MANCHESTER 1824
The University of Manchester

Probability-Preserving Scenario Clustering of Renewable Probabilistic Forecast Envelopes for Flexibility-Oriented Power System Operational Planning

Mohammad Habieb Al-Khayat, Mohammad.alkhayat@postgrad.manchester.ac.uk

Supervisor: Eduardo Alejandro Martinez Cesena

Date: 19/03/2026

Introduction and motivation

Modern decarbonised power system:

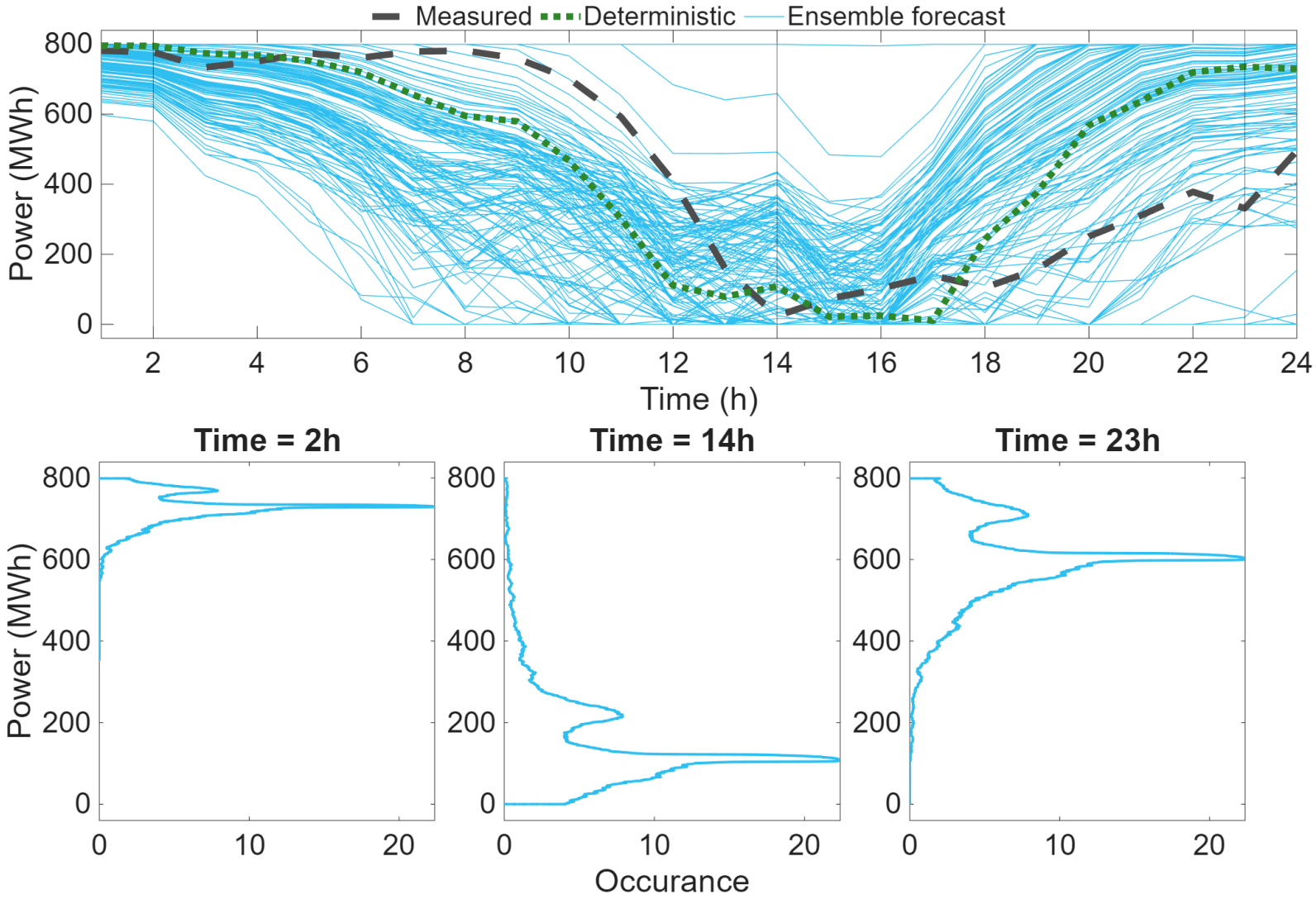
- Increasing penetration of Variable Renewable Energy (VRE)
- Operational planning relies on forecast information
- Forecasts today are increasingly probabilistic

