Boosting energy system resilience in the face of future weather extremes.

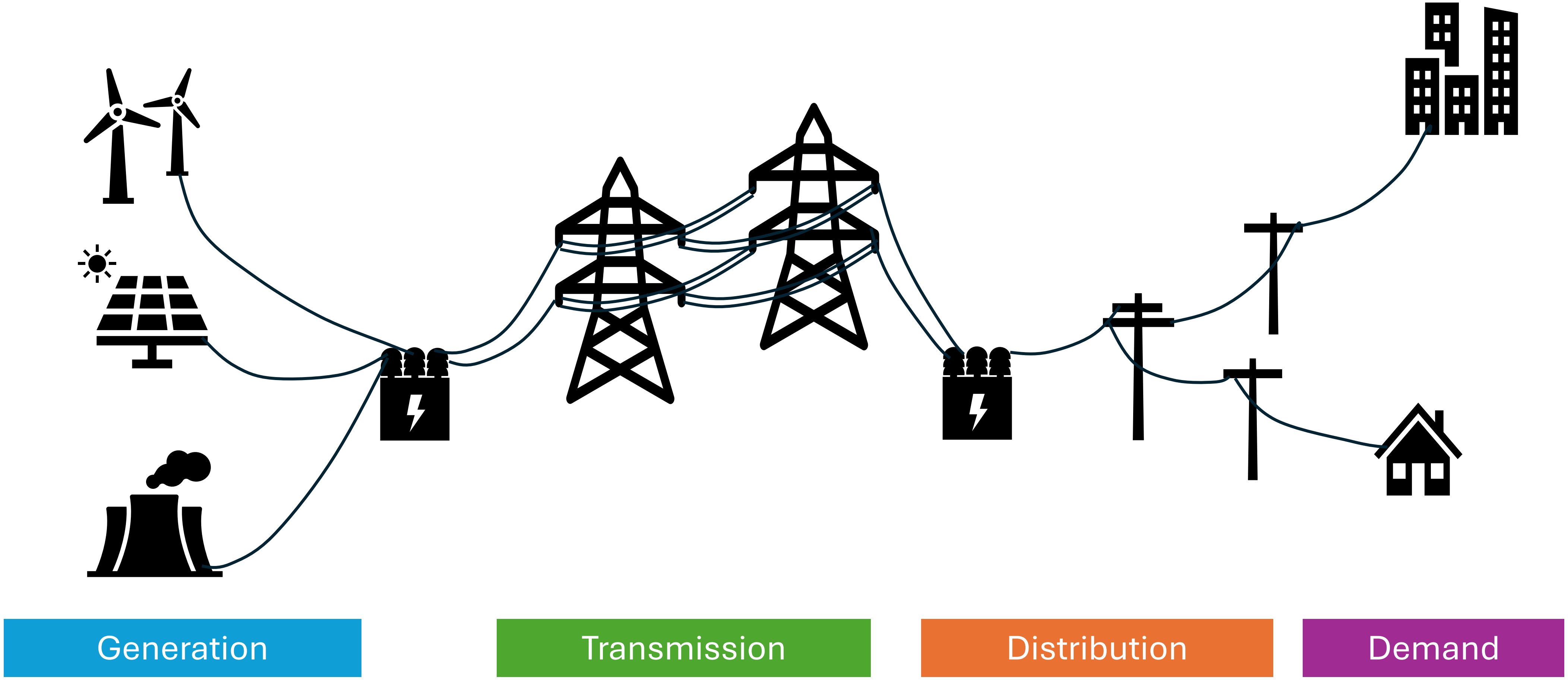
Sarah Sparrow

Sara Abdelaziz, Eleanor McIndoe, Weijia Yang, Dermot Leggett, Aubrey Taylor, Natalie Sauter, Nicole Miranda, Jesus Lizana, David Wallom, and many others!

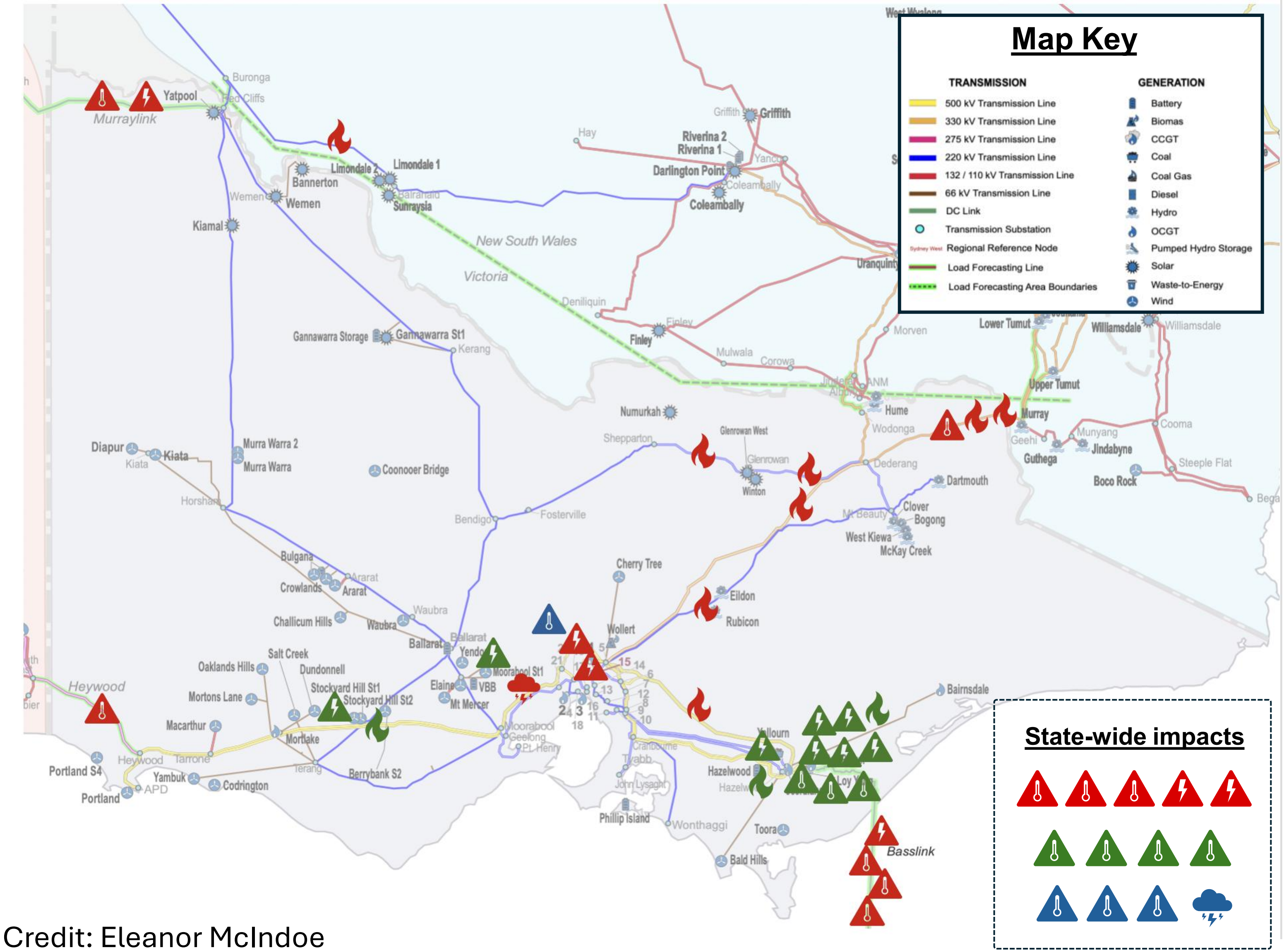
Weather Impact on Energy Infrastructure



Schematic of the Energy System

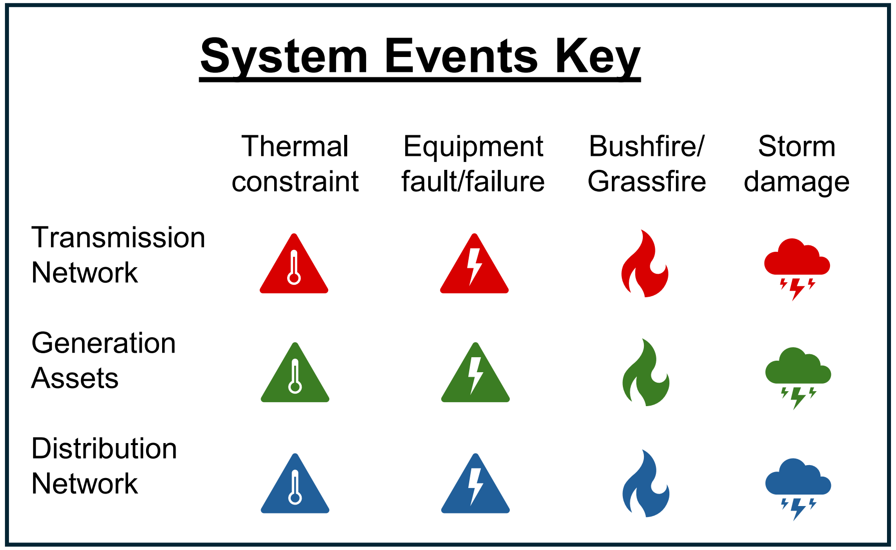


Heatwaves: Energy System in Victoria



Credit: Eleanor McIndoe

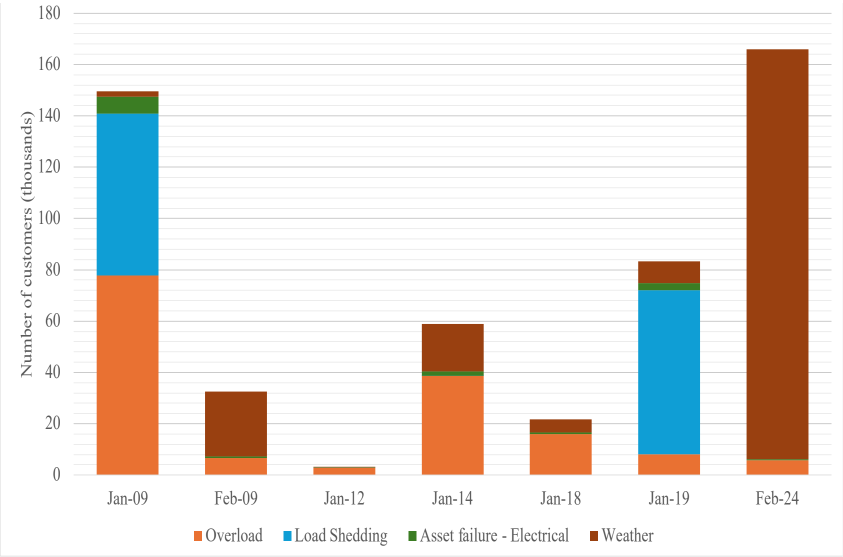
Causes of the seven large-scale heatwave-outage events



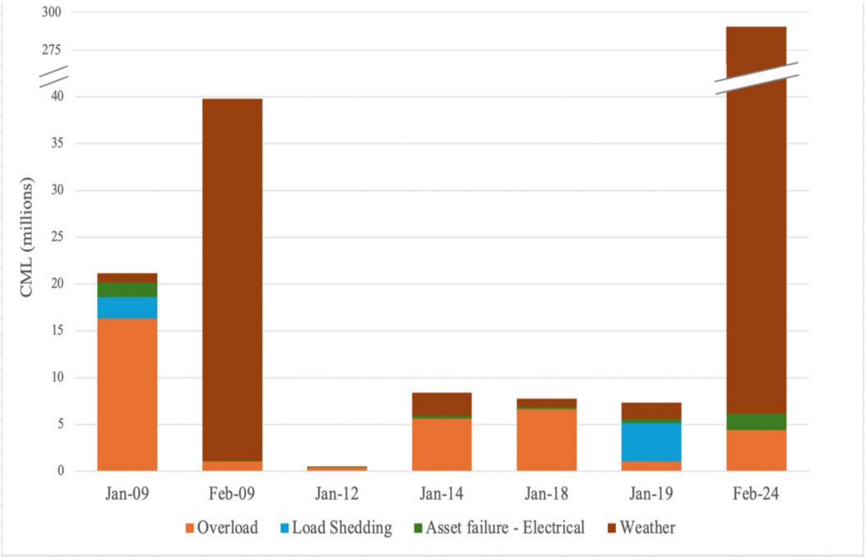
- Twelve separate incidences of load shedding
- Two incidents over 1GW, ~18% of average peak daily summer load

Heatwaves: Energy System in Victoria

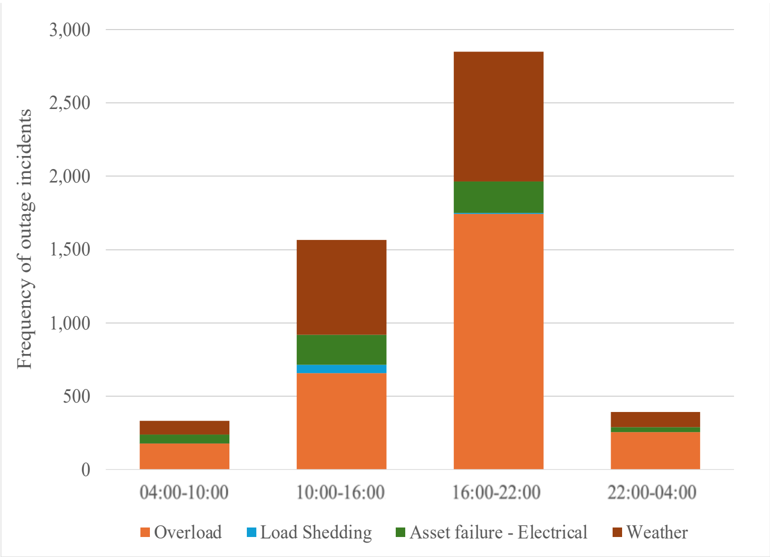
Number of customers affected by outage cause



Total customer minutes lost by outage cause



Frequency of outages by 6-hour period and cause



Overload Load Shedding Asset failure - Electrical Weather

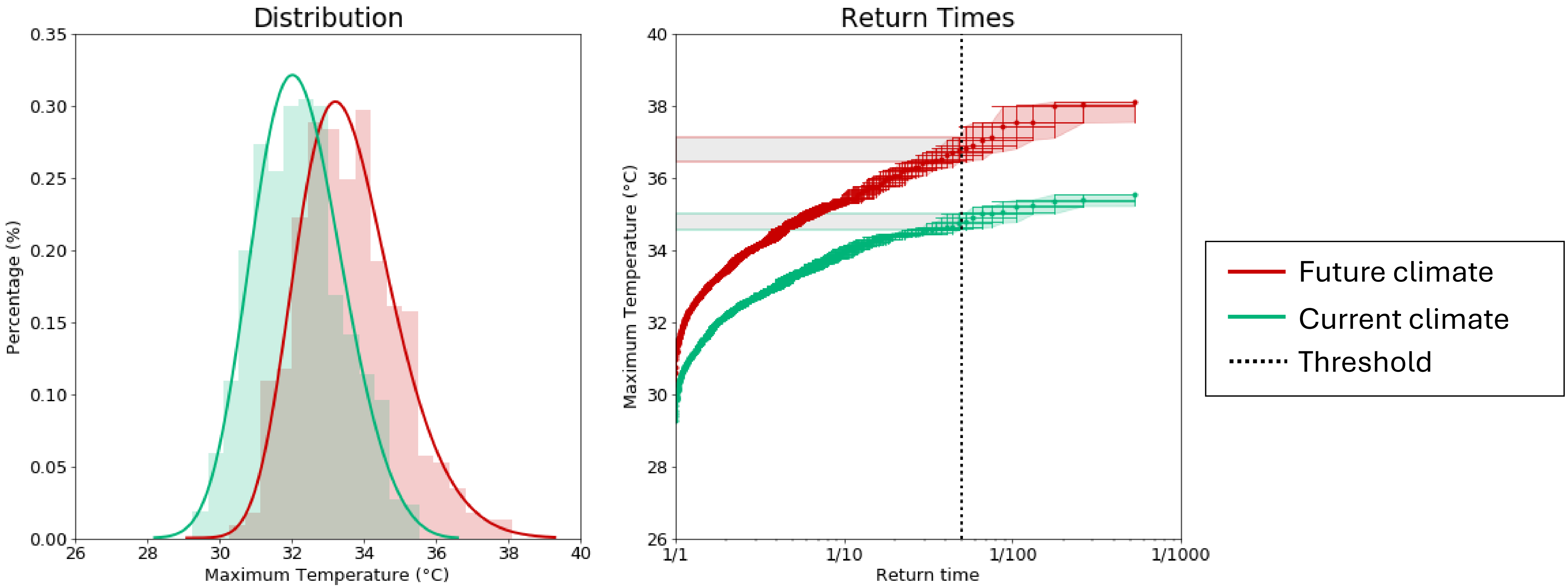
Data retrieved from: PowerCor, CitiPower, UnitedEnergy, Ausnet

- Overloading and extreme weather were primary drivers of outages and outage severity
- The presence of concurrent extreme weather during heatwaves greatly exacerbates the severity of outages

Credit: Eleanor McIndoe

Probabilistic extreme event attribution

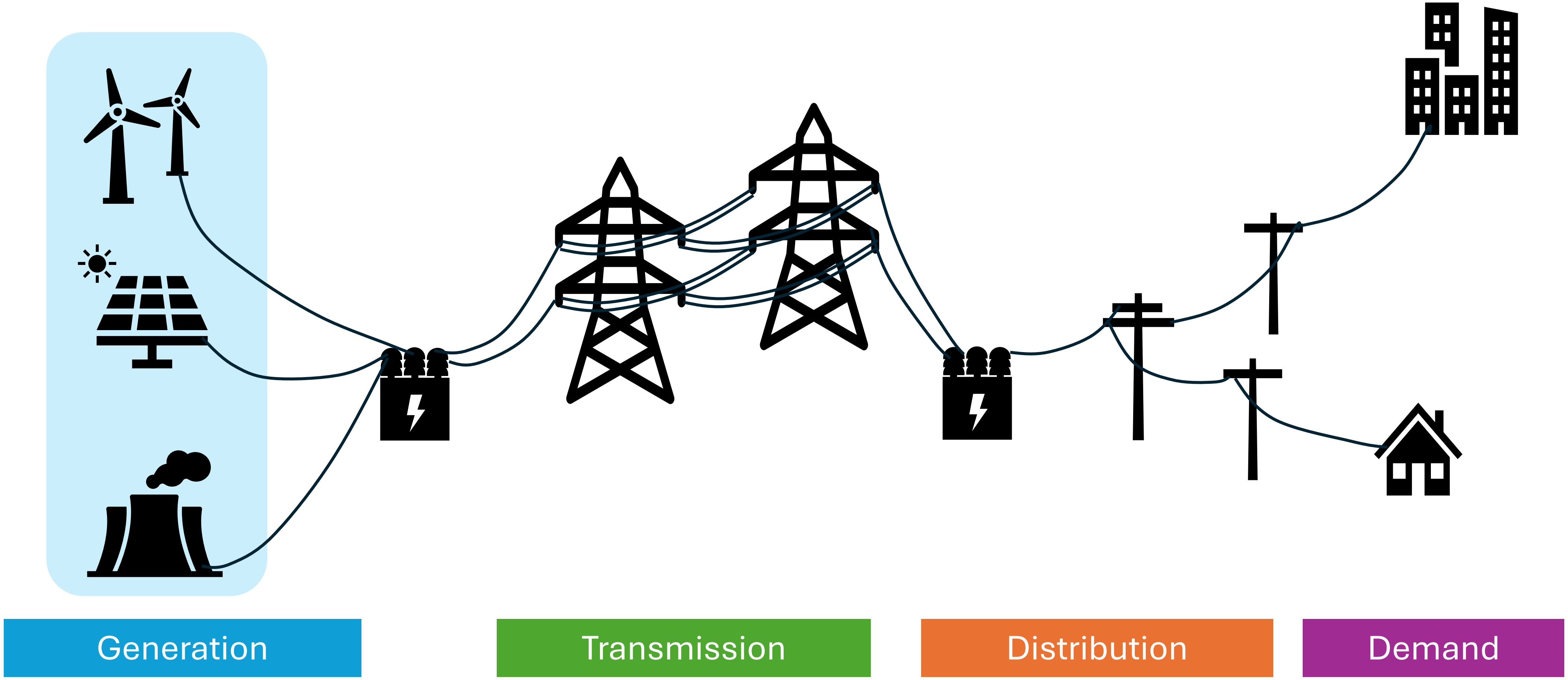
$$\text{Probability Ratio} = \frac{\text{Chance in future world}}{\text{Chance now}}$$



