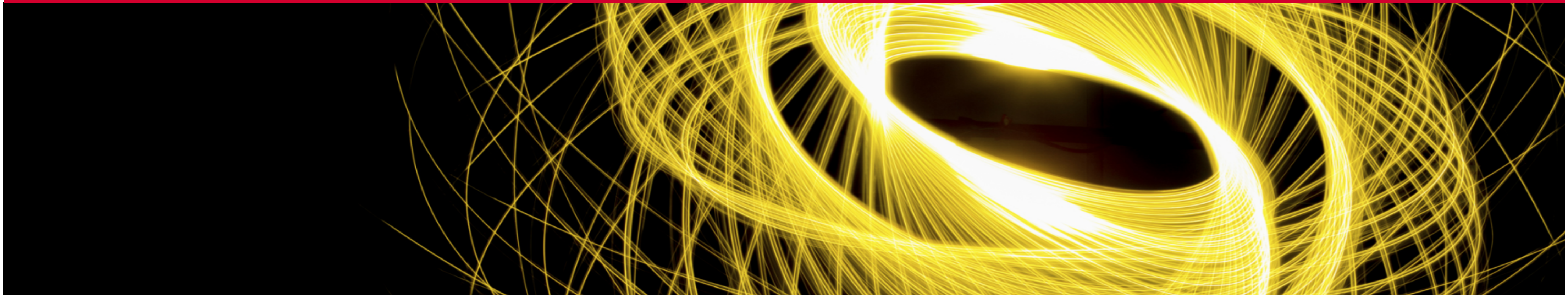
Department of Meteorology
School of Mathematical, Physical and Computational Sciences

University of Reading

WEATHER AND CLIMATE IN ENERGY MODELLING: (SOME) QUESTIONS, ISSUES AND DIRECTIONS



David Brayshaw
Associate Professor in Climate Science and Energy Meteorology
Lead: Energy-Meteorology research group
d.j.brayshaw@reading.ac.uk

PRIMAVERA | S2S4E Climate Services for Clean Energy | Climate Change Service

Erratum

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- During the talk, the climate data truck figure (here slides 13 & 14) was incorrectly attributed to the PLAN4RES project.
- The correct attribution is CLIM2POWER (https://clim2power.com/).
- This has been corrected in this version of the slides.

Challenges in Energy-Climate Modelling

- Energy sector has long been exposed to weather (extremes, demand) but:
  - Rapidly changing climate ➔ decarbonization (e.g., renewables)
  - Decarbonization ➔ increasing and changing the exposure of energy system to climate

- Historically weak connections between energy- and climate- research. Timely to build bridges in order to:
  - Anticipate *impacts* of future climate on energy (e.g., changes in wind, solar, temperature, extremes)
  - Ensure future energy system "solutions" (e.g., design, practice, policy) are robust to *climate uncertainty*

- Workshop – *Next Generation Challenges in Energy-Climate Modelling* (June 2020):
  - research.reading.ac.uk/met-energy/next-generation-challenges-workshop
  - **Bloomfield et al, in press; Bulletin of the American Meteorological Society**

- Today:
  - Characterizing climate risk for power system planning (GEP/TEP) not, e.g., IAMs or operations/trading applications
  - Very happy to discuss other areas offline!

Why climate risk matters to energy

The ability of physical energy system and infrastructure to cope with climate change or variation

Often viewed as associated with ”stress events” such as:

- Damaging weather extremes
- Compound impacts (e.g., low wind / high demand)

