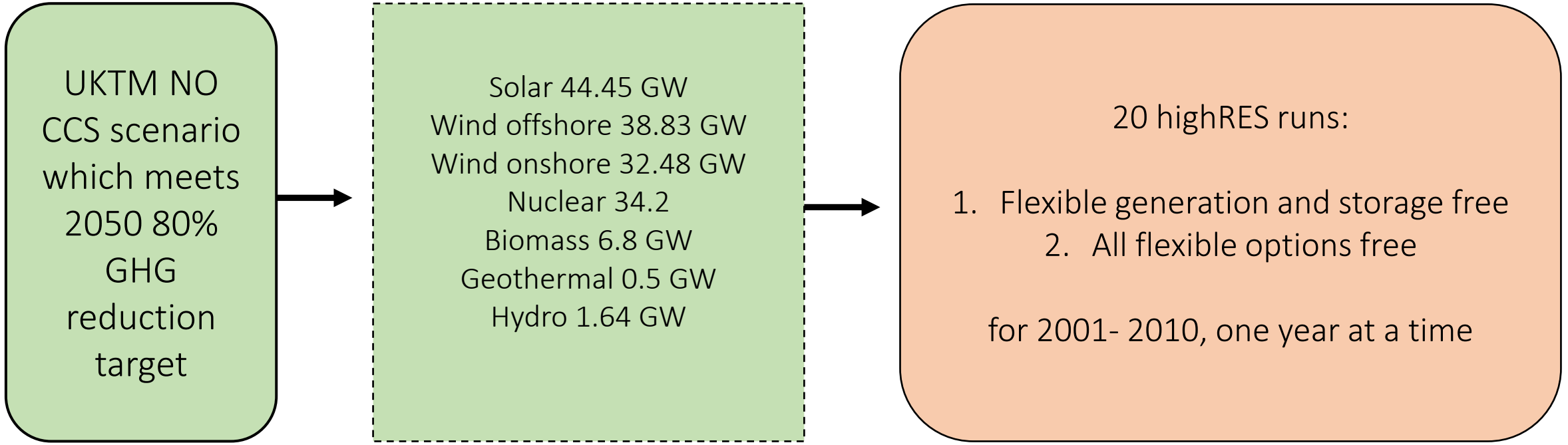
- Use bathymetry data to determine water depth of Crown Estate's leasing rounds
- Hornsea: maximum depth (70 m)
- Exclude areas with a water depth of more than 70 m