Better system operation planning:

- Translate probabilistic forecasts into operational decisions
- Capture reliability-economic trade-off under uncertainties

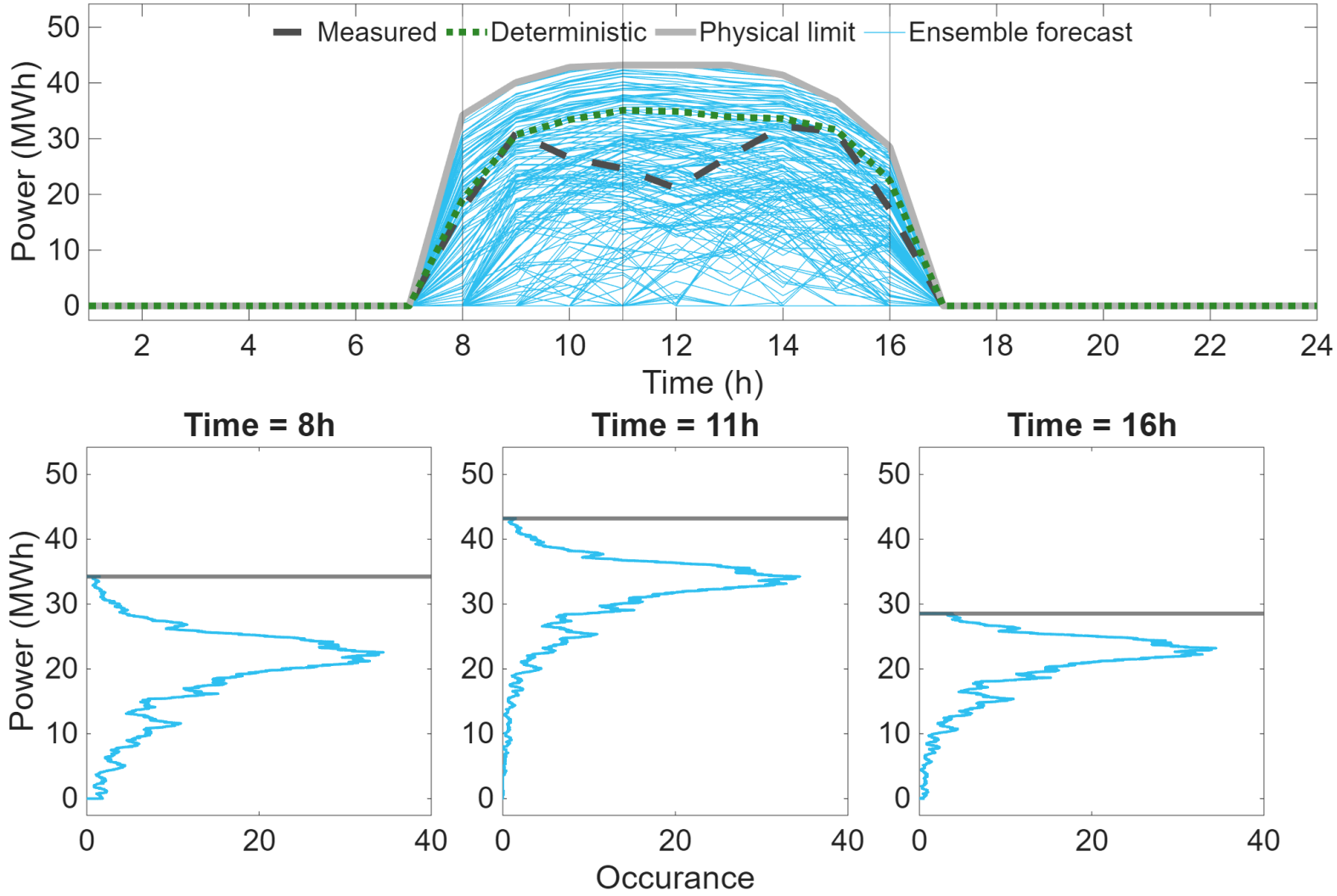
Probabilistic forecast of VRE

- Range of possible future outcomes **(Ensemble)**
- Translate into Probability Distributions (PD) instead of forecast errors



