Uncertainty quantification of virtual monitoring information through probabilistic Bayesian neural networks

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23 – 26 May 2023 – WESC - Glasgow, UK

PhairywinD

Belgian Offshore PhD Expertise

PROJECT CONSORTIUM

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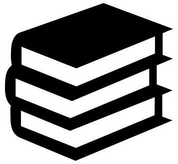
(1) Uncertainty quantification

Aleatory uncertainty

Inherent physical randomness



Standards and guidelines

Measurement uncertainty of sensing devices

ST2 FBG strain sensors
Embedded in composites
Strain accuracy 1%

S11 FBG strain sensors
Glued to various materials
Strain accuracy 1%

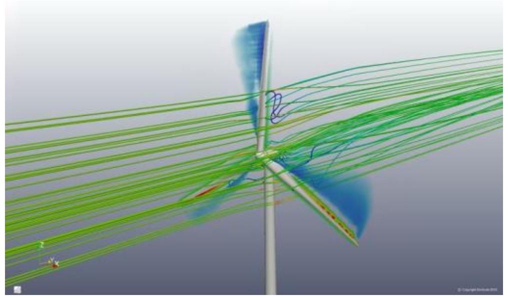
Ref: https://www.fibergratings.com/

Model uncertainty

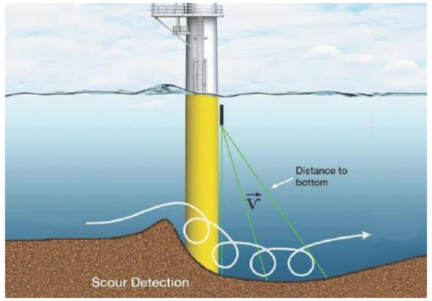
Labels ⇔ Model predictions (e.g., MAE, RMSE)

