Más allá de los promedios de flota: modelado de confiabilidad sensible al clima

Aplicación a los componentes del tren de potencia de aerogeneradores



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Problem Statement

OPEX ≈ 20-30% of LCOE

Major components are a large contributor

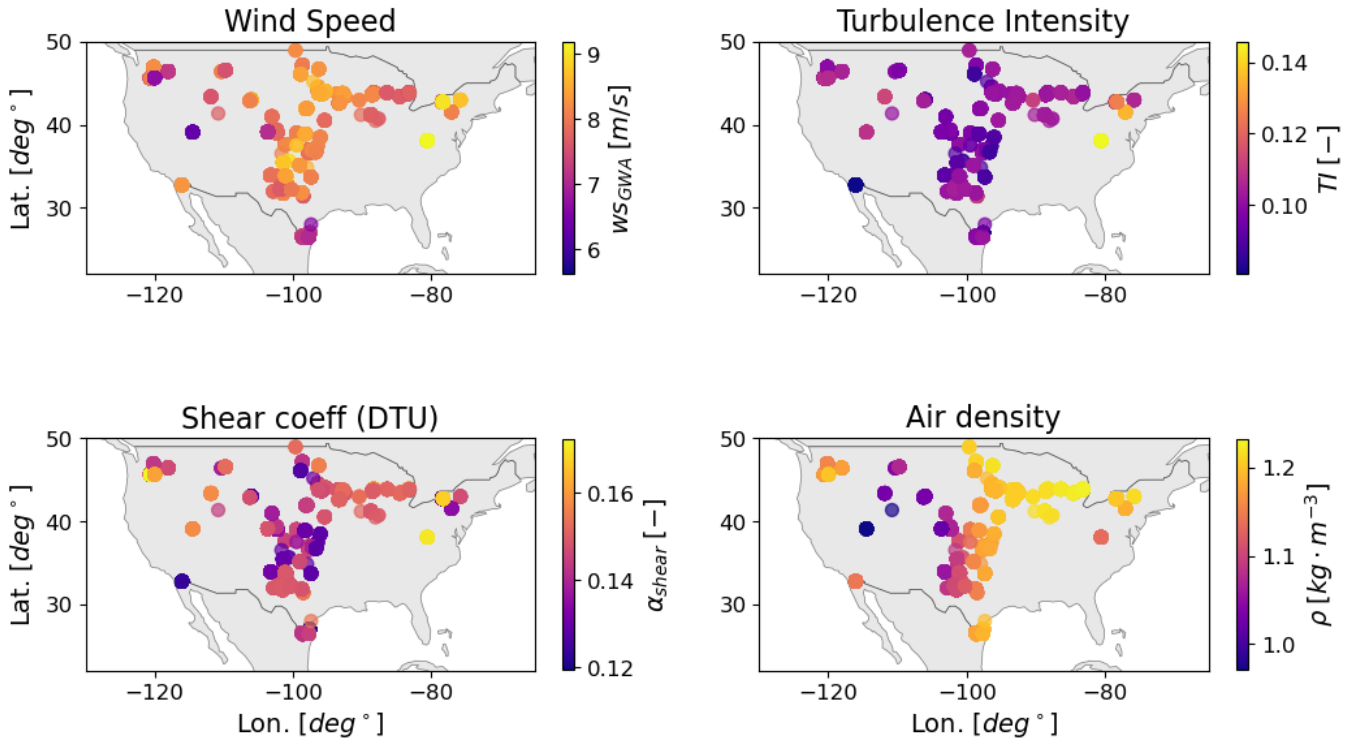
- Typical failure rate (yearly): 1% – 5%
- High cost and extended downtime.

Planning helps to reduce the cost

but

Requires accurate failure rates

Low failure rate require aggregation over large heterogeneous population exposed to variable wind conditions



How does varying wind conditions influence component's reliability?