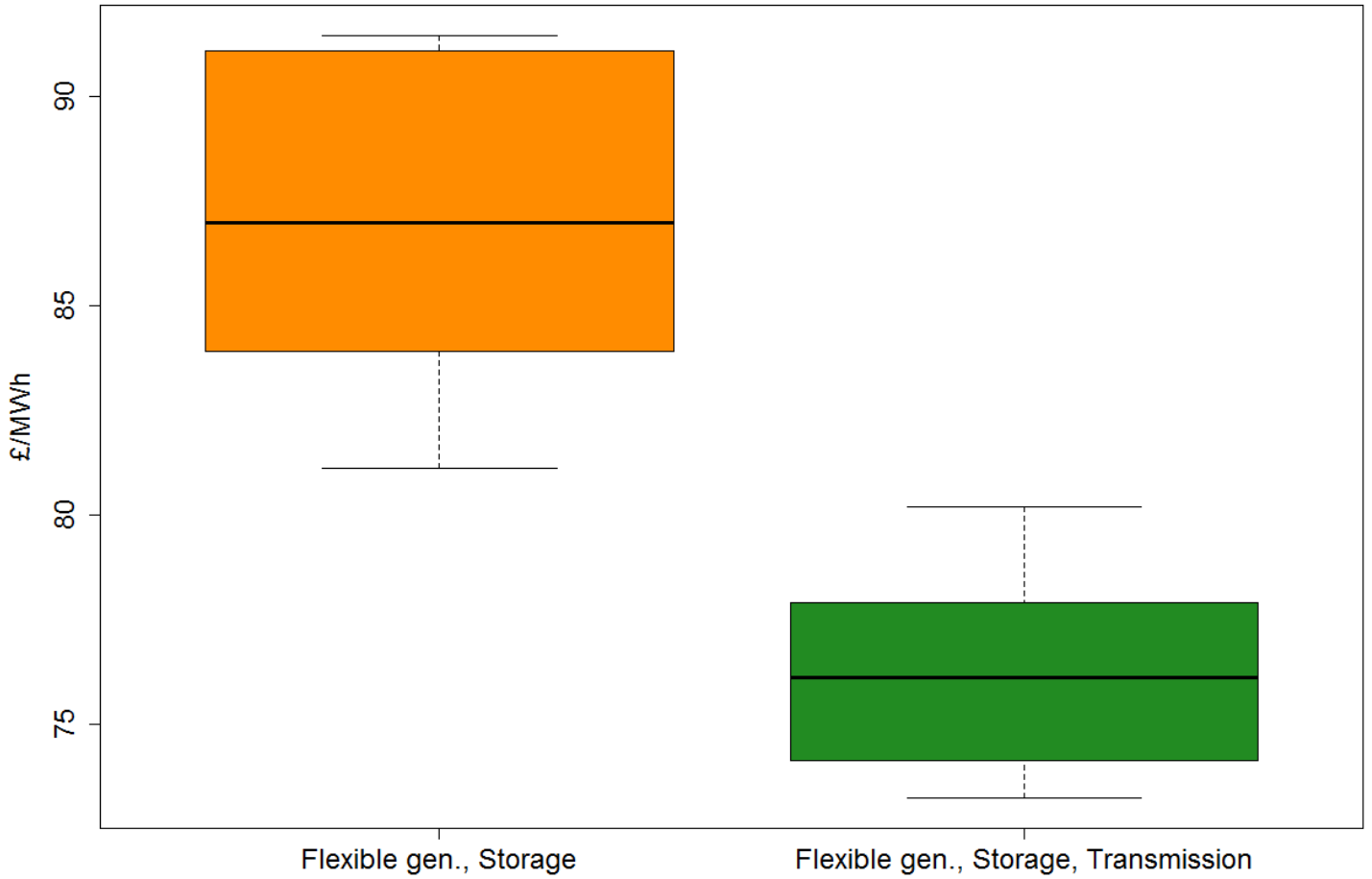
UKTM- highRES linkage



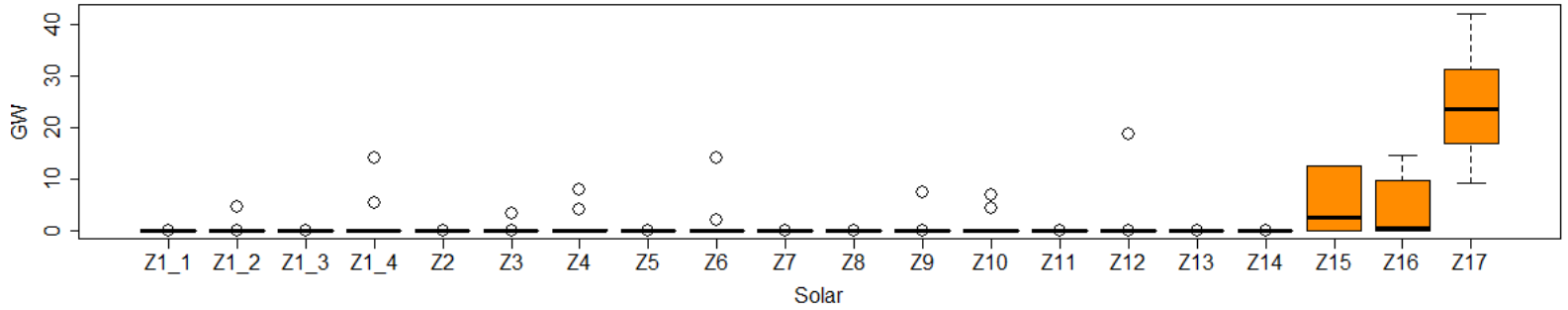