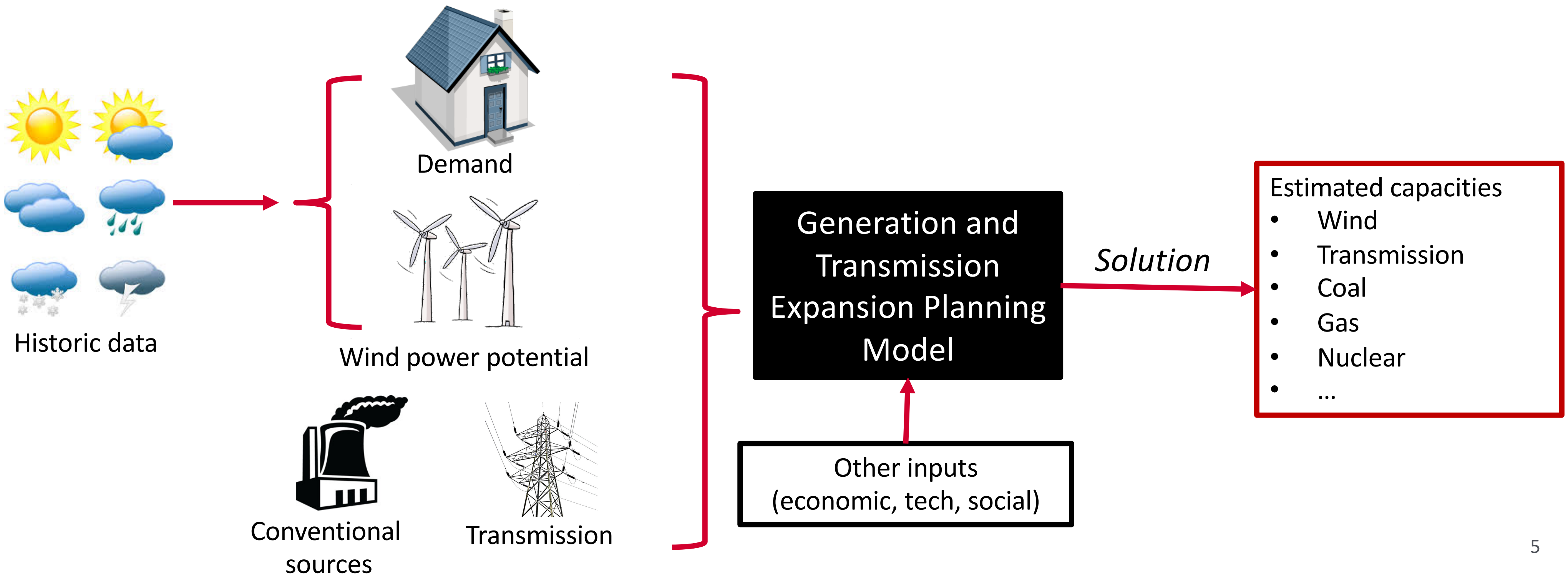
Climate change	Example impacts	Consequences
Temperature rise	Demand patterns for cooling / heating	Plant efficiency, permafrost melt
Sea level rise	Increasing sea levels, storm surges	Coastal plant; wave and tidal generators
Heat waves	More persistent, more extreme	Infrastructure tolerance, cooling demand
Storm frequency and intensity	Possible increases	Infrastructure damage
Precipitation / evaporation	Likelihood of floods and droughts	Hydropower, biofuels/crops
Wind and solar	Changes in resource	RE production

Table derived from Ebinger (2011).
Figure: pxhere.com/en/photo/1408472

Why climate risk matters to energy

The robustness of simulated energy system model "solutions" to future climate uncertainties

Relates to the modelling used to inform the operation or design of energy systems, e.g., consider simple GEP problem



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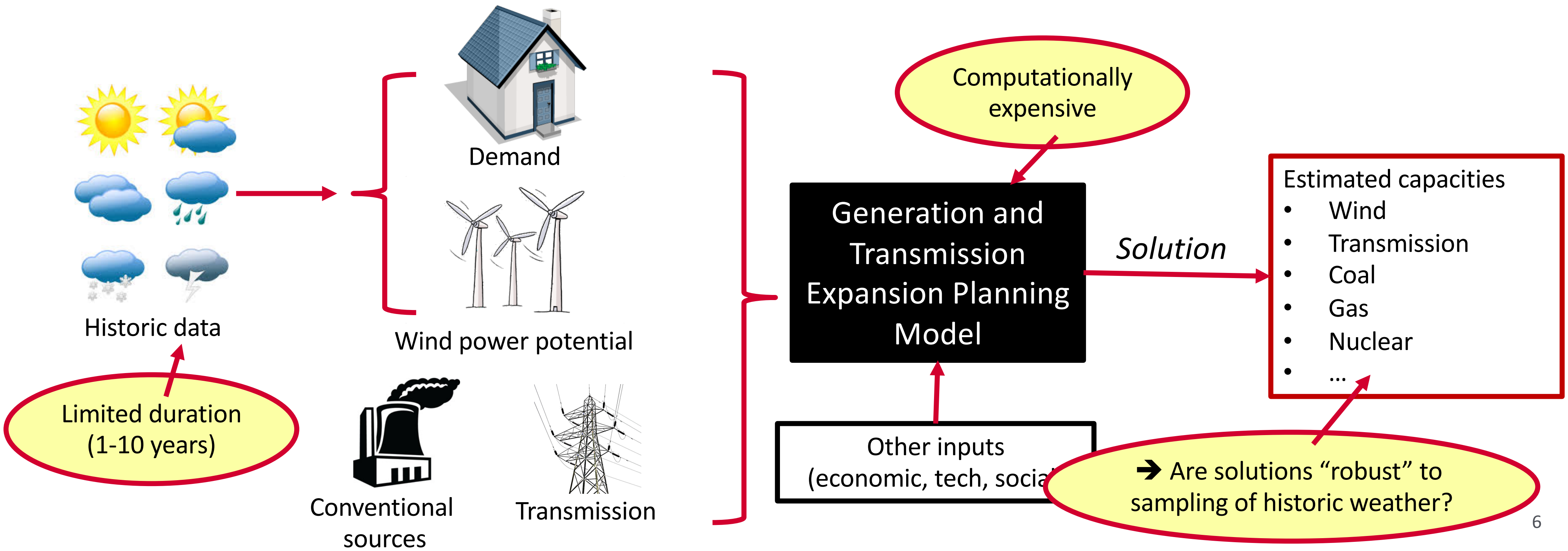

