THE IMPACT OF CLIMATE UNCERTAINTY ON POWER SYSTEM OPERATIONS

Dr **Hannah Bloomfield**

with thanks to: David Brayshaw, Matthew Deakin, David Greenwood, Sarah Sheehy, Philip Taylor, Sara Walker. Alberto Troccoli, Clare Goodess, Matteo De-Felice, Laurent Dubus, Philip Bett and Yves-Marie Saint-Drenan,

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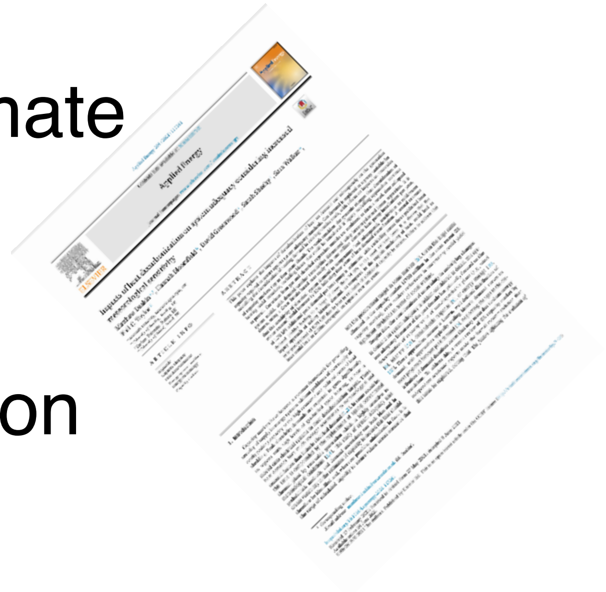
OUTLINE

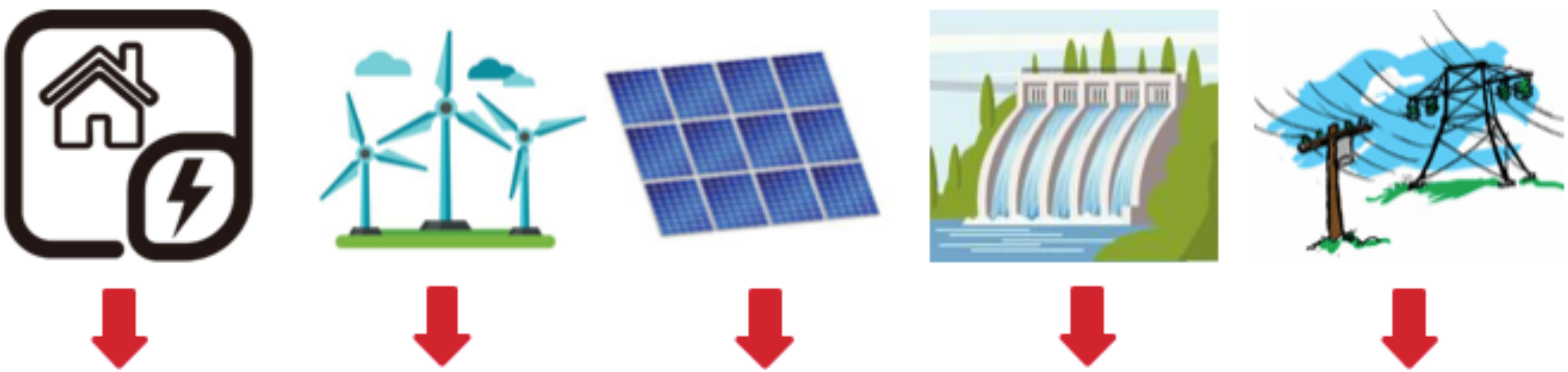
- **Part 1**
- Motivation: Why the energy industry needs weather and climate information?
- **Part 2**
- System Adequacy: Climate variability vs. heat decarbonisation scenarios
  - Possible heat pump profiles
  - Possible decarbonisation scenarios
- **Part 3**
- Potential impacts of climate change on European power systems
  - Power system vs climate uncertainty
  - Impacts on Demand, Wind power, Solar PV



- Highlighting some newly developed datasets from the CLEARHEADS project.

MOTIVATION

- To meet government targets power systems are becoming increasingly weather-dependent
- This weather-dependence results in increased power system variability on numerous timescales from seconds-decades
- The meteorological conditions associated with this variability must be understood for reliable power system operation



Temperature Wind Chill Relative Humidity	Wind Speed	Shortwave Irradiance Temperature	Precipitation River Run-off	Precipitation Snowfall Wind Speed Temperature

WHY DO I NEED METEOROLOGICAL DATA?

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- Energy systems are rapidly changing to meet climate mitigation targets, so metered data contains large trends, and past years data are less useful.
- Climate variability is extremely important to account for.
- Year to year variations in weather can cause large differences in power system modelling results.

GB: since 2010 wind surges, coal collapses and fossil fuel use nearly halves

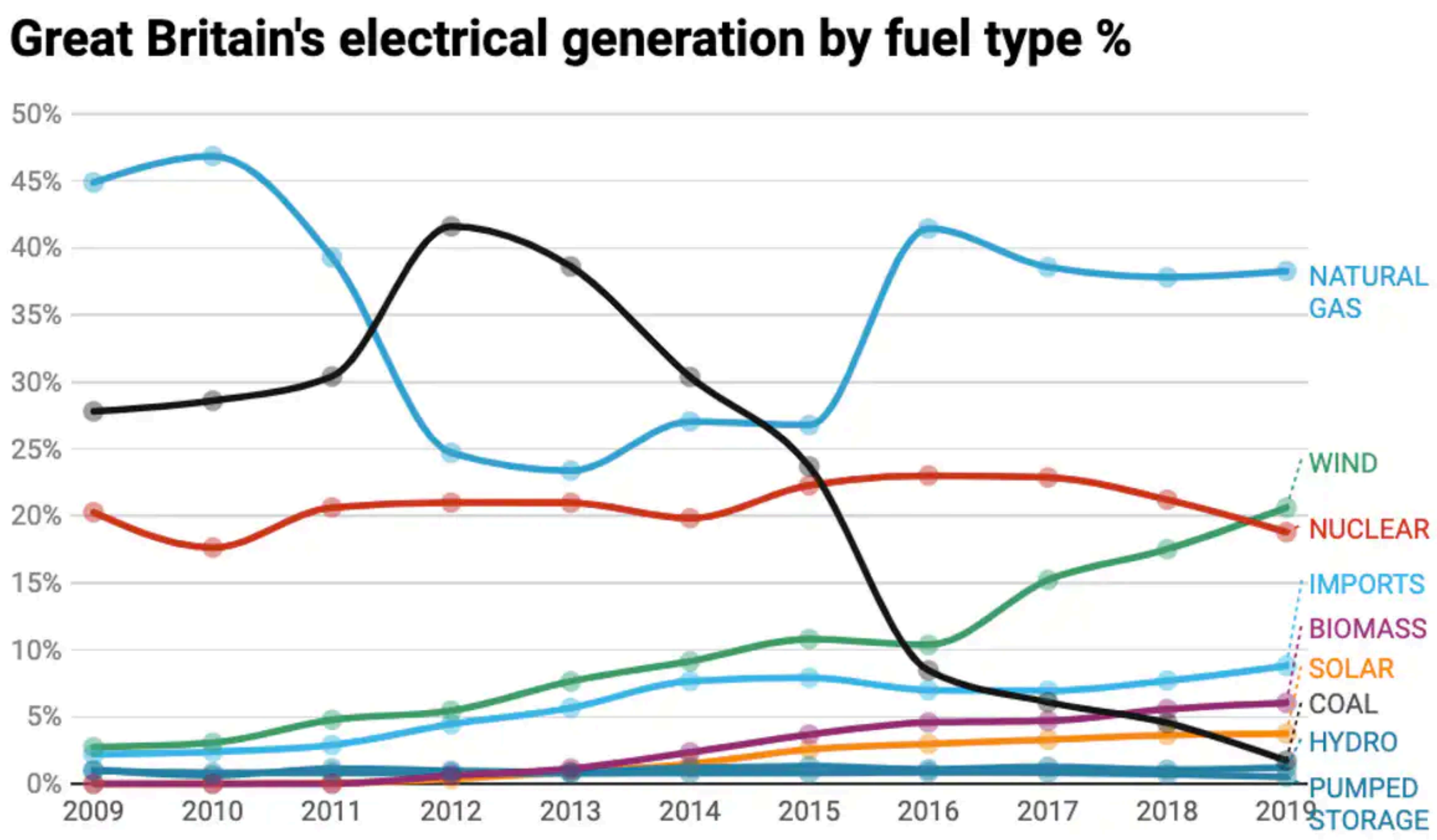


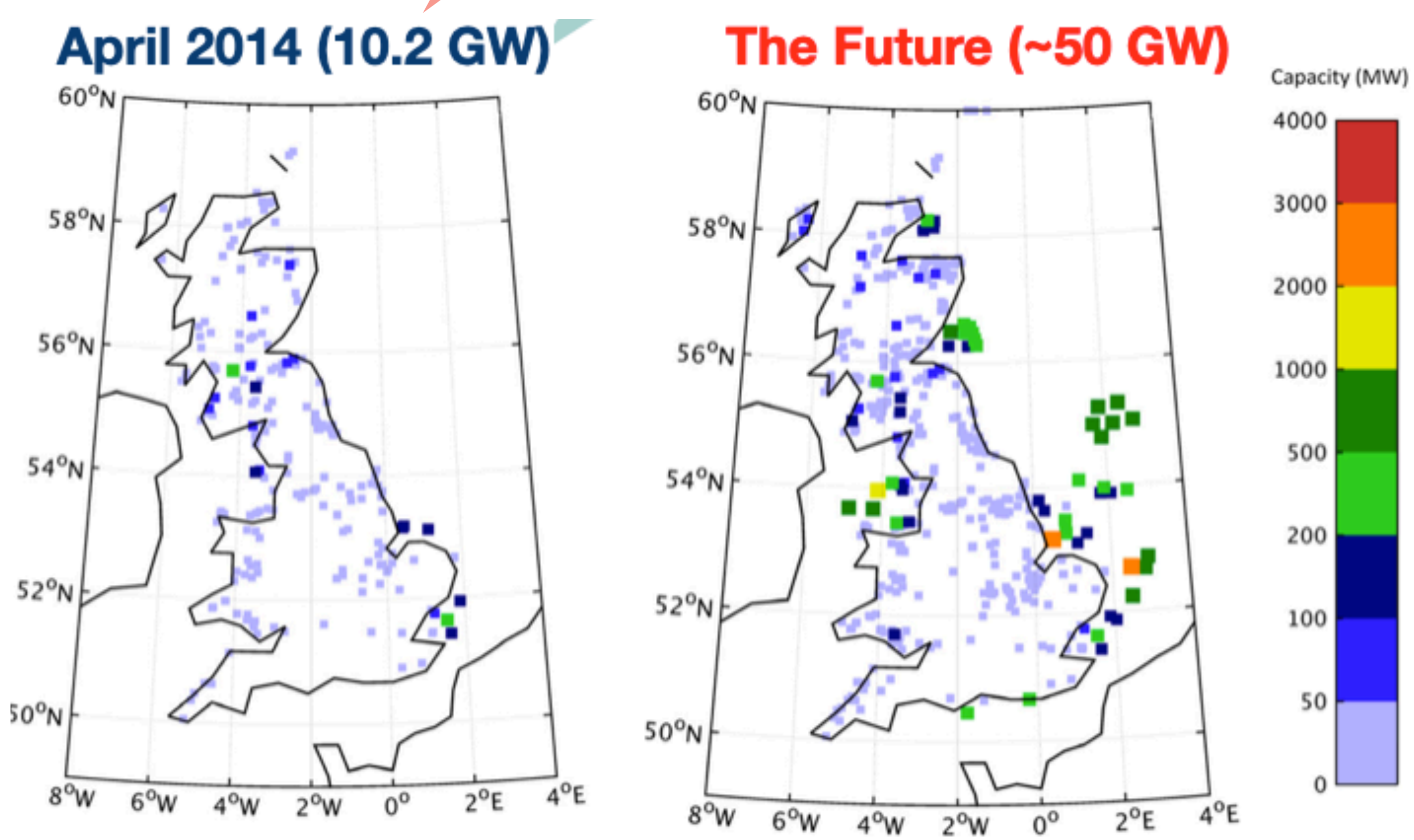
Chart: Dr Grant Wilson, University of Birmingham • Source: Elexon and National Grid • Get the data • Created with Datawrapper

WHY CAN THE WEATHER DATA BE USEFUL?

Can we predict these components in advance?

Does weather even matter in the grand scheme of things?

What happens to my renewables at peak demand?



Summer was bad, will that happen again next year?

What about climate change?

Wind turbine distributions taken from Drew et al., (2015) https://doi.org/10.3390/resources4010155

IMPORTANT TIMESCALES

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Operational seconds – days	Grid management, plant scheduling Anticipating extreme weather	Nowcasting & short range
Trading days – 1 year	Maintenance/resource planning Longer-term wholesale energy contracts	Extended range & seasonal forecasts
Strategic year – year climate variability	Characterising demand and supply Impacts of year-year variability	Reanalysis & control runs
Planning climate change	Impacts of climate change Trade-off between climate change and energy system change	Climate model projections
Extremes disrupting weather	Risk and impact of extreme disruptive weather local vs. far afield impacts	All of the above!

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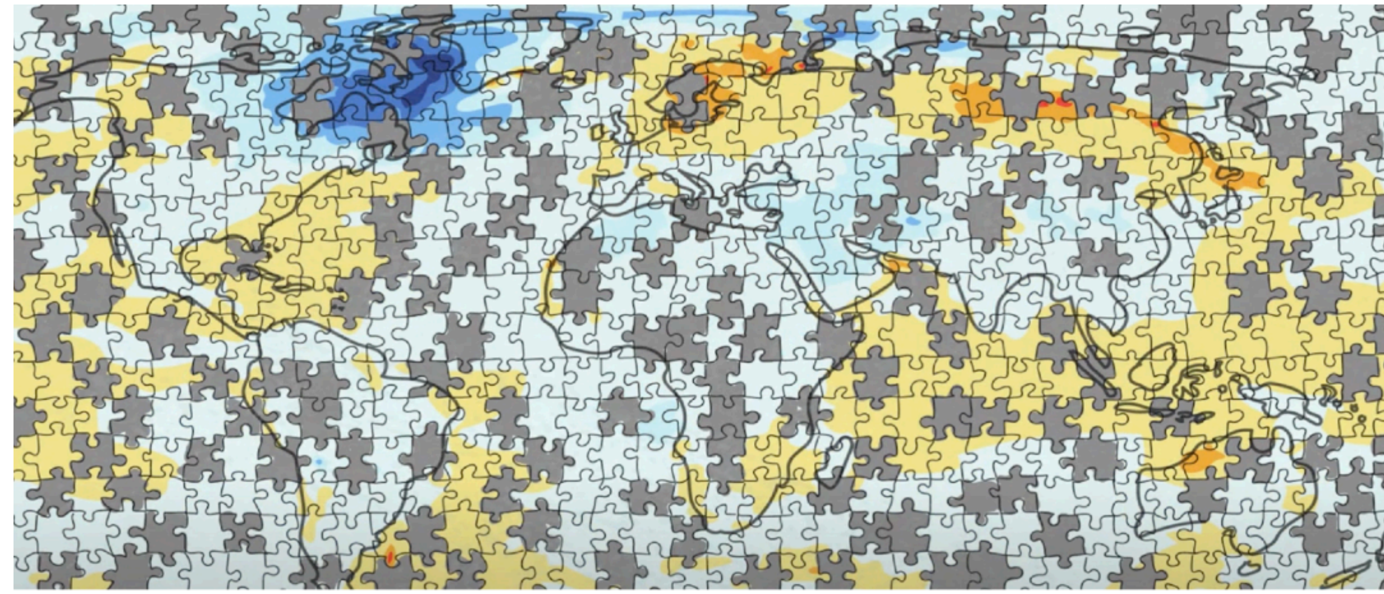
WHAT IS A REANALYSIS?