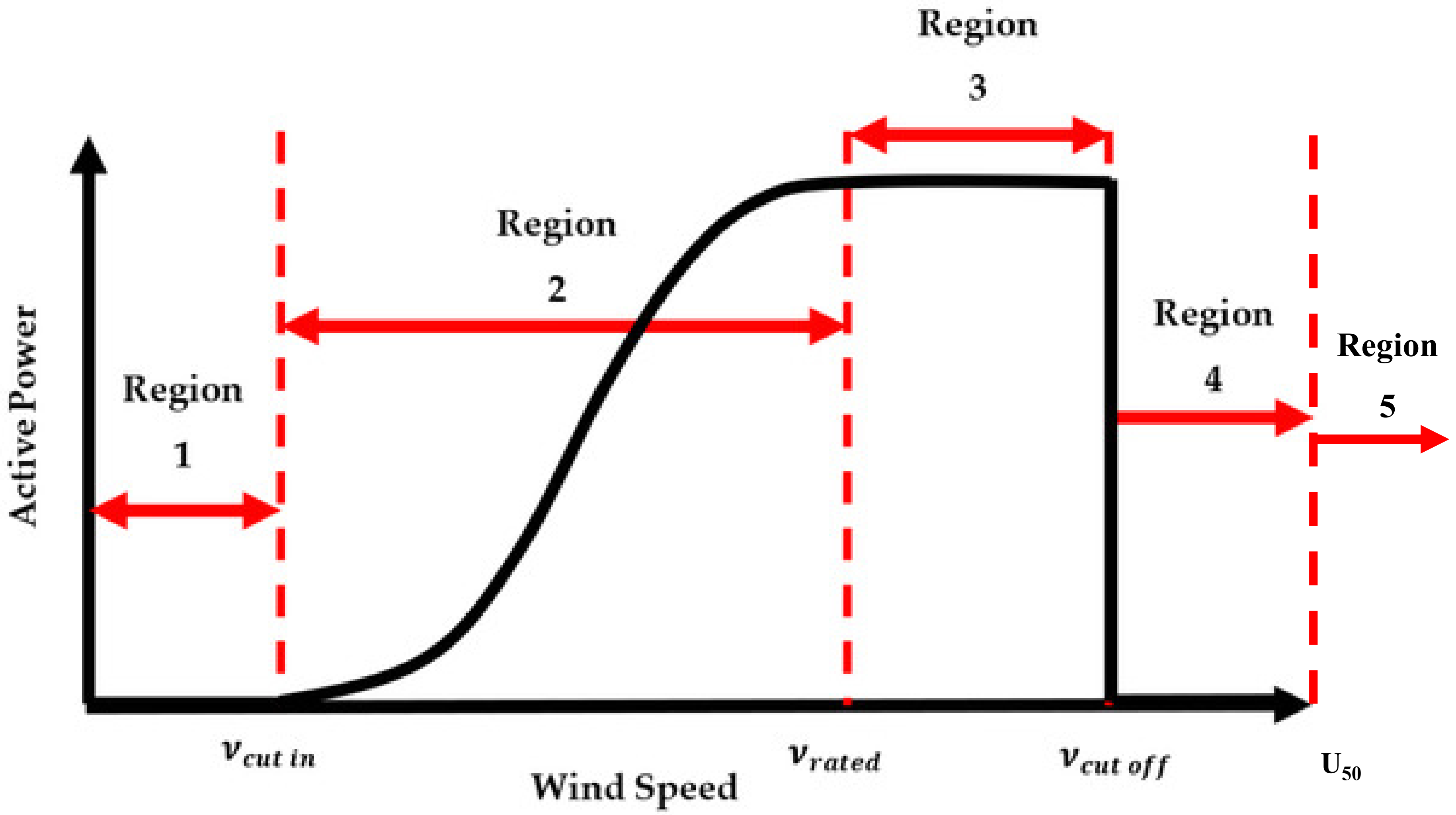
Example Heatwave Event

Generation Example: UK Offshore Wind

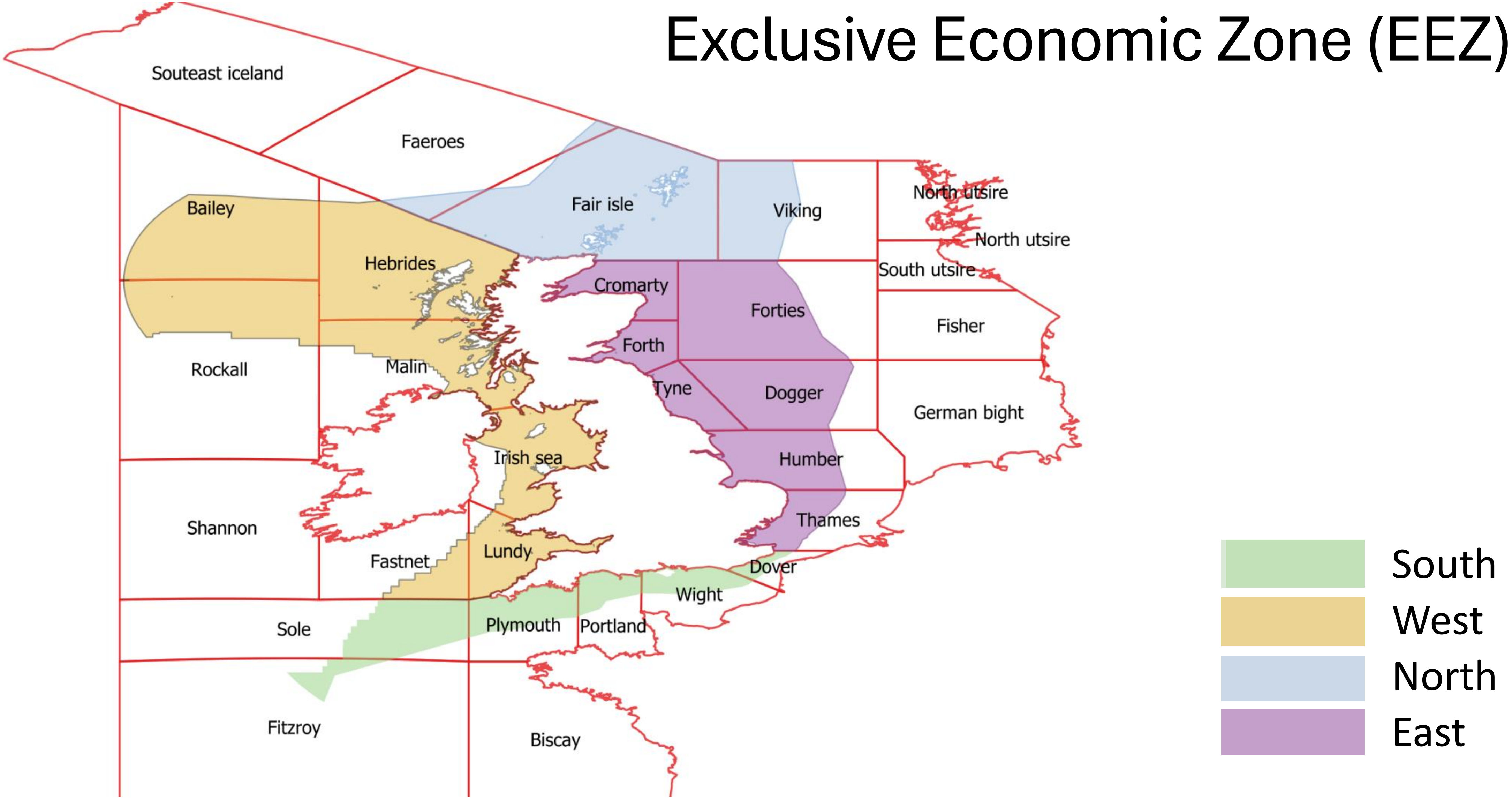
Sara Abdelaziz



Wind turbine operation conditions



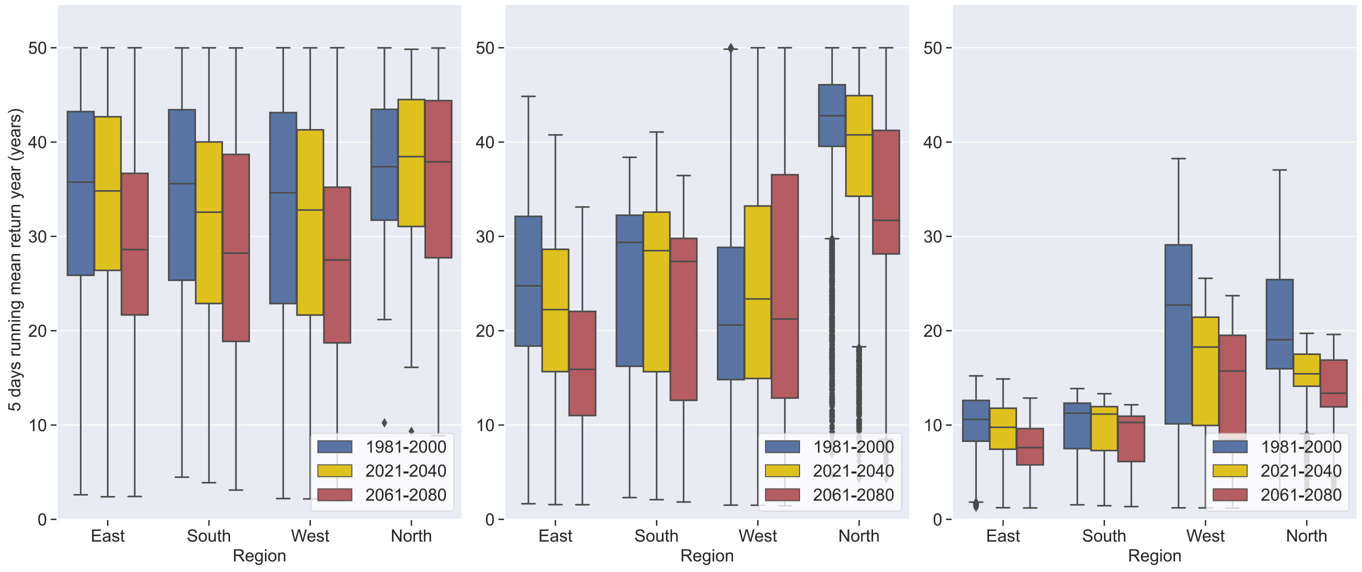
The UK shipping regions and Exclusive Economic Zone (EEZ)

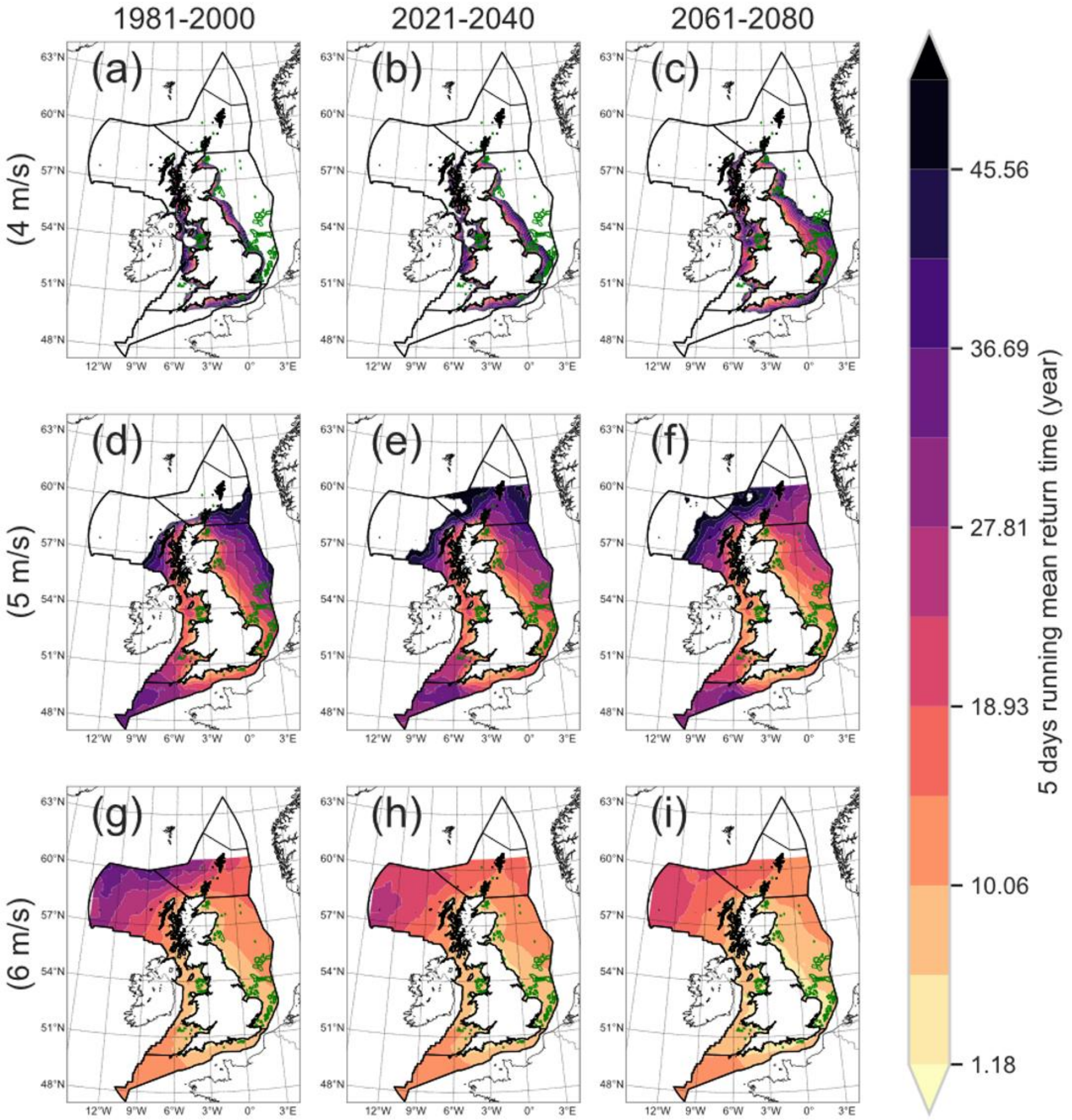


Low Wind: Region 1

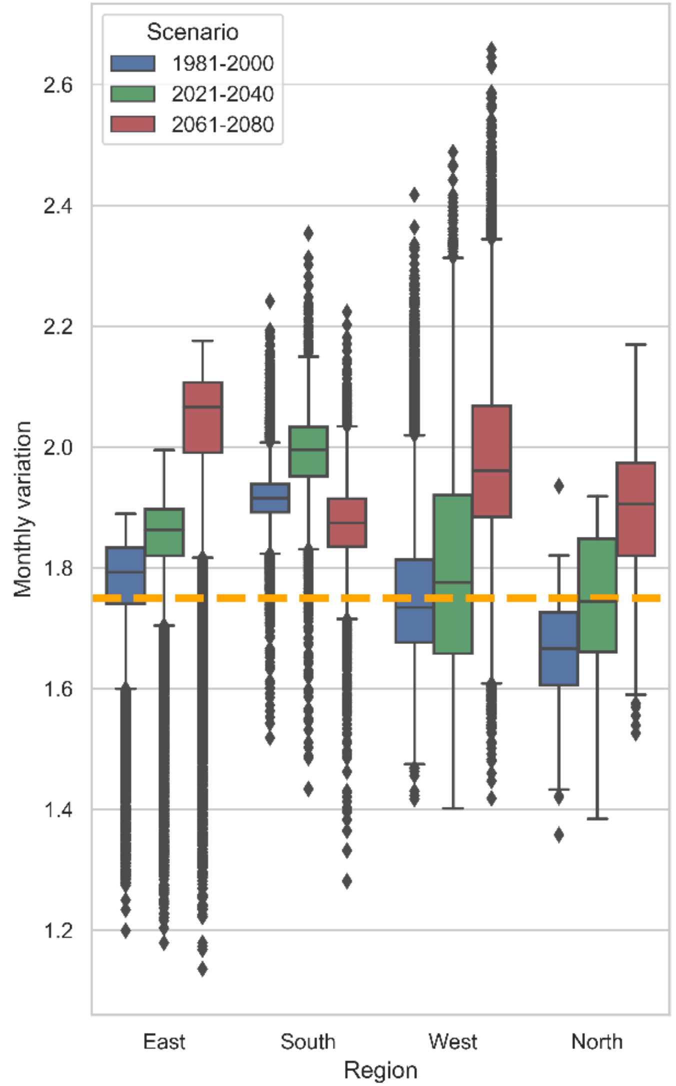
Return period of 5-day running mean wind speeds less than cut in speeds of 4 m/s, 5m/s and 6m/s