UKTM- highRES linkage

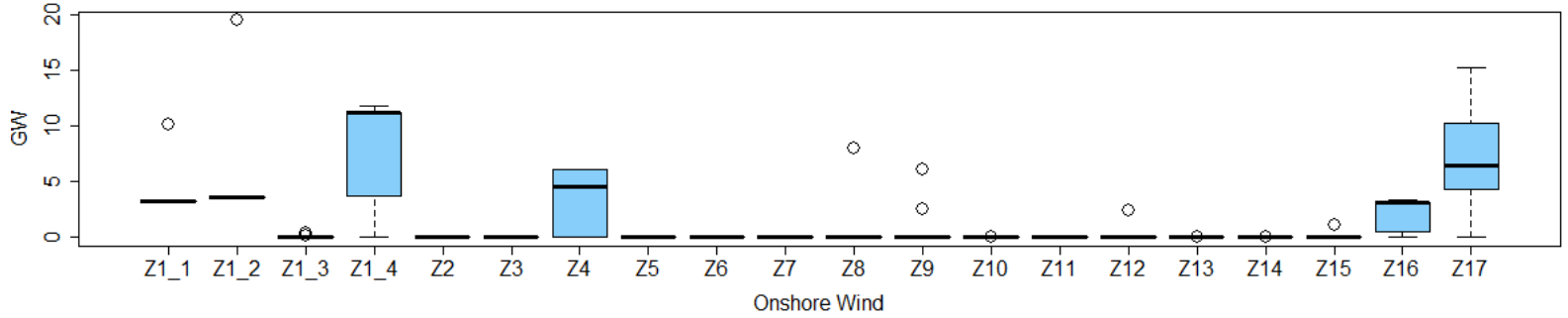


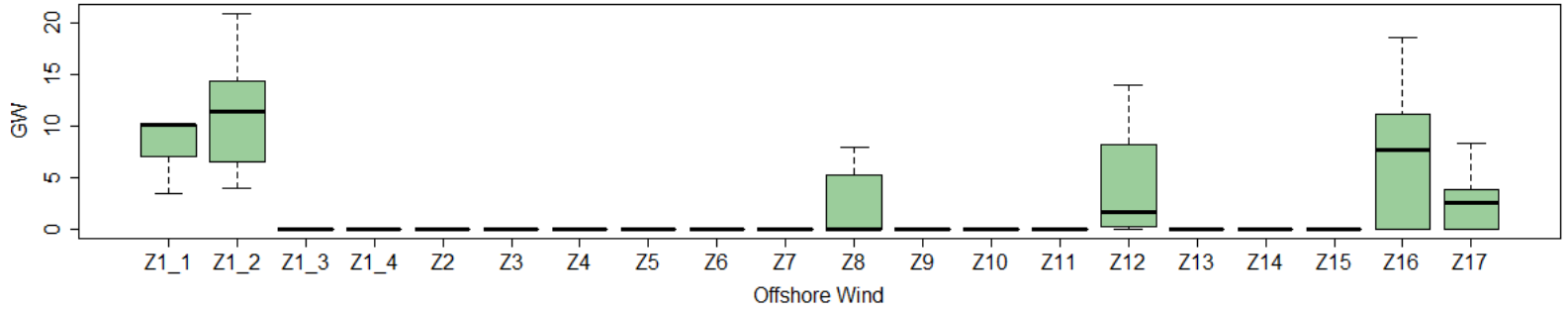