Technology physical limits

- Time dependent physical irradiance limits
- Capping the distribution
- Capacity 51.6MW vs max limit 43.2MW

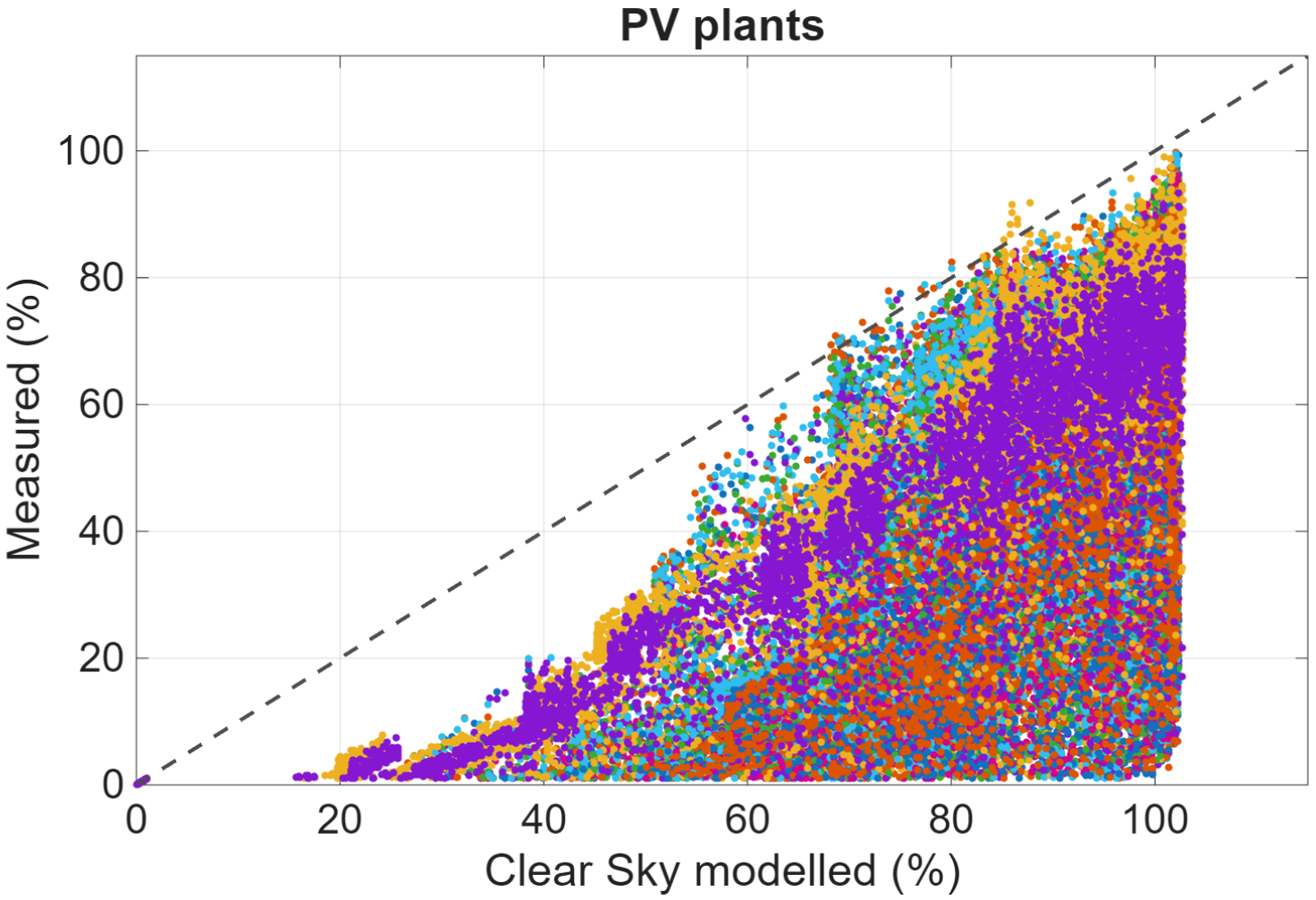


Technology physical limits 2

How effective is the physical limit?

Test with 25 PV plants full year data (110258):

- 29 data points with violations
- Extreme cases exists (~0.0263%)
- Smoothed out at system level



Planning optimisation gap

Existing practice