(a) 4m/s (b) 5m/s (c) 6m/s

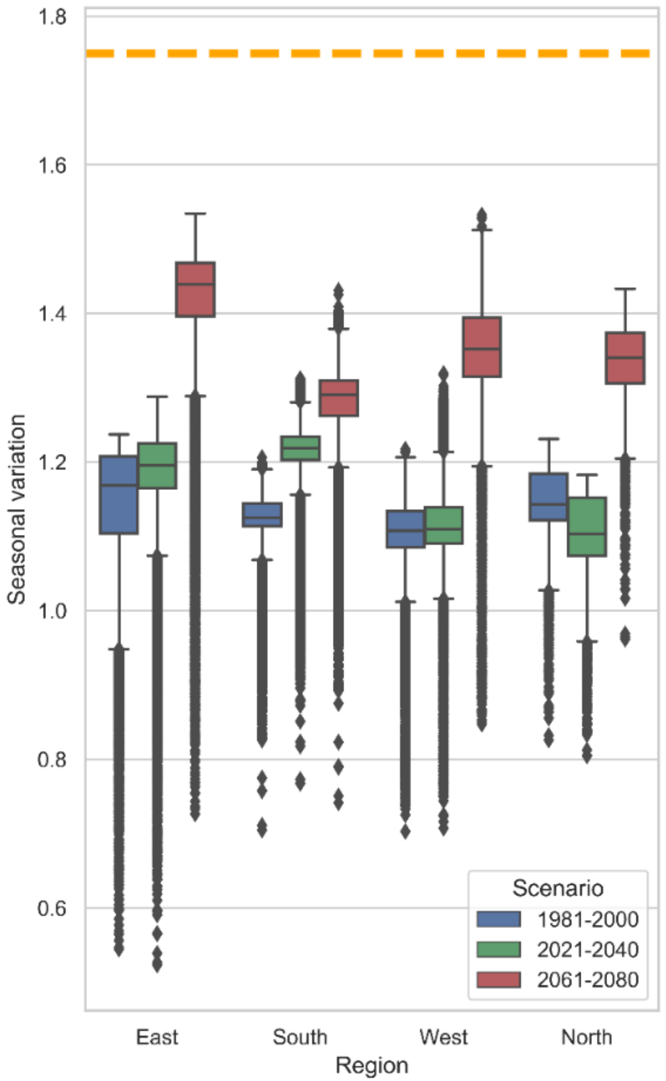




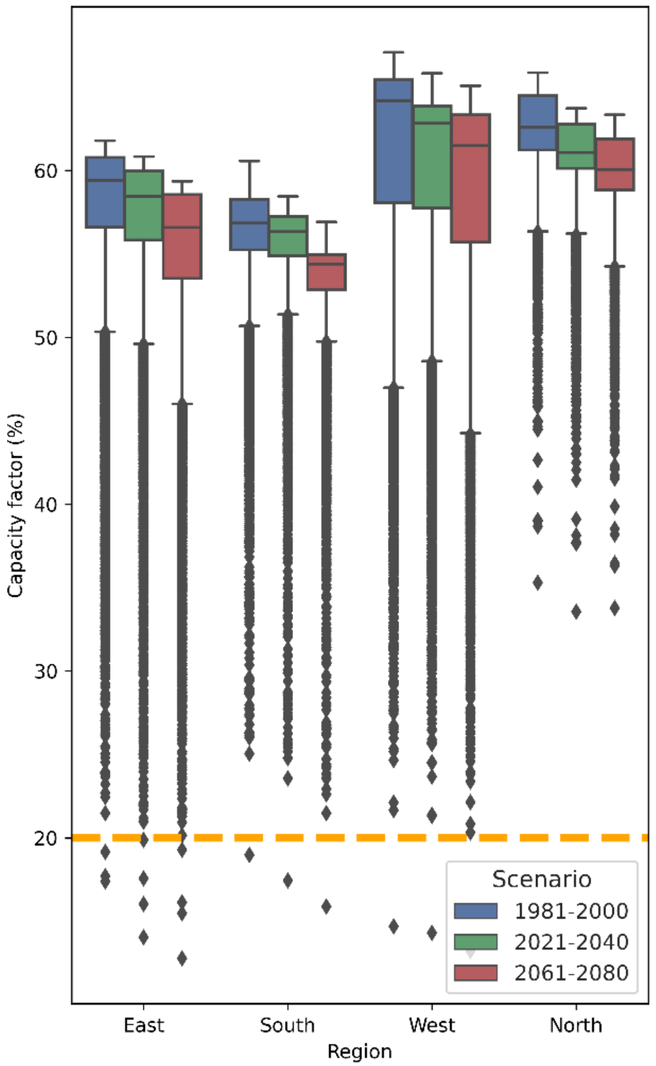
Production: Regions 2 & 3



Monthly variation



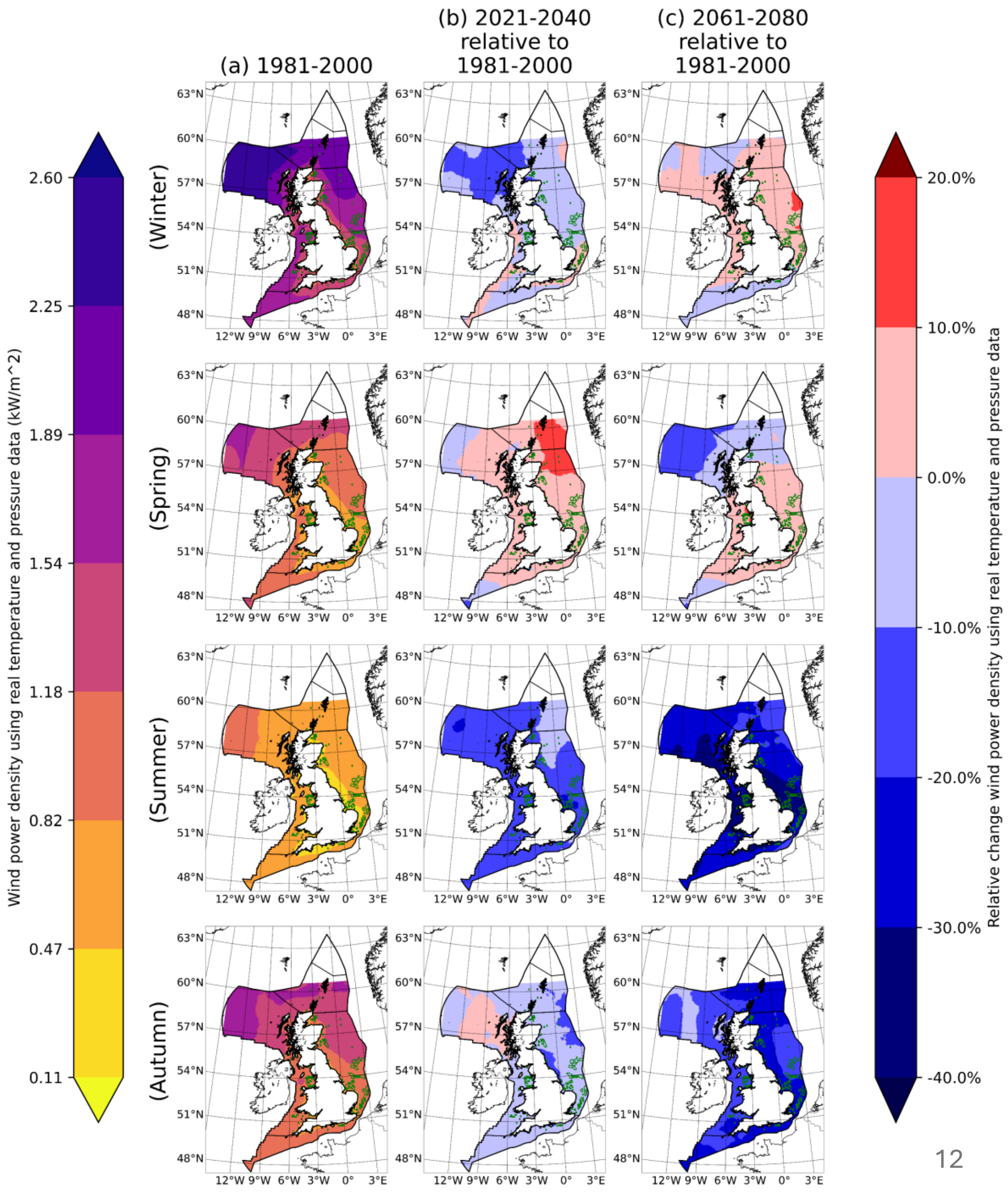
Seasonal variation



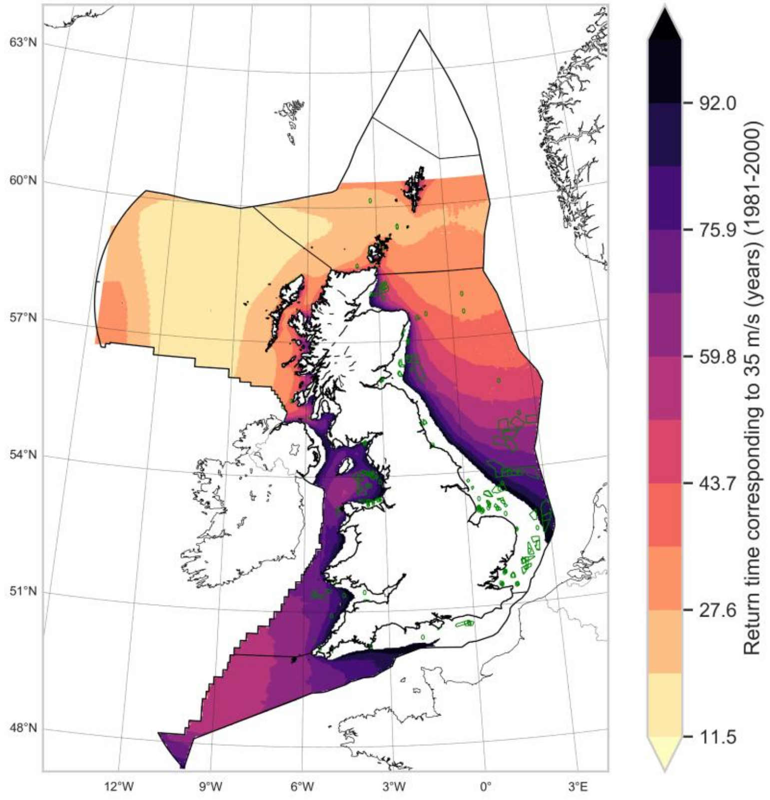
Capacity factor

Production: Regions 2 & 3

Seasonal Changes

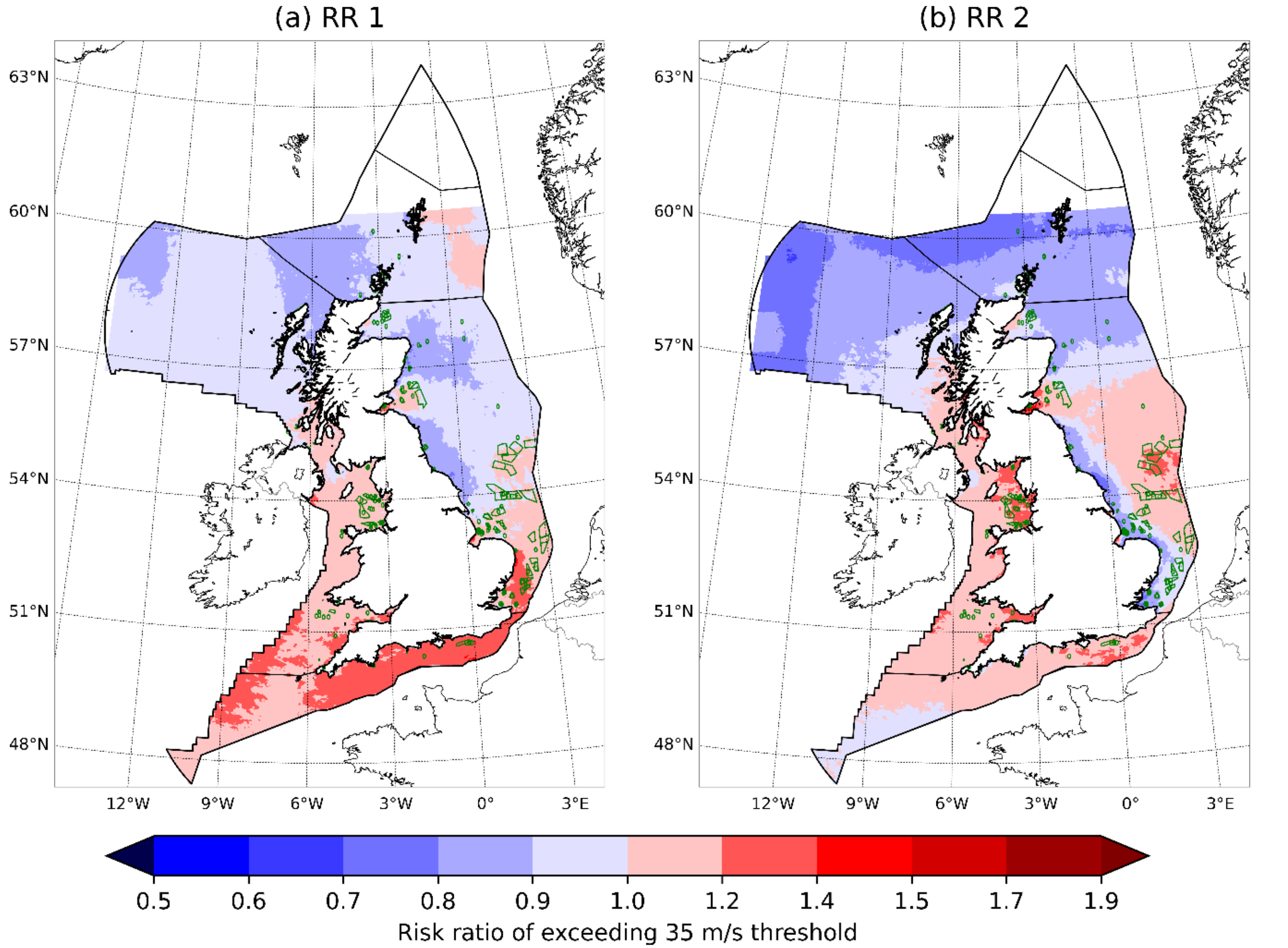


High Wind: Region 4



Current return time of hourly maximum wind gusts exceeding 35 m/s.

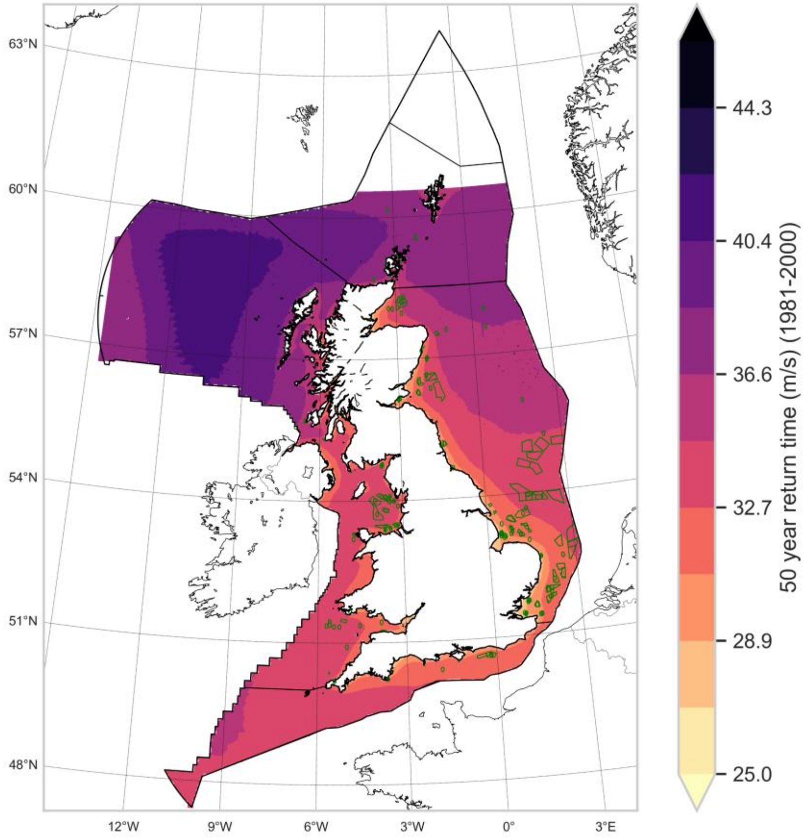
Risk in near future (2021-2040) Risk in far future (2041-2060)



Risk reduced

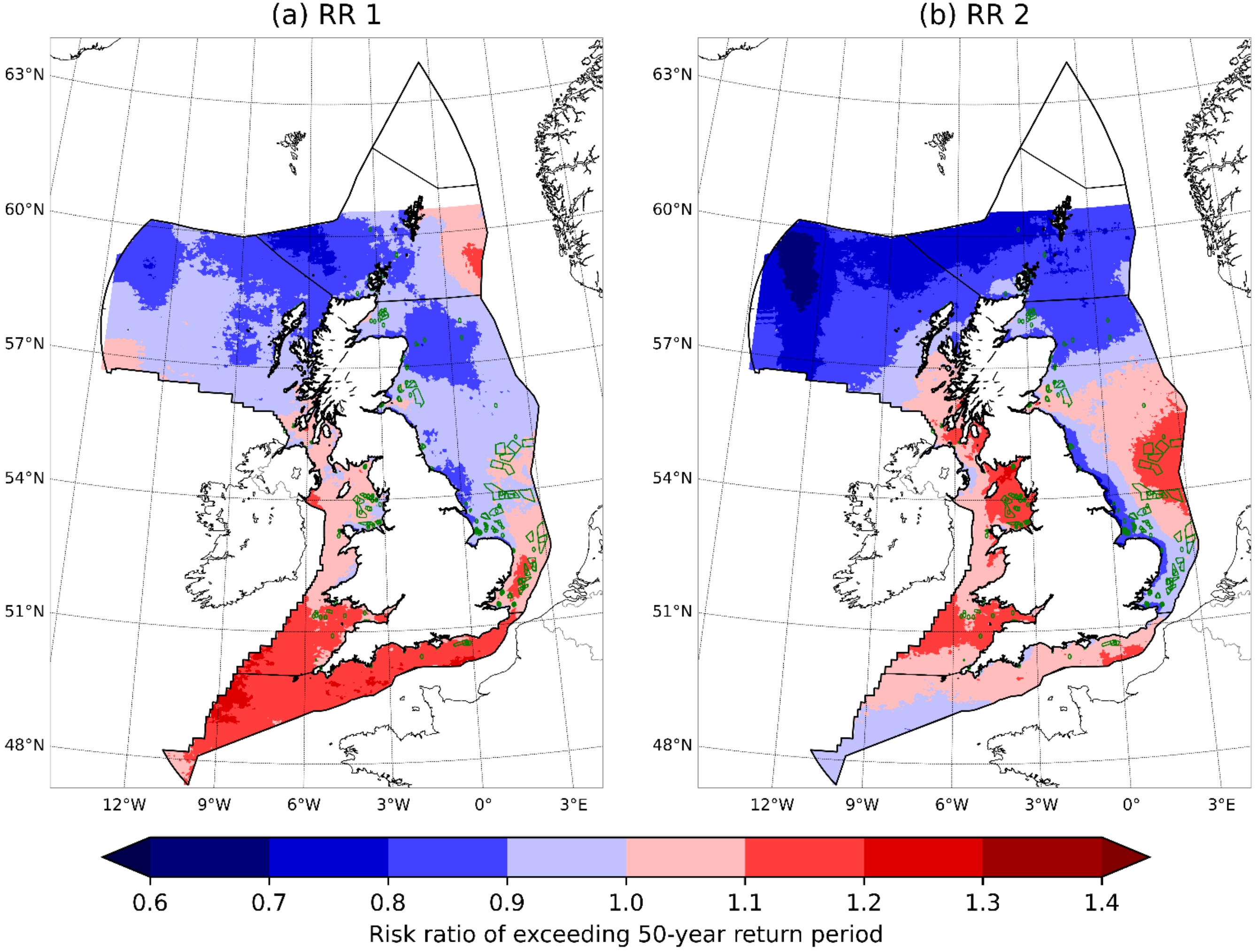
Risk increased

High Wind: Region 5



Current 50 year return period hourly maximum wind gust magnitude

Risk in near future (2021-2040) Risk in far future (2041-2060)