Conditions of strain gauges

Wind turbine dynamics changes over time…



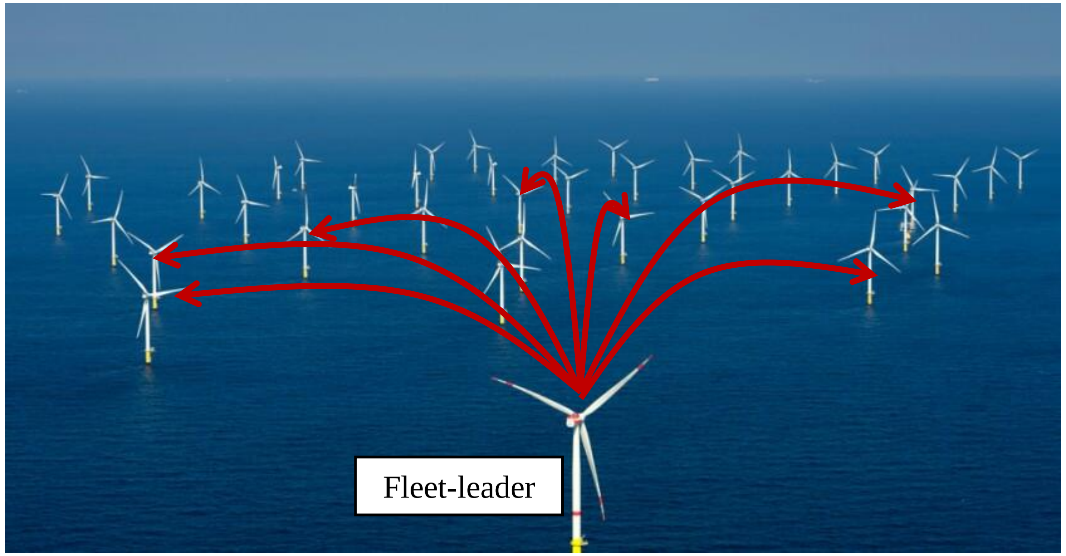
Ref: https://www.pinterest.com/



Ref: https://www.offshorewind.biz/

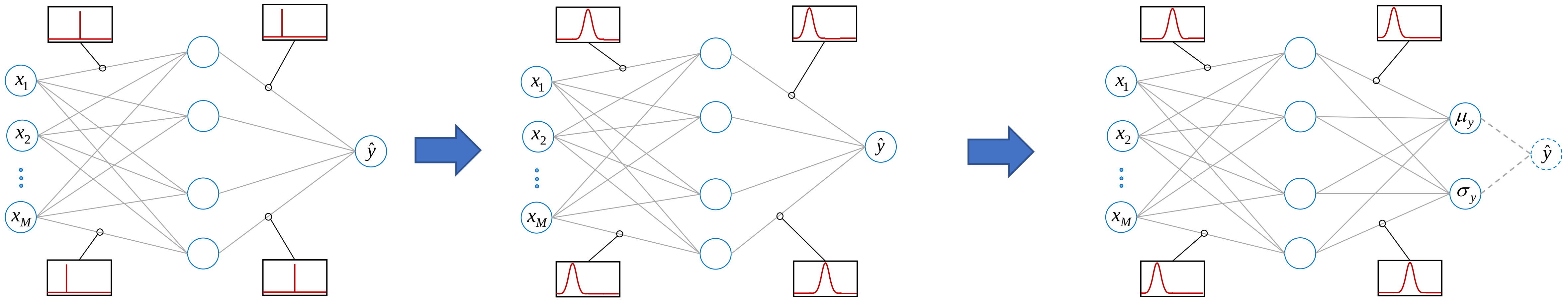
(2) Farm-wide applicability

- Economic constraints to fully instrument all turbines
- Absence of strain measurements, only SCADA and accelerations are available
- Variations in water depth, soil properties, structural designs
- Extrapolation of model uncertainty?



Ref: https://www.governing.com/now/wind-turbines-and-lawsuits-are-coming-to-the-jersey-shore

Bayesian Neural Networks



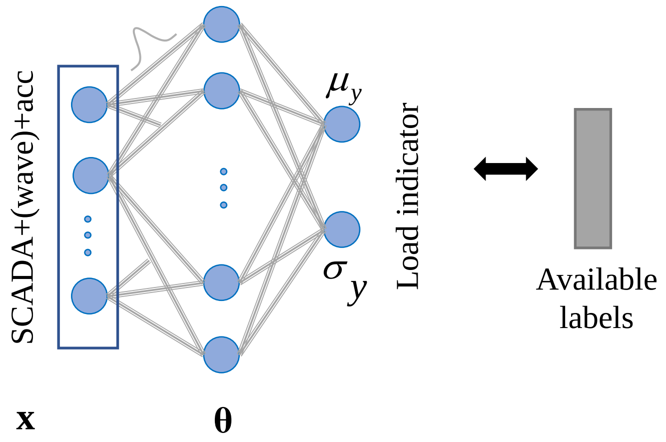
Standard deterministic neural networks
- Point weights and biases
- Point estimate output

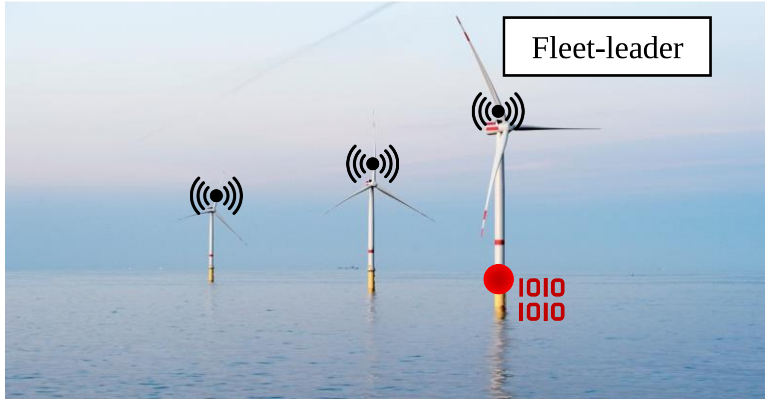
Epistemic Bayesian neural networks
- Probability distribution weights and biases
- Point estimate output

Probabilistic Bayesian neural networks
- Probability distribution weights and biases
- Probability distribution output