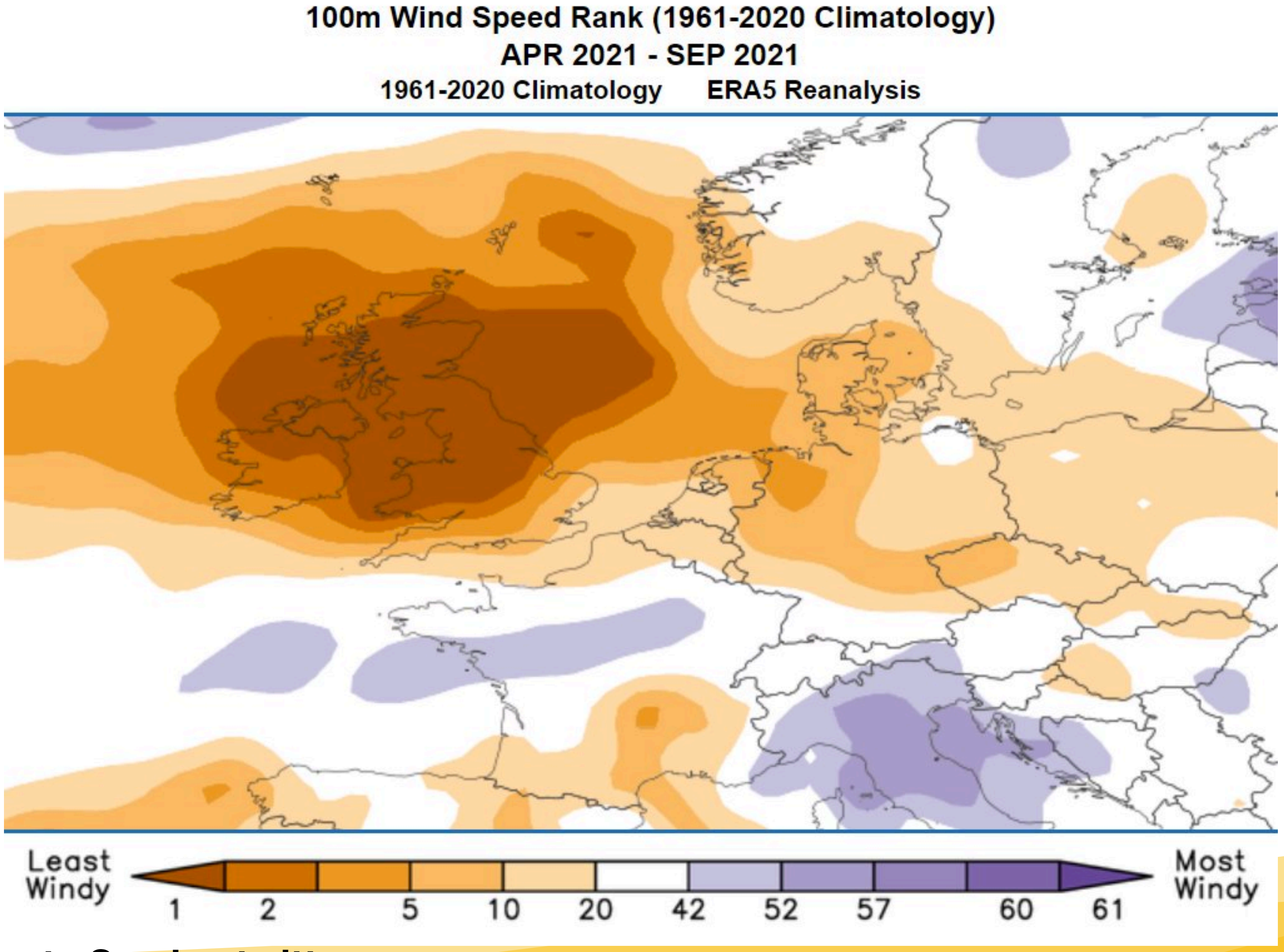
- **Reanalysis data:** A weather model which is run including all past observations. The gaps are then ‘filled in’ using a technique called data assimilation to give a comprehensive gridded record of weather data for many years.
- The ERA5 and MERRA2 meteorological reanalysis datasets contain **>40 year reconstructions** of hourly gridded weather variables at multiple heights through the atmosphere.



credit: Copernicus ECMWF
https://www.youtube.com/watch?v=FAGobvUGI24

TOPICAL SITUATION

- European wind drought currently in progress.
- Lowest wind period in the last 60 years. - A challenge when you come to rely heavily on renewable generation!



Source: World Climate Service twitter

IMPACTS OF HEAT DECARBONISATION ON SYSTEM ADEQUACY CONSIDERING INCREASED METEOROLOGICAL SENSITIVITY

MOTIVATION

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Weather - it's not the same every year.

Evolution of demand-weather sensitivity

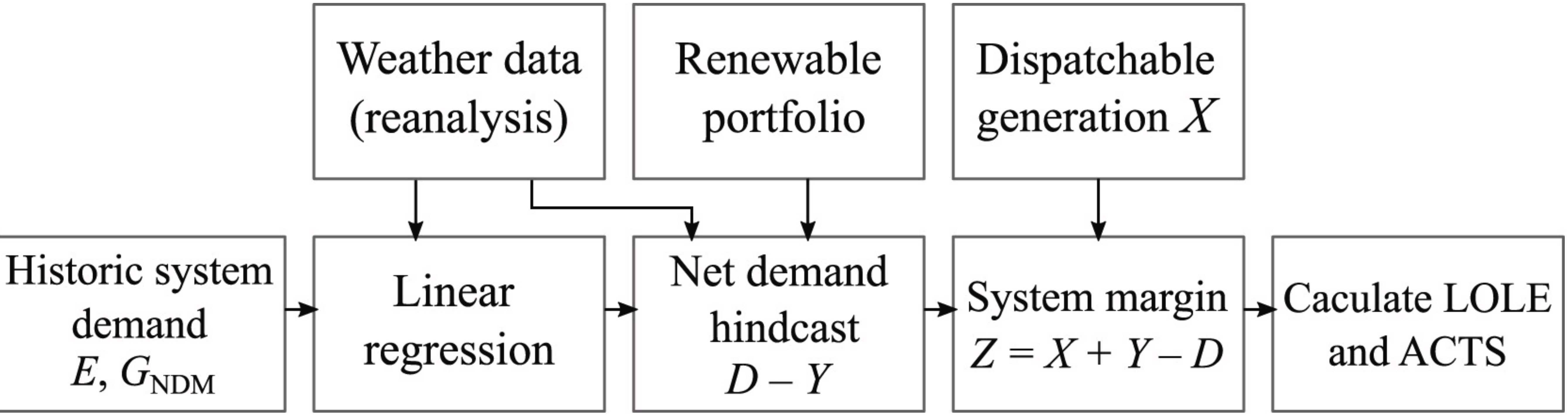
What is happening in the 2025 capacity market?

Heat pump profile uncertainty

Method of estimating heat demand growth uncertain

MODELLING FRAMEWORK

- Key interaction with energy modellers to make reanalysis data inputs as useful as we possibly can:



- Time collapsed system adequacy model with key assumptions:
  - 1 million heat pumps installed a year, directly replacing existing gas demand (1.75KW additional peak demand per pump installed)
  - Dispatchable generation retired based on current projections

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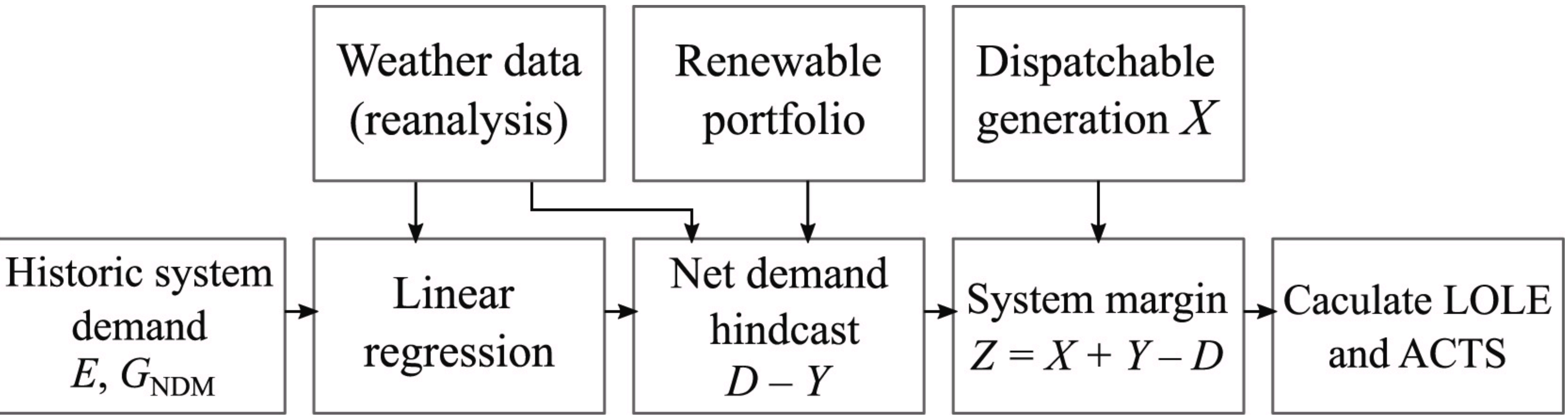
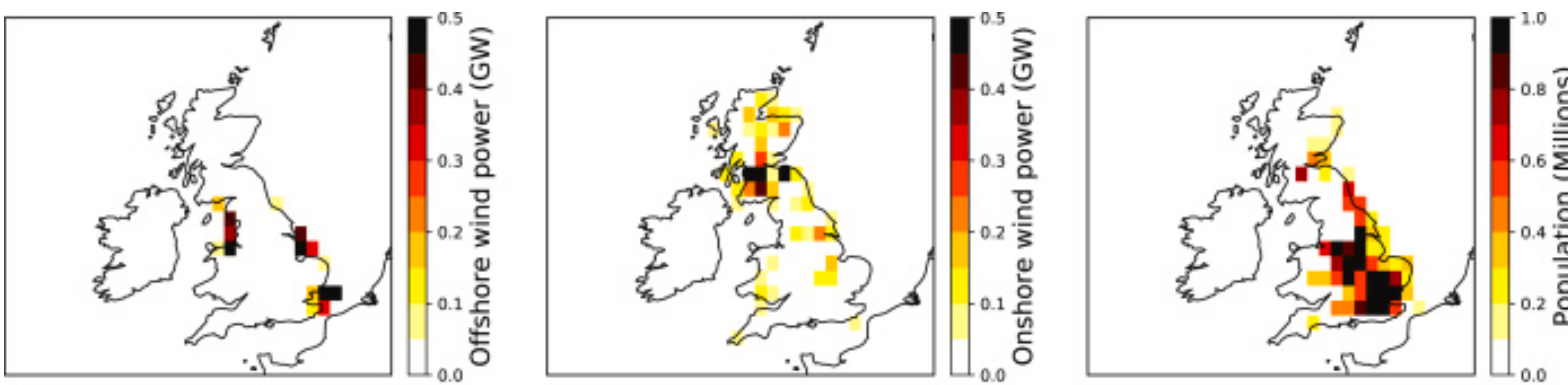
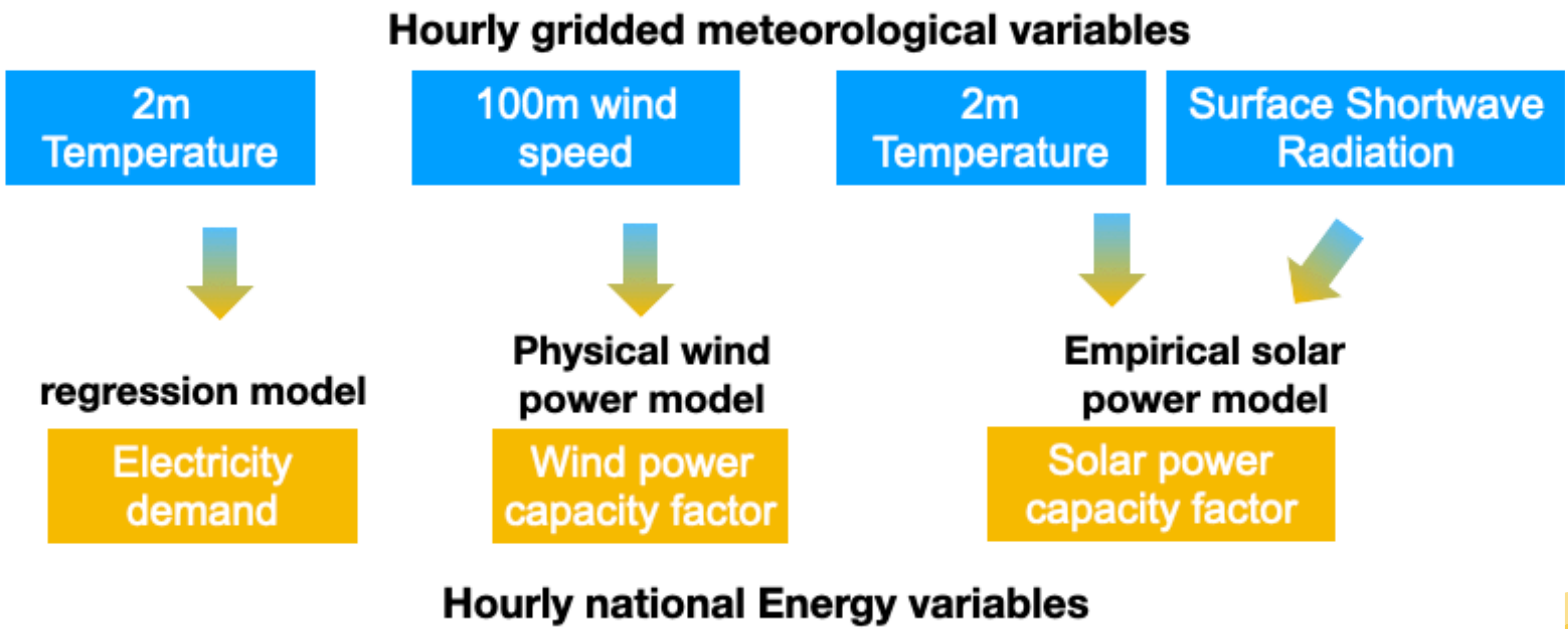




(a) Offshore Wind (b) Onshore Wind (c) Population

HOW DO I GET FROM WEATHER TO ENERGY VARIABLES?