Results: LCOE



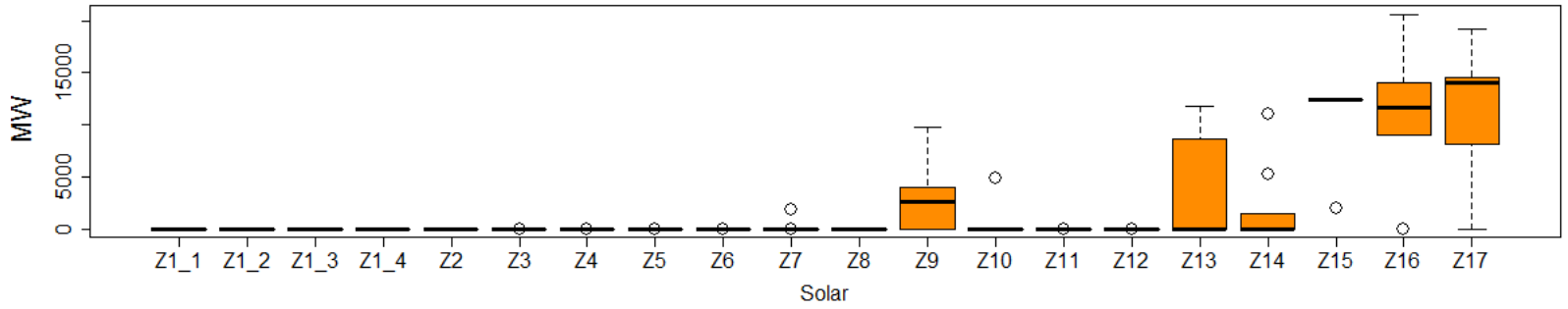
Results: Where are VRE located in the all flex scenario?