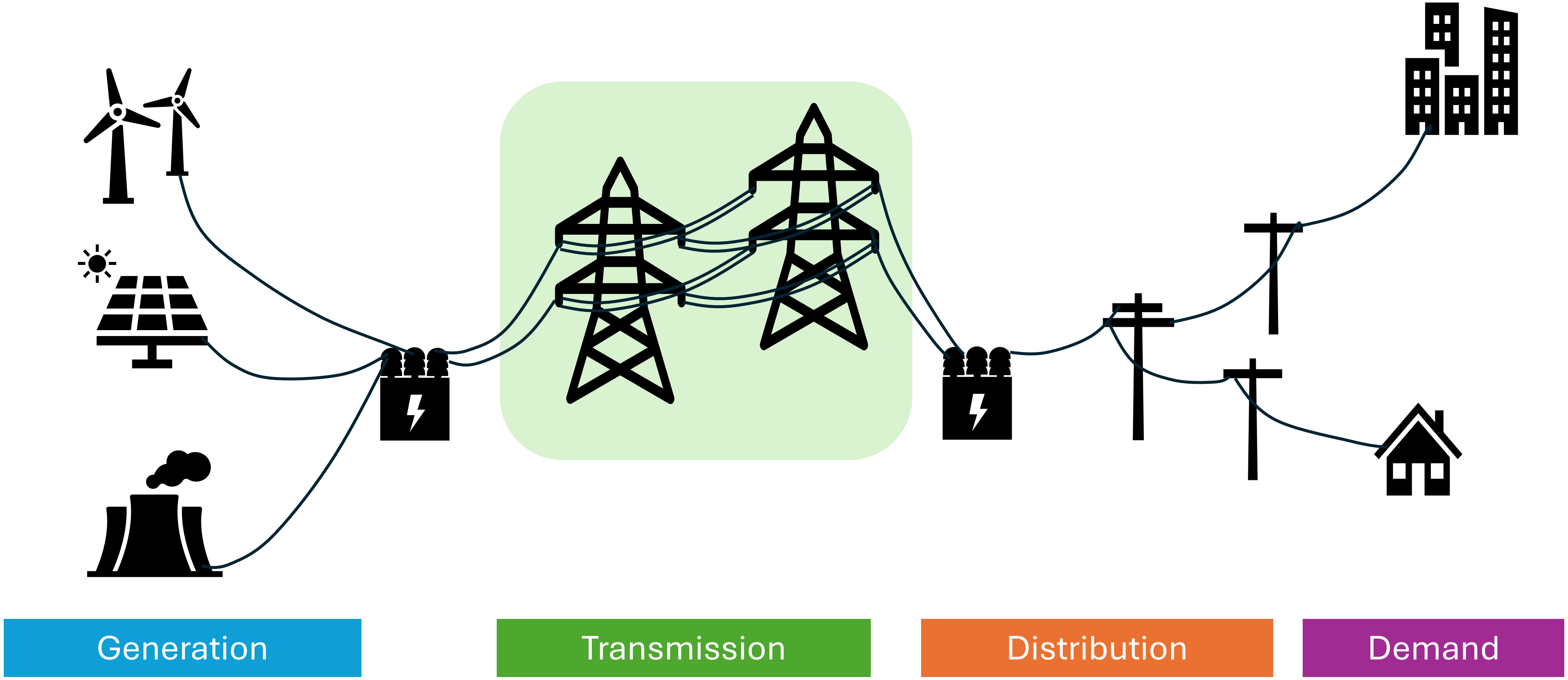


Risk reduced

Risk increased

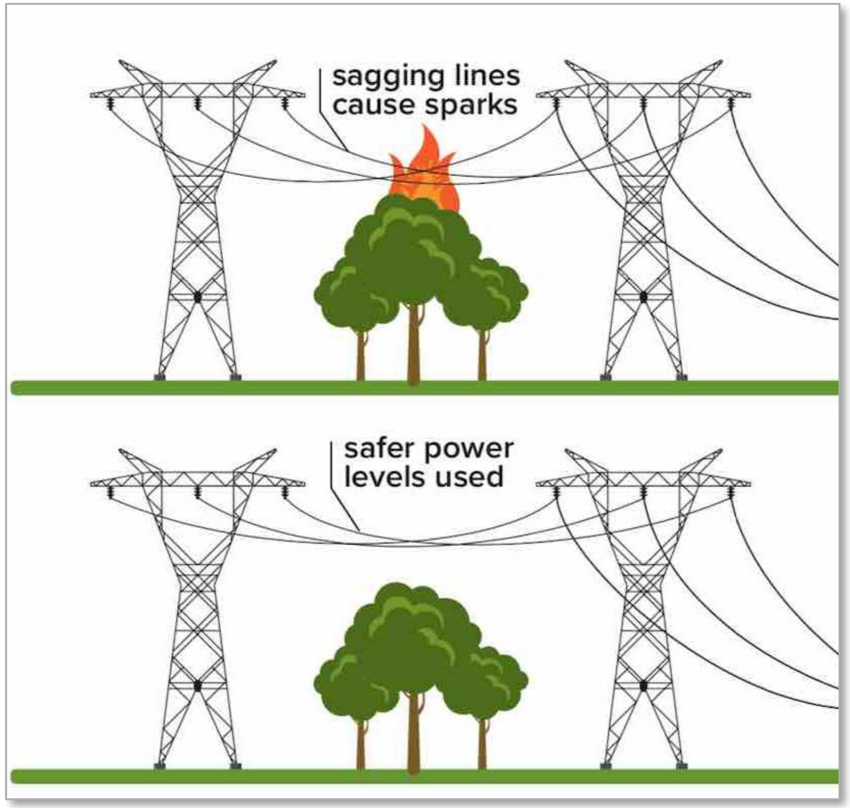
Transmission Example: Australian heatwaves

Eleanor McIndoe

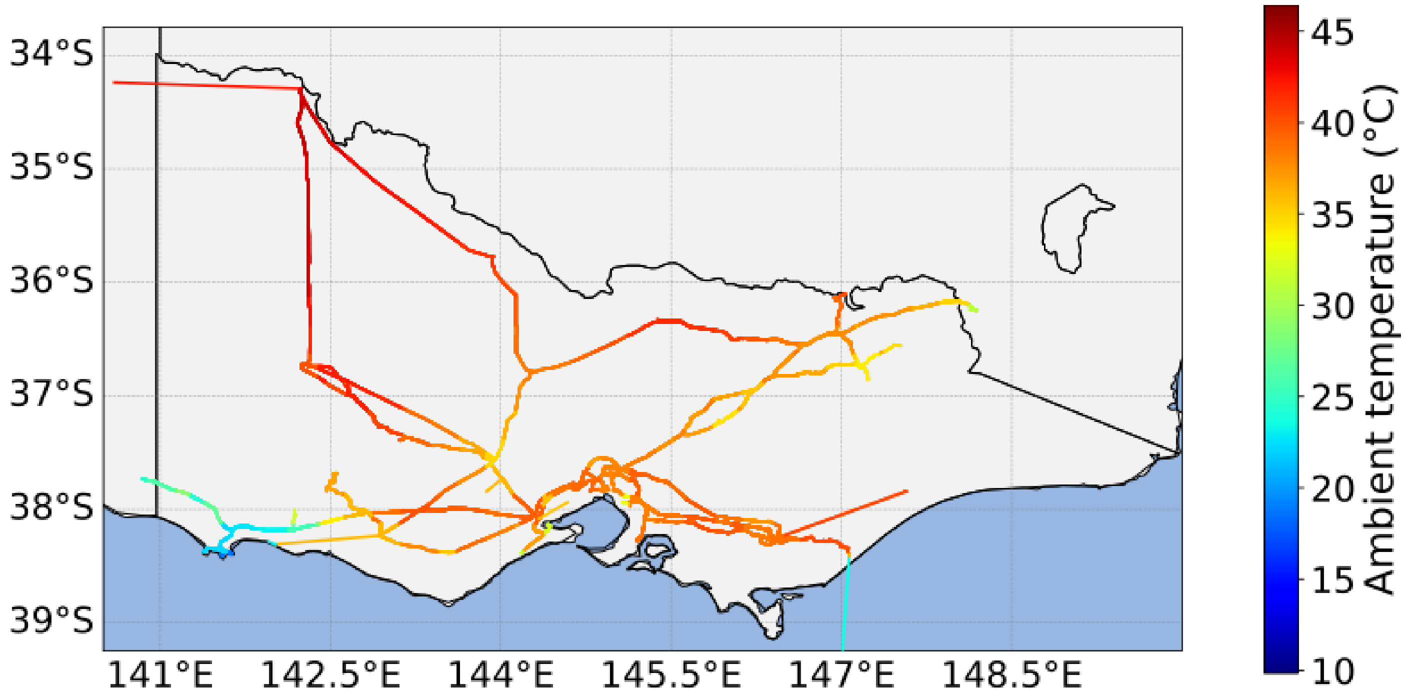


Extreme temperatures lower conductor transfer capacity

- High temperatures causes greater conductor sag, increased risk of flashover, and physical equipment damage
- Passing current through a conductor causes it to heat up, so operators reduce power transfer capacity during high temperature events to minimise risks
- Power lines are assigned static or dynamic temperature ratings indicating the maximum allowable current for safe operation

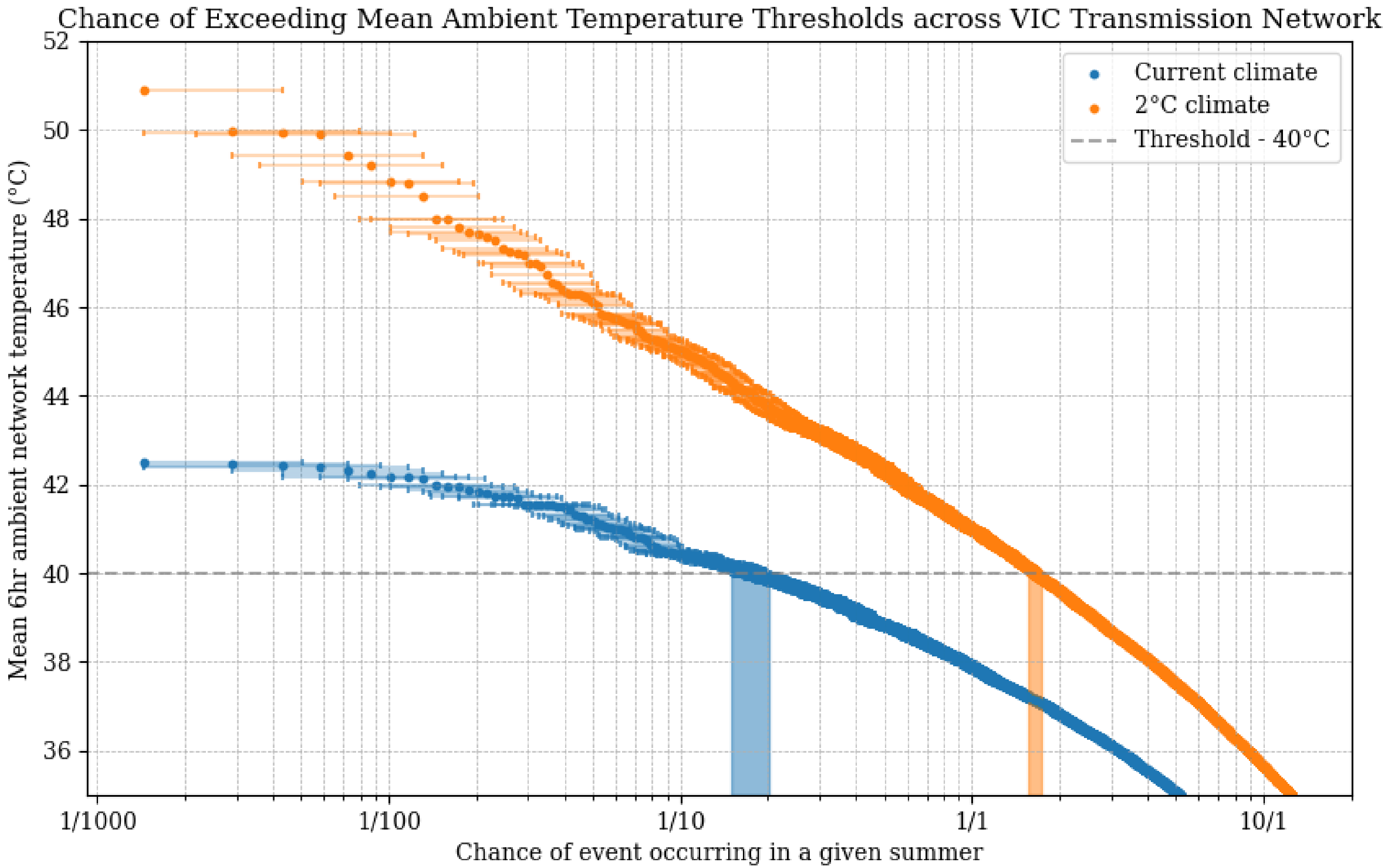


Event Definition: Transmission



Event scale	Event severity threshold
• Mean 6-hourly ambient temperature averaged over area covered by transmission network	• Static ratings: 35°C and 40°C • Dynamic ratings: 28°C and 24°C

Transmission risks

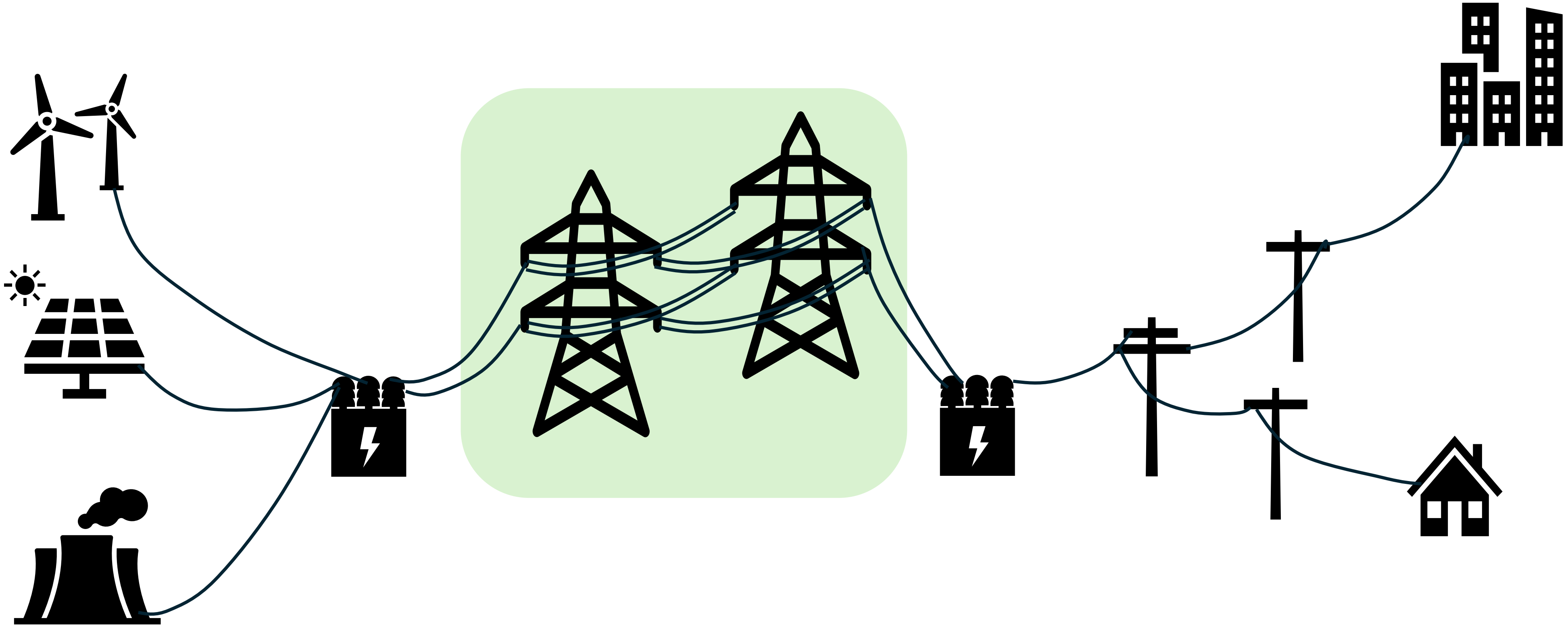


Probability Ratio

9.45 (+1.95/-1.38)

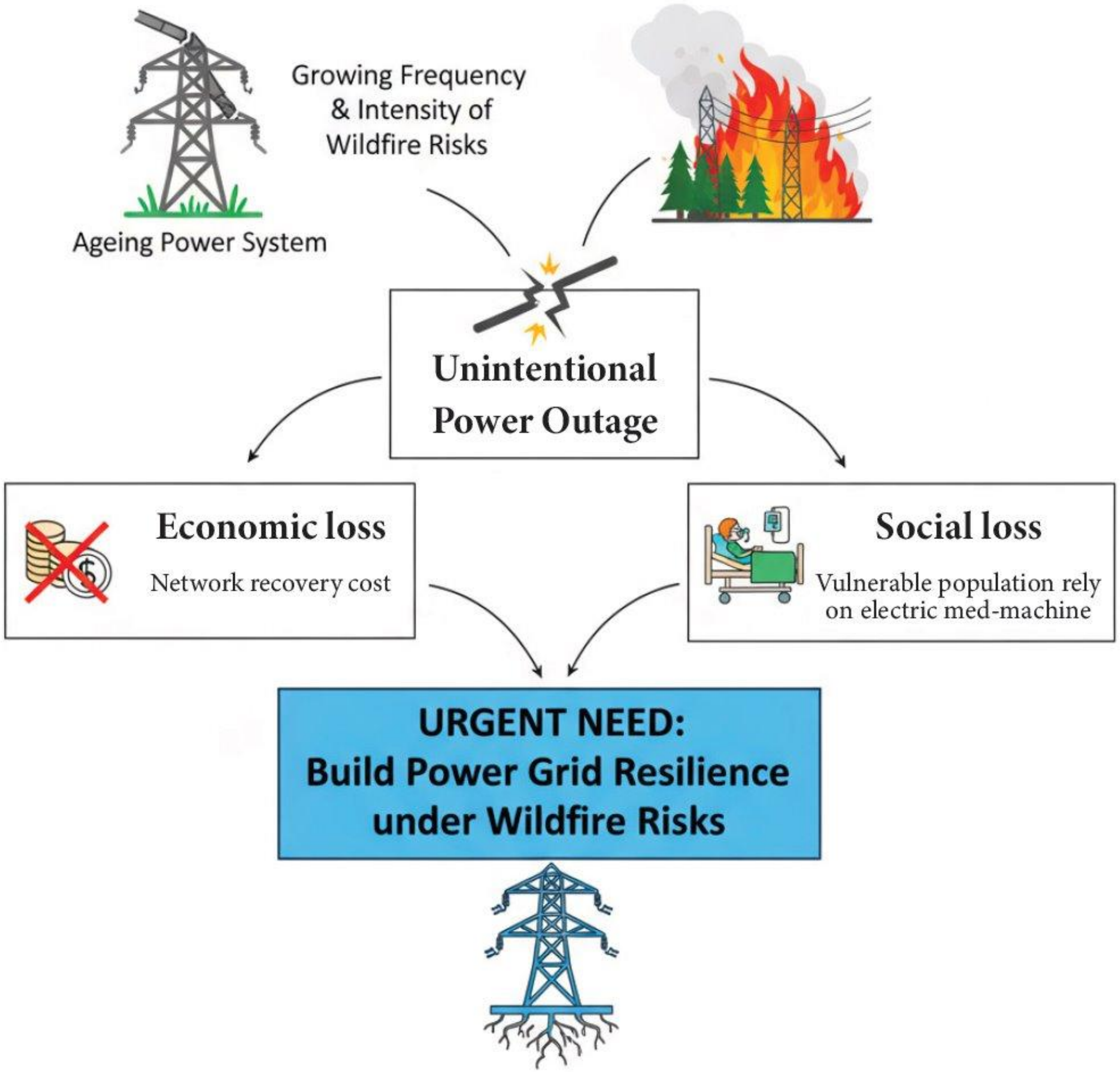
Transmission Example: Australian wildfires