Why climate risk matters to energy

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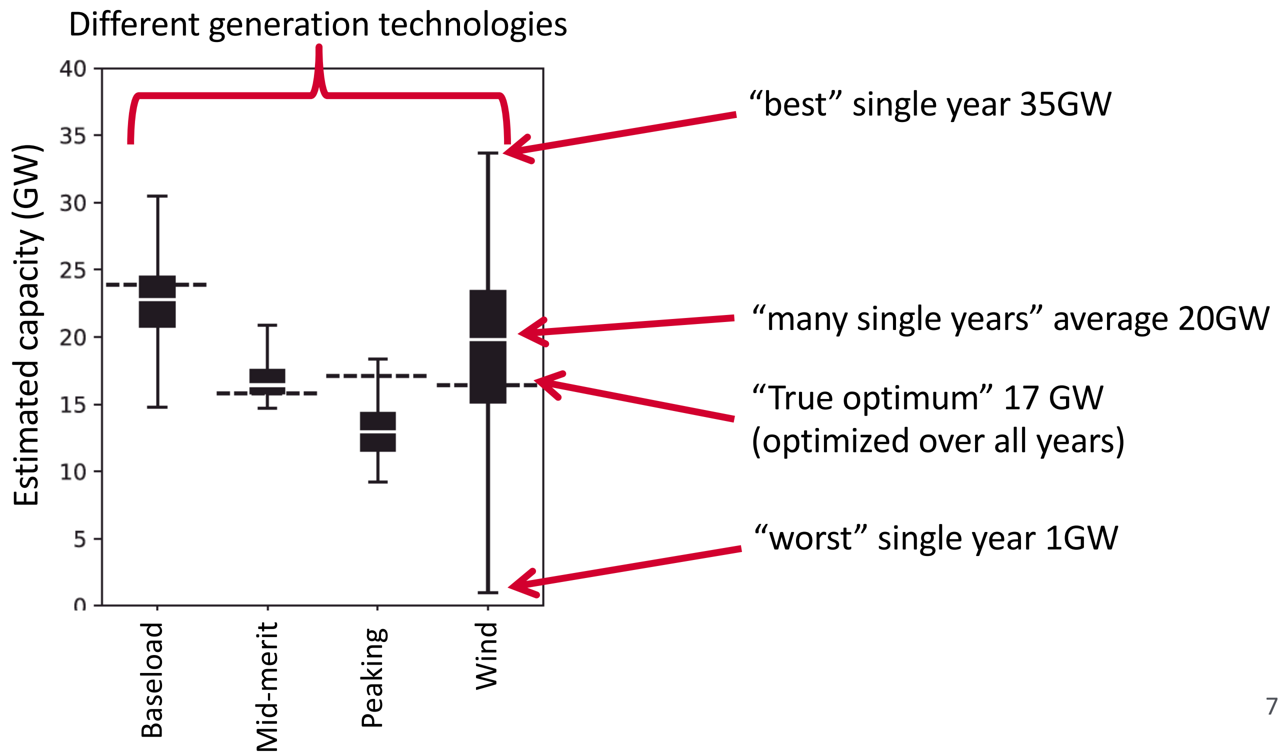
The robustness of simulated energy system model “solutions” to future climate uncertainties

Relates to the modelling used to inform the operation or design of energy systems, e.g., consider simple GEP problem

- Are solutions “robust” to (poor) sampling of historic weather? ➔ **likely not!**

Figure: Hilbers et al (2019), builds on Bloomfield et al (2016, 2018).

See also, e.g., Hilbers et al 2020 & in press; Zeyringer et al 2018; Collins et al 2018.



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- Are solutions "robust" to (poor) sampling of historic weather? ➔ **likely not!**
- Are solutions robust to **future climate uncertainty**? ➔ **uncertainty only just beginning to be unexplored!**
  - Climate forcing (GHG concentrations)
  - Climate response (impact of GHG increases)
  - Climate sampling (decadal variability)