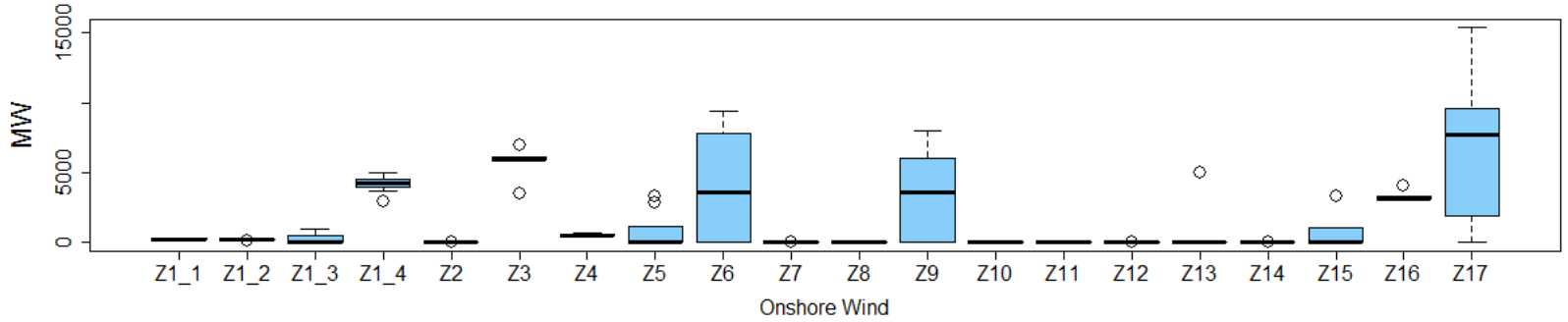


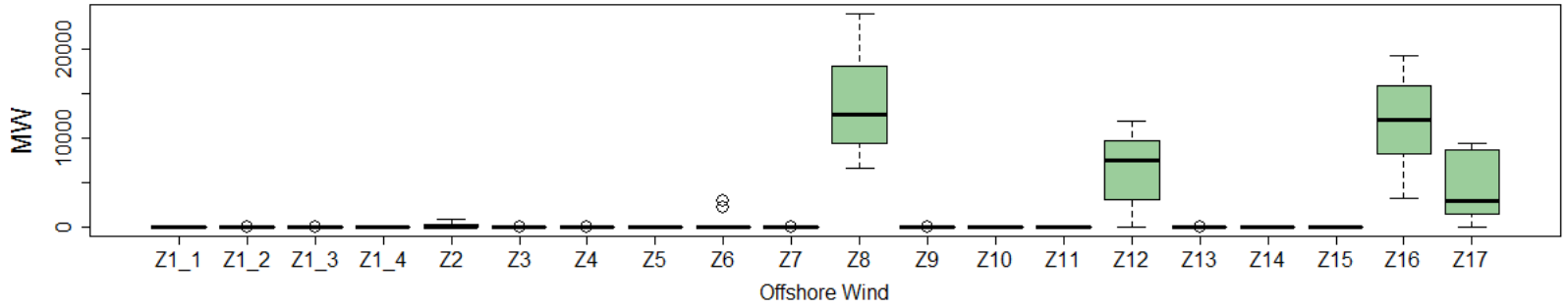




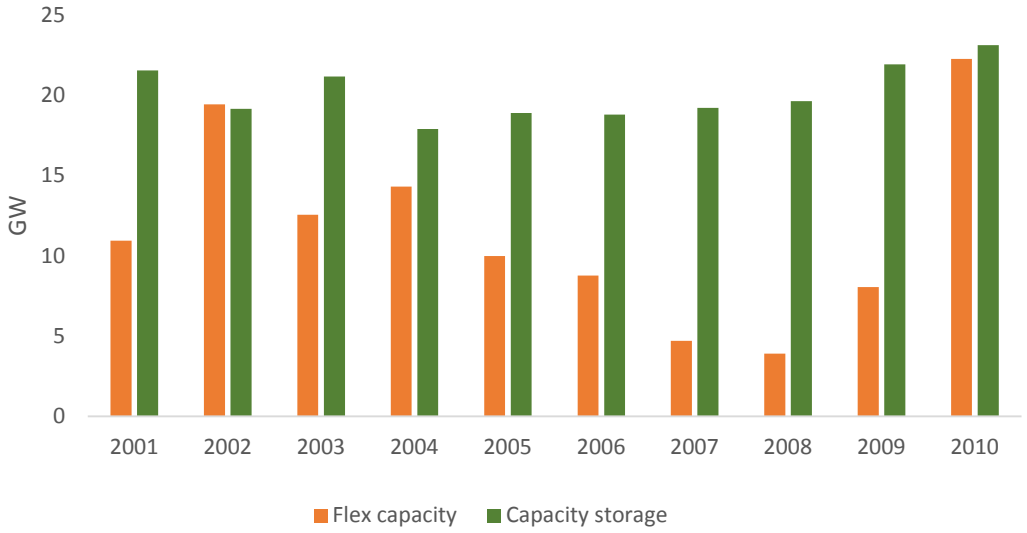
Results: Where are VRE located in the storage+ flex generation scenario?