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Wind Network for Enhanced Reliability (WinNER™)

40+ organizations collaborative effort

- 90GW+ wind fleet, 600+ wind farms
- 15 Turbine OEMs, 90+ turbine models
- 100+ system models

Cover most major wind turbines components

Gearbox

Generator

Blades

Main bearing

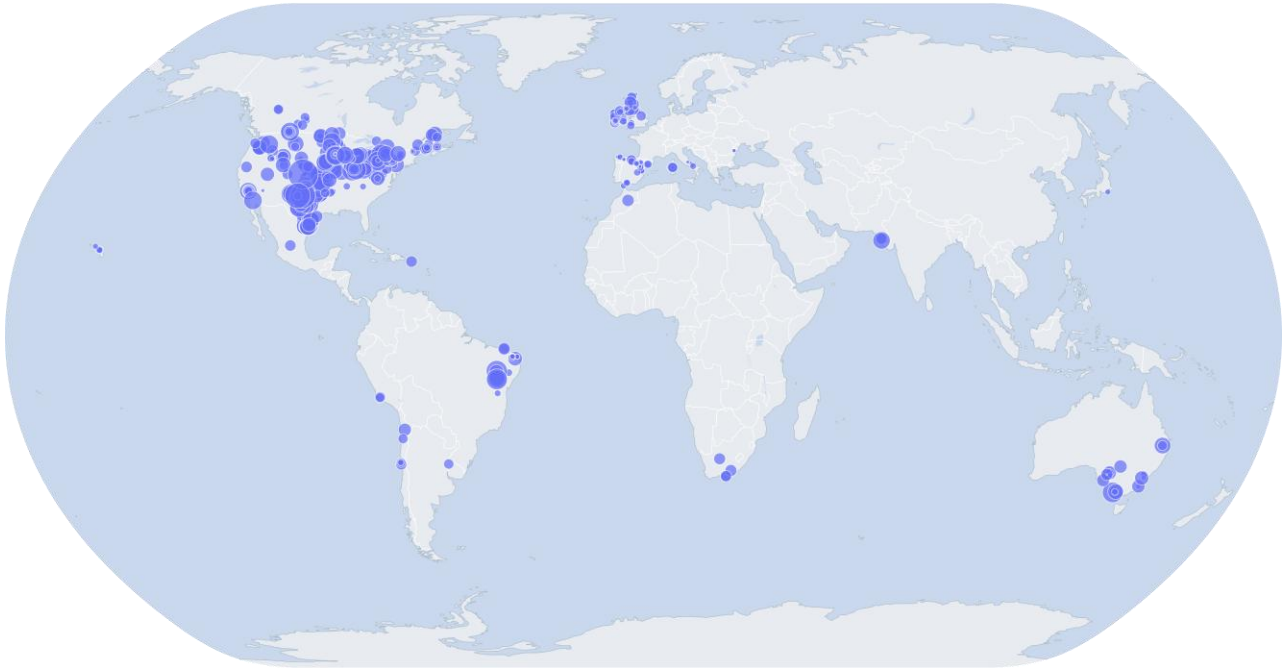
Pitch bearing

Transformers (2025)

Failure mode classification.

Cost information

More than 31,000 monitored assets worldwide (Onshore)