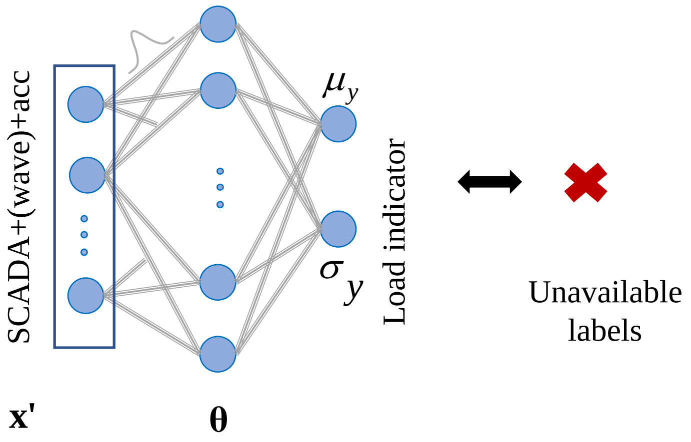
Farm-wide virtual load monitoring framework through BNNs

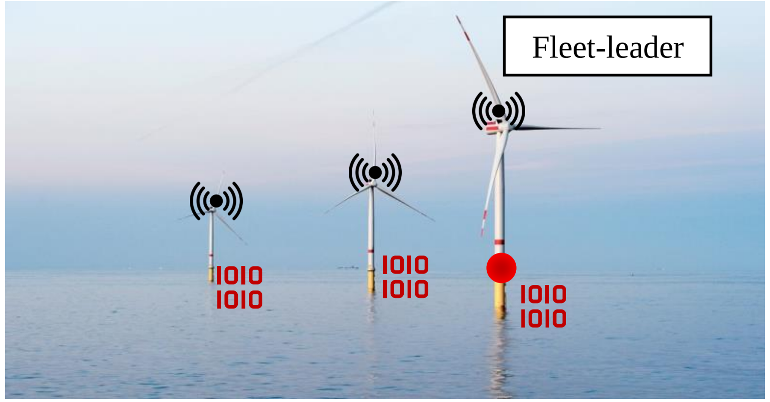
1. Training with fleet-leader data (input + labels)





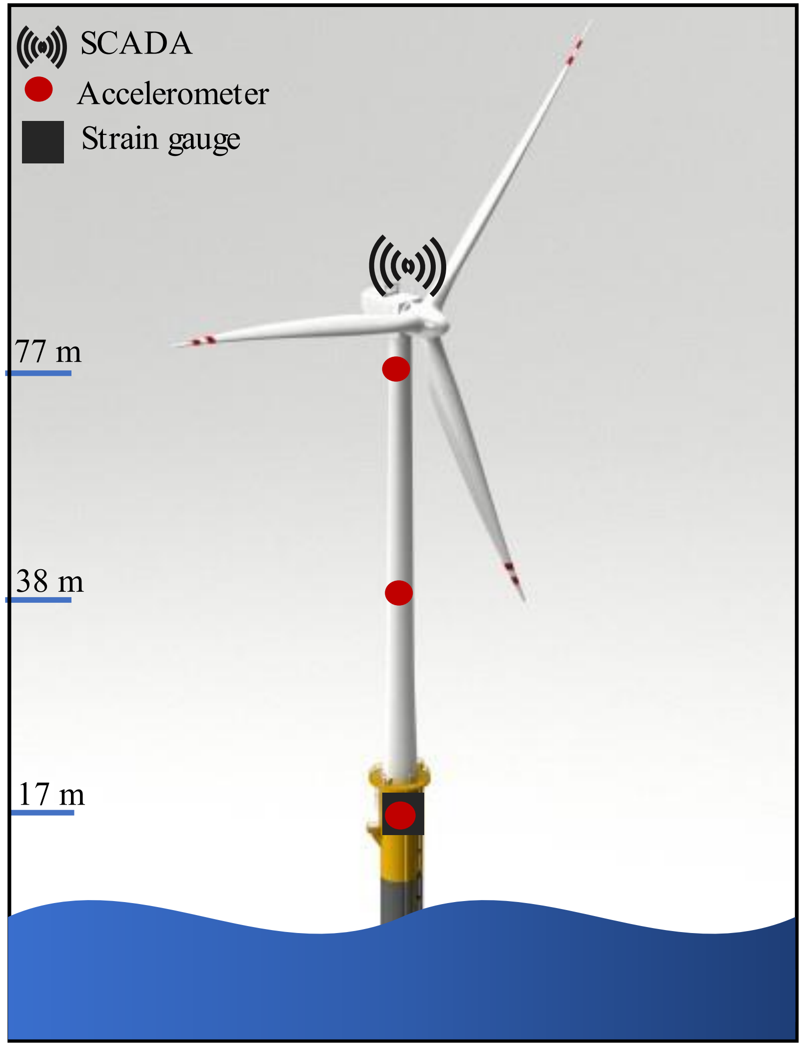
2. Deployment on fleet-leader or other turbines (only inputs)