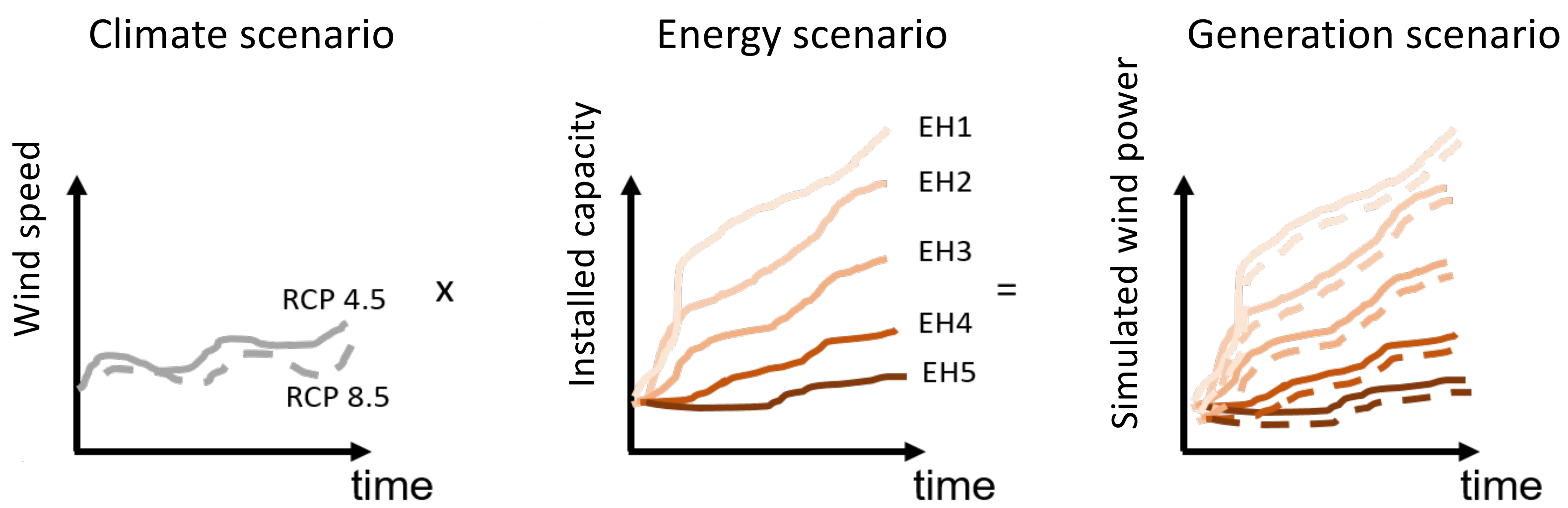

Figure: Bloomfield et al (in press, Renewable Energy)

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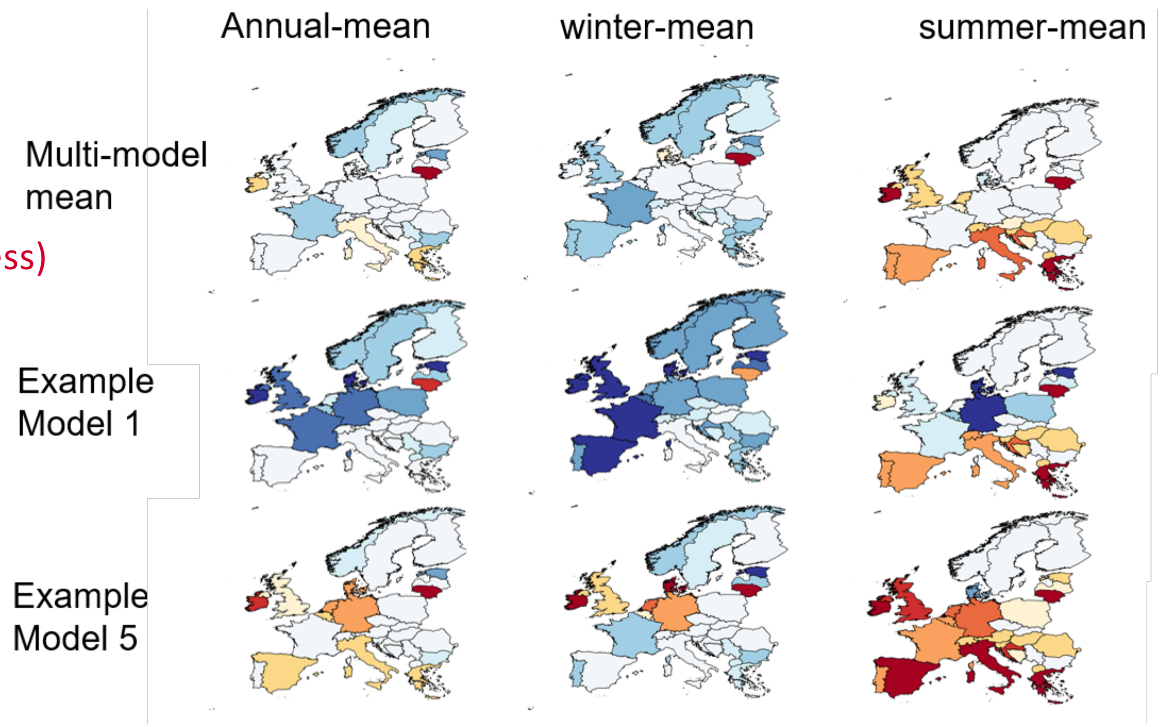
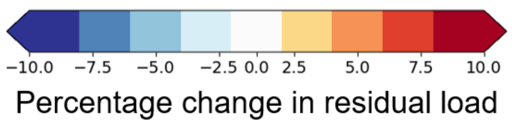
- Are solutions robust to **future climate uncertainty**? ➔ **uncertainty only just beginning to be unexplored!**
    - Climate forcing (GHG concentrations)
    - Climate response (impact of GHG increases)
    - Climate sampling (decadal variability)
- Regional and seasonal diversity (Bloomfield et al, in press)
- Poorly understood mechanisms (Gonzalez et al, 2019)



Difference in residual demand (~2050 – ~1990) for a single power system scenario.