Weijia Yang

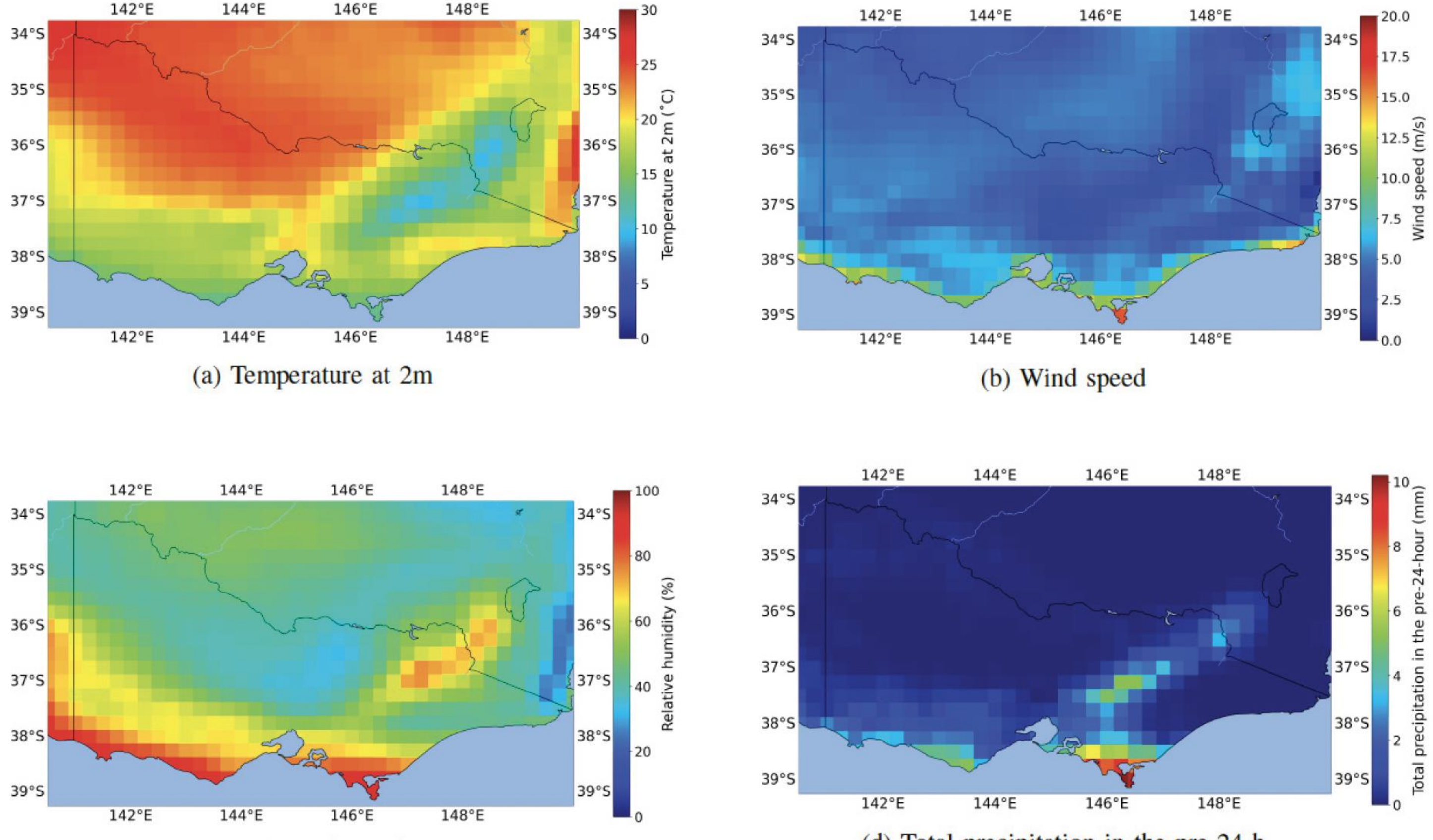


Generation | Transmission | Distribution | Demand

How can we model and enhance power system resilience under extreme wildfire risks?



Using FWI with Power System Model

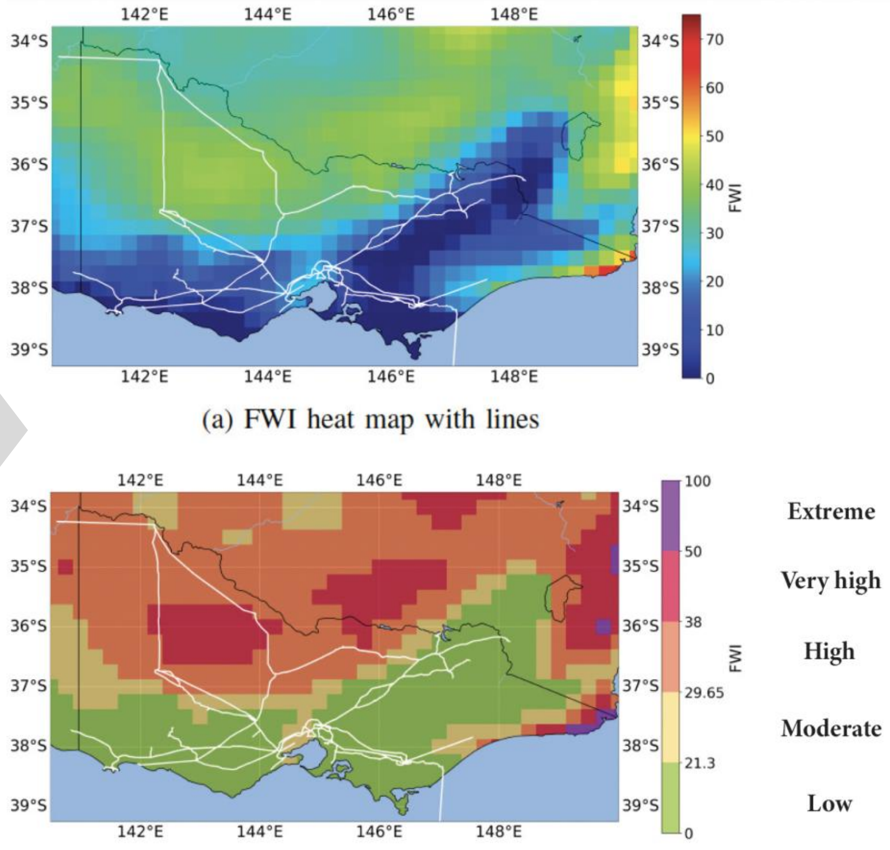


(a) Temperature at 2m

(b) Wind speed

(c) Relative humidity

(d) Total precipitation in the pre-24-h



(a) FWI heat map with lines

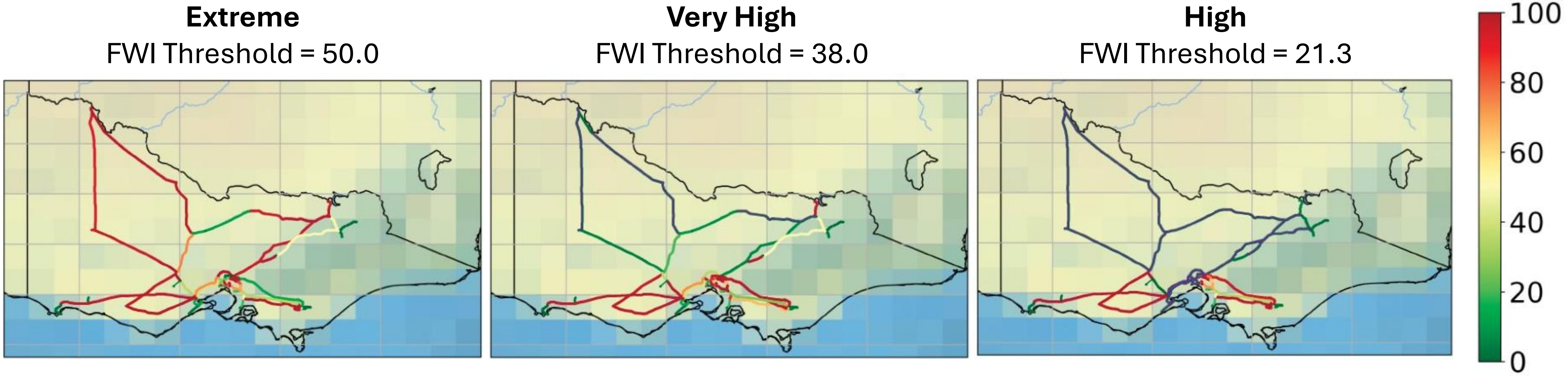
(b) FWI risk levels with lines

Power System Model: Line loading

Extreme
FWI Threshold = 50.0

Very High
FWI Threshold = 38.0

High
FWI Threshold = 21.3



0/122 lines pre-disconnected

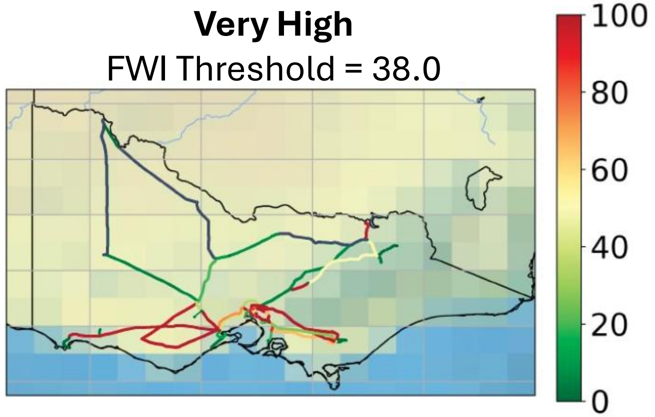
5/122 lines pre-disconnected

36/122 lines pre-disconnected

Dark purple = lines pre-disconnected due to the violation of the preset FWI risk thresholds

Grid operational cost and carbon emissions increase

Additional wind generation



5/122 lines pre-disconnected

Renewable wind distributed generation are deployed at vulnerable nodes to recover the 15.32% load shed.

➢ Lower carbon emission, but higher operational cost

Scenarios	TS_{cost} $AU\$$	Load shed MWh	VoLL $AU\$$	SO_{cost} $AU\$$
1.b	290,825	700	10,490,370	10,781,195
2.a	829,114	0	0	829,114

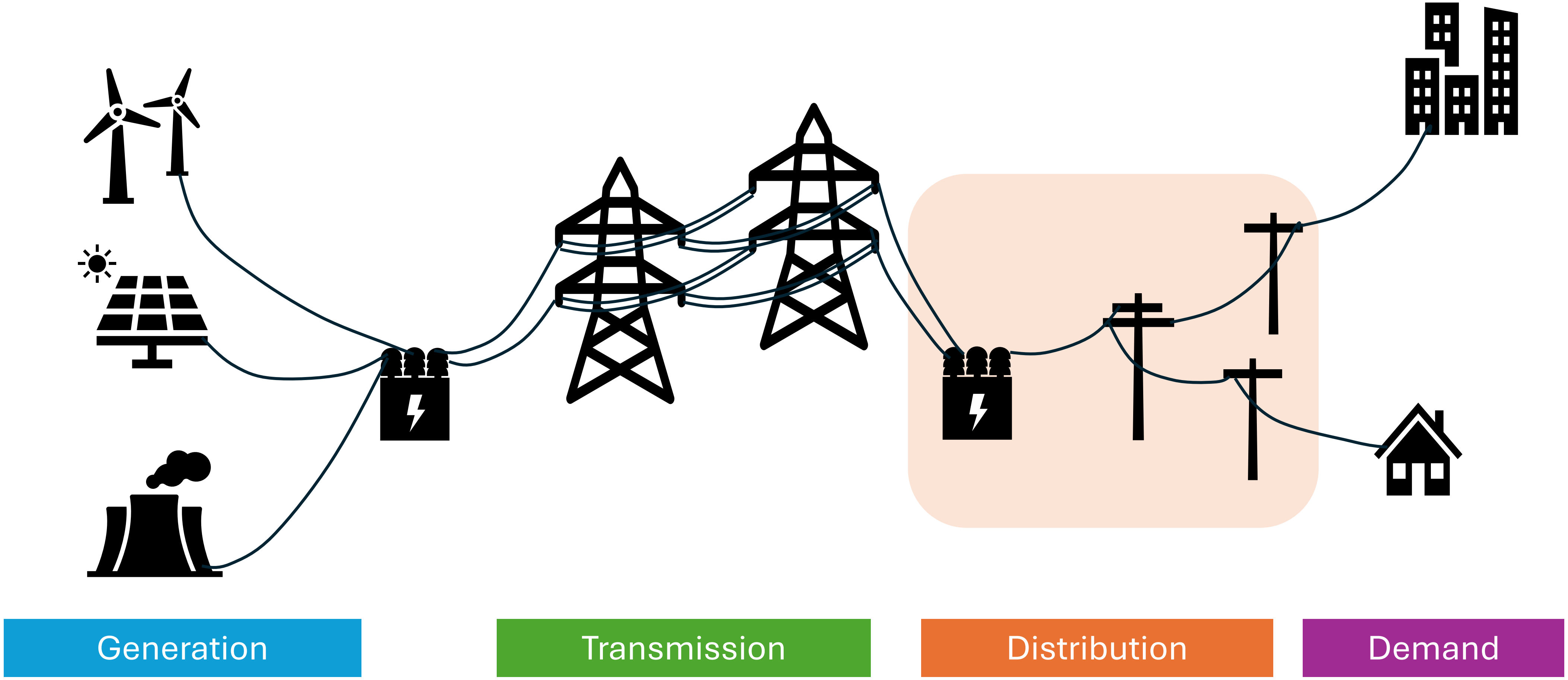
The overall system cost is reduced significantly after we consider the VoLL.

Value of Lost Load (VoLL) represents the economic and social cost associated with unserved energy, reflecting losses incurred by disconnected customers.

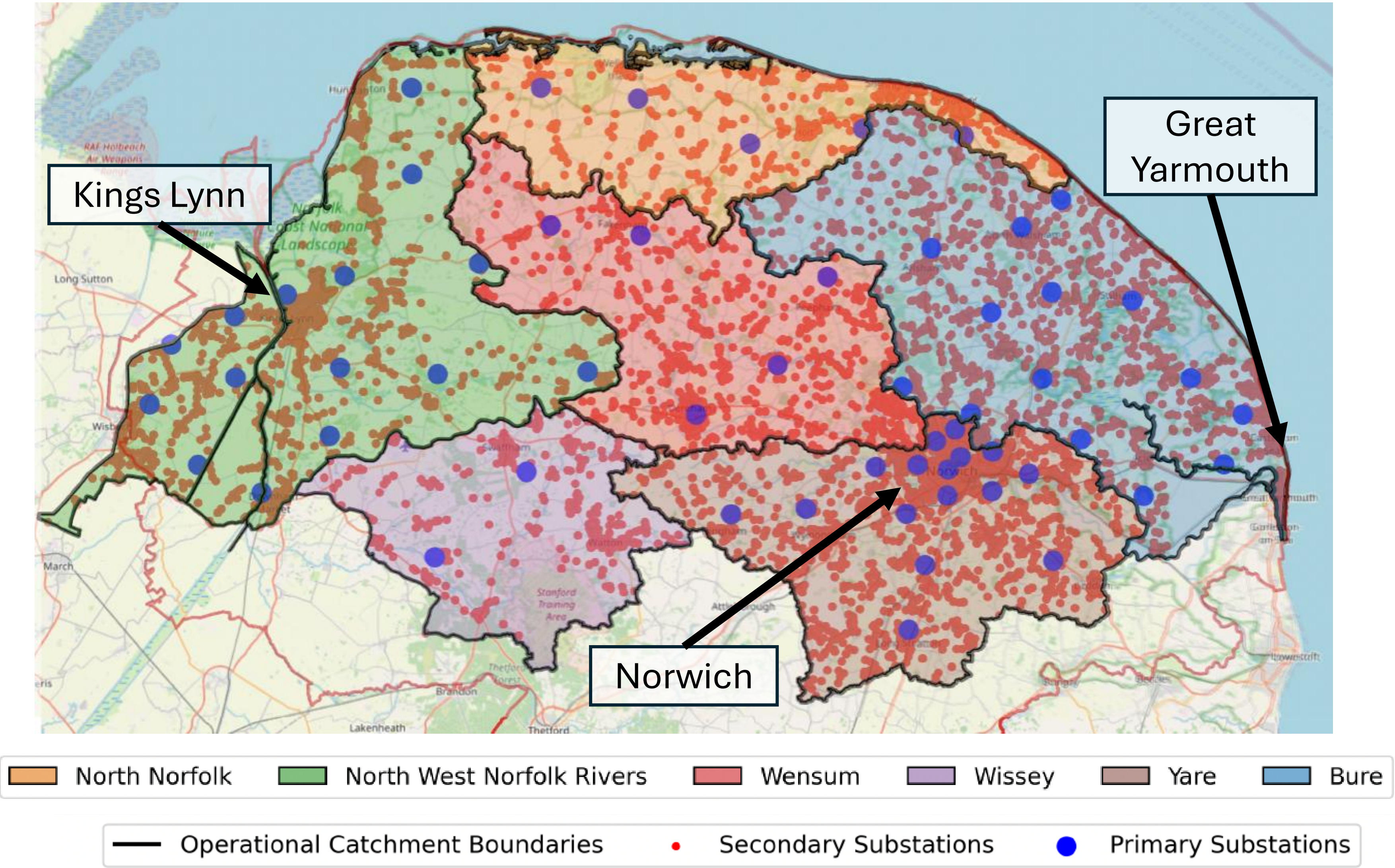
Can calculate the breakeven value for renewable wind distributed generation deployment for grid planning