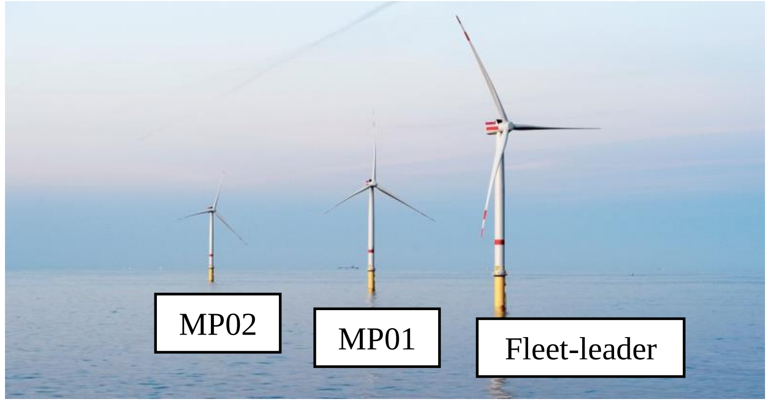




Ref: Hlaing, N., Morato, P. G., de Nolasco Santos, F., Weijtjens, W., Devriendt, C. & Rigo, P. (2023). Farm-wide virtual load monitoring for offshore wind structures via Bayesian neural networks. arXiv preprint. DOI:[10.48550/arXiv.2211.00642](https://doi.org/10.48550/arXiv.2211.00642)

Case study: Belgian offshore wind farm



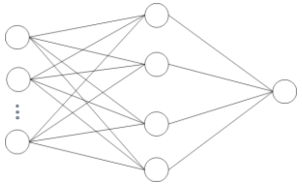


Ref: https://www.gov.uk/

SCADA
Rotational speed (mean)
Yaw angle (mean)
Pitch angle (mean)
Power (mean)
Wind speed (mean)
Wind speed (std)
Wind direction (mean)

Wave buoy
Wave height
Average wave period
Wave direction

Accelerometers
FA acceleration (max, min, rms)
SS acceleration (max)