- Gridded weather and climate data can be converted into energy variables using statistical or physical models
- Fix the power system setup (e.g. 2020 levels of demand/wind/solar, or 2030 expectations of demand/wind/solar) and pass 40 years of reanalysis through the demand/wind/solar models



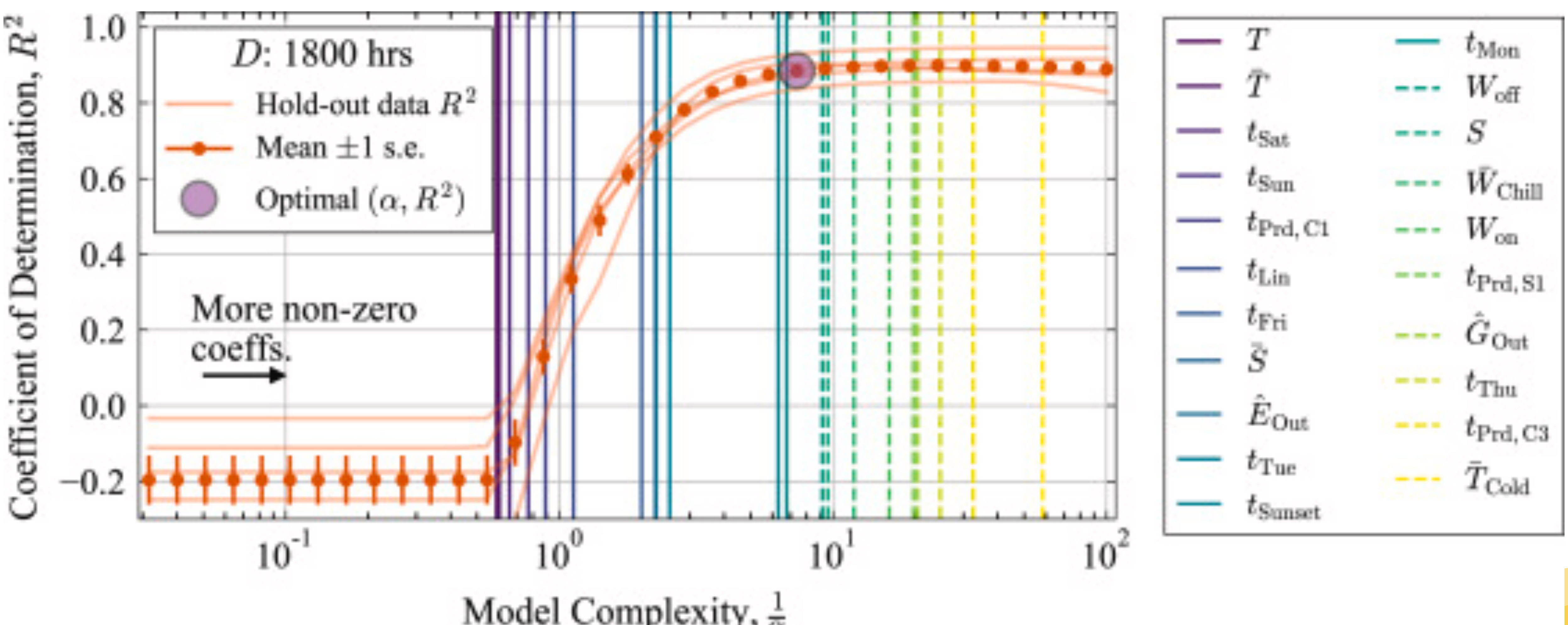
Data available from the Reading Research Data Repository: https://researchdata.reading.ac.uk/

see: Characterizing the winter meteorological drivers of the European electricity system using targeted circulation types for detailed methods https://rmets.onlinelibrary.wiley.com/doi/full/10.1002/met.1858

DEMAND MODELLING

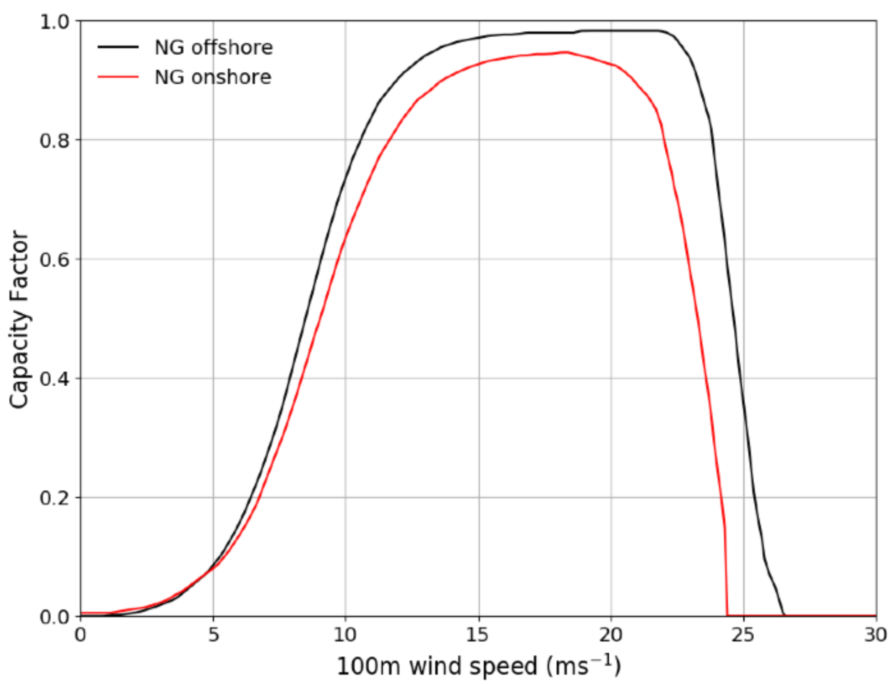
- Linear regression with Lasso Regularisation
- An optimal correlation threshold is chosen to define useful variables in the demand model to prevent overfitting and maximise out of sample performance.
- Many weather variables were trialed for this process.

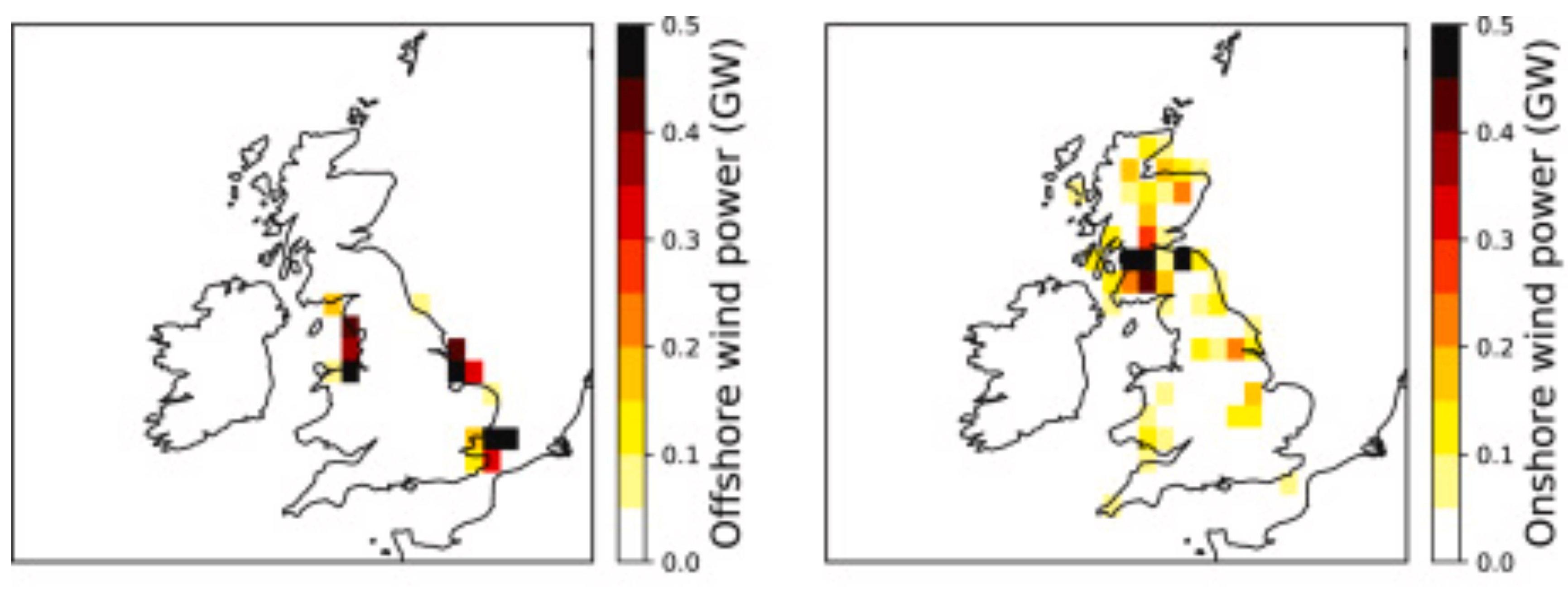
Model for 6pm



WIND POWER MODELLING

- Wind power models are based on the non-linear relationship between wind speed and wind power
- Gridded reanalysis wind speeds are required at turbine hub-height (58.9m onshore 85.5m offshore) Interpolate these from model levels (2m, 10m, 50m).
- The locations of wind turbines are known, so the gridded wind power output can be calculated, or aggregated over onshore and offshore regions.





(a) Offshore Wind (b) Onshore Wind

See Deakin et al., (2021) for further details

SOLAR PV MODELLING

- Empirical model based on surface shortwave radiation and 2m temperatures in each grid box.
- Can be population weighted as a proxy for where the solar panels are installed.

relative efficiency factor Irradiance

$$CF = \frac{Power}{Power_{STC}} = \eta_{rel}(G,T)\,\frac{G}{G_{STC}}$$

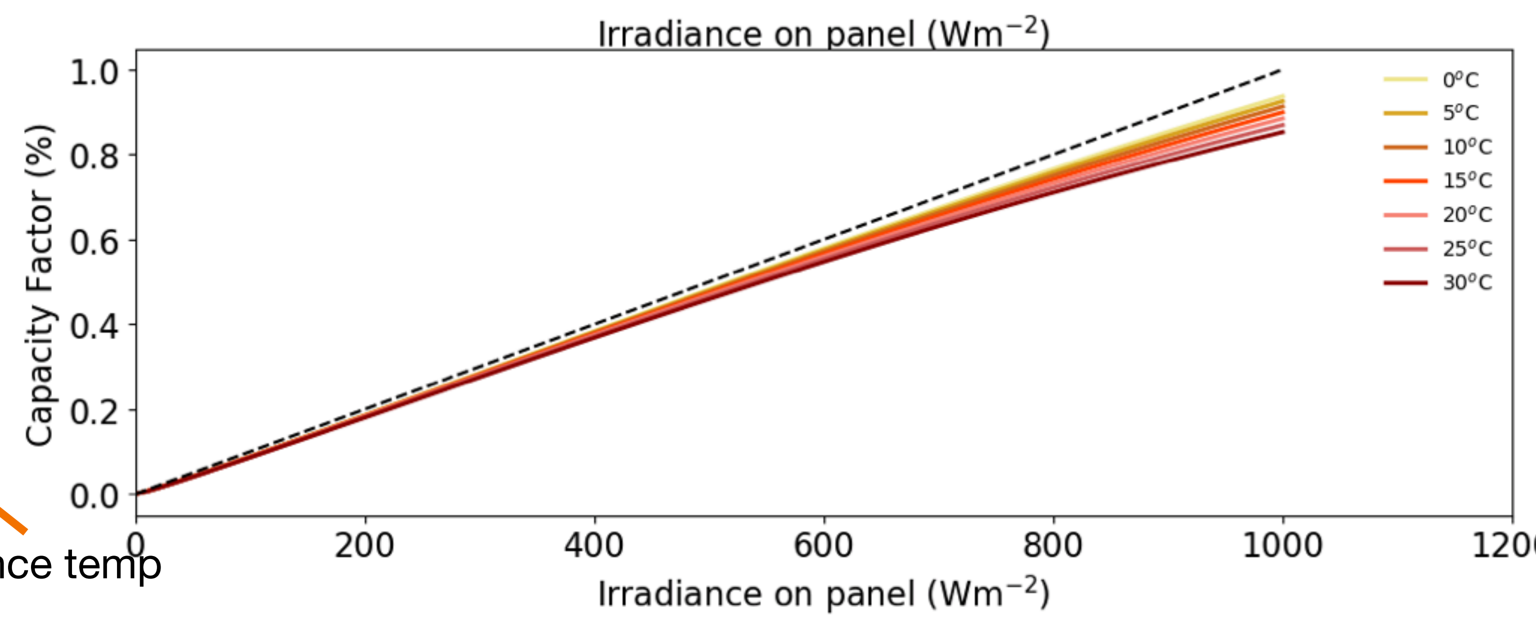
$$\eta_{rel}(G,T) = \eta_r[\,1 - \beta_r(T_c - T_r\,)]$$

efficiency at reference temp

decrease in efficiency per unit temp

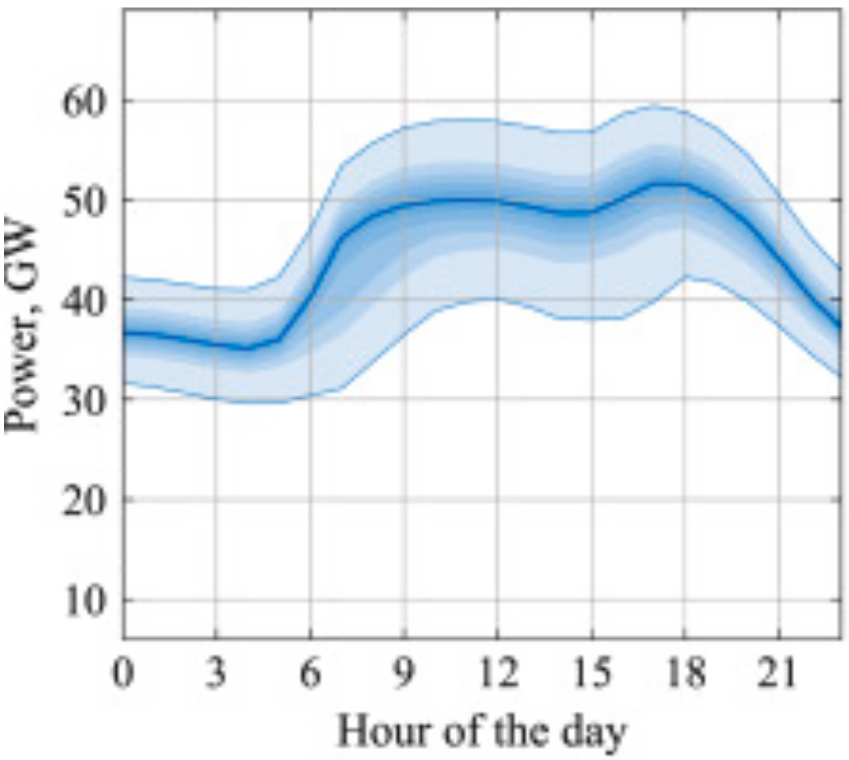
cell temperature

reference temp



See Bloomfield et al., (2020) and Bett and Thornton (2016) for further details

DEMAND-NET-RENEWABLES



(a) Demand, D

See Deakin et al., (2021) for further details

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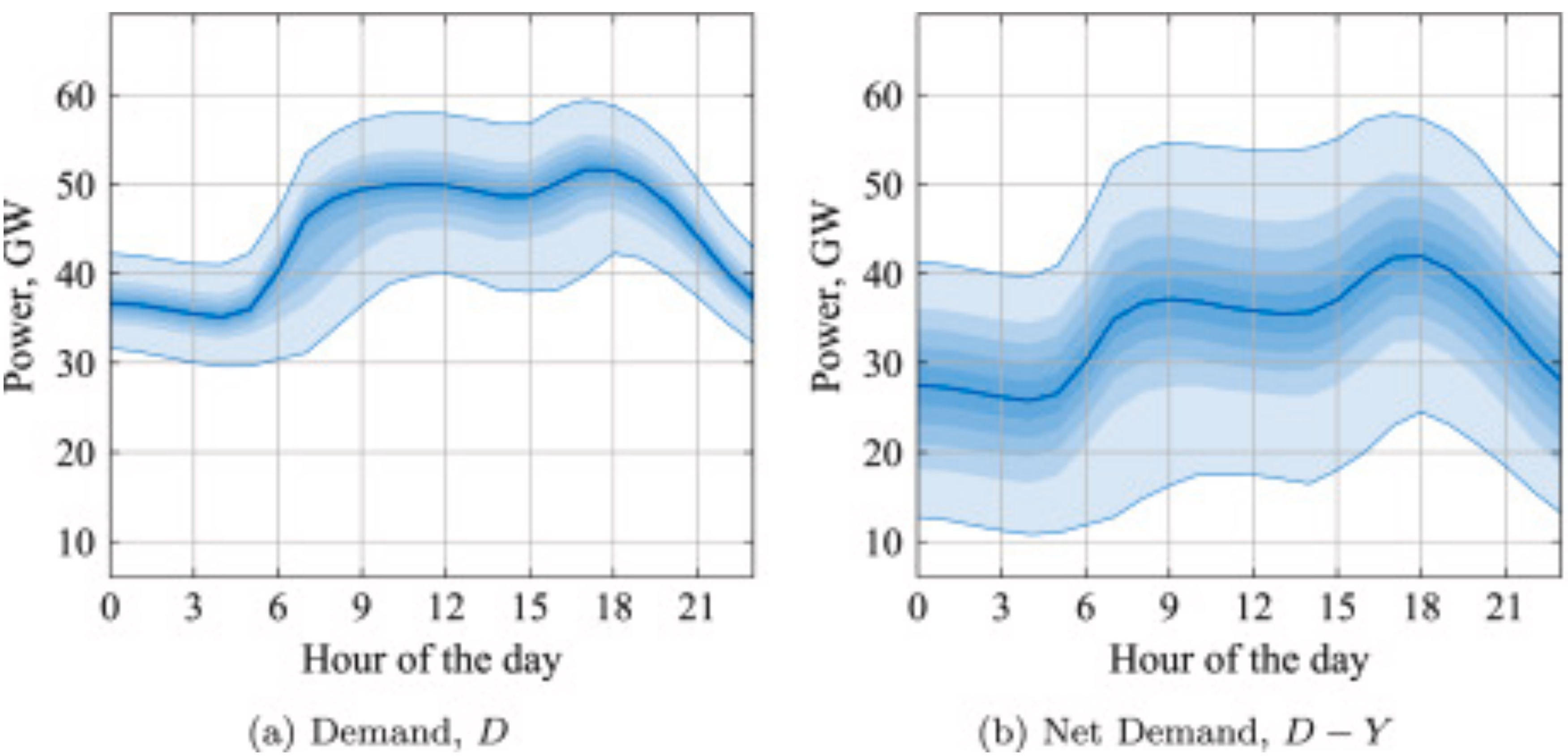