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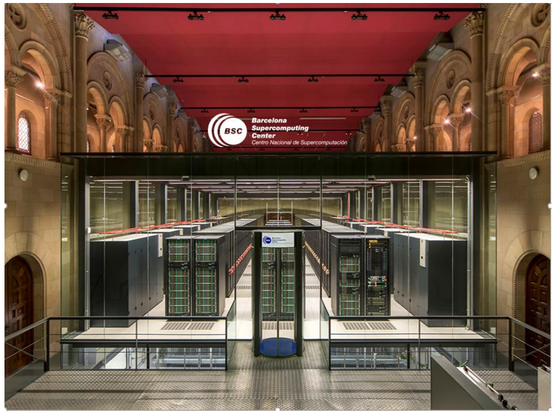
Climate data capabilities

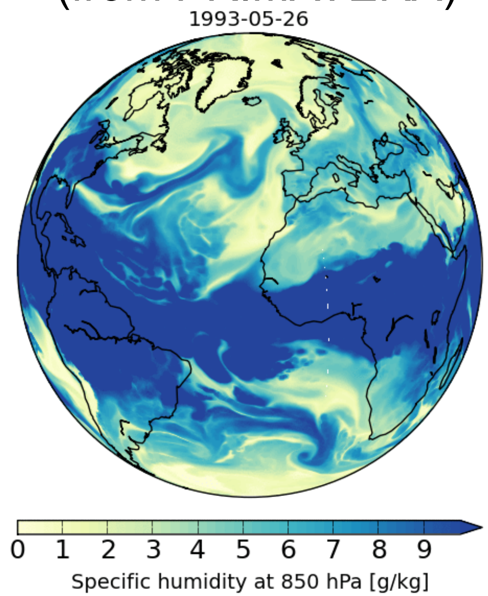
- Reanalyses spanning 40-100+ years (ERA5, JRA55, MERRA2, ERA-20C, 20CR, …)
- Climate models of increasing fidelity → forecasts and projections: days to decades ahead
- Huge international efforts with carefully designed protocols, curated data archives, and standardized data formats
- High frequency (1-6h), high resolution (few 10's km) surface data becoming increasingly common



Mare Nostrum and ECMWF's Cray (just two of several leading HPC systems used for PRIMAVERA simulations)

https://www.bsc.es/news/bsc-news/the-bsc's-bid-host-one-the-largest-supercomputers-the-eu-strengthened-the-support-three-additional, https://www.ecmwf.int/en/computing/our-facilities/supercomputer

EC Earth, hi-res simulation (from PRIMAVERA)



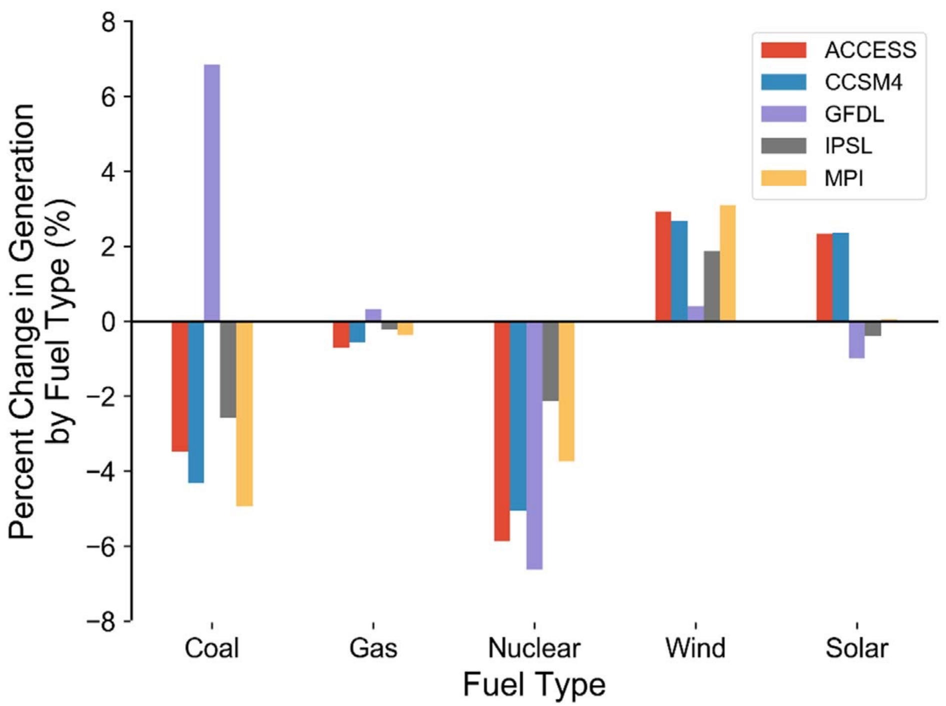
Substantial progress…

- **“Primary renewable energy” estimates from meteorological data now becoming common**
  - Carrying through into stress event characterization, energy system design, forecasting …

- **Beginning to use GCM data in detailed energy system planning**

E.g., Craig et al 2019 (figure)

- Complex power system model (UC/ED) driven by data from 5 different GCMs
- Assessed how much the use of different types of generators would be effected under a future climate



… but many challenges remain

Upper figure (Craig et al, 2019):

- Why does one GCM give a completely different response?
- How should this impact our confidence in the results?