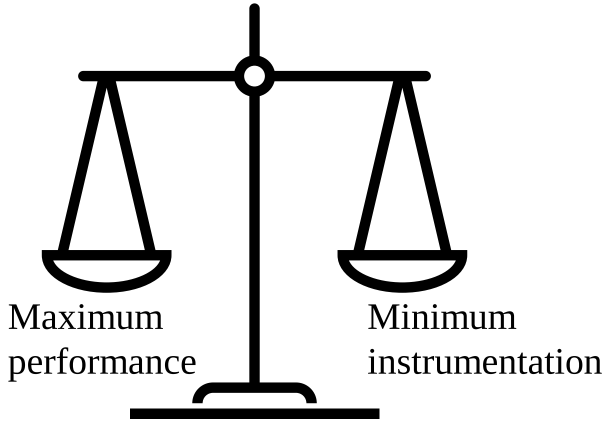


Strain gauges at 17m LAT
DEM_{tl}
DEM_{tn}

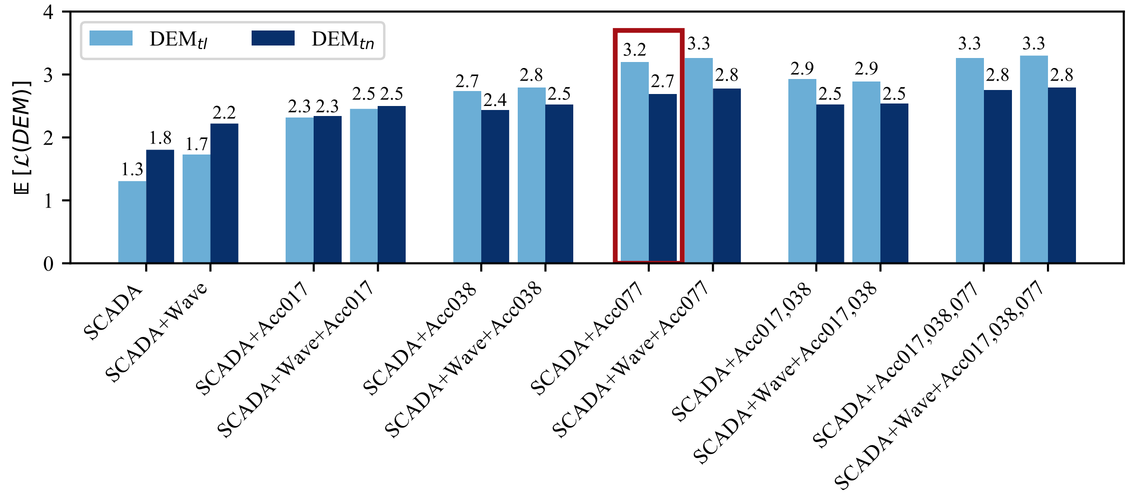
Case study: Belgian offshore wind farm

Selection of input monitoring signals

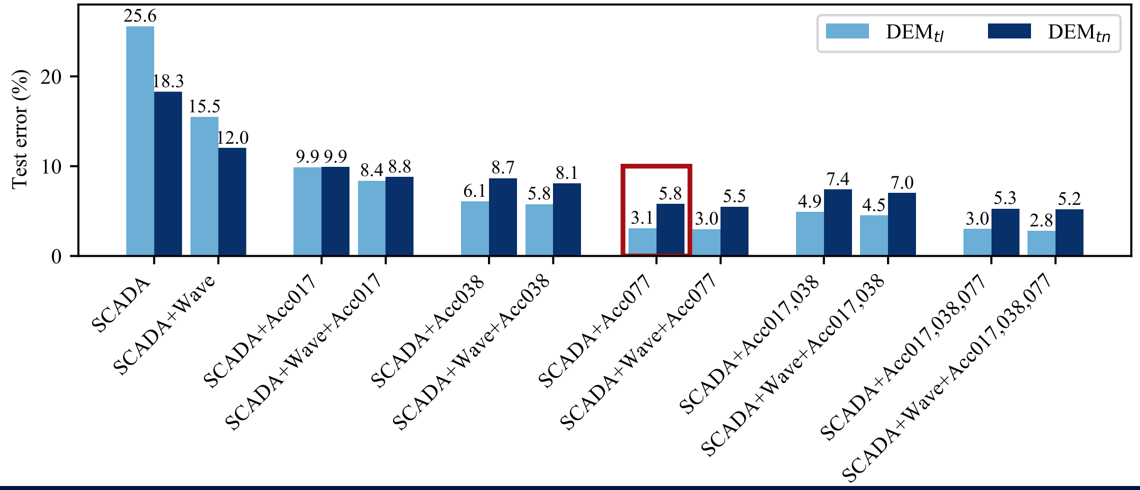
- Aimed for farm-wide application



Bayesian neural networks