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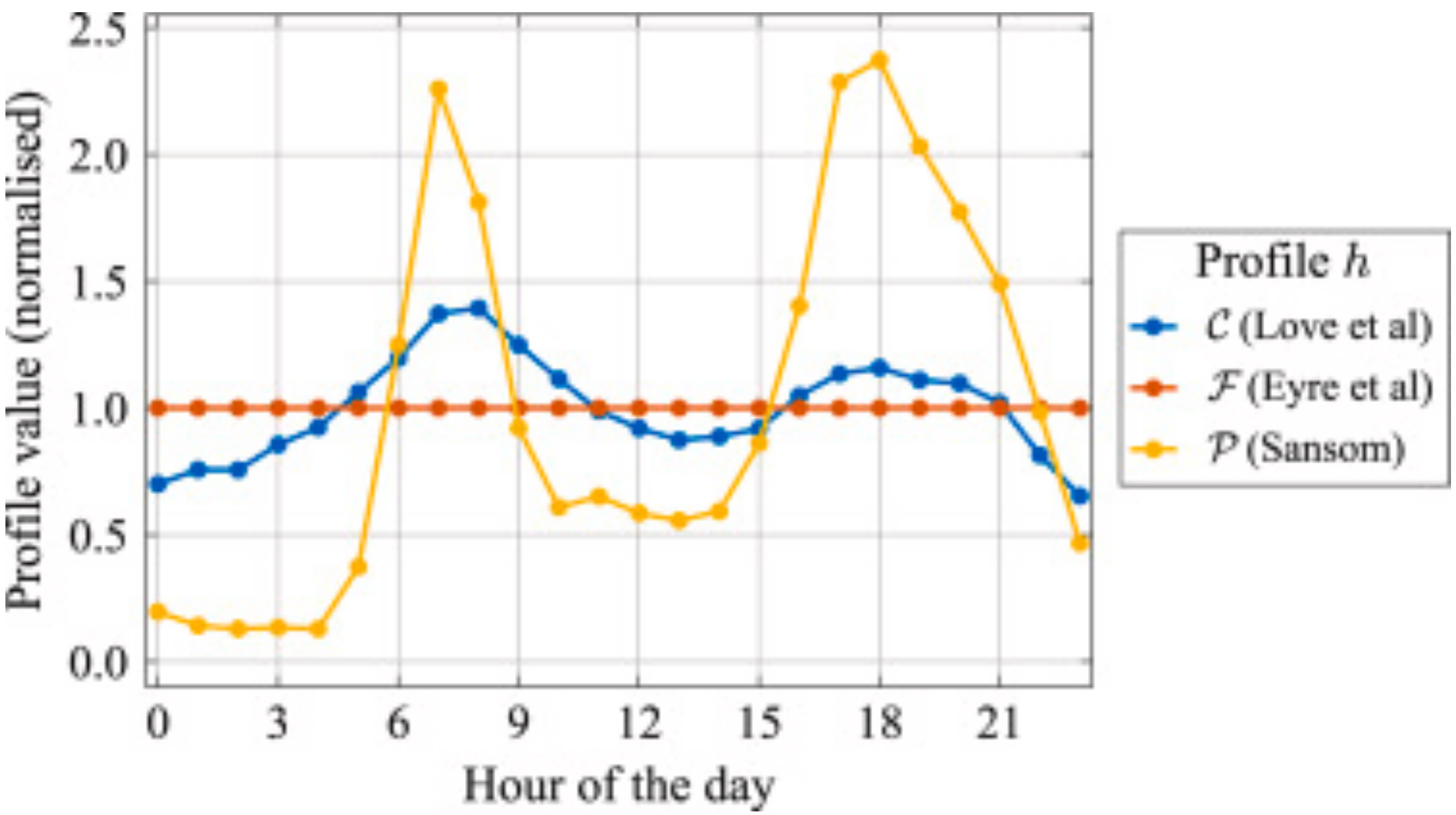
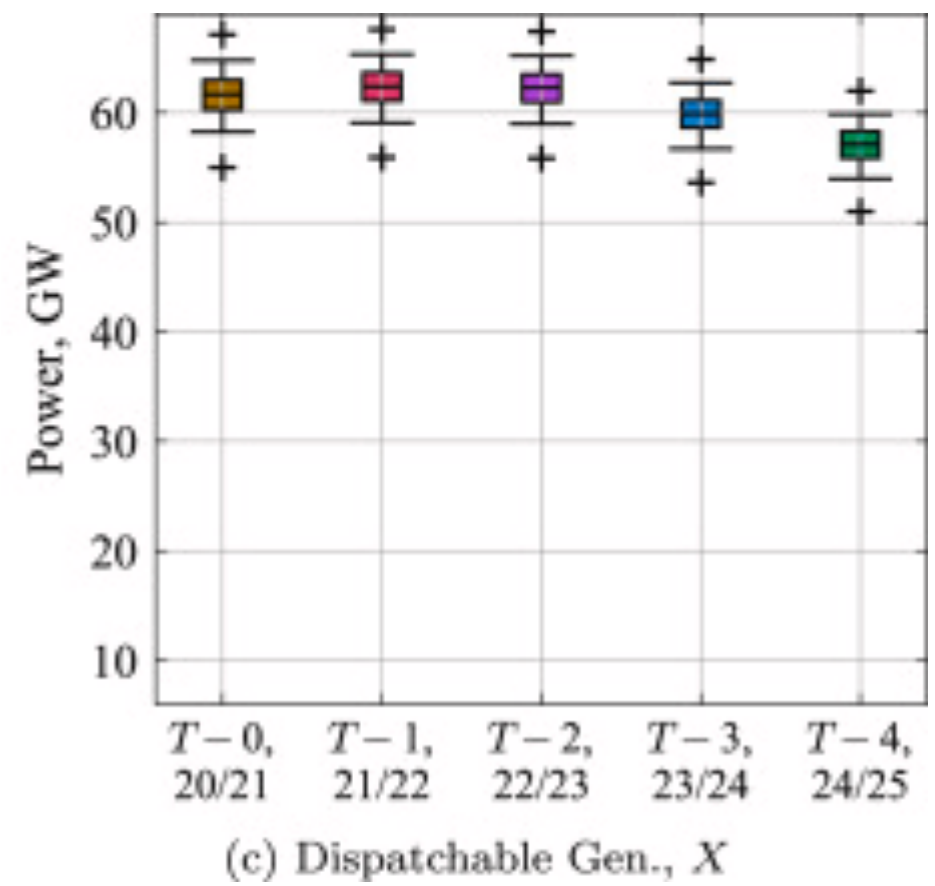
OTHER MODELLING CONSIDERATIONS

Heat pump profiles



Retired coal/gas generation



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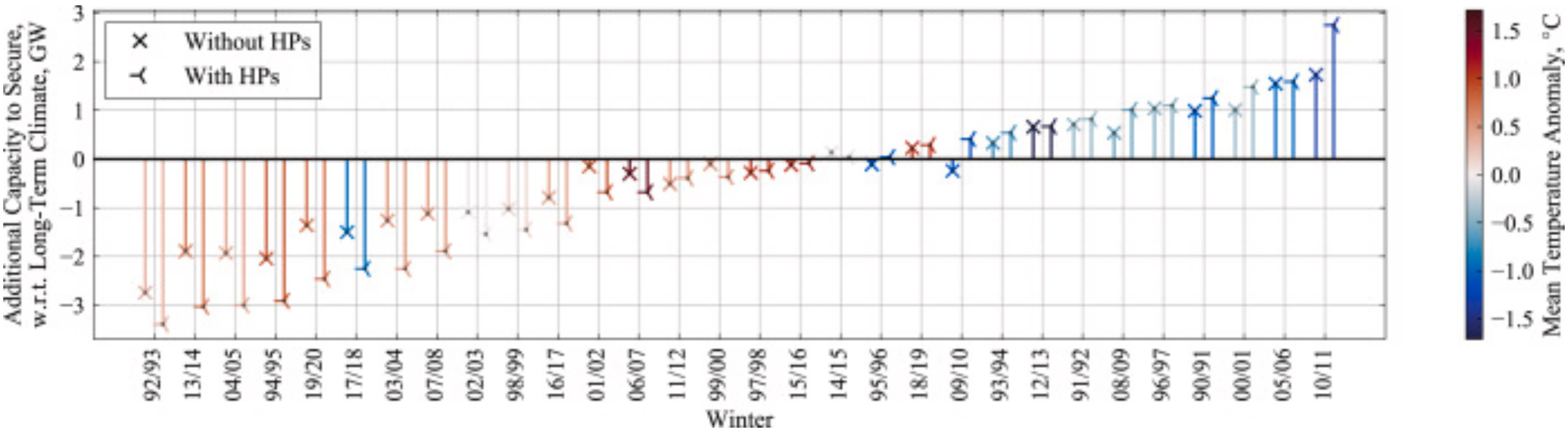
ADDITIONAL CAPACITY TO SECURE

'Cold weather weekday' heat pump profile
Coeff of performance = 2

Impacts of year-year climate variability.

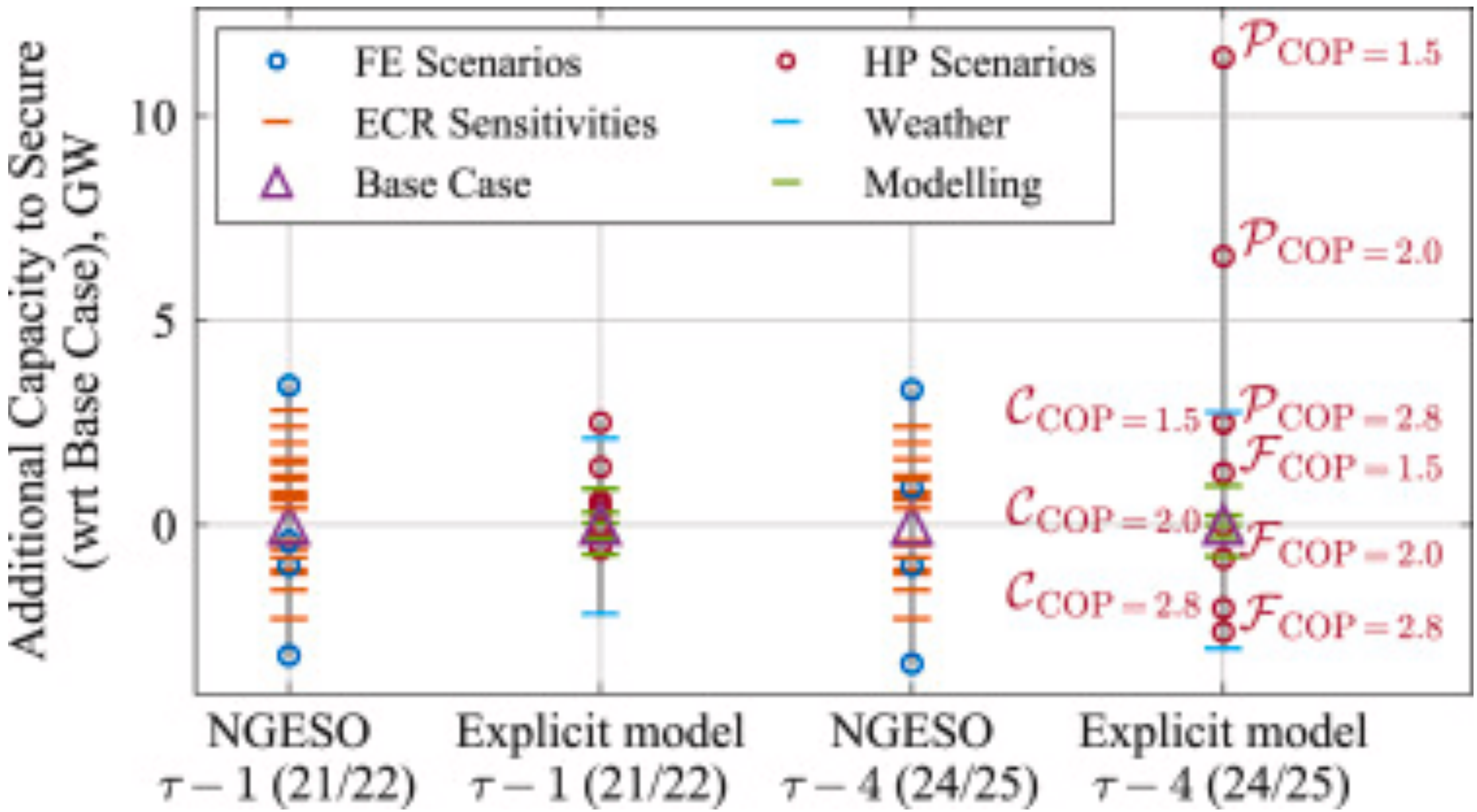


With heat pumps there is a greater weather sensitivity

Not a linear relationship with temperature

See Deakin et al., (2021) for further details

UNCERTAINTY ANALYSIS



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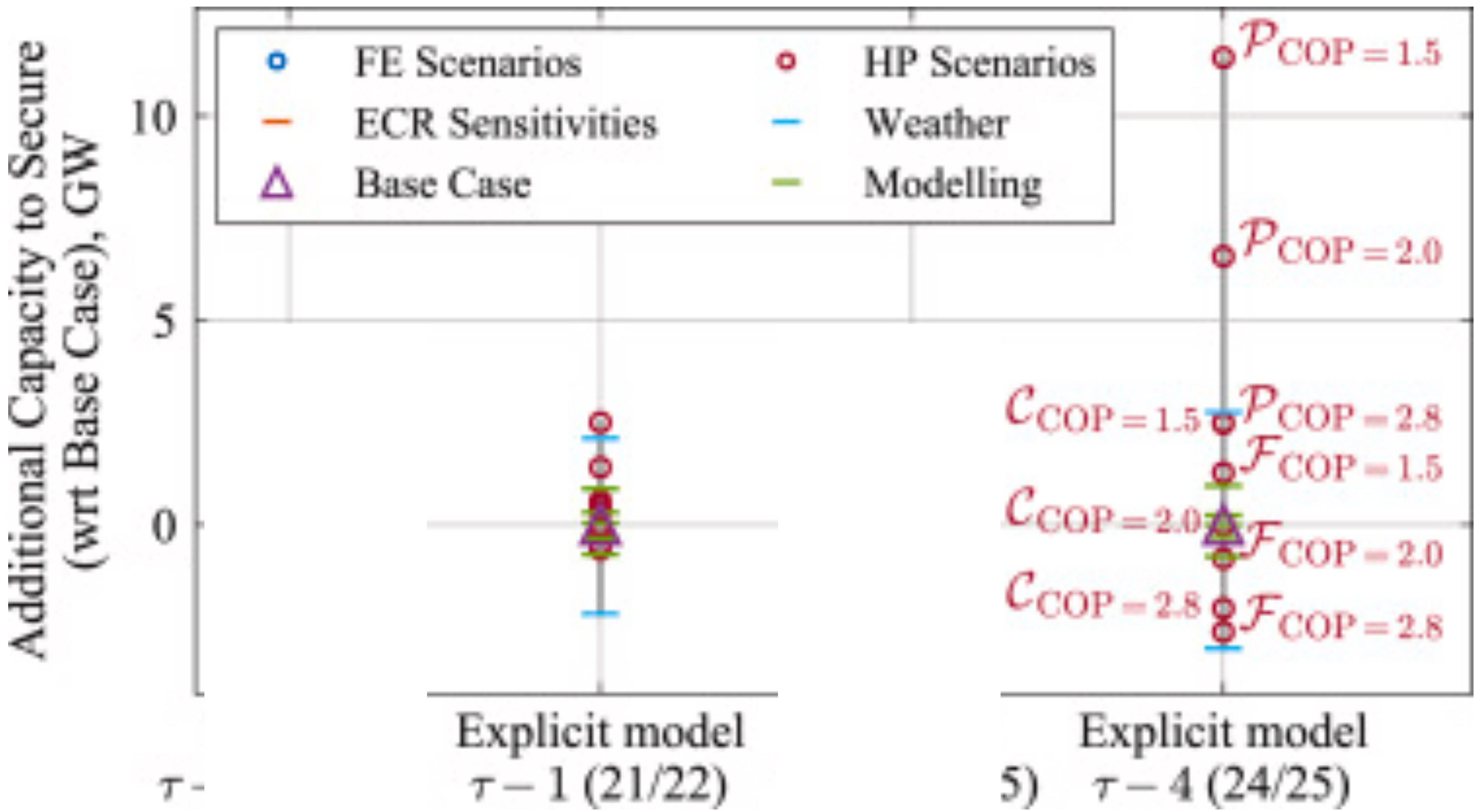

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UPDATED DATASETS

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Hourly historical and near-future weather and climate variables for energy system modelling

Hannah C. Bloomfield et al.