Reliability benchmarking, O&M budget forecast, Failure mode analysis

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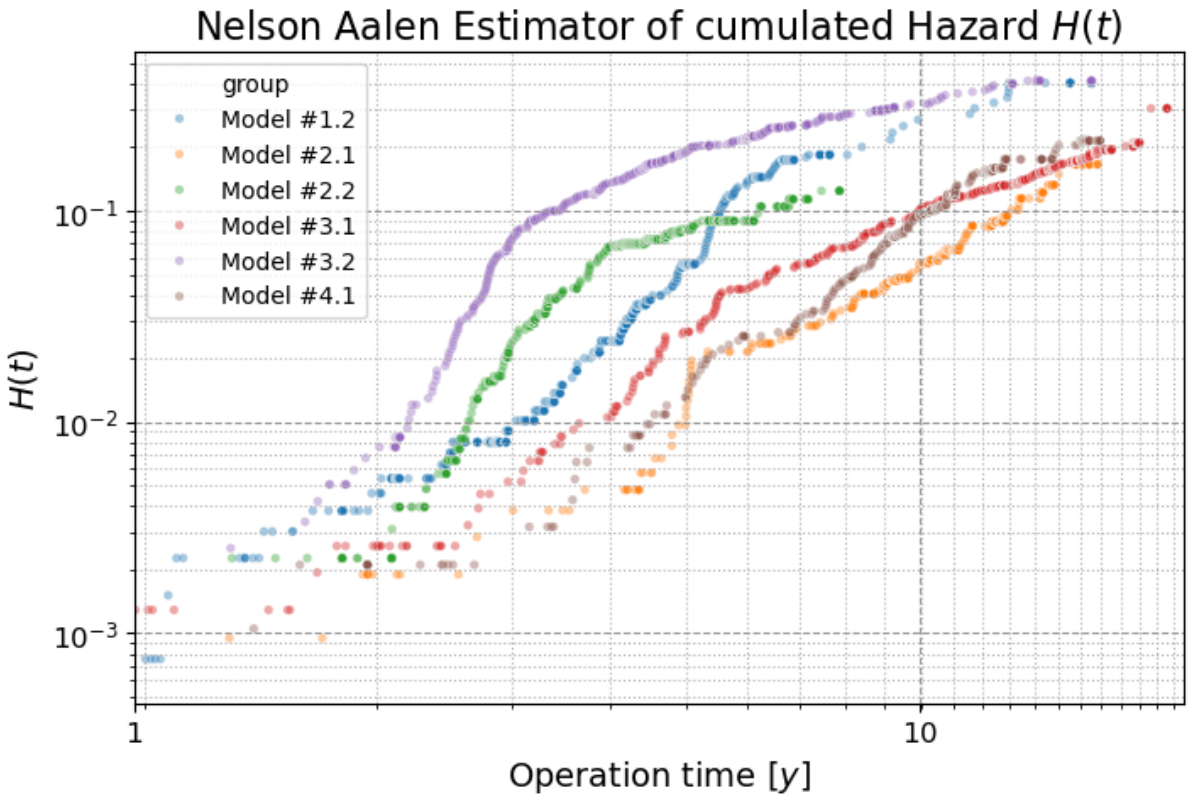
Methodology

Check our paper:

Hierarchical Accelerated failure time (AFT) model

$$log(T_i) = \mu_{0,i} + \sum_k \alpha_k \cdot x_{i,k} + \frac{\varepsilon_i}{\beta_i}$$

- Baseline reliability function ($\mu_{0,i}, \beta_i$) defined at group level (bearing model).
- Effect of covariates (α_k) only affects the scale parameter.