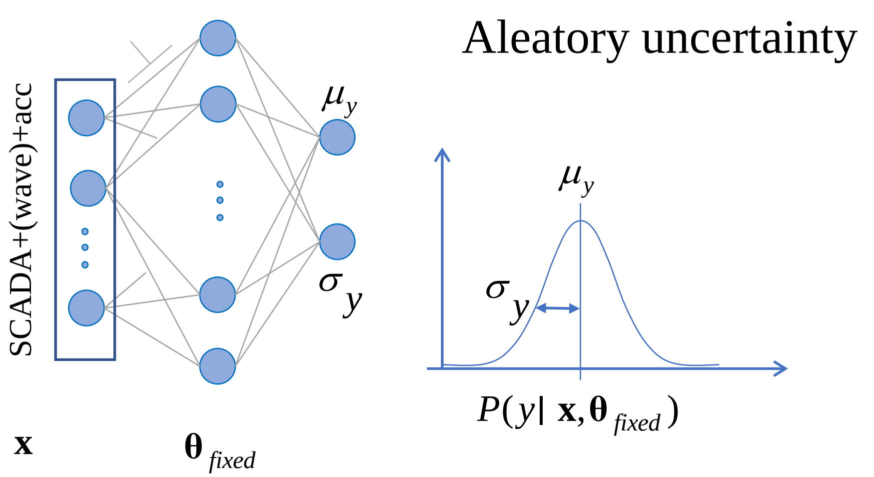


Deterministic neural networks

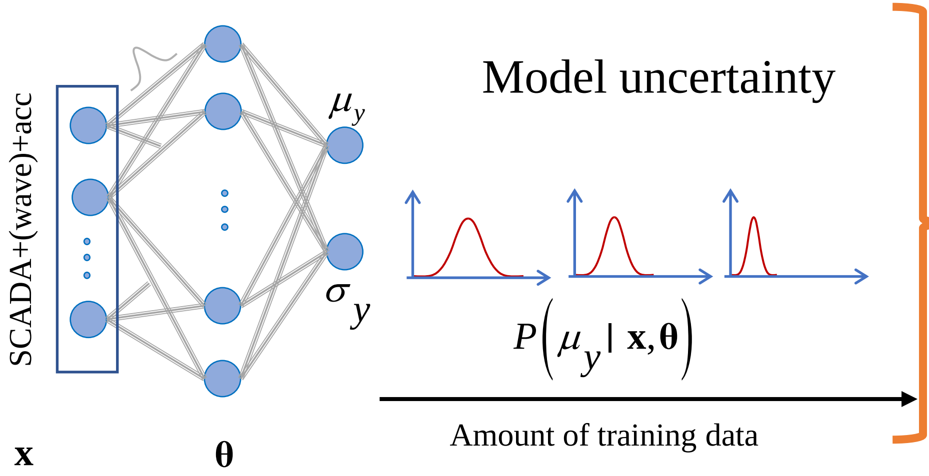


Case study: Belgian offshore wind farm

Uncertainty quantification of load predictions



- Inherent physical randomness
- Measurement uncertainty of sensing devices

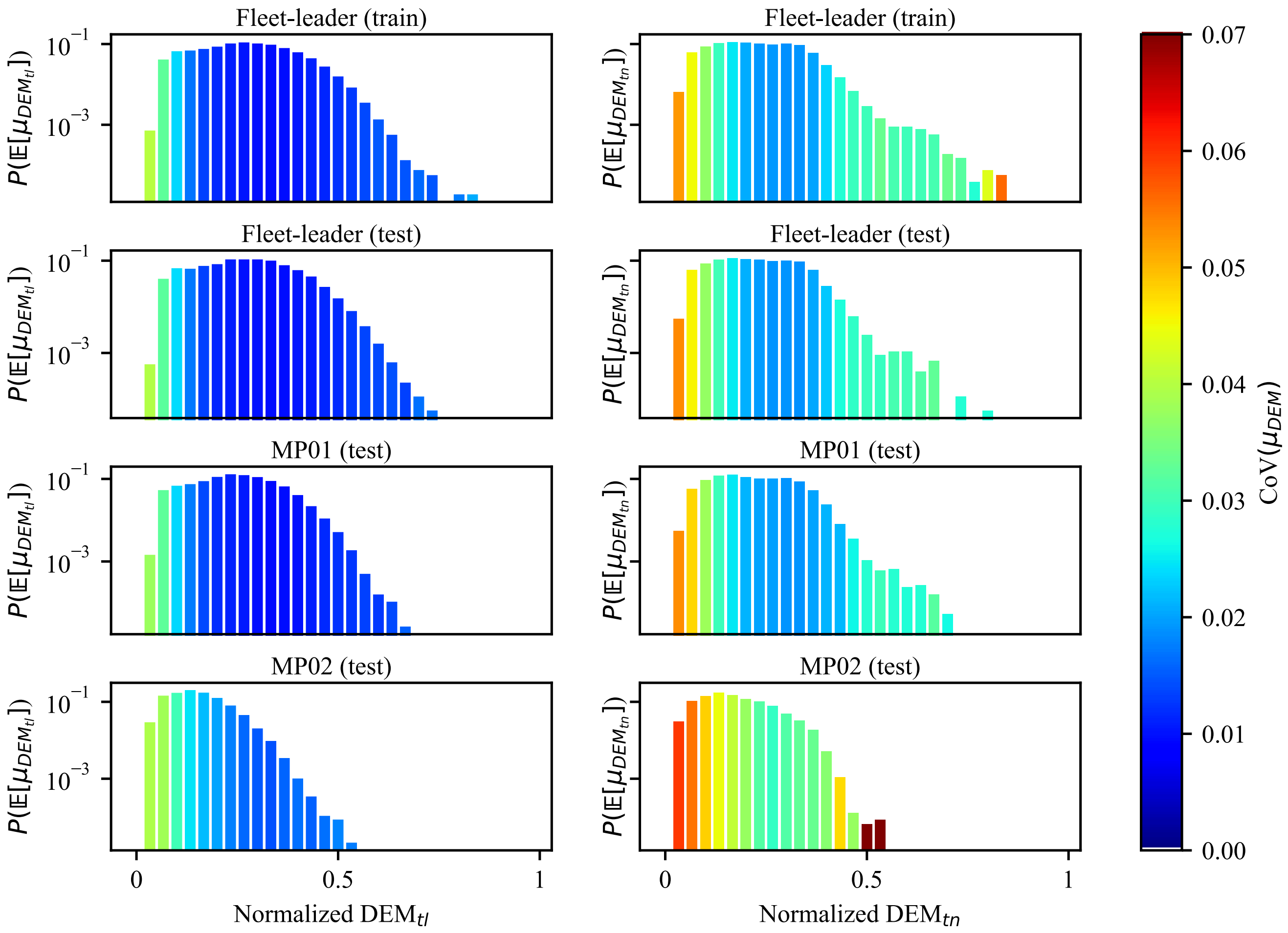