Data sets

ERA5 derived time series of European aggregated surface weather variables, wind power, and sola power capacity factors: hourly data from 1950-2020.
Bloomfield, H. C. and Brayshaw., D. J.
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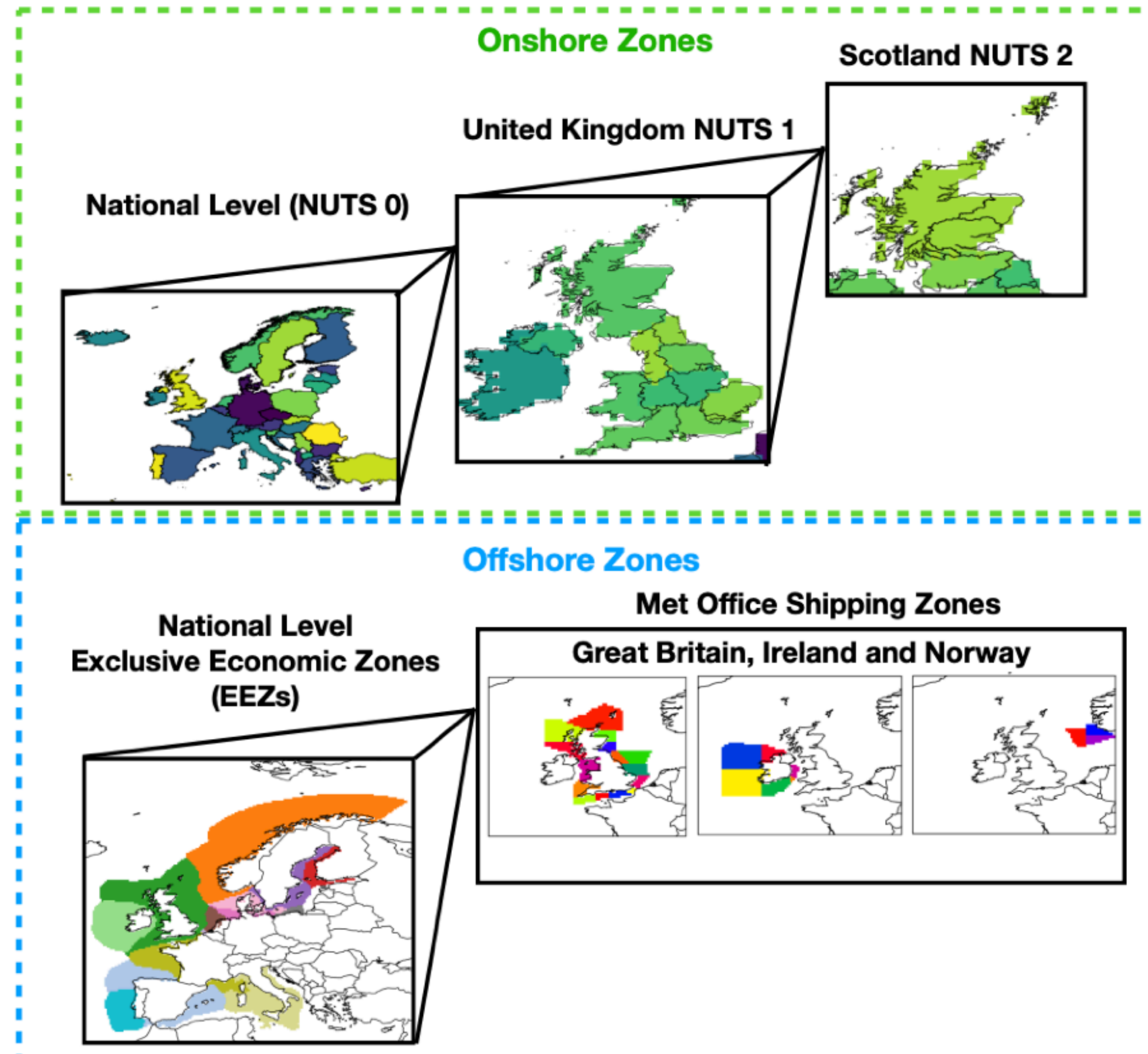

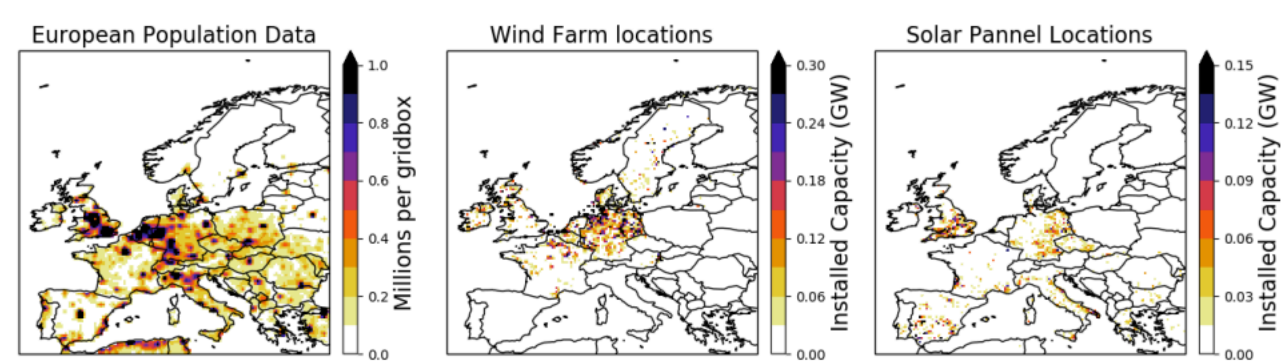

ONGOING SCIENCE

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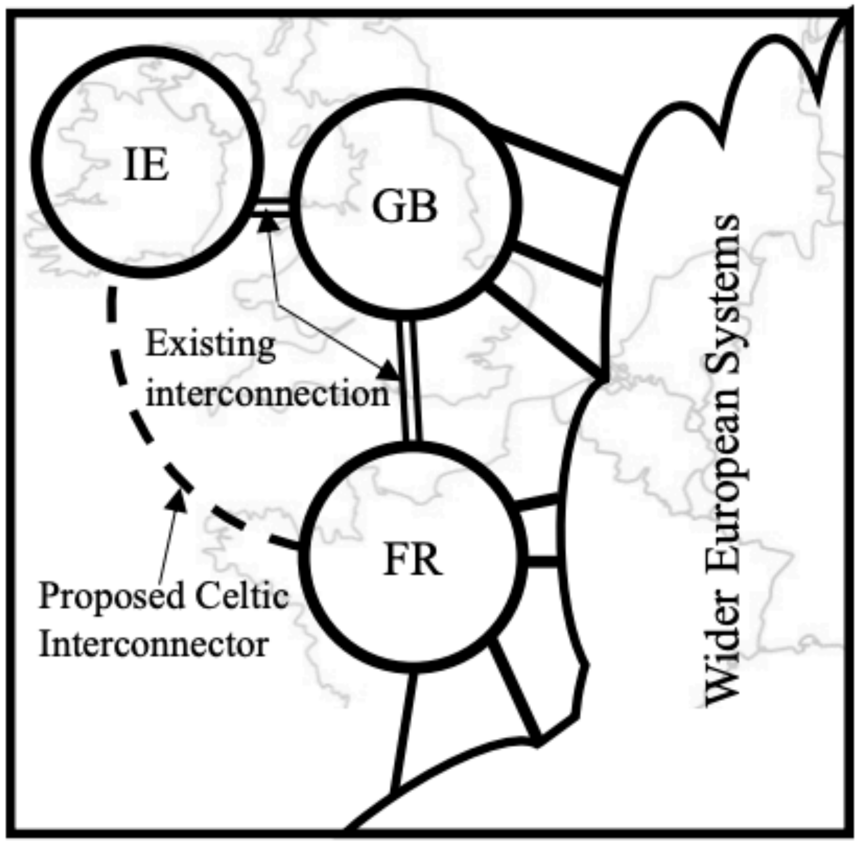

Fig. 2. The IE-GB-FR multi-region system.

The capacity value of inter-connectors depends on the coincidence of stress events in interconnected regions, which is partially driven by the weather within those regions

SUMMARY OF PART 2

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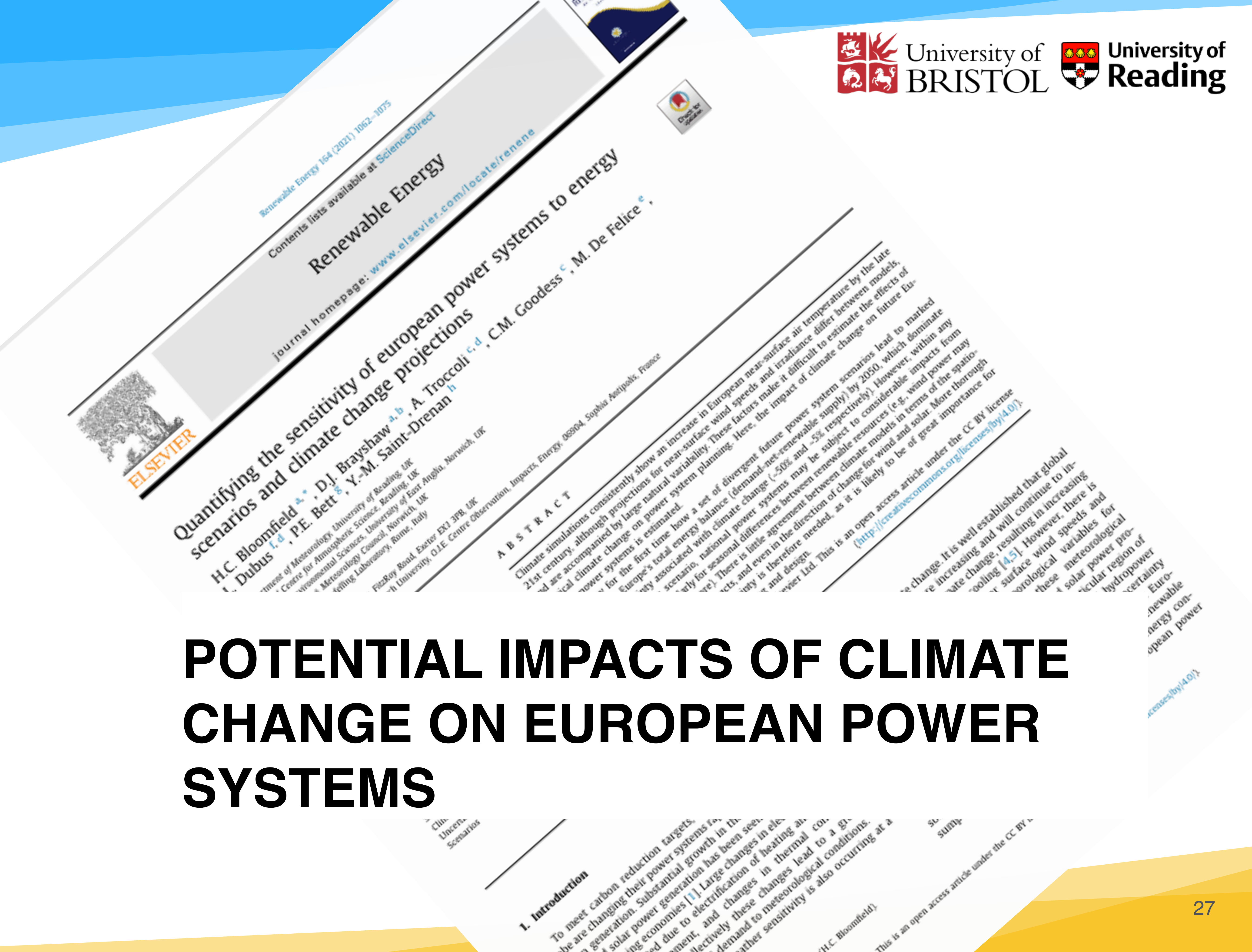
System adequacy considered in context of transition to electrified heat.

30-year demand and wind power generation hindcast from weather reanalysis data.

- GB temperature-demand sensitivity could increase by 54% in just 4 years with the addition of heat pumps.
- Electric heat demand growth uncertainty doubles variability in additional capacity to secure.



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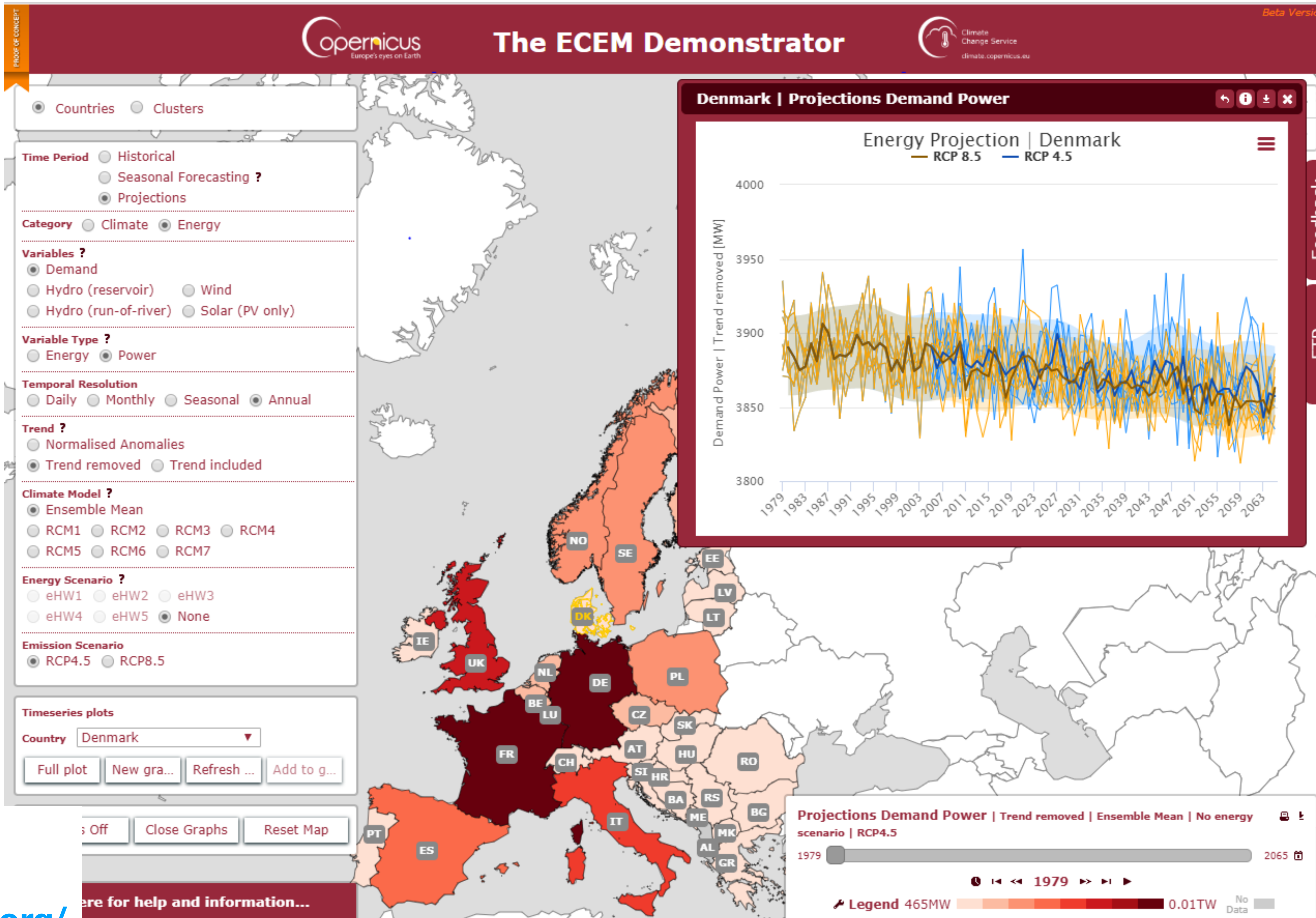
POTENTIAL IMPACTS OF CLIMATE CHANGE ON EUROPEAN POWER SYSTEMS