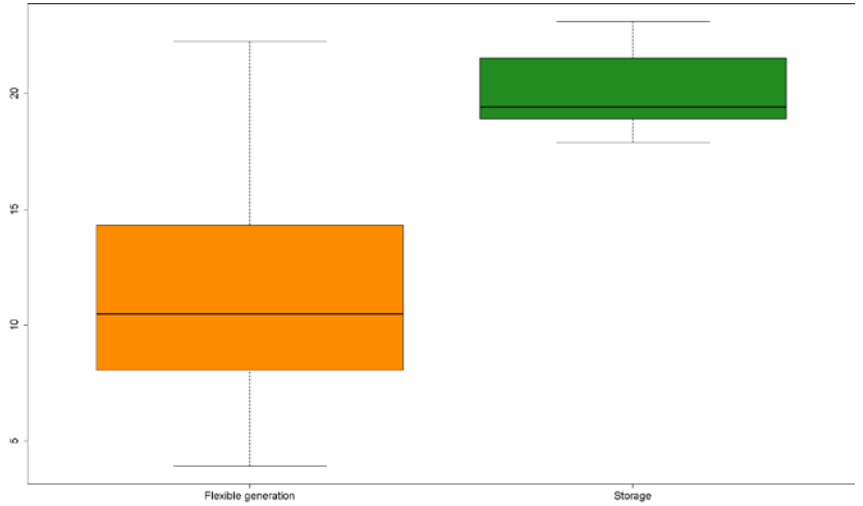


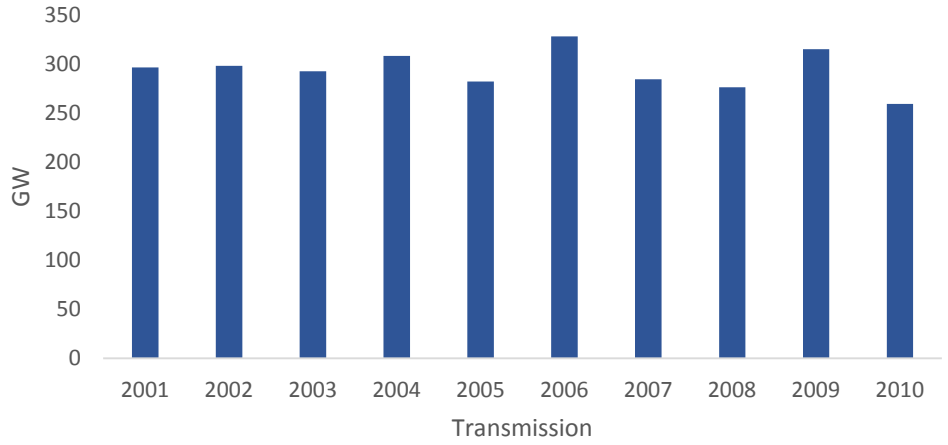


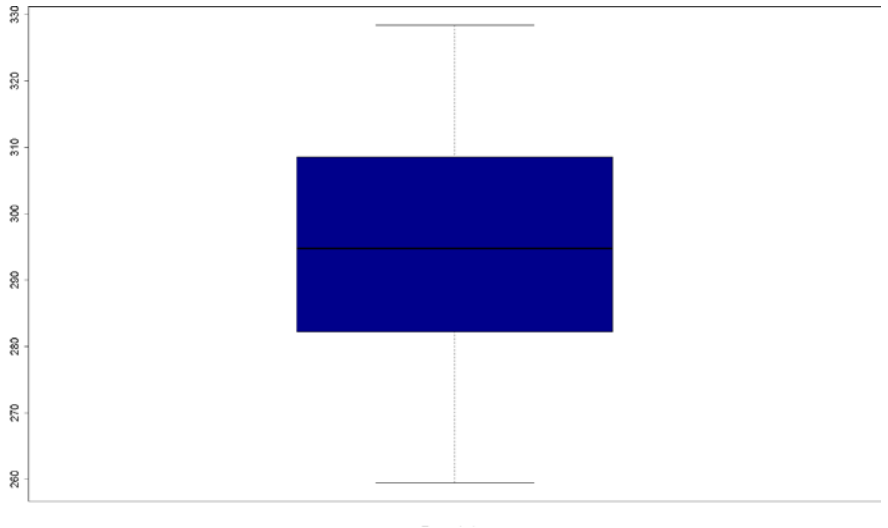


Results: What are the installed capacities of flexibility options (all flex scenario)?