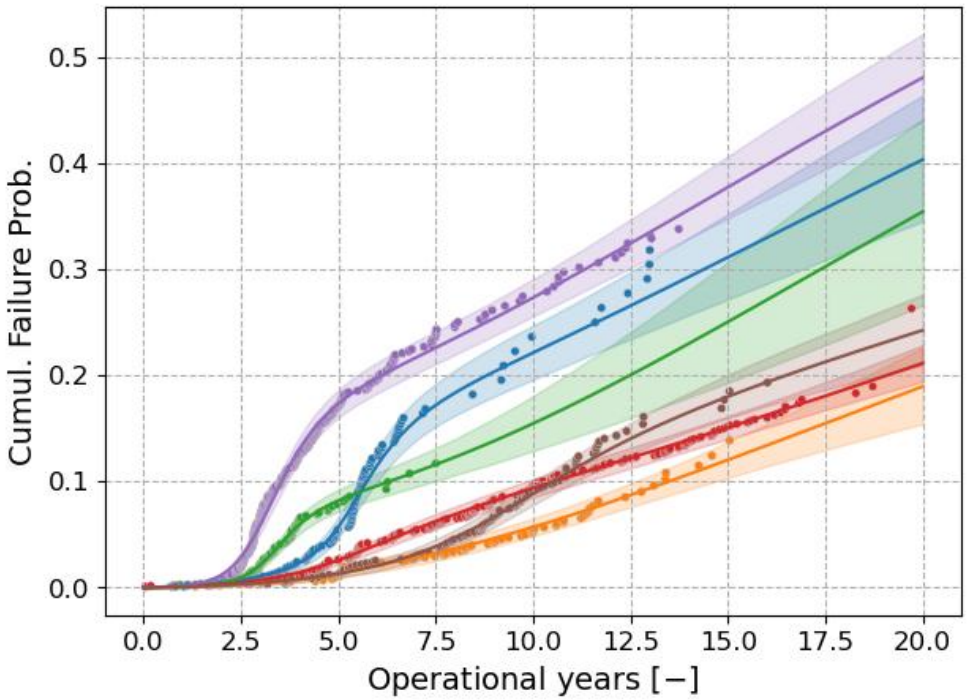
Flexible climate-aware framework for reliability modelling

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Application to main bearings: Results

Baseline reliability modelled using a mixture of logistic distribution

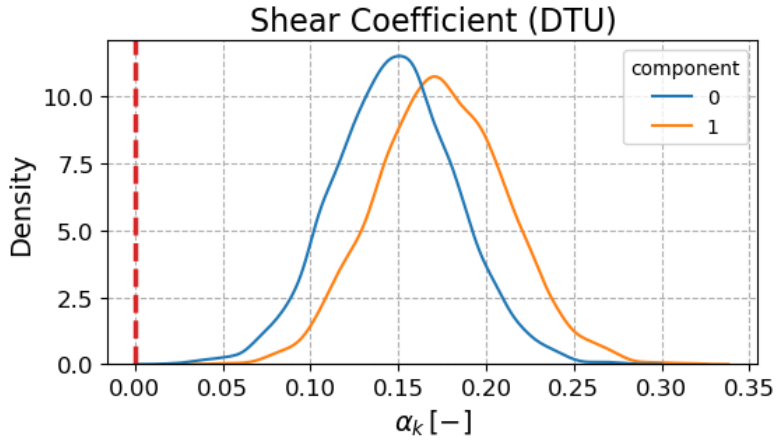
$$f(y) = \sum_k w_k \cdot f_k(y) \qquad f_k(y) = \frac{e^{-\frac{y-\mu}{\beta}}}{\beta\left(1 + e^{-\frac{y-\mu}{\beta}}\right)^2}$$



Shear and wind speed identified as influence parameters

Shear:

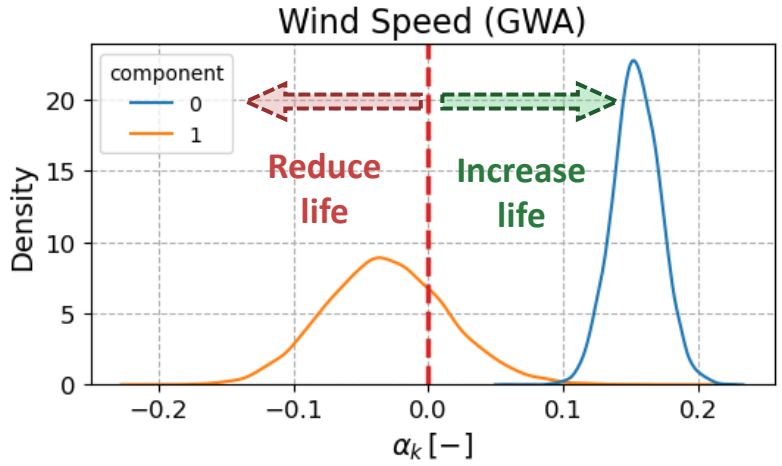
Improves life overall.