Distribution Example: Substation flooding

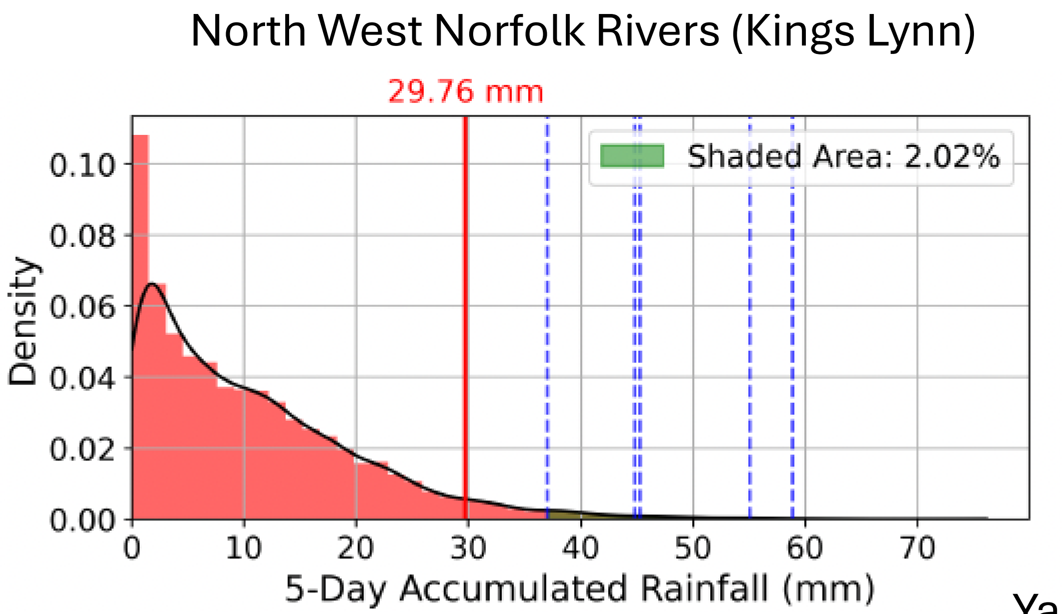
Dermot Leggett

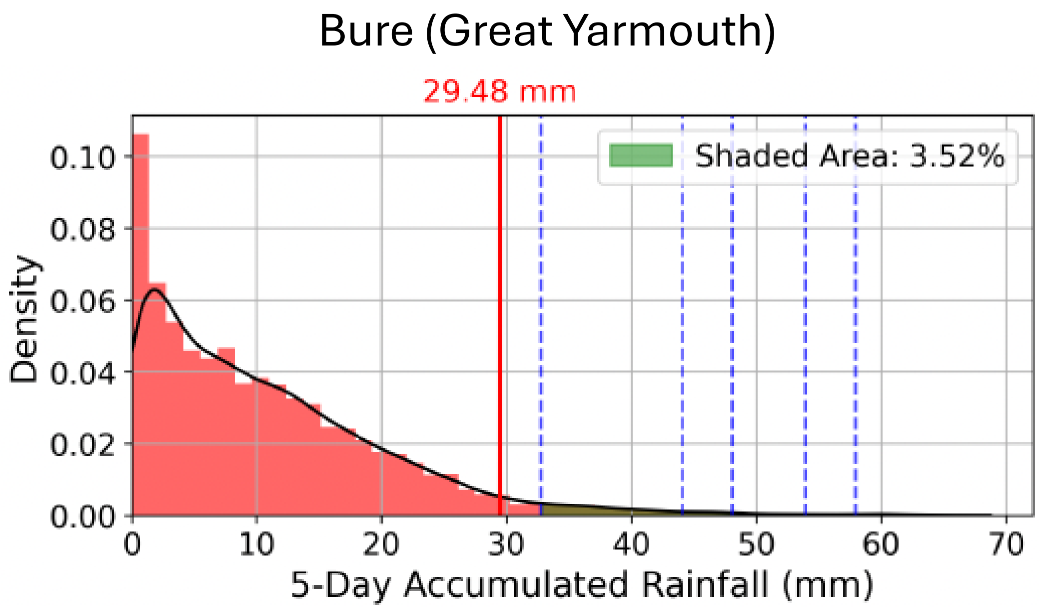


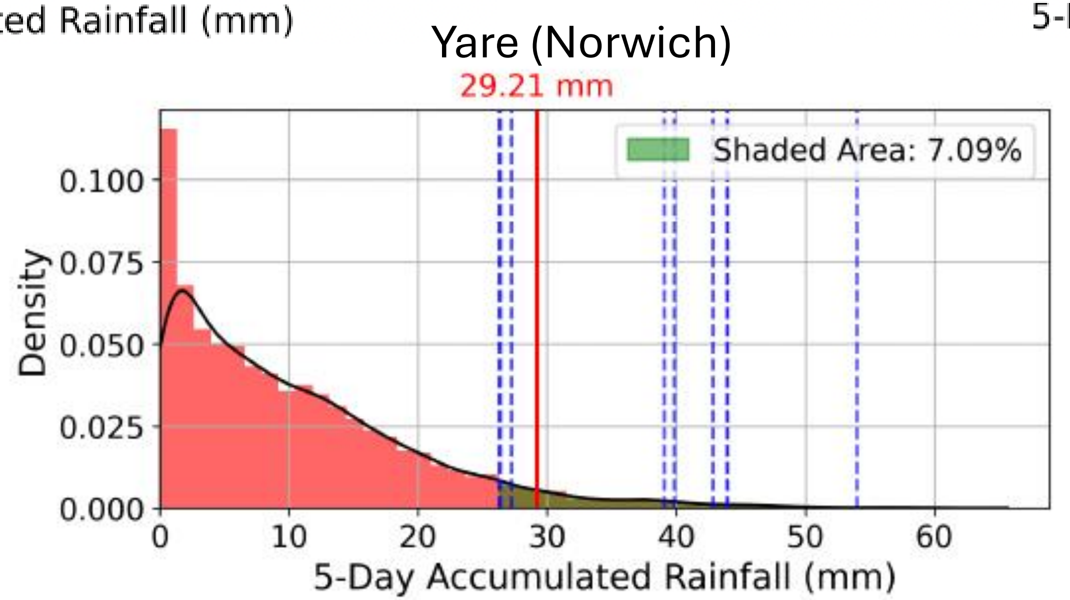
Norfolk substations and river catchments

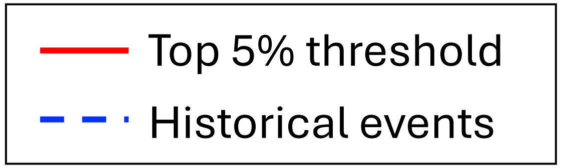


Rainfall Thresholds







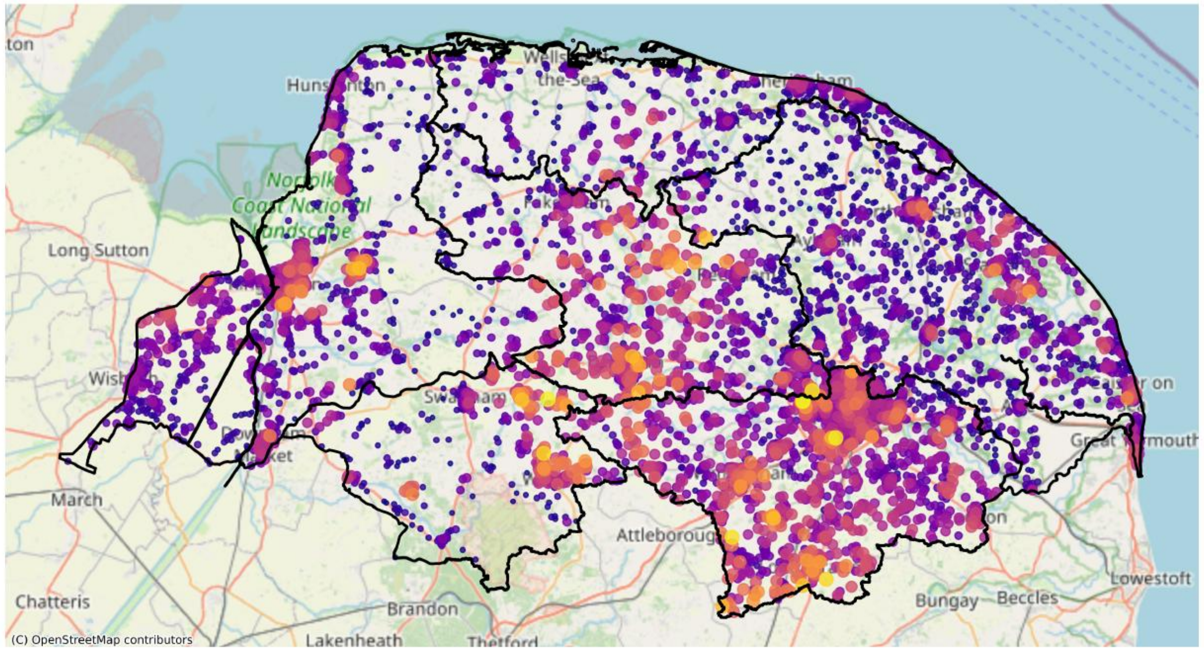


Additional risk factors

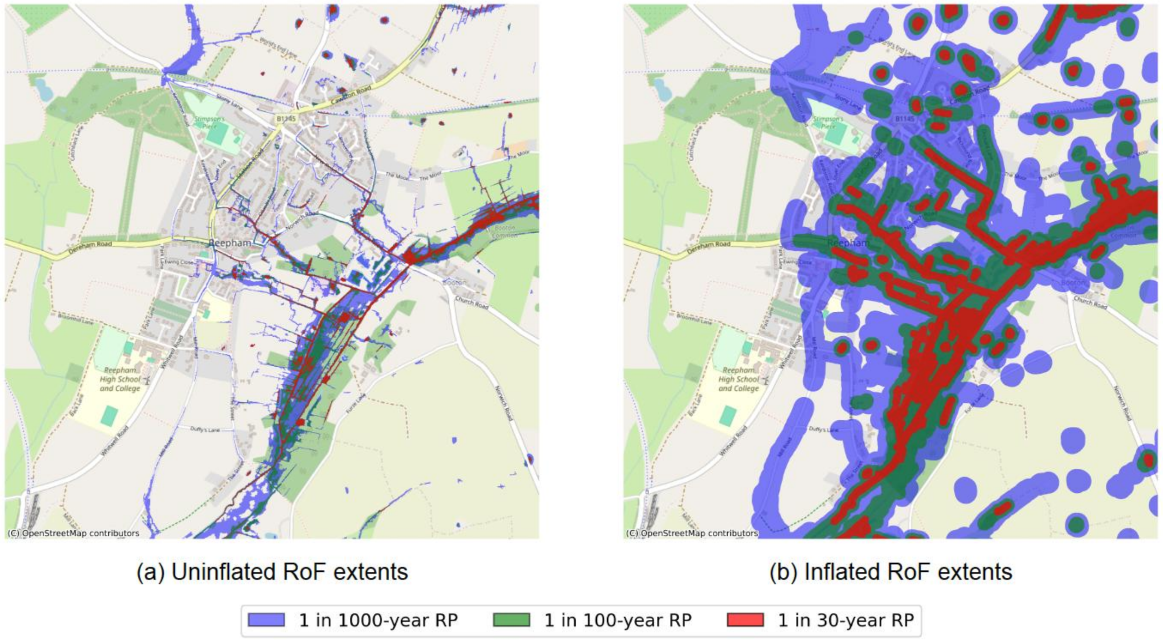
UK Power Networks Severity Indicators:

- Number of transformers on site
- Customer count
- Indoor/Outdoor substation

Difficulty to access (proximity to road)