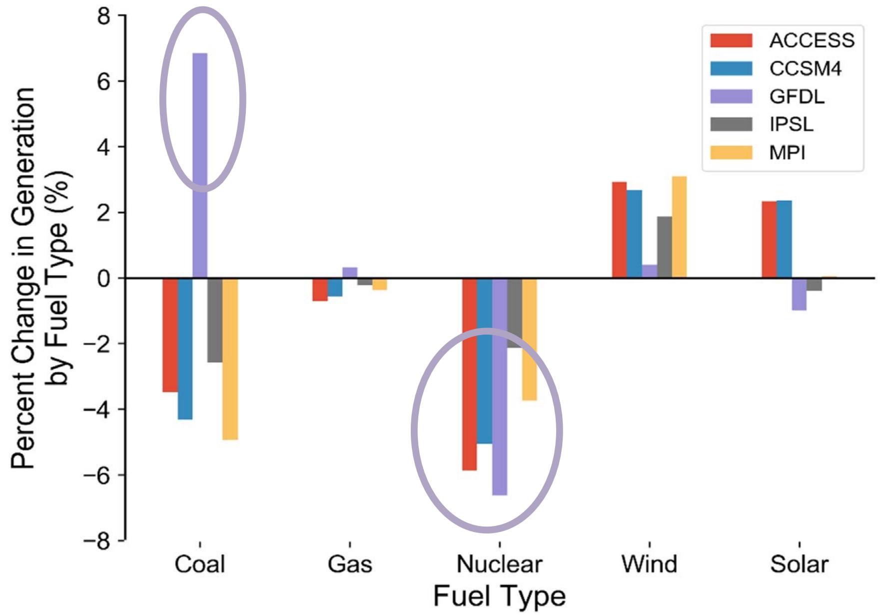
Lower (Bloomfield et al 2018, 2020)

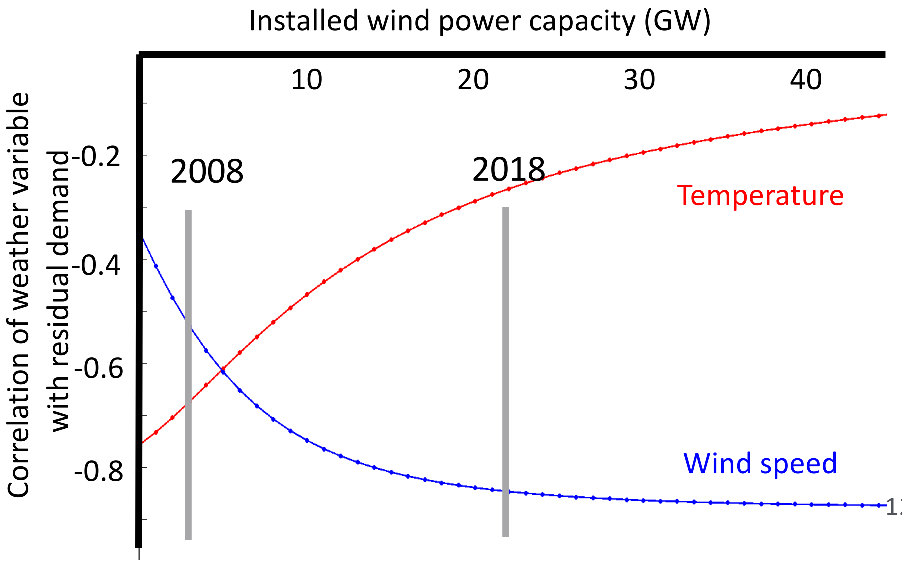
- Changes in the energy system impact it's weather sensitivity
- Future "stress events" may not resemble past "stress events"

More generally, questions & issues around:

- Differences between reanalyses
- Uncertainty in weather → energy "conversion" (e.g., wind, solar)
- Resolution, biases, deficiencies in climate models
- Sampling multi-decadal *natural* variations in climate
- Sampling possible *future* climate projections
- Role of imperfect foresight hours-weeks ahead
- Error propagation in modelling chains

Computational feasibility of long power system simulations





The Problem with having Too Much Data

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Climate data volumes (~TB+) needed for "standard" uncertainty quantification

➔ Intractable for many energy modelling applications

➔ Need for *appropriate* sampling techniques (dangers of oversimplification!)