Approach	Uncertainties	Limitations
Deterministic	Ignored	High risks
Robust	Worst-case	Conservative
Chance-constrained	Probability limit	High computational costs, probability limits chosen by user
Scenario based stochastic	Sampled scenarios with weights	Tractability vs accurately representing uncertainty trade-off

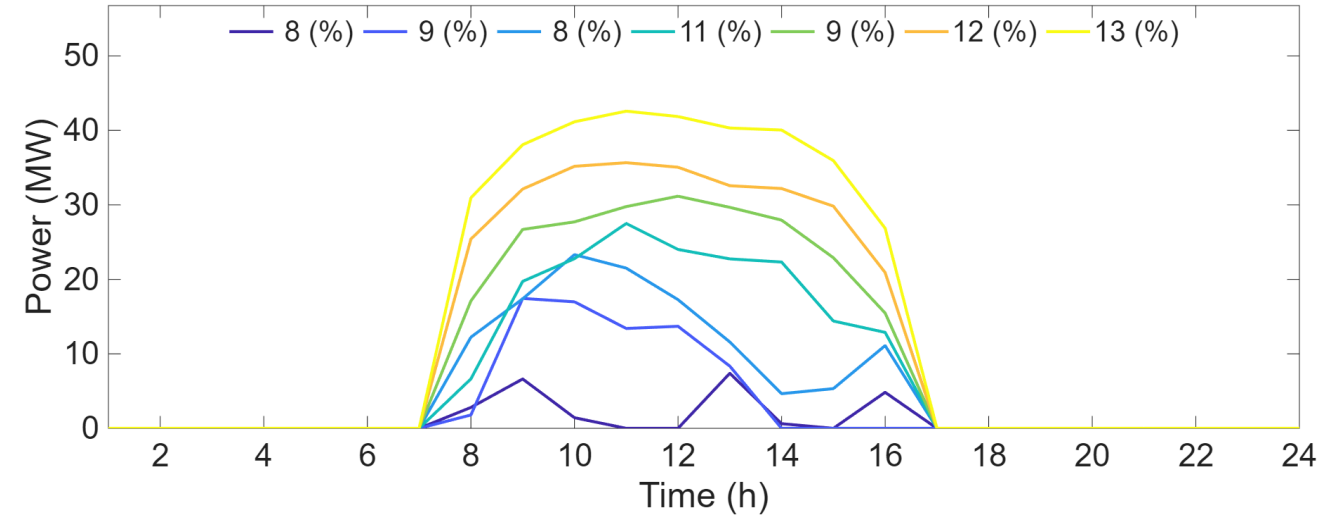
Probabilistic forecast information – Structural gap – planning models