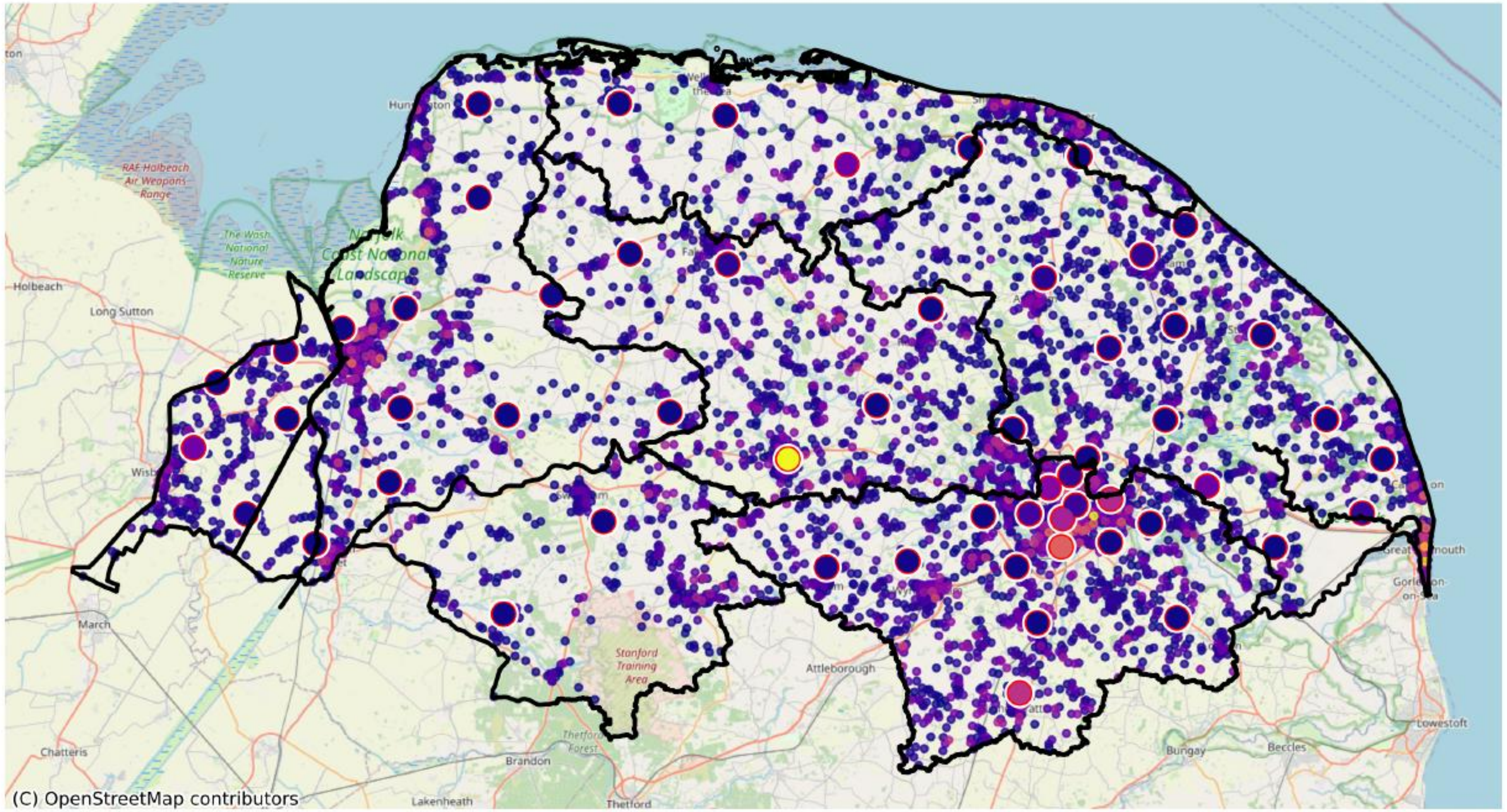
Environment Agency Flood Risk

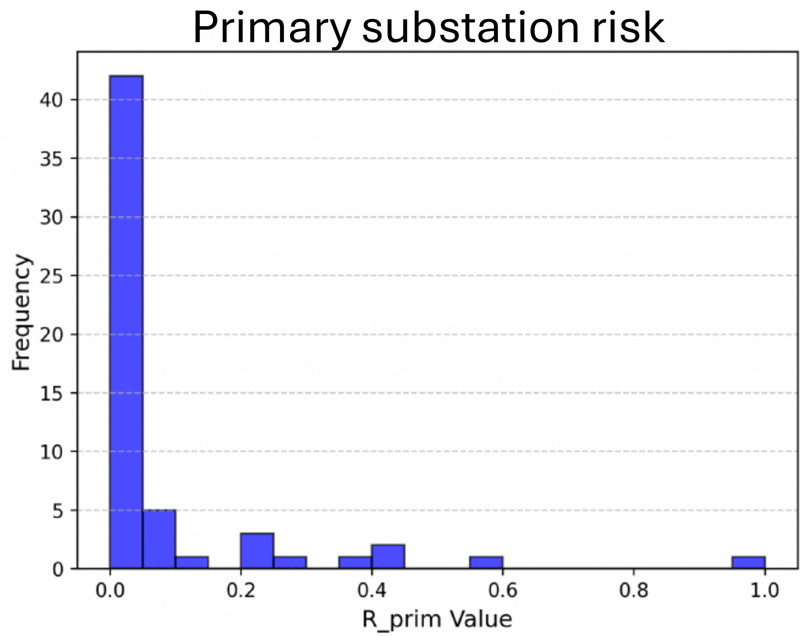


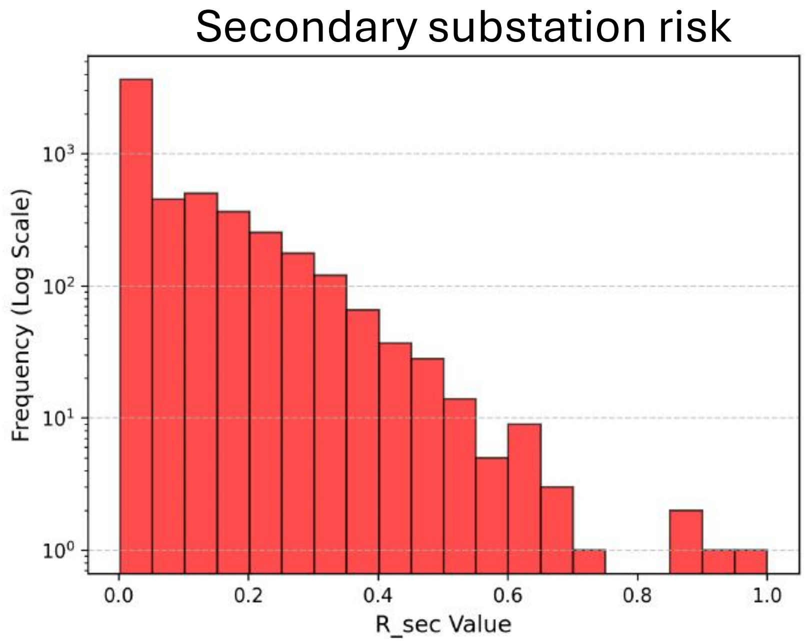
(a) Uninflated RoF extents

(b) Inflated RoF extents

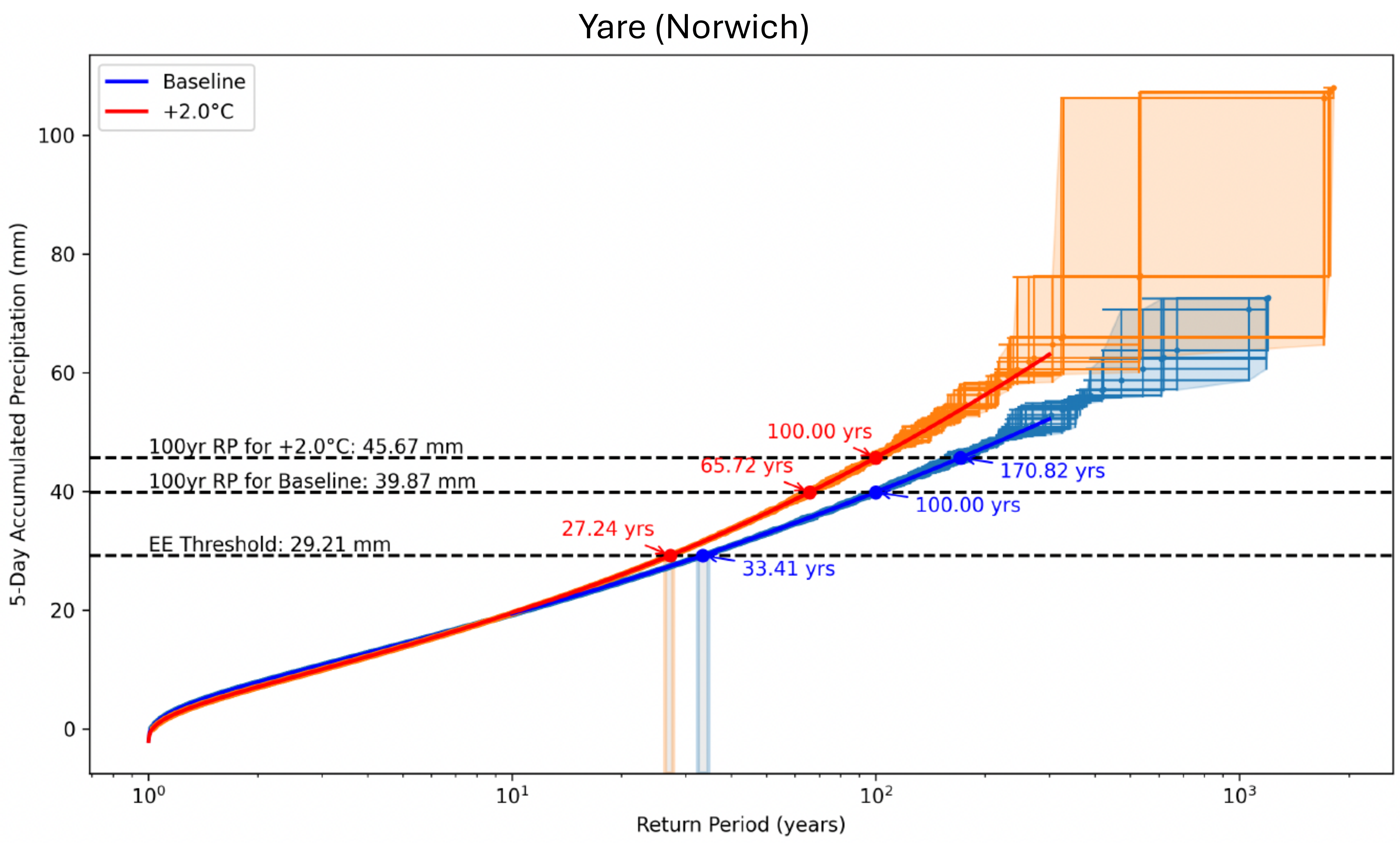
Normalised risk factor



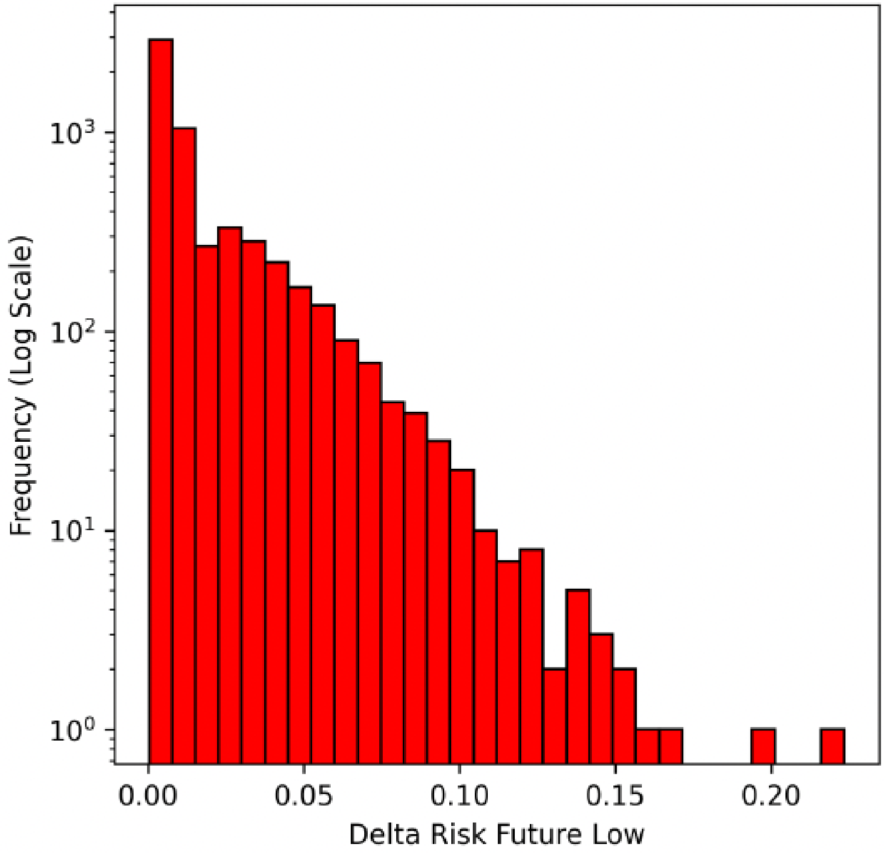




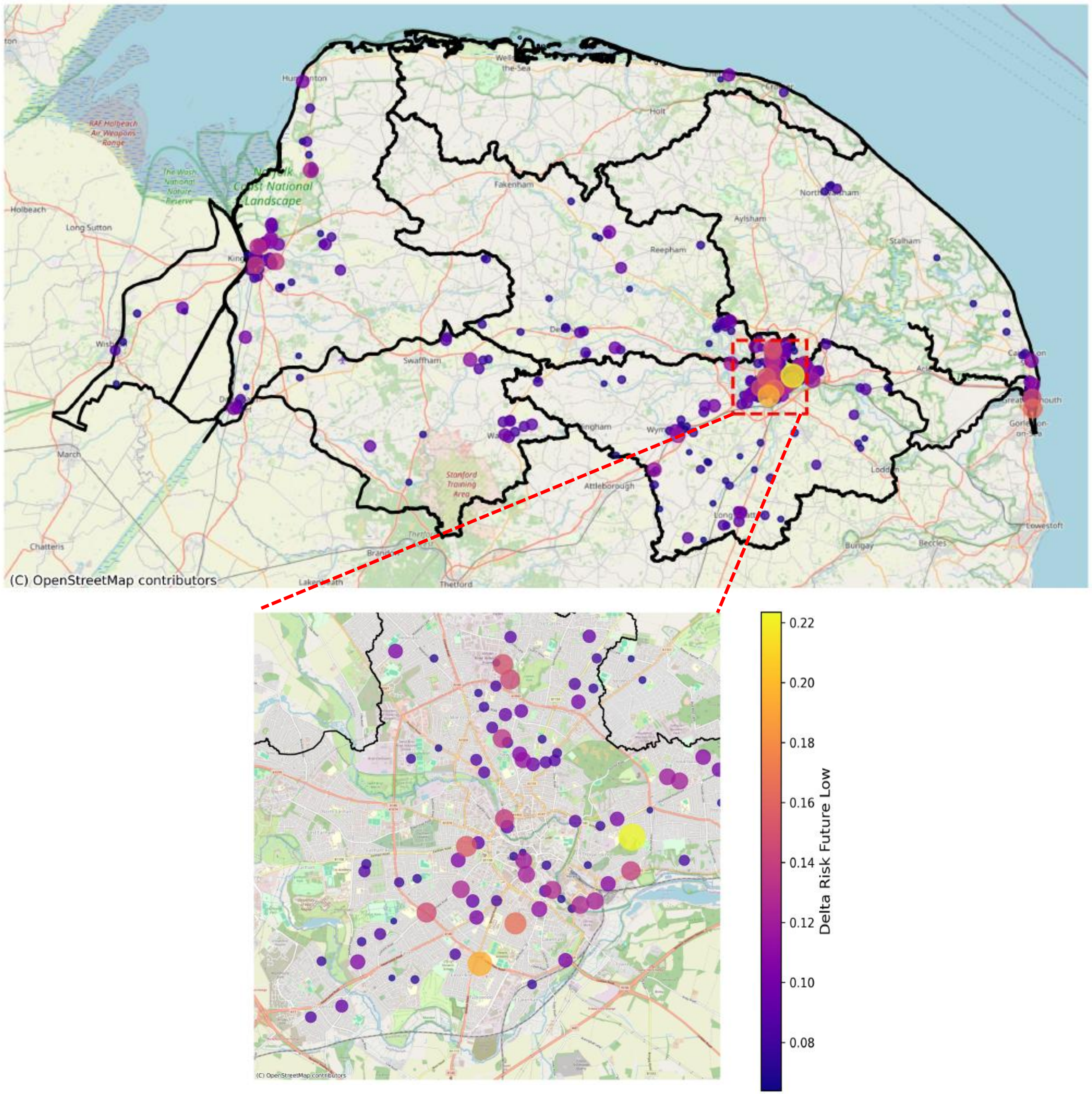
Projected Climate Change Impact



Change in risk under future climate

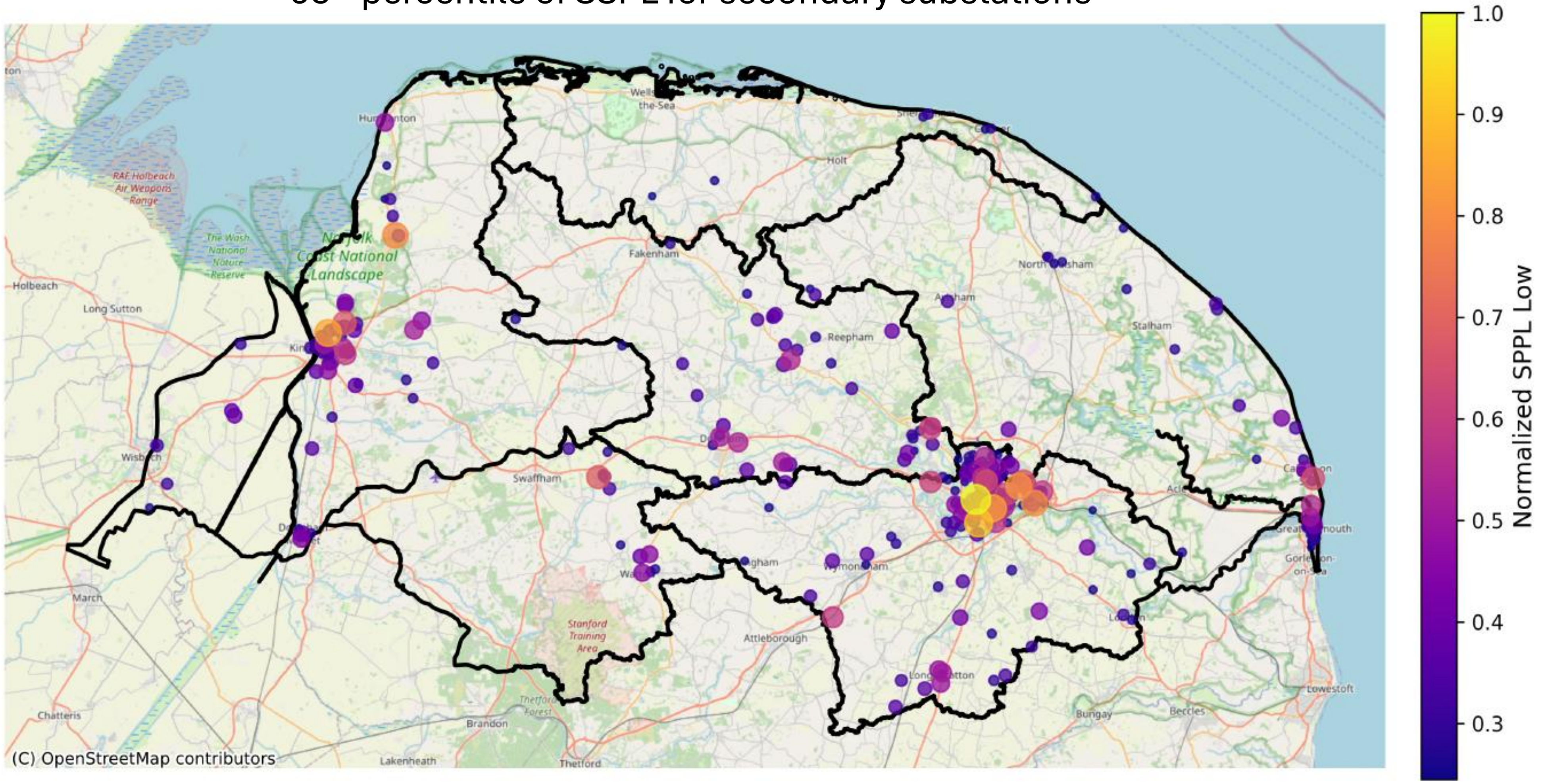


95th percentile of change in risk



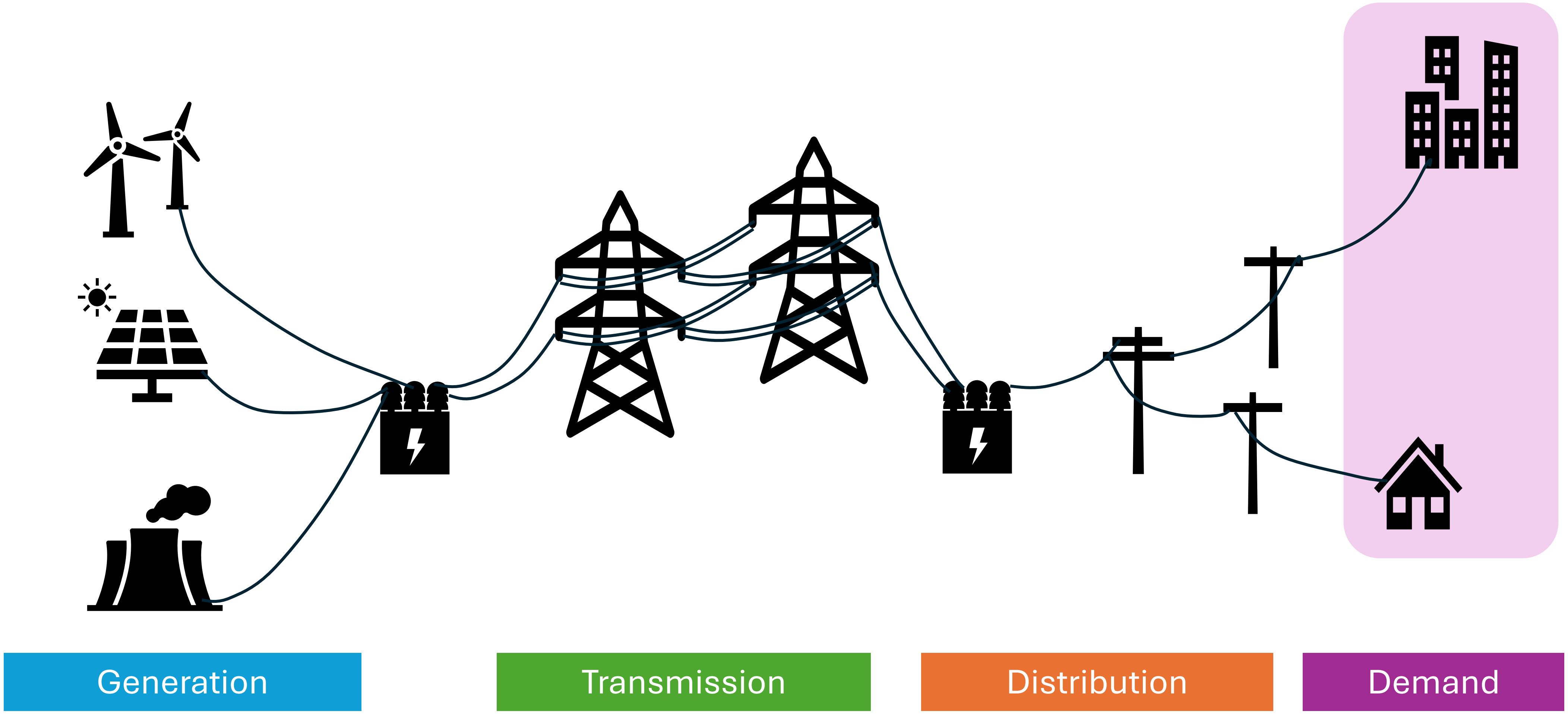
Substation protection priority list (SSPL)