➔ Must Intersect with familiar energy-modelling practice

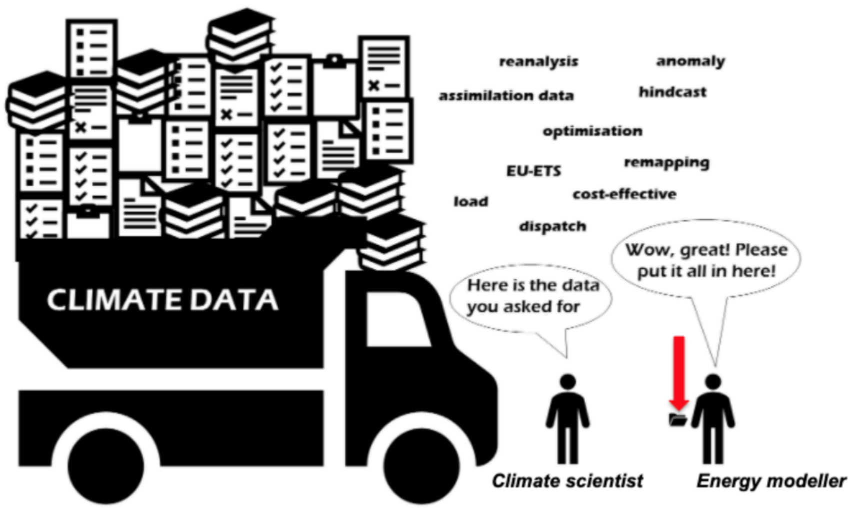

Figure from CLIM2POWER project.

As shown by Prof Simoes in Next Generation Challenges in Energy Climate Modelling workshop (June 2020).

Reproduced in Bloomfield et al (in press, Bull. Am. Soc)

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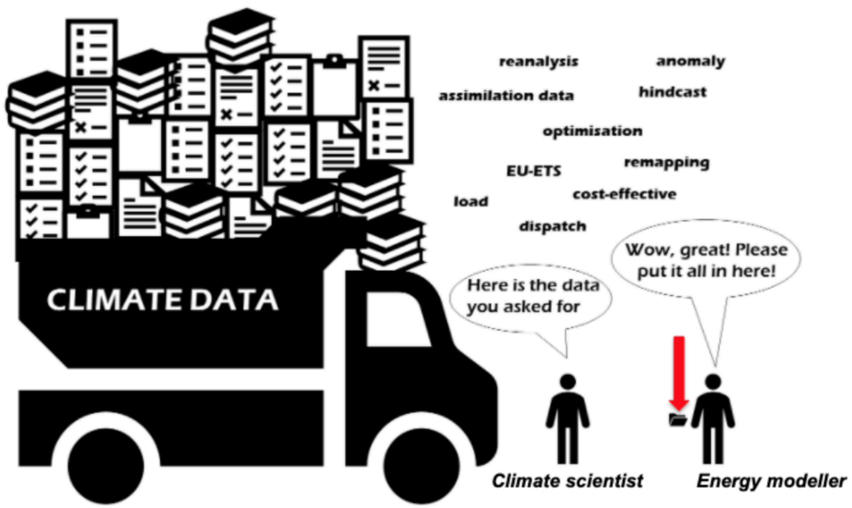

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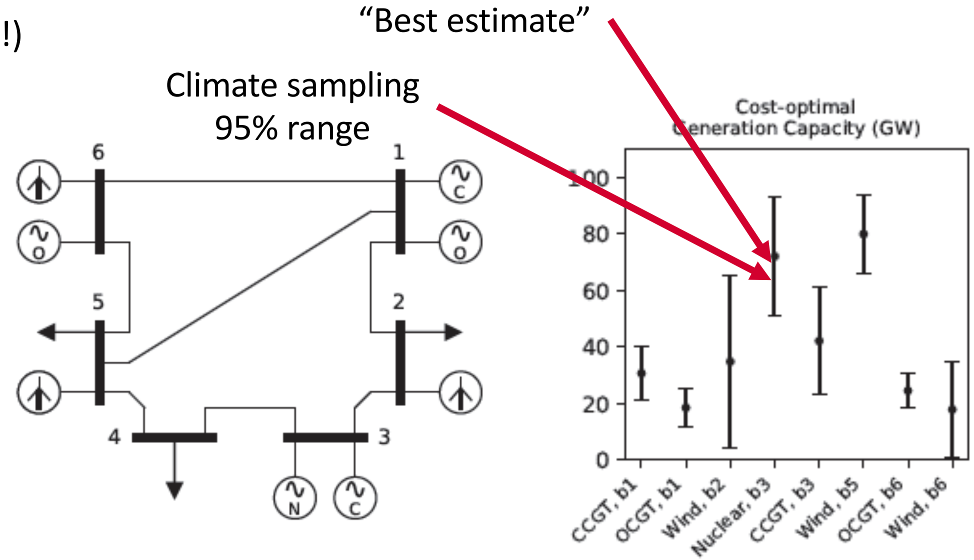

Hilbers et al (2019, 2020, in press):

- "Toy" GEP/TEP LPs & MILPs using extensive climate data
- Estimate optimal technology capacities for each bus including an estimate of sampling uncertainty
- Innovative application of sampling strategies specifically to energy/climate problem
- **Computationally tractable: years → hours/days**

Conclusion

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For climate scientists: **Energy systems are more than just a set of weather inputs and stress events.**