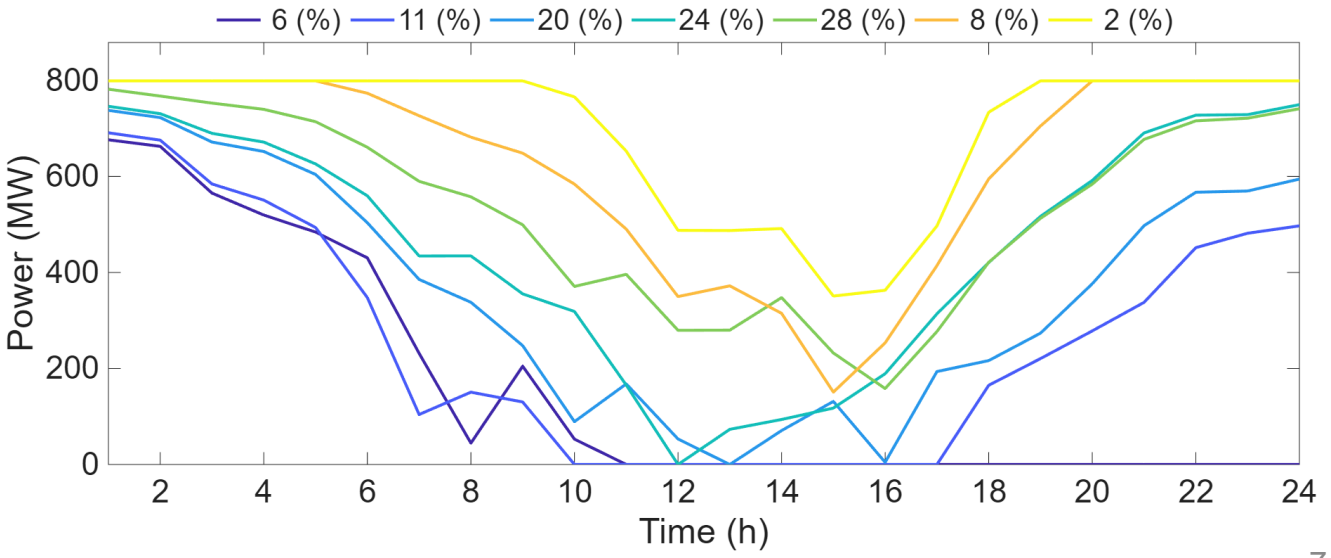
Conventional scenario-based method

- Scenarios with probabilistic weights
- Derived from PD of forecast profiles
- Scenario sampling approach affects results strongly
- Challenging to address extreme cases

Optimisation form
Minimise:

- ❑ Commitment Costs: Start-up, shutdowns, online
- ❑ Scenario Dispatch Costs: Probability x (dispatch + load shedding)