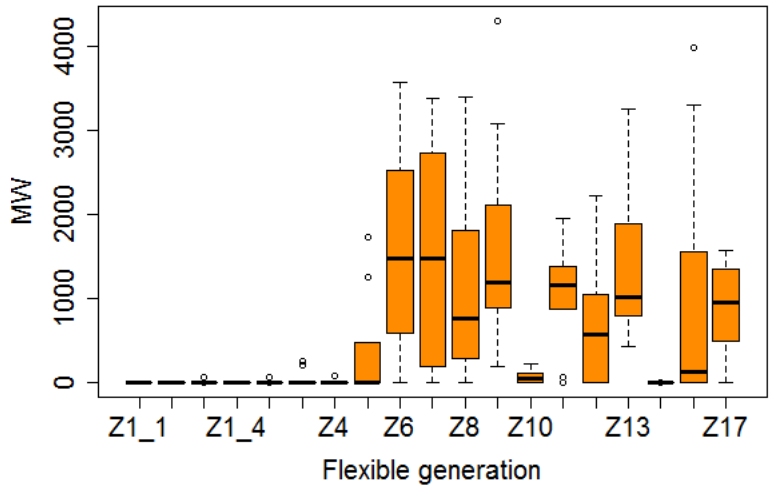


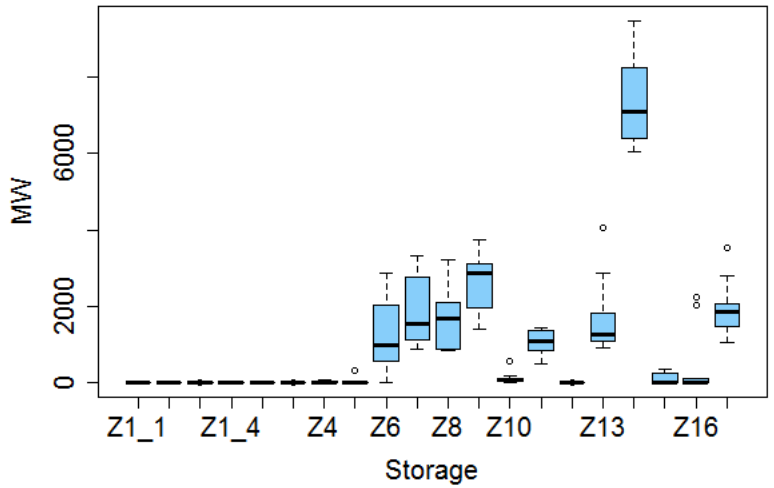


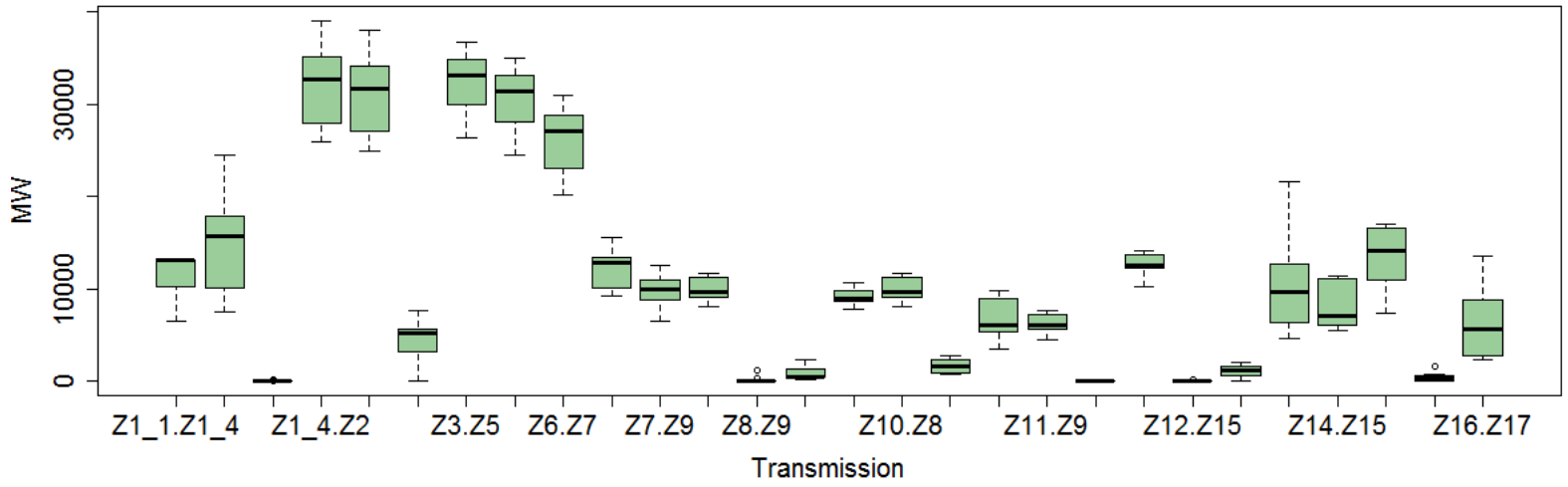




Results: Where are the flexibility options located (all flex scenario)?