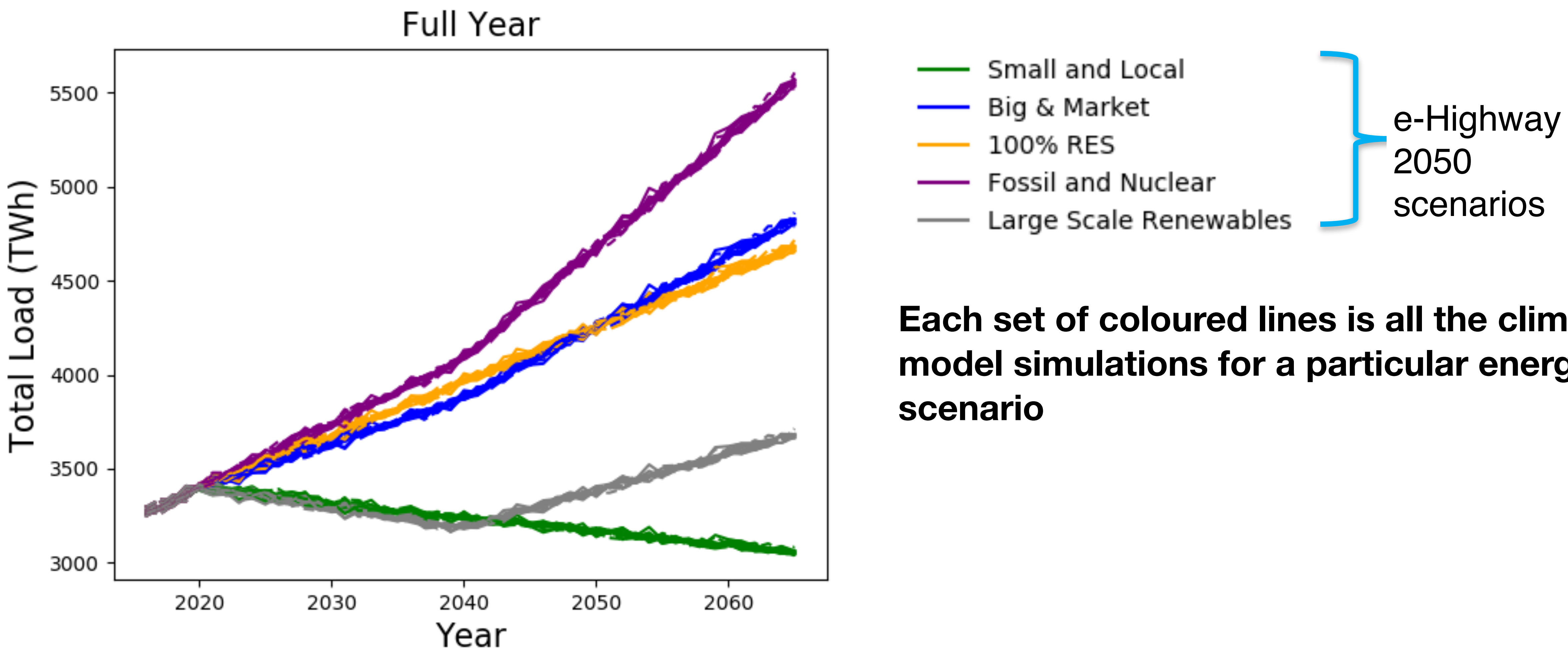
THE ECEM DEMONSTRATOR

- Data from the European Climate Energy Mixes (ECEM) project
- **7 Different climate models:** to understand the impact of climate change
- **5 different energy scenarios:** to understand the impact of energy policy choice



Data from this study available at:
http://ecem.wemcouncil.org/

LARGE UNCERTAINTY IN POWER SYSTEM CHOICE



Each set of coloured lines is all the climate model simulations for a particular energy scenario

Future power system uncertainty is dominated by the energy policy choice.

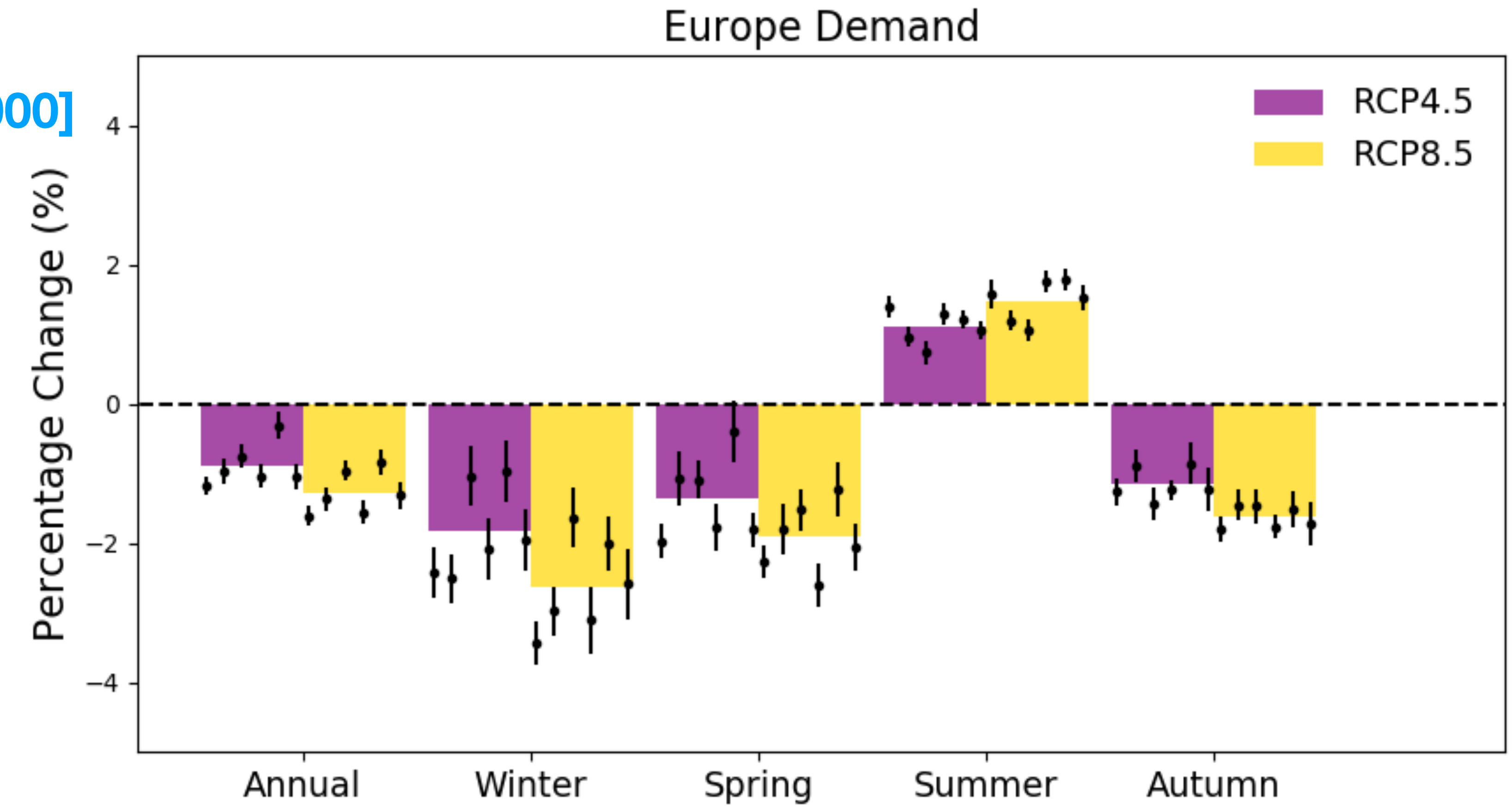
But that doesn't mean that the climate uncertainty isn't important…

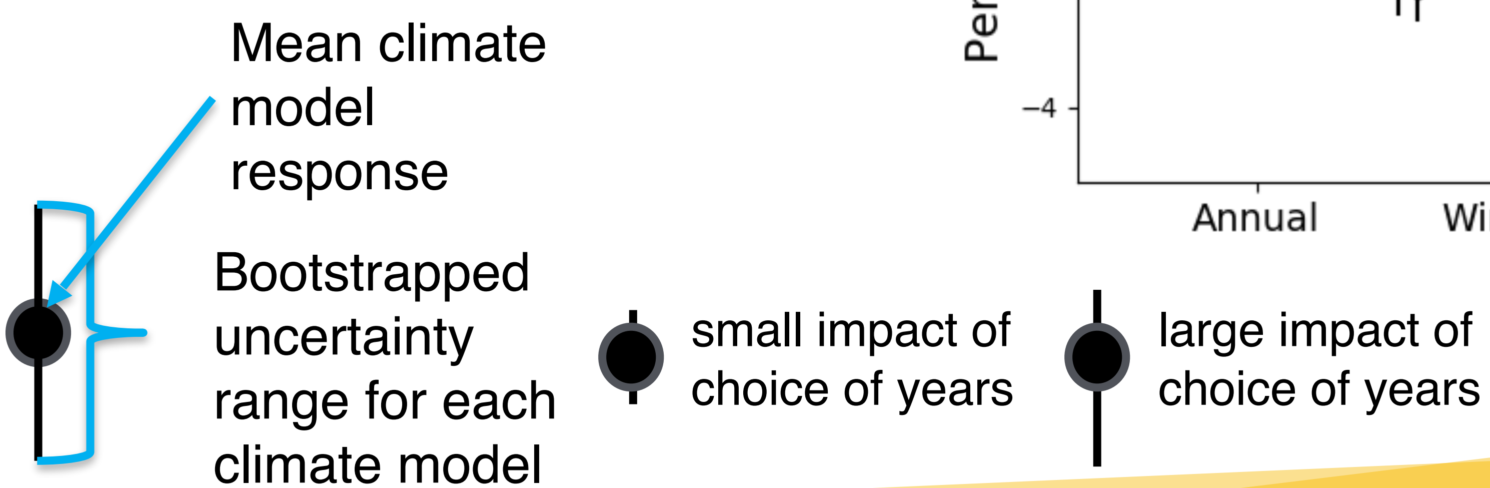
Once a policy choice is made (i.e. if we pick one of the scenarios above) the impacts of climate change can be seen clearly…

CLIMATE CHANGE IMPACTS ON ENERGY DEMAND

- By 2050 National power systems may be subject to considerable impacts from climate change
- The impact of climate change on demand is robust to the choice of RCM. A larger impact is seen in the higher RCP scenario
- The impact of inter-annual climate variability is relatively small

Percentage change:
mean[2045-2065] - mean [1980-2000]





see Bloomfield et al., (2020)

CLIMATE CHANGE IMPACTS ON ENERGY DEMAND

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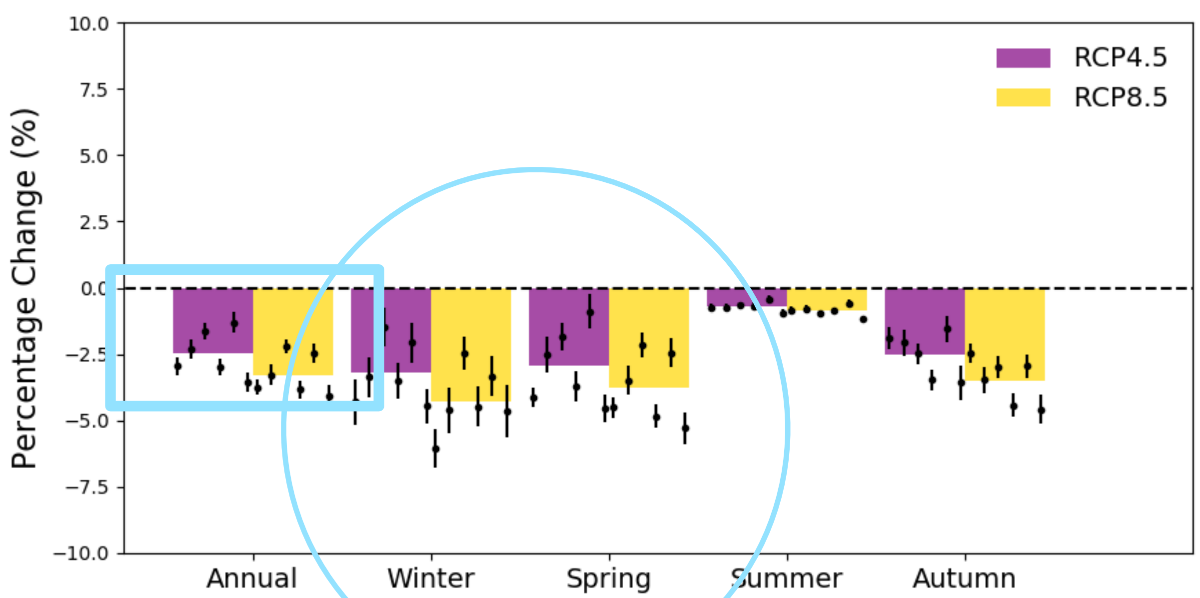
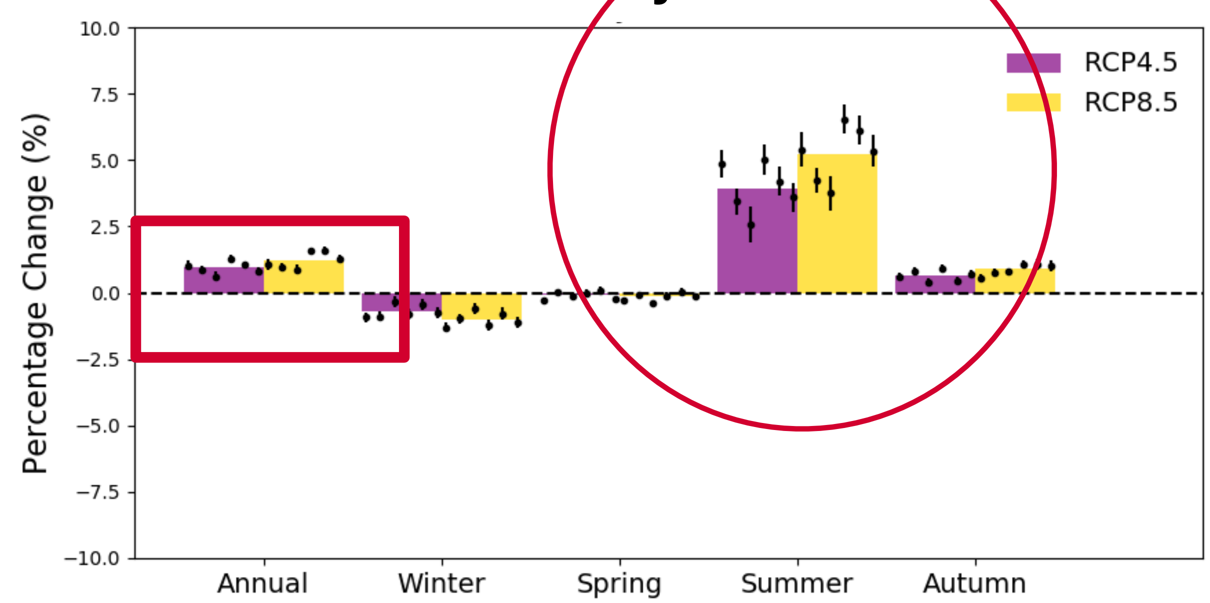
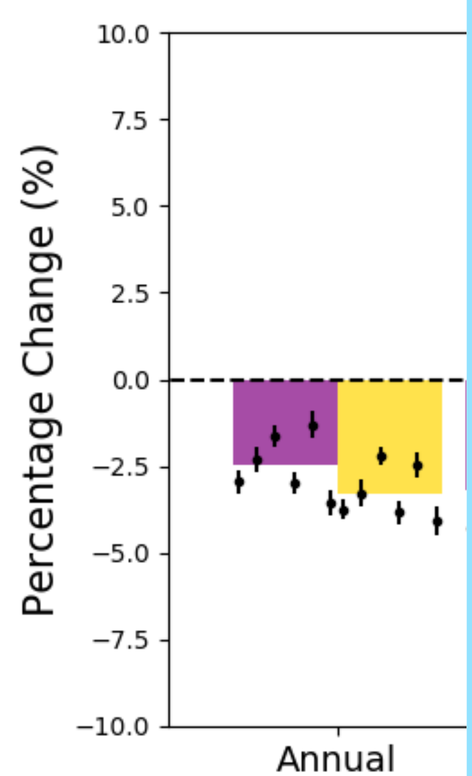
Percentage change:
mean[2045-2065] - mean [1980-2000]