- Discrepancy between strain gauge measurements and model predictions
- Receiving unexplored data
- **Not require labels**

Case study: Belgian offshore wind farm

Farm-wide deployment

Distribution of DEM (side-to-side and fore-aft) and model uncertainty

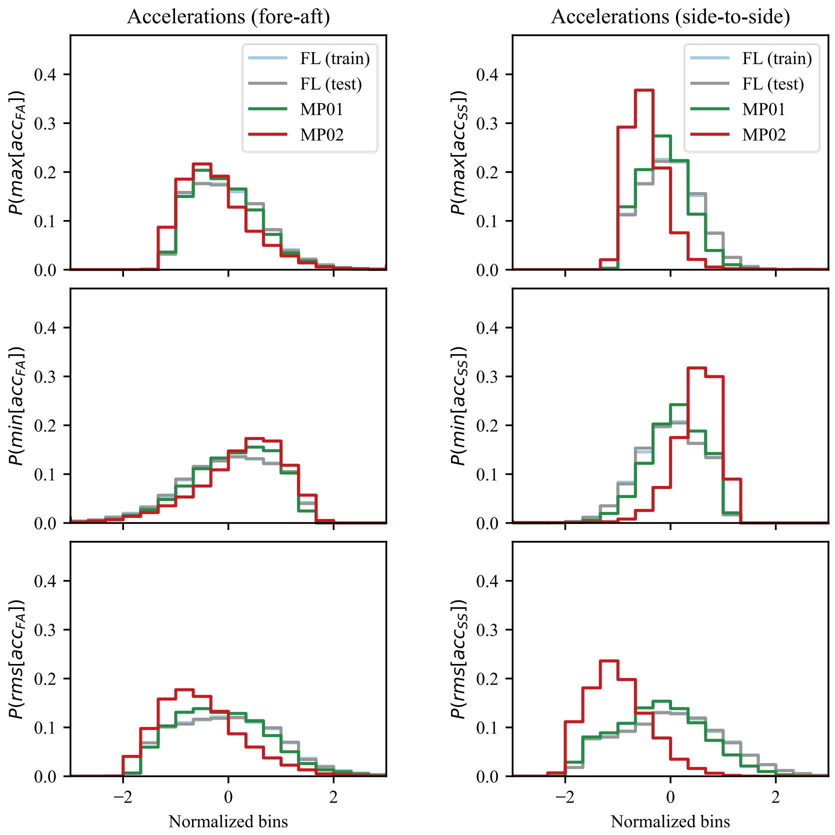


Okay

Okay

↑ CoV(μ_y)