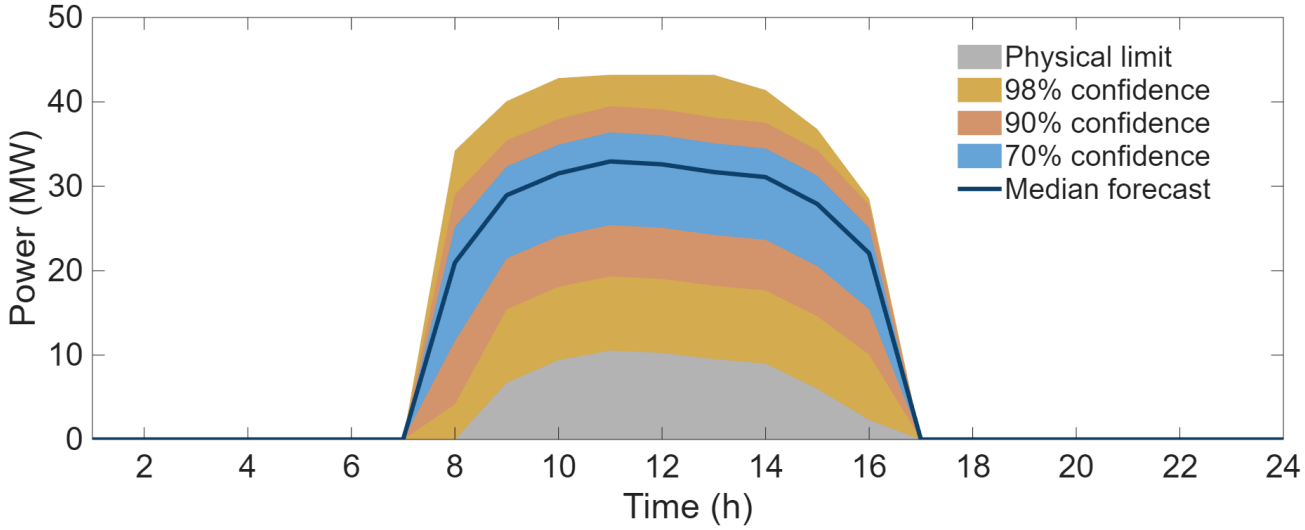
Proposed clustering structure

- Interpret envelopes as risk layers
- Assign probability to each layer
- Translate probabilities into costs weights

Confidence Layer	Probability	Coverage
70%	70%	Likely operation
90%	20%	Unexpected
98%	8%	Rare events
100%	2%	Full range (physical limit)

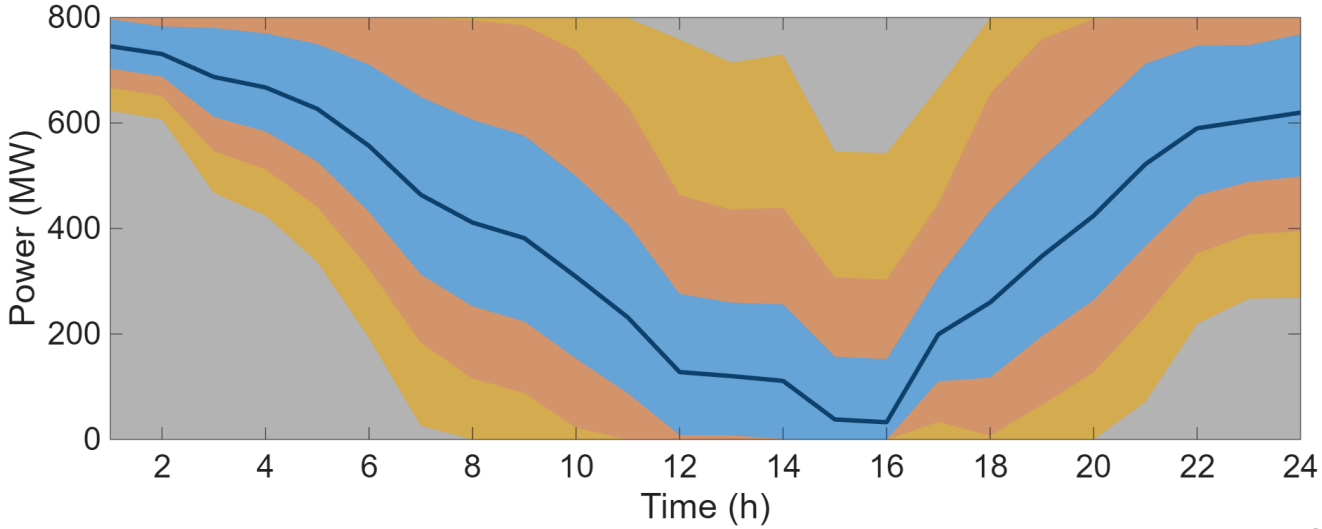
Sample of structure

- Aligns better with probabilistic forecast information (minimal processing of data)
- Central forecasts with risk layers
- Allows the optimisation to mitigate full range of events
- Challenge: pricing reserves dispatch



Optimisation form
Minimise:

- ❑ Schedule Costs: Operating costs meeting central forecast
- ❑ Risks Costs: Probability x (Reserve dispatch + load shedding)



Conclusion

- Proposed structure: translate probabilistic forecast information into risk layers instead of scenarios
- Allows to integrate renewables physical limits as additional layer – full range of potential events
- More control over reliability-economics trade-off
- Avoids distortions introduced by scenario sampling methods

Future work

- Tune the choice of confidence layers
- Address multi-area uncertainties in the network
- Implement in optimisation formulation with representation of reserves cost

MANCHESTER 1824
The University of Manchester

"Uncertainty is not the problem — the inability to plan for it is."

Thank you

Questions?