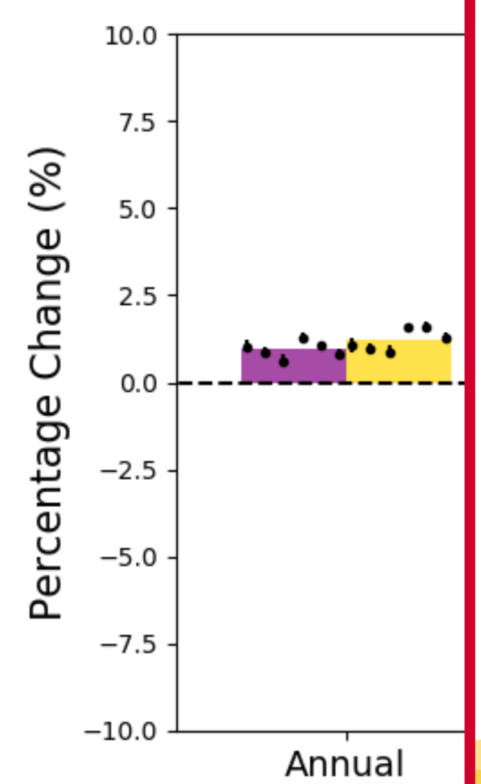
Sweden



Italy







Not All European countries have the same response, as their Heating v.s. cooling requirements change

see Bloomfield et al., (2020)

CLIMATE CHANGE IMPACTS ON WIND POWER

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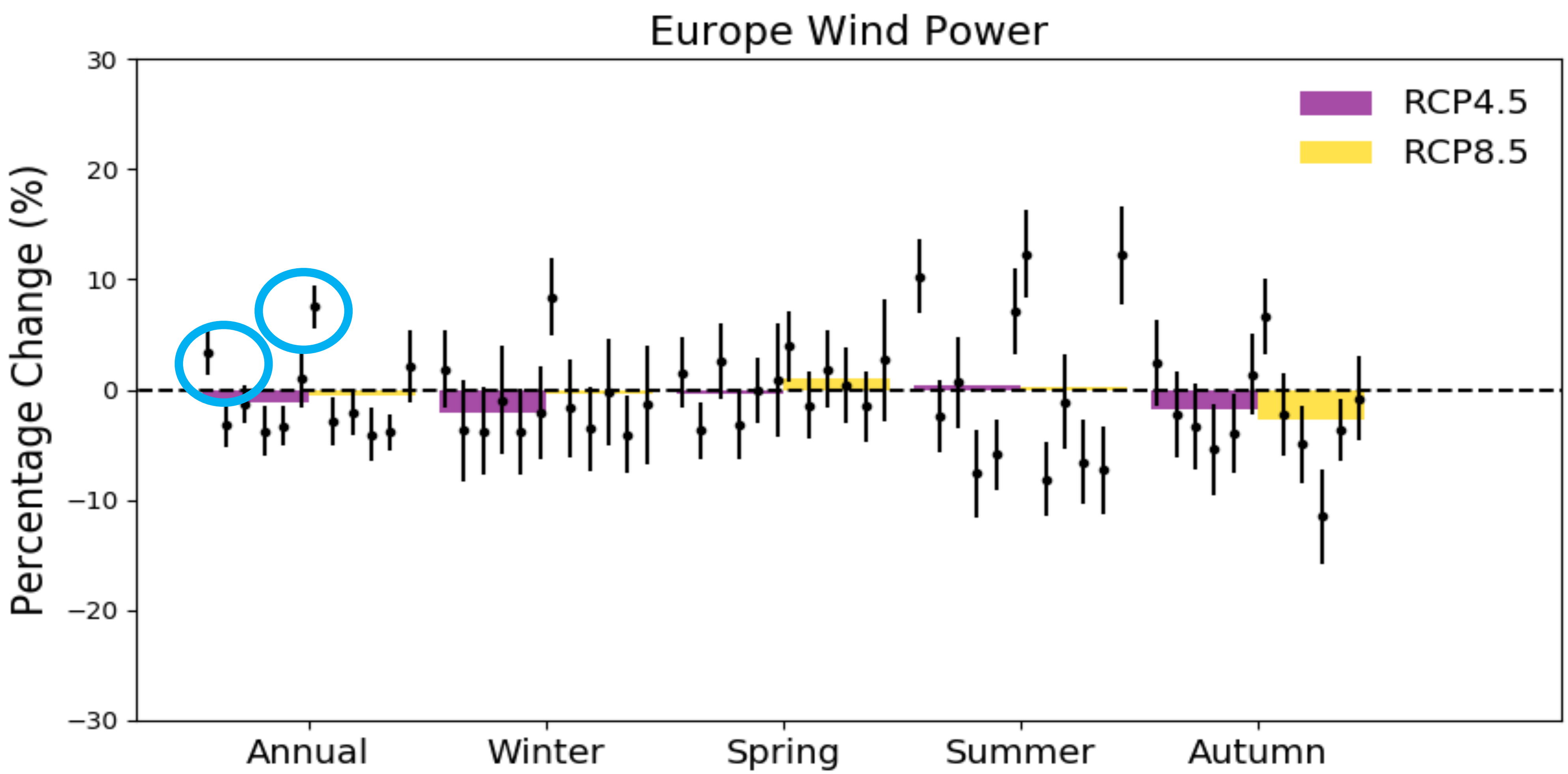
- The impact of climate change on wind power generation is very sensitive to the choice of climate model, and the choice of years used to compute the results

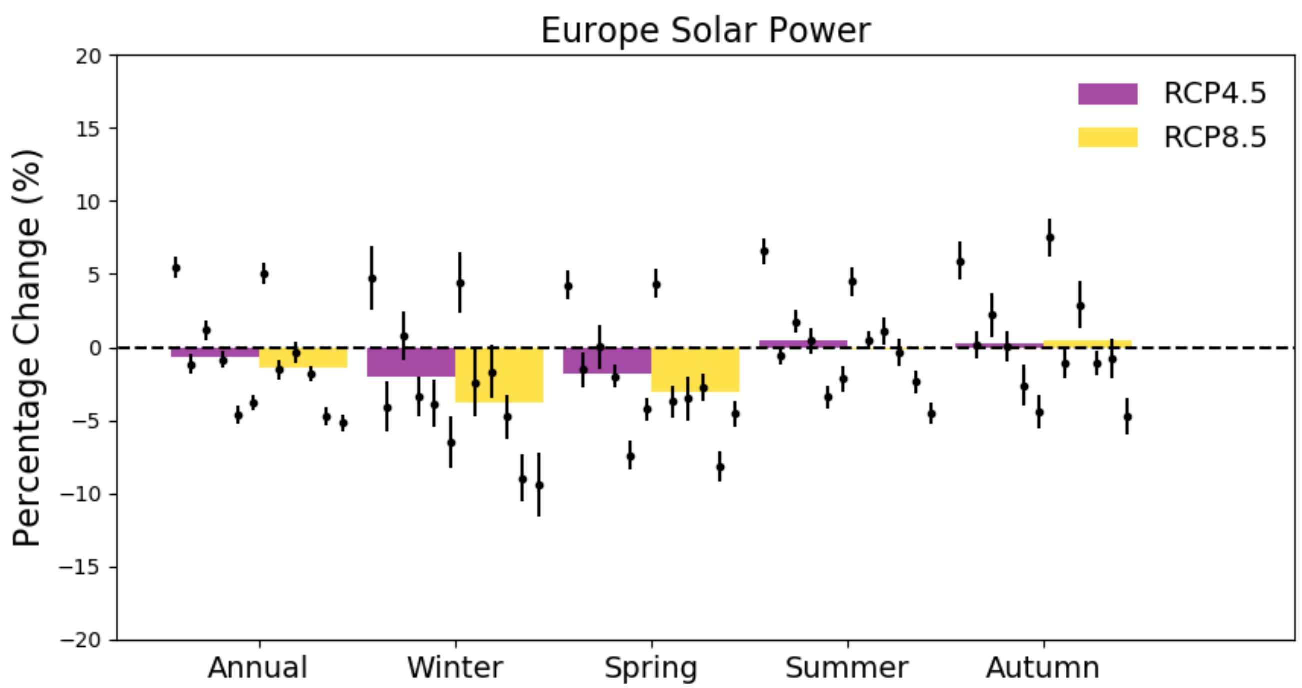


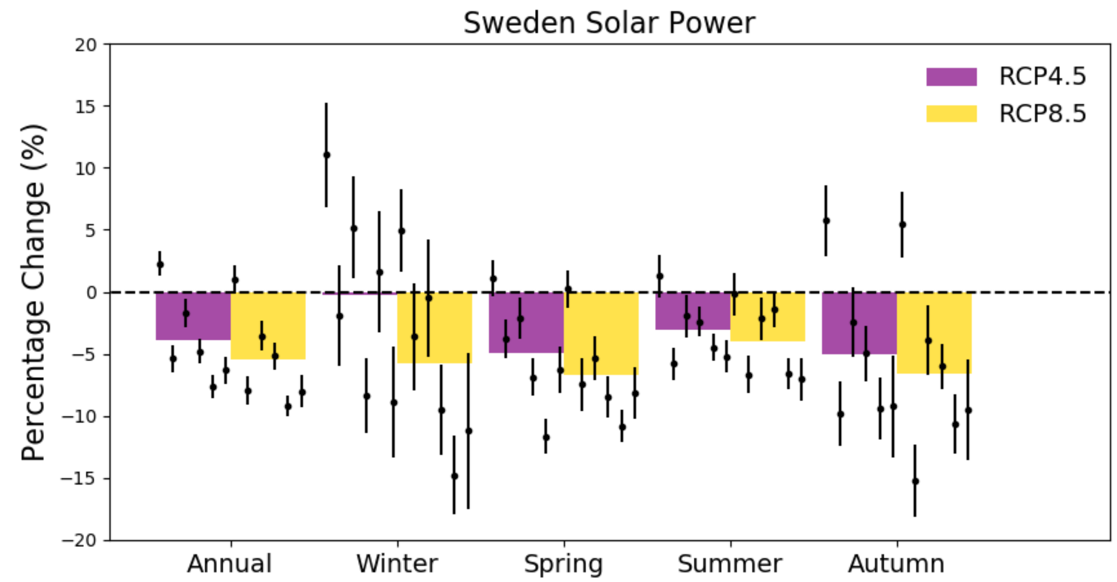
Outlier models can skew multi-model mean results

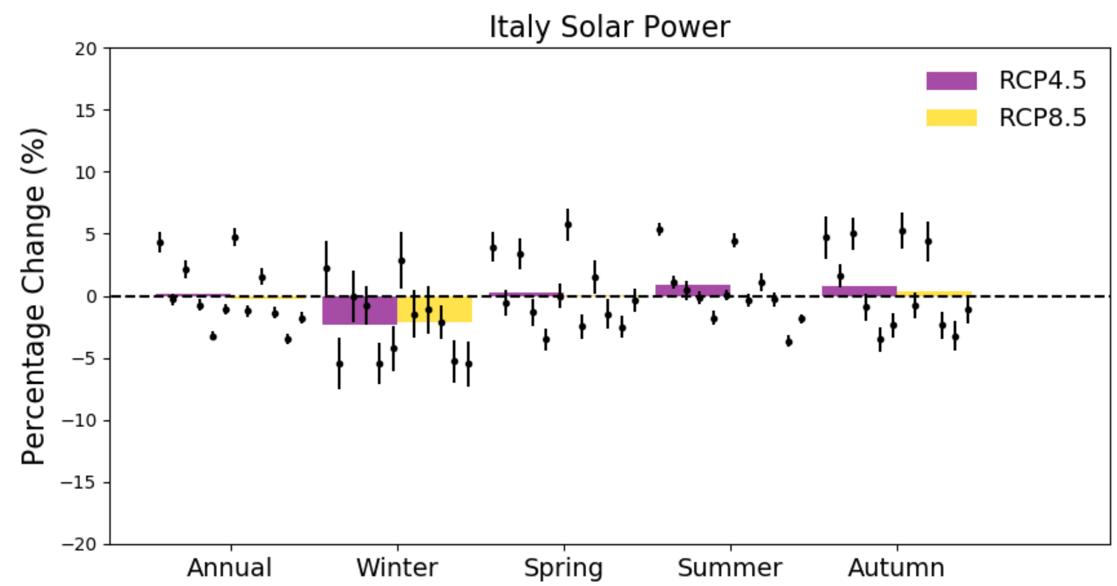
see Bloomfield et al., (2020)

CLIMATE CHANGE IMPACTS ON SOLAR POWER

- The impact of climate change on solar power generation is sensitive to the choice of RCM. It is less sensitive to the choice of years used to compute the results in most regions (lots of uncertainty over N.Europe)







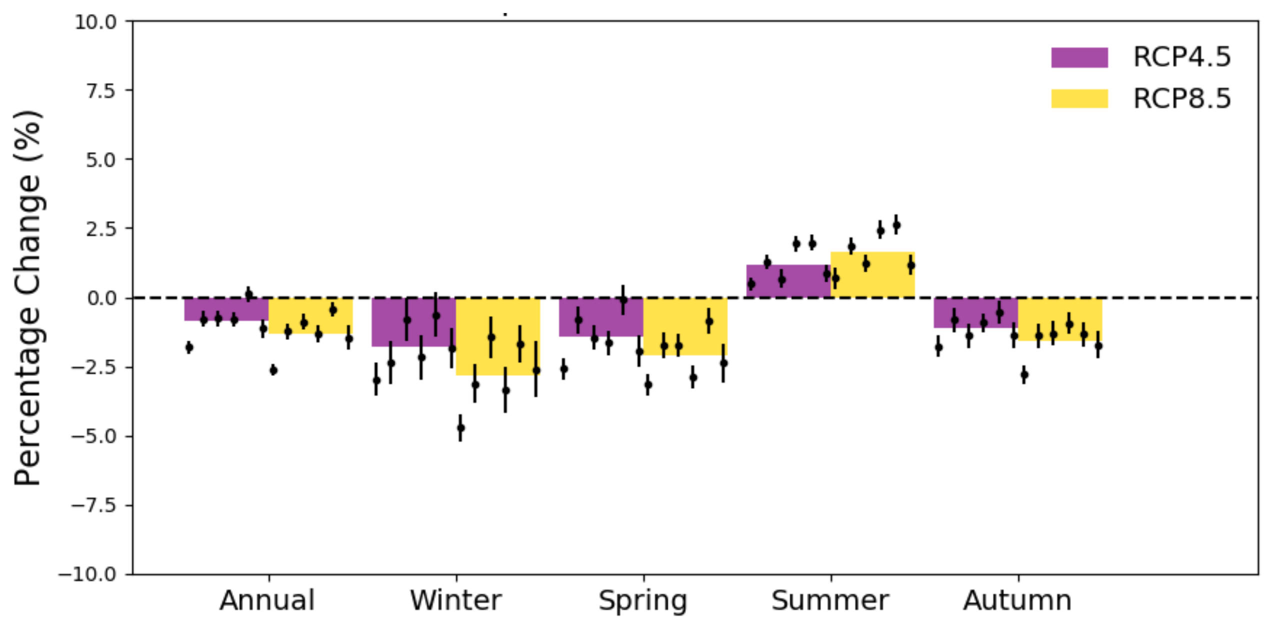
More uncertainty in winter, and in Northern European Countries

see Bloomfield et al., (2020)

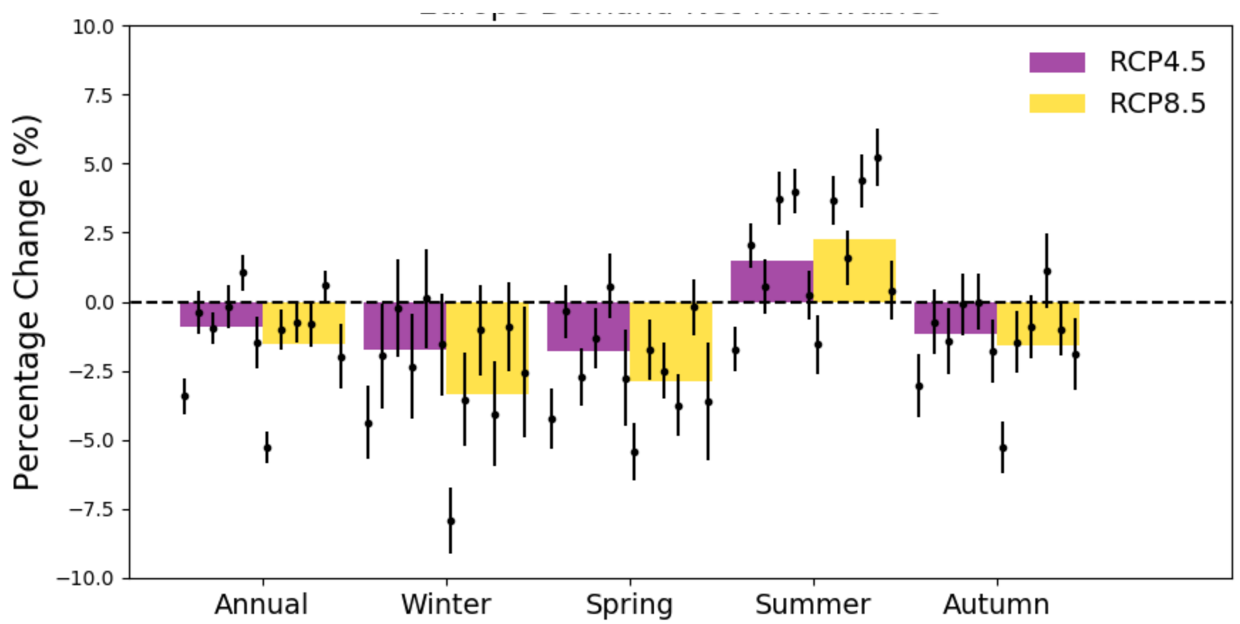
CLIMATE CHANGE IMPACTS ON SYSTEM DEVELOPMENT

- Increasing the amount of wind power and solar power installed on the system increases the sensitivity of the European power system to climate change.
- The relatively certain response of demand becomes more complex due to the large sensitivity of WP and SP projections to model choice and IAV.