- ➔ Provision of high-resolution/high-frequency surface data necessary for energy modelling
- ➔ Need to integrate “energy system thinking” into climate model evaluation

For energy scientists: **Climate is more than just a set of statistical inputs**

- ➔ Access to “climate data” is necessary but not sufficient
- ➔ Non-trivial challenges in, e.g., sampling, bias/deficiency, skill assessment, uncertainty quantification, …

Humber Bridge (near Hull, UK) constructed 1973-81.
At the time, the longest single-span suspension bridge in the world.
Fig: driventowrite.com/2019/10/06/bridge-across-the-humber/#jp-carousel-55246

Building bridges – an opinion

- Shared/open models & data and common language are *necessary and valuable* but not *sufficient* for good research
- Also need:
    - Deeper *engagement* between research communities
    - Shared scientific *understanding* of issues, concepts, methods, data *and their limitations*

Links and selected group papers

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- Energy-Meteorology group (datasets and group information): https://research.reading.ac.uk/met-energy/
- Next Generation Challenges in Energy-Climate Modelling workshop: https://research.reading.ac.uk/met-energy/next-generation-challenges-workshop/
- H2020 PRIMAVERA https://www.primavera-h2020.eu; H2020 S2S4E https://s2s4e.eu; COPERNICUS ECEM http://ecem.wemcouncil.org/

- **Bloomfield, Gonzalez, Lundquist, Stoop, Browell, Dargaville, De Felice, Gruber, Hilbers, Kies, Panteli, Thornton, Wohland, Zeyringer & Brayshaw (in press). The Importance of weather and climate to energy systems: A workshop on Next Generation Challenges in Energy-Climate modelling. Bulletin of the American Meteorological Society.**
- Bloomfield, H. C., Brayshaw, D. J., Shaffrey, L. C., Coker, P. J. and Thornton, H. E. (2016) Quantifying the increasing sensitivity of power systems to climate variability. Environmental Research Letters, 11 (12). 124025. ISSN 1748-9326 doi: https://doi.org/10.1088/1748-9326/11/12/124025
- Bloomfield, H., Brayshaw, D. J., Shaffrey, L., Coker, P. J. and Thornton, H. E. (2018) The changing sensitivity of power systems to meteorological drivers: a case study of Great Britain. Environmental Research Letters, 13 (5). 054028. ISSN 1748-9326 doi: https://doi.org/10.1088/1748-9326/aabff9
- Bloomfield, H. C., Brayshaw, D. J. and Charlton-Perez, A. J. (2020) Characterizing the winter meteorological drivers of the European electricity system using targeted circulation types. Meteorological Applications, 27 (1). e1858. ISSN 1469-8080 doi: https://doi.org/10.1002/met.1858
- Bloomfield, Brayshaw, Troccoli, Goodess, De Felice, Dubus, Bett, Sain—Drenan (in press) Quantifying the sensitivity of European power systems to energy scenarios and climate change projections. Renewable Energy.
- Cannon, D.J., Brayshaw, D.J., Methven, J., Coker, P.J. and Lenaghan, D. (2015) Using reanalysis data to quantify extreme wind power generation statistics: a 33 year case study in Great Britain. Renewable Energy, 75. pp. 767-778. ISSN 0960-1481 doi: https://doi.org/10.1016/j.renene.2014.10.024
- Gonzalez, P. L. M., Brayshaw, D. J. and Zappa, G. (2019) The contribution of North Atlantic atmospheric circulation shifts to future wind speed projections for wind power over Europe. Climate Dynamics, 53 (7-8). pp. 4095-4113. ISSN 1432-0894 doi: https://doi.org/10.1007/s00382-019-04776-3
- Hilbers, A. P., Brayshaw, D. J. and Gandy, A. (2019) Importance subsampling: improving power system planning under climate-based uncertainty. Applied Energy, 251. 113114. ISSN 0306-2619 doi: https://doi.org/10.1016/j.apenergy.2019.04.110
- Hilbers, A. P., Brayshaw, D. and Gandy, A. (2020) Importance subsampling for power system planning under multi-year demand and weather uncertainty. In: International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), 18-21 Aug 2020, Liege, Belgium. doi: https://doi.org/10.1109/PMAPS47429.2020.9183591
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- Santos-Alamillos, F. J., Brayshaw, D., Methven, J., Thomaidis, N. S., Ruiz-Arias, J. A. and Pozo-Vazquez, D. (2017) Exploring the meteorological potential for planning a high performance European Electricity Super-grid: optimal power capacity distribution among countries. Environmental Research Letters, 12 (11). 114030. ISSN 1748-9326 doi: https://doi.org/10.1088/1748-9326/aa8f18
- Thornton, H. E., Scaife, A. A., Hoskins, B. J. and Brayshaw, D. J. (2017) The relationship between wind power, electricity demand and winter weather patterns in Great Britain. Environmental Research Letters, 12 (6). 064017. ISSN 1748-9326 doi: https://doi.org/10.1088/1748-9326/aa69c6