Potential prediction inaccuracies

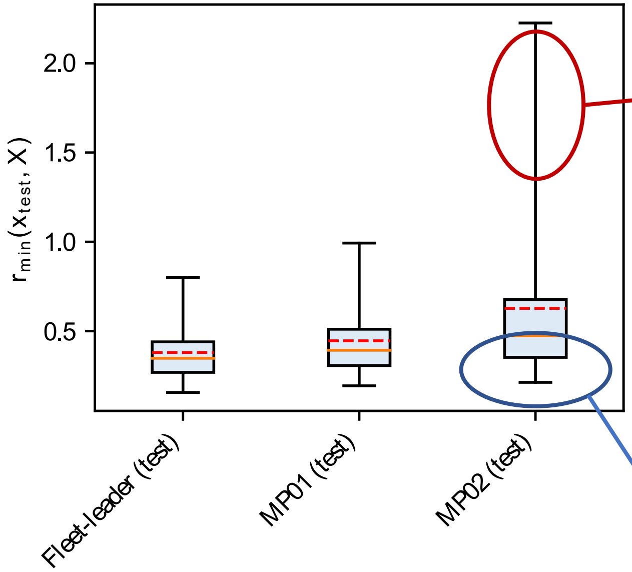


The BNN is receiving some unexplored data when deployed for MP02.

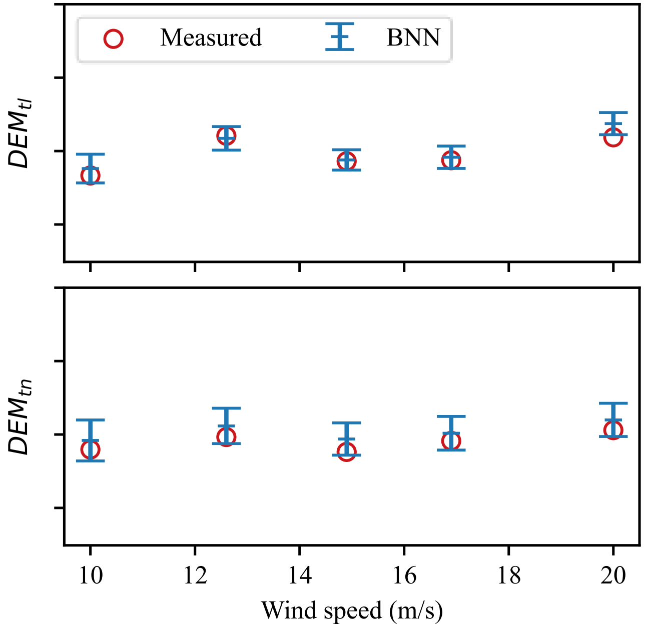
Case study: Belgian offshore wind farm

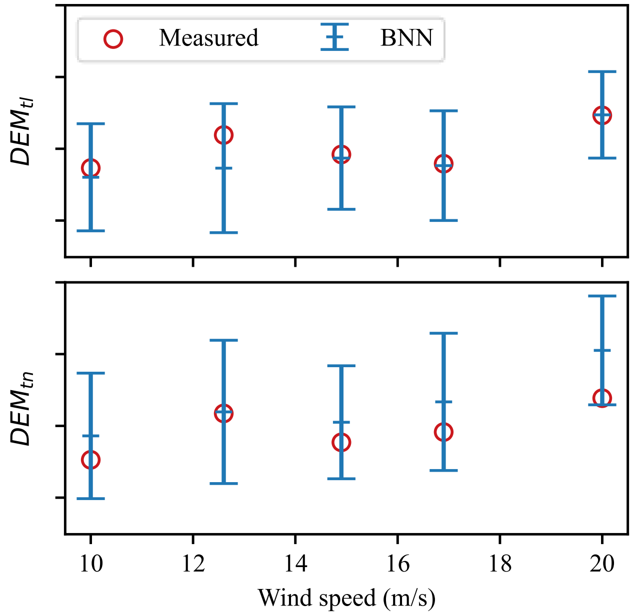
Comparison with measured labels (A subset of MP02 test data)

Minimum Eucleadian distance to the nearest training point.



In-training test samples.





Out-of-training test samples.

Future Work

- To thoroughly compare DNNs and BNNs.
- To compare with kernel-based methods, e.g., Gaussian processes.
- To implement in decision-making for life-cycle management.


Source: energy.gov


Source: www.istockphoto.com


Source: rsdiving.de


Source: rsdiving.de

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For questions and comments:

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