2016 Demand-Net-Renewables



2050 Demand-Net-Renewables



Models agree on the sign of the change

Models no longer agree

34

see Bloomfield et al., (2020)

UPDATED FUTURE CLIMATE DATASETS

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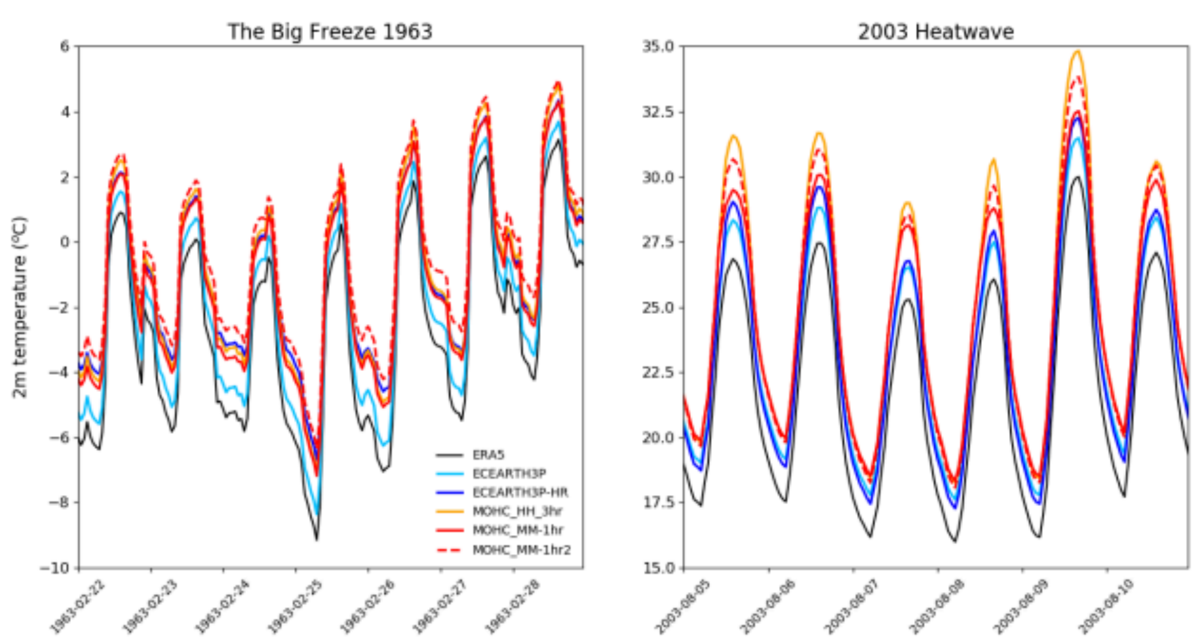

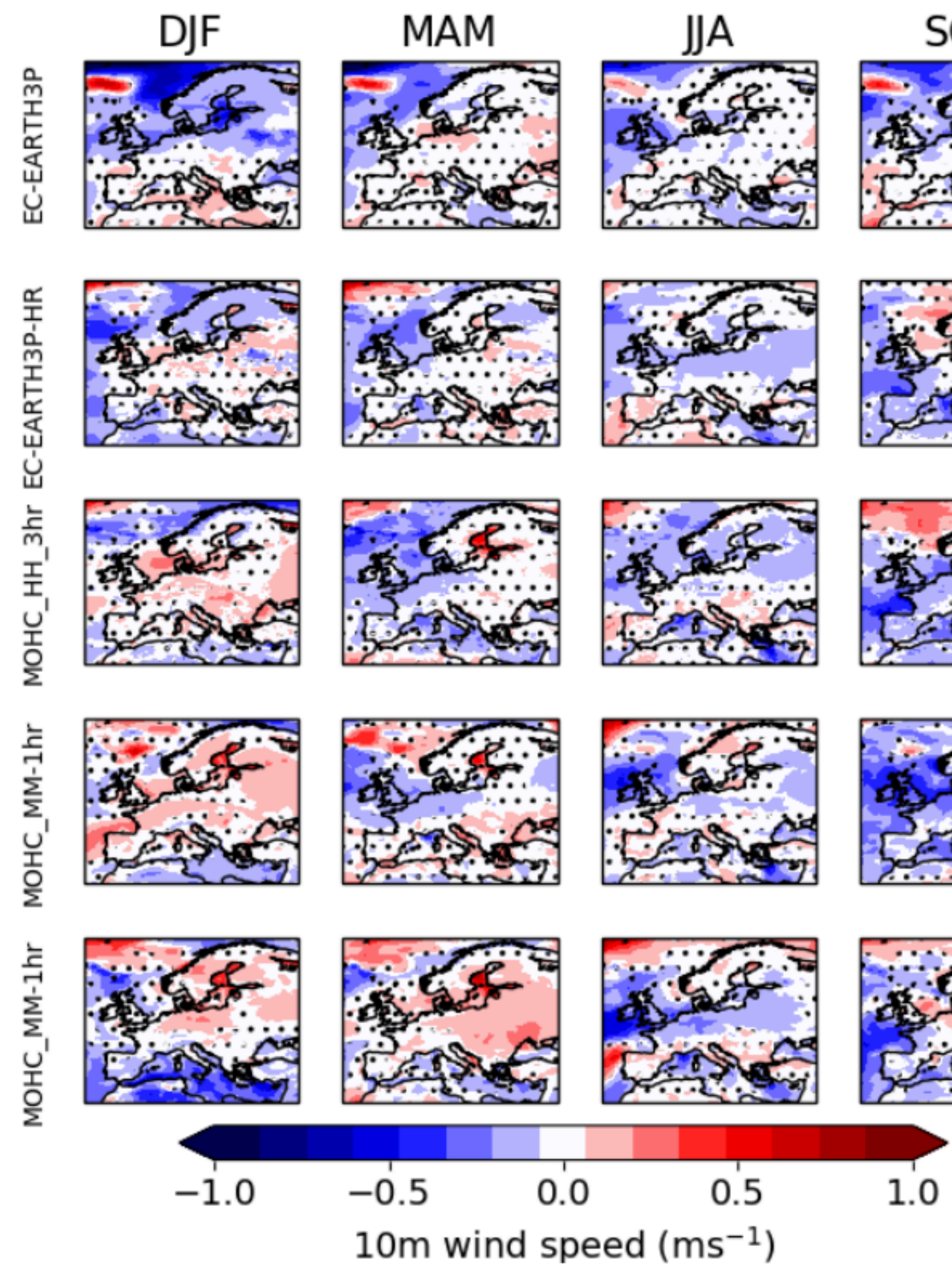

see Bloomfield et al., (2022)

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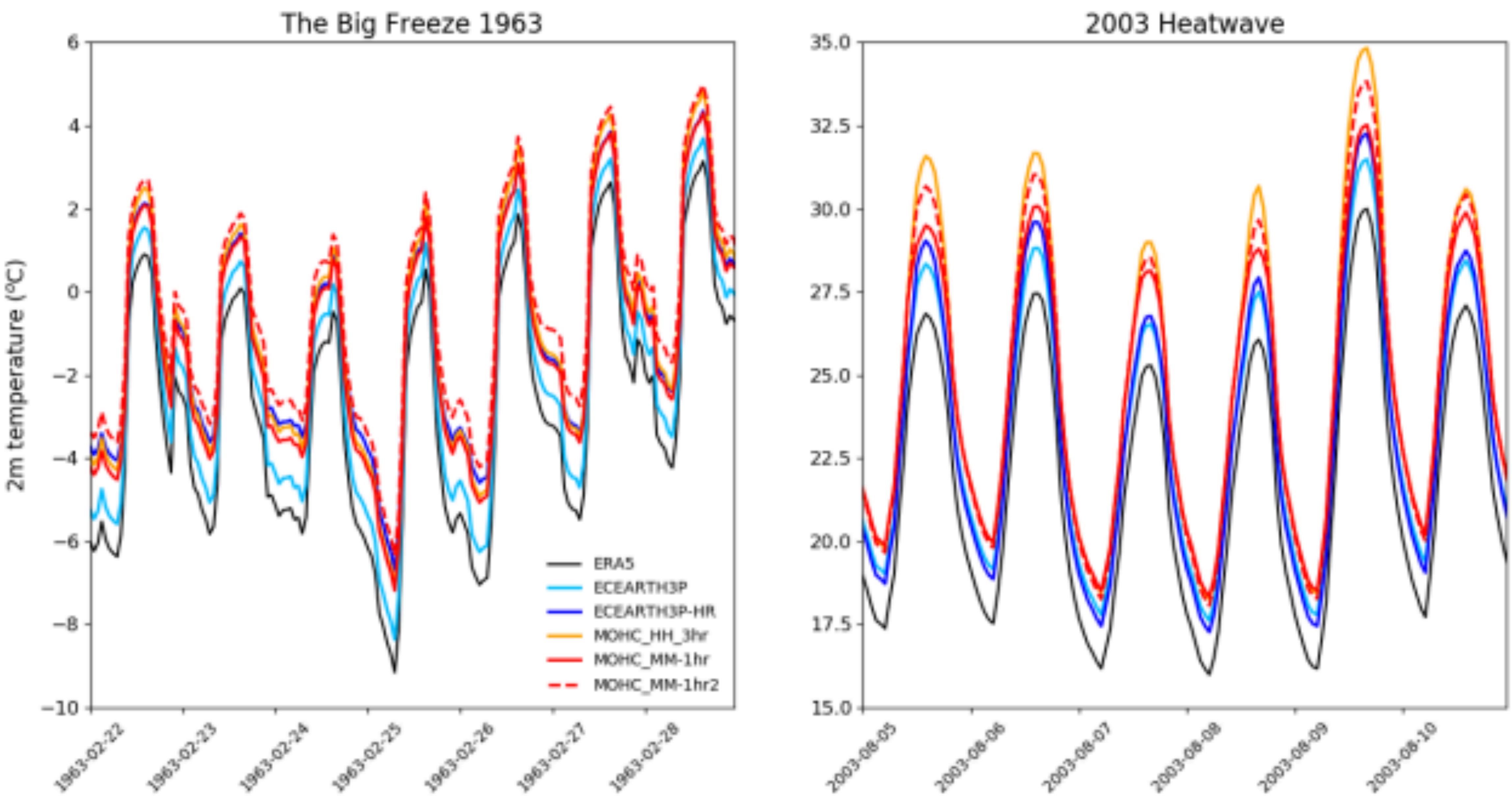

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MISMATCH IN DELIVERY VS REQUIREMENTS

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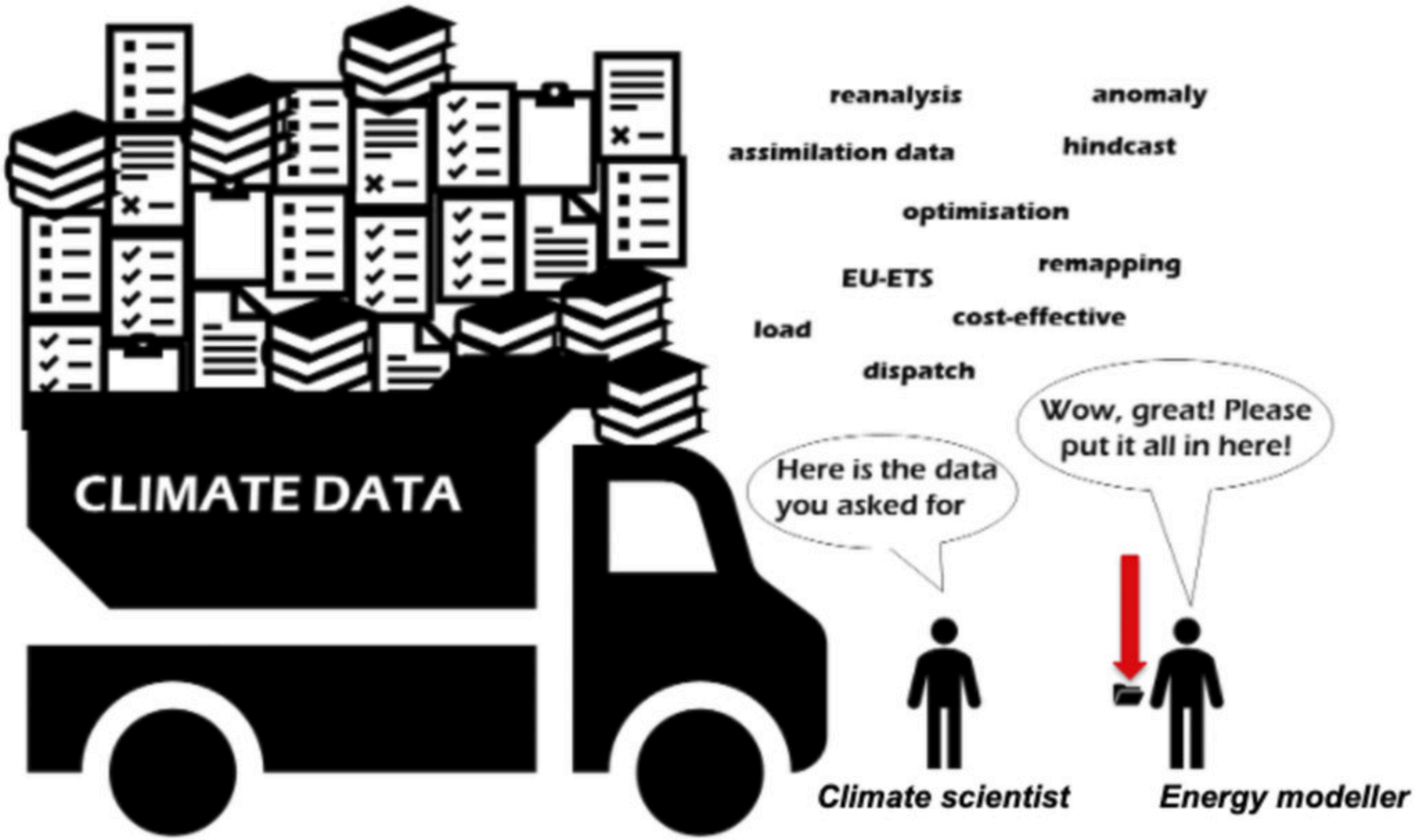

Citation: Bulletin of the American Meteorological Society 102, 1; 10.1175/BAMS-D-20-0256.1

SUMMARY PART 2

1. Future power system uncertainty is dominated by the choice of energy pathway. However, there is significant sensitivity still present due to the choice of climate model, RCP scenario, and the impacts of inter-annual variability.

2. The response of European demand to climate change is consistent with a reduction in heating-induced demand and increases in cooling-induced demand

3. The response of European WP/SP generation to climate change is much more uncertain, models do not generally agree on the sign of the change and the changes are sensitive to the choice of period used

4. **More thorough consideration of climate uncertainty is therefore needed within energy policy choices as it is likely to be of great importance for robust future power system planning and design.**

5. There is lots more work to do in this area! Collaboration with energy/power system modellers is particularly important for us to tailor our analysis/datasets.

   Access to data is a huge challenge!

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