95th percentile of SSPL for secondary substations

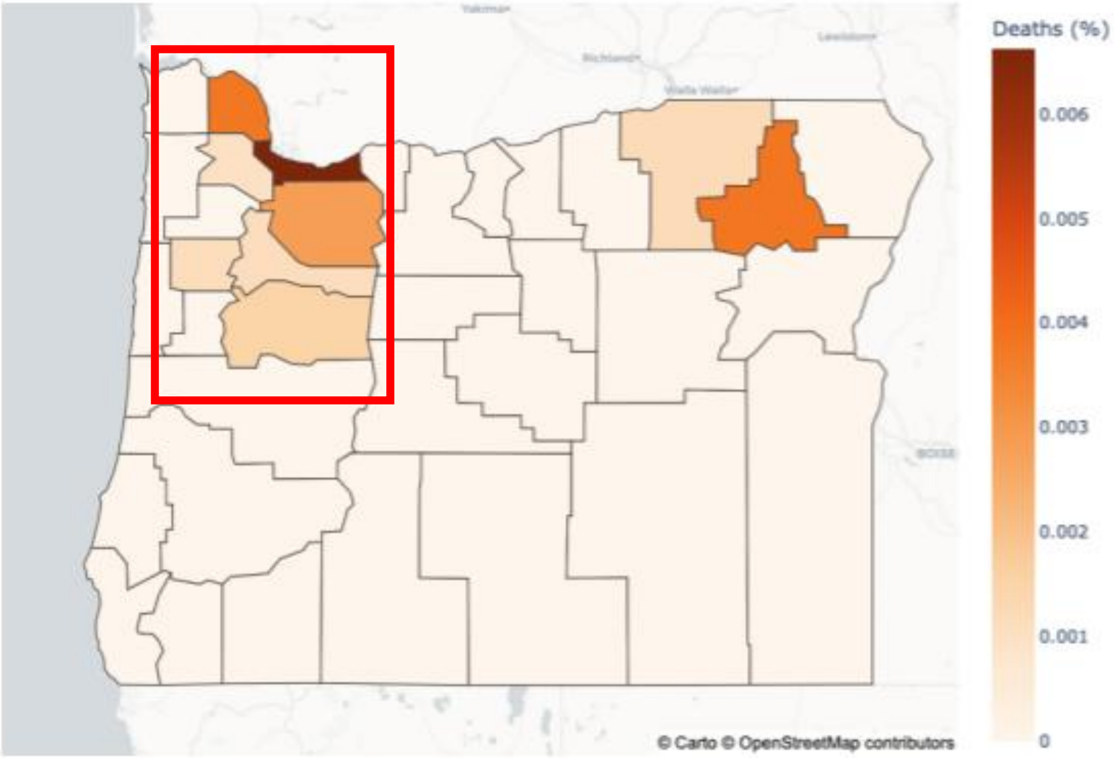


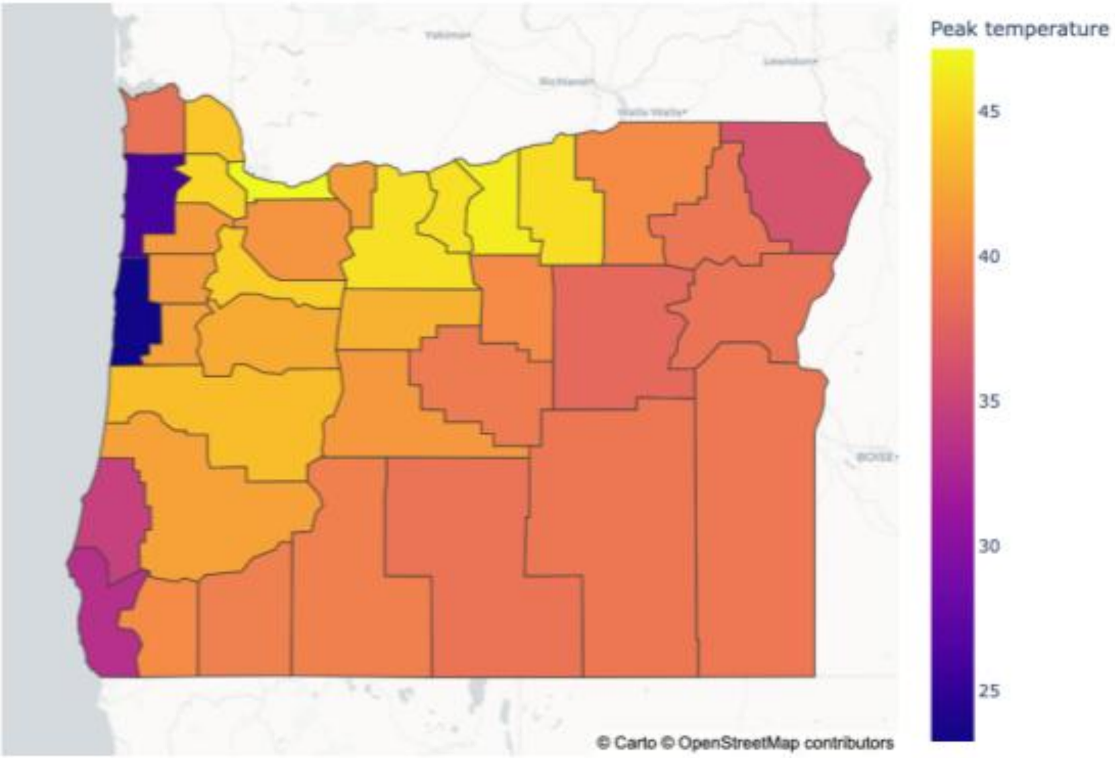
Demand Example: Cooling requirements

Aubrey Taylor, Natalie Sauter, Nicole Miranda, Jesus Lizana



2021 Heat Dome in the Pacific Northwest





Credit: Aubrey Taylor

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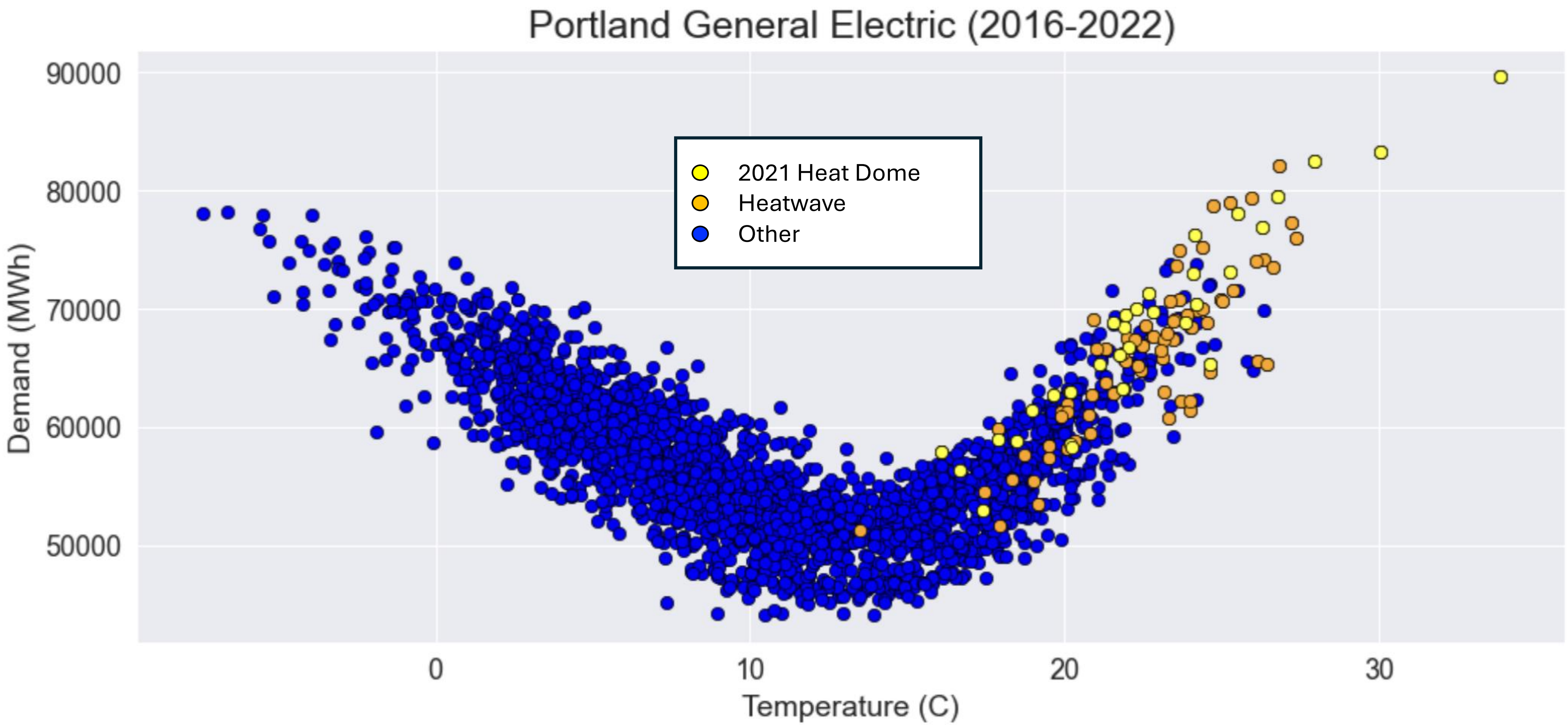
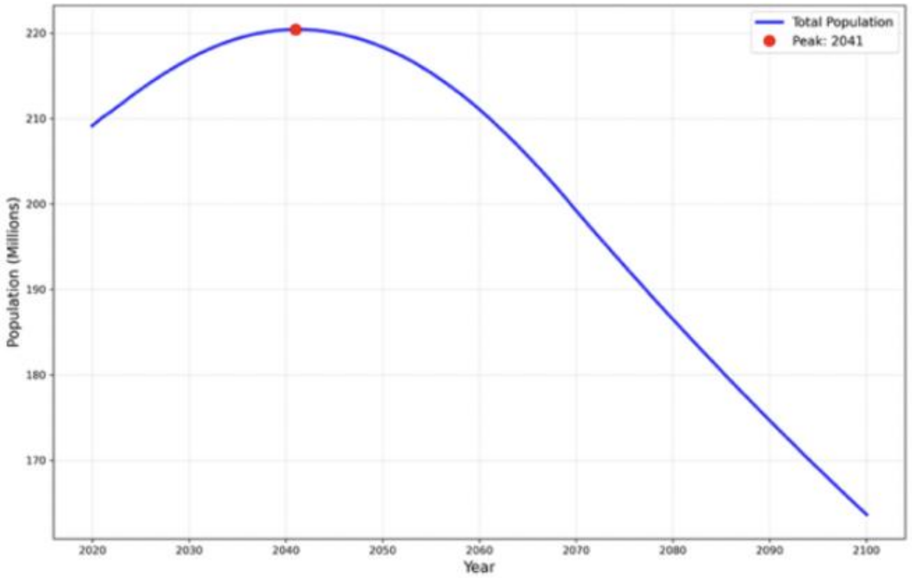
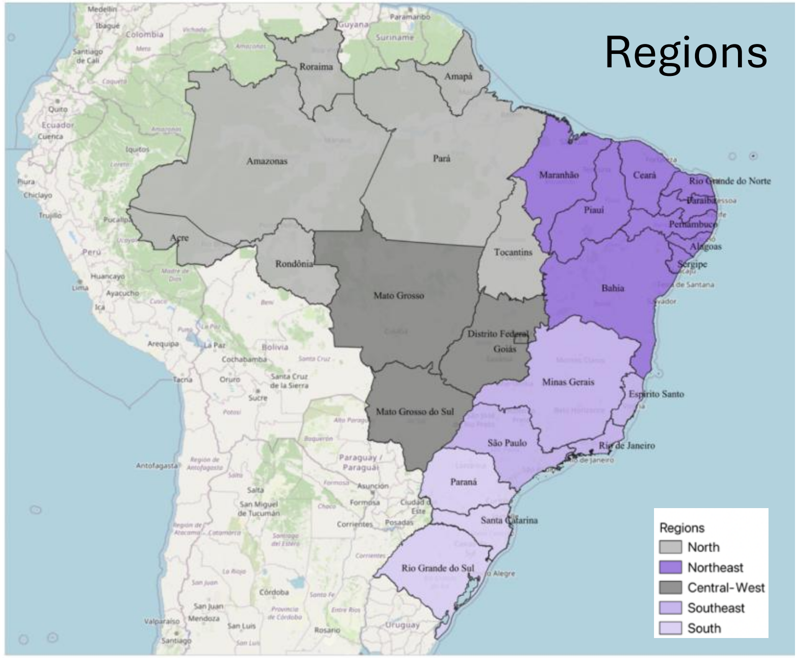
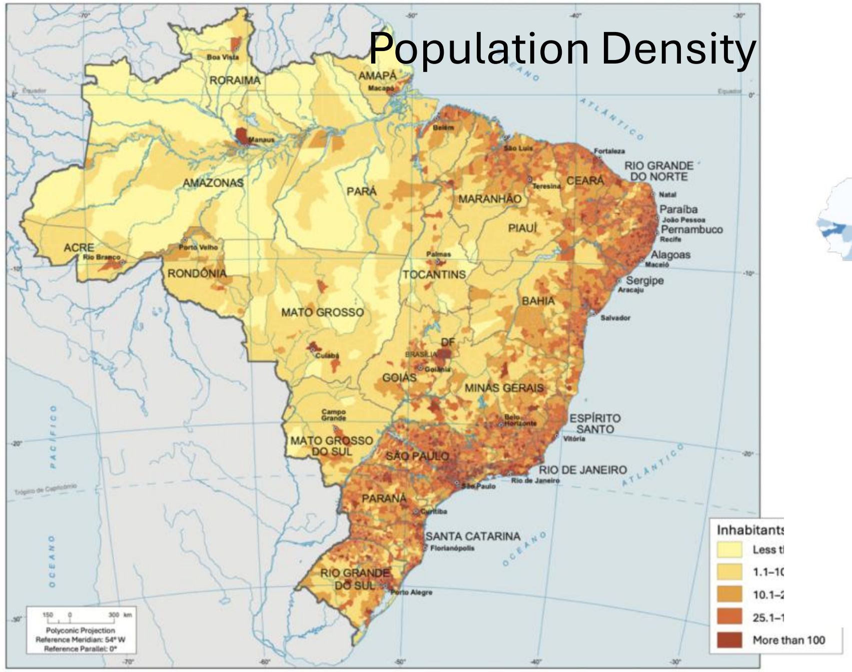


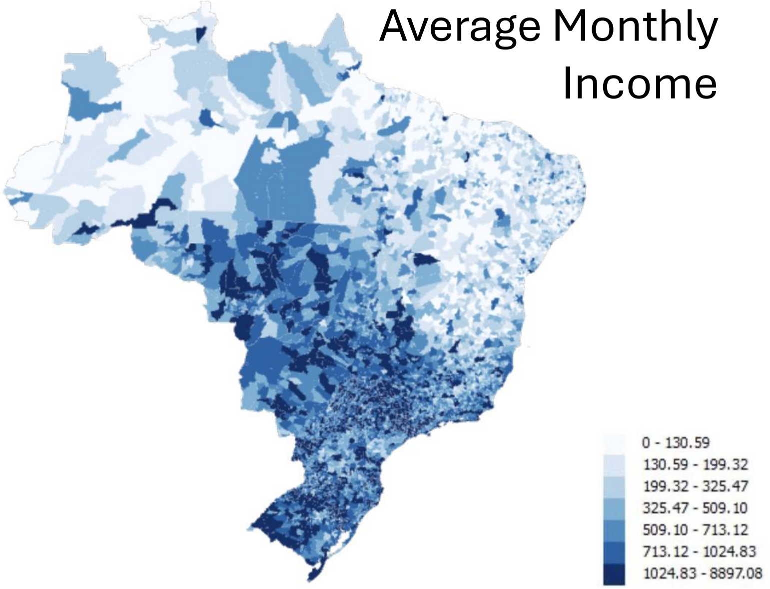
Credit: Aubrey Taylor

Brazil Heatwaves and Energy Demand Projections









Credit: Natalie Sauter

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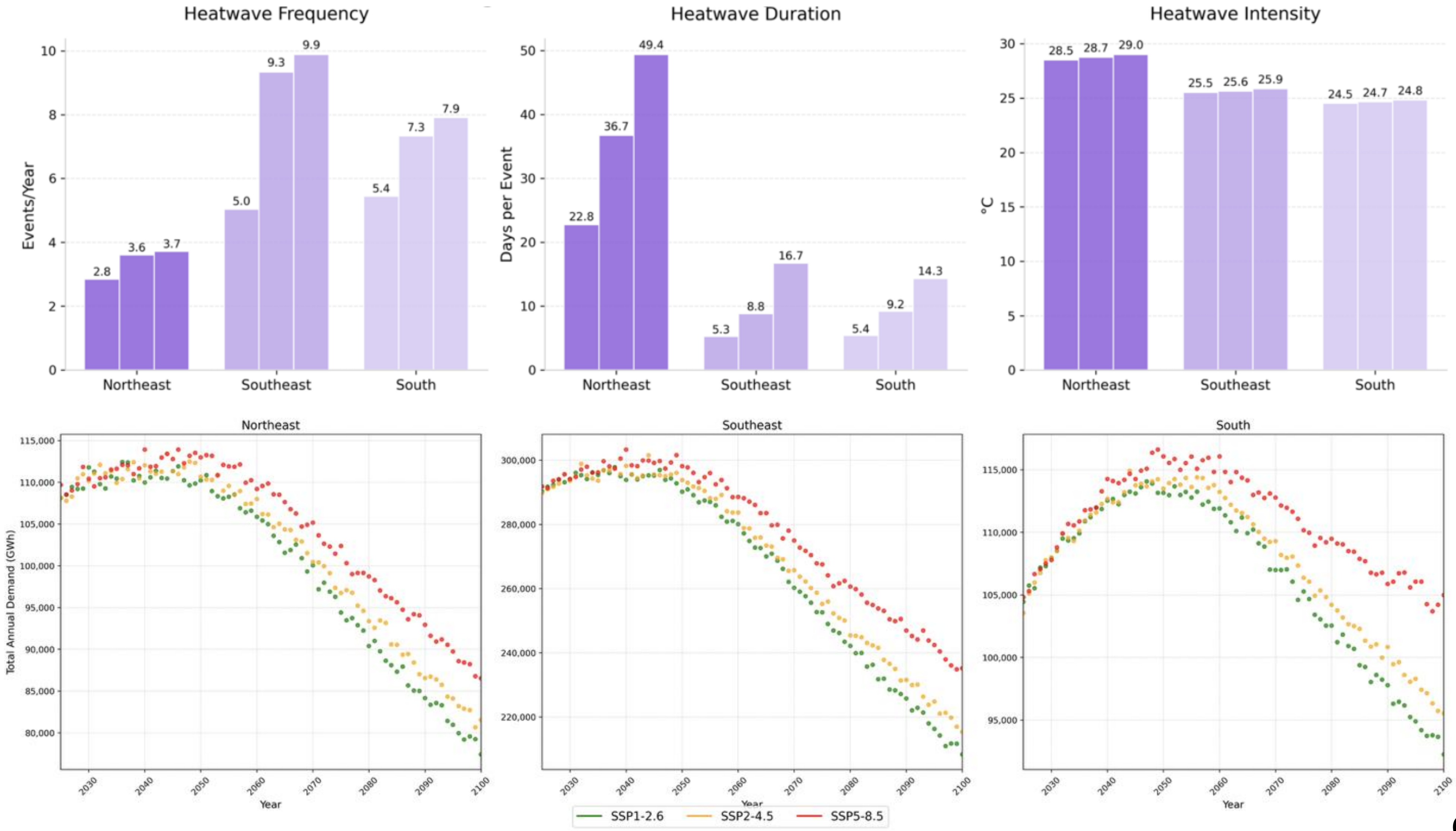


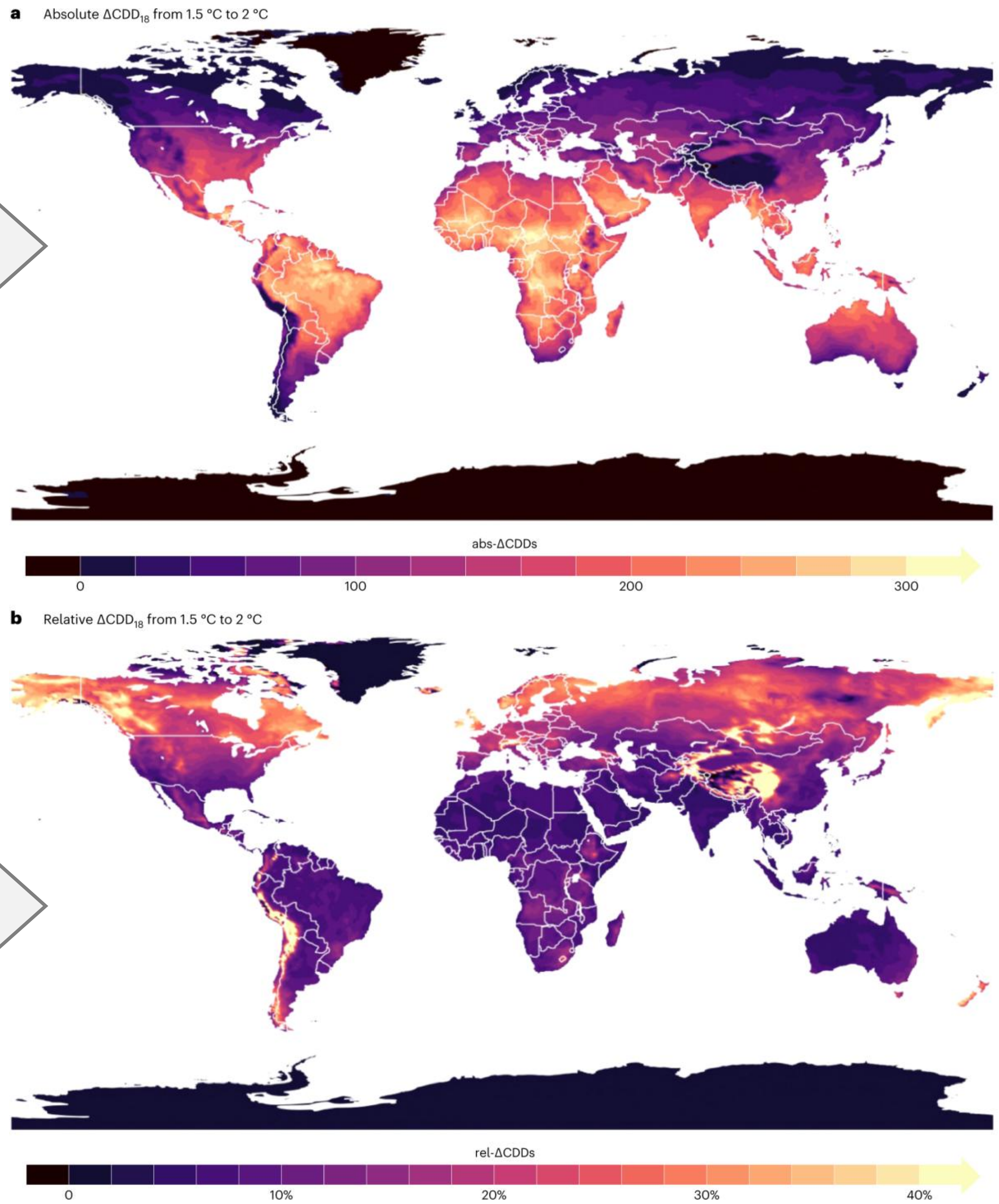
2025, 2050, and 2100, SSP2-4.5

Credit: Natalie Sauter

Absolute Change

Relative Change

Change in annual Cooling Degree Days between 1.5 C and 2 C climate simulations



Credit: Nicole Miranda, Jesus Lizana, et al

Conclusion

01

Climate change impacts all aspects of the energy system

02

Future development is needed to enhance resilience

03

Extreme event attribution can help target effort