Conclusions

- Using different weather years is important:

  → Flexibility options:
  - Capacities of storage and transmission are most consistent, flexible generation is most variable of the three
  - Transmission from North to South, Flexible generation and storage where demand is but the precise location is sensitive to the year

  → VRE:
  - Consistency: Wind (North, North-Sea and South), Solar (South) but there are outliers in some years

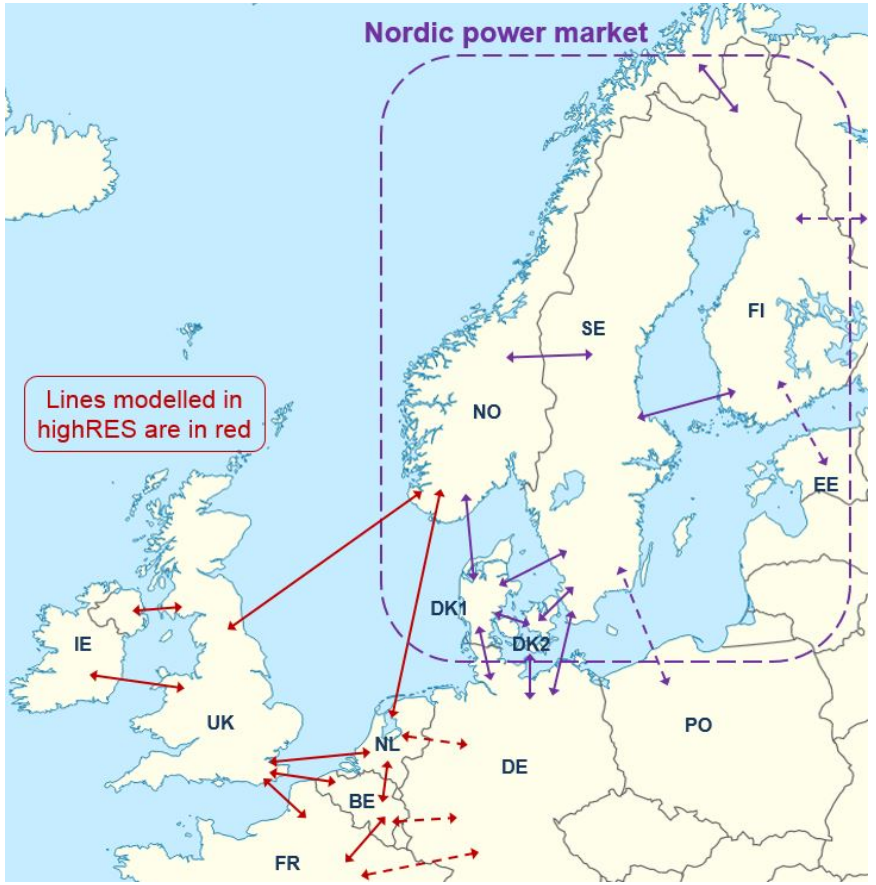
- Consistency when using all three integration options that LCOE are lower than flexible generation + storage

Ongoing work

→Renewable energy deployment and costs in the UK: spatial analysis taking into account policy, social and environmental constraints

- Scenarios of technical and socio- political constraints
- What is the difference in costs between the scenarios?

→Modelling of neighbouring countries to include interconnection as additional flexibility option (recent wholeSEM fellowship: Behnam Zakeri from Aalto University)



Thank you!

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