Wind speed

Reduce early life failures

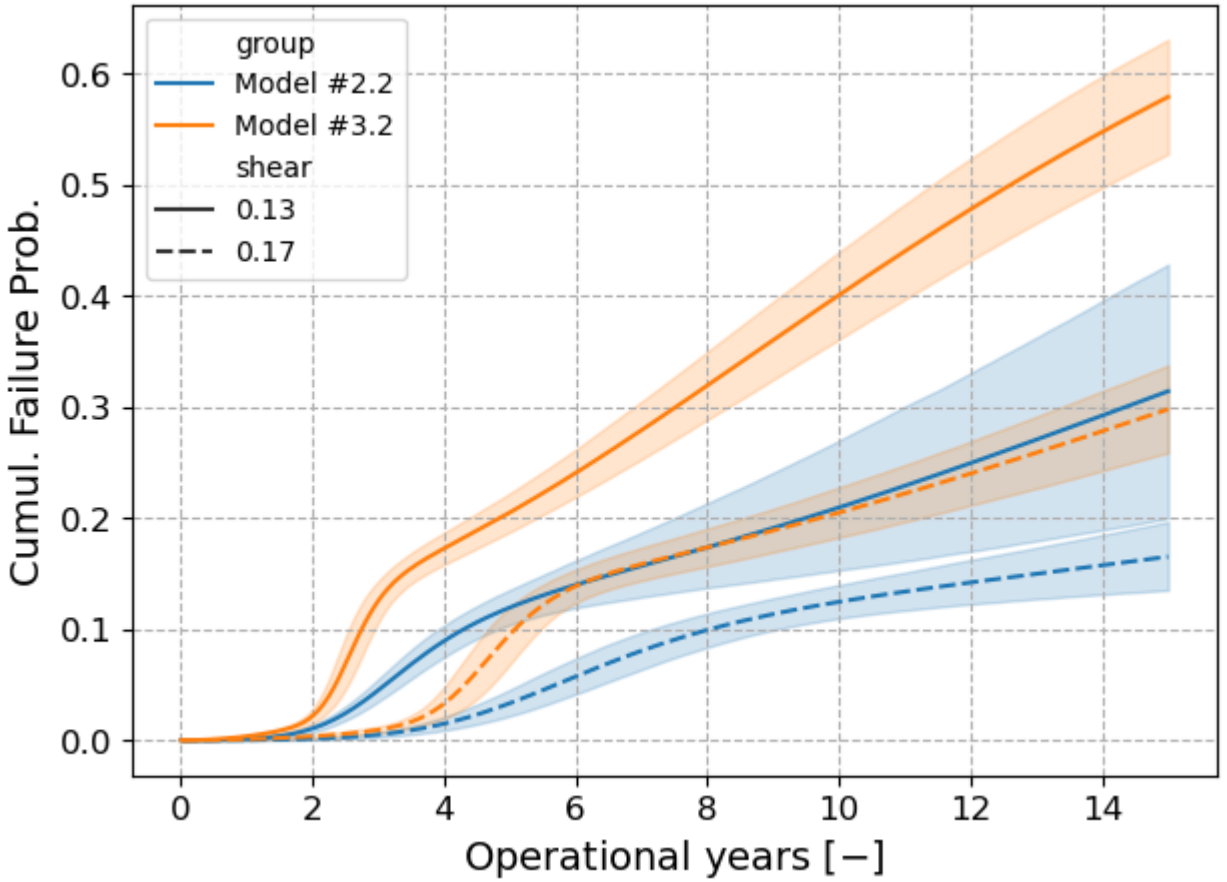
Increase late life failures



Allows for a separating the effect of design from site specific conditions

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Application to main bearings: Posterior Predictive



Cumulated Failure probability after 15 year

shear\model	Model #2.2	Model 3.2
0.13	31%	58%
0.17	15%	30%

Site conditions drive failure risk as much as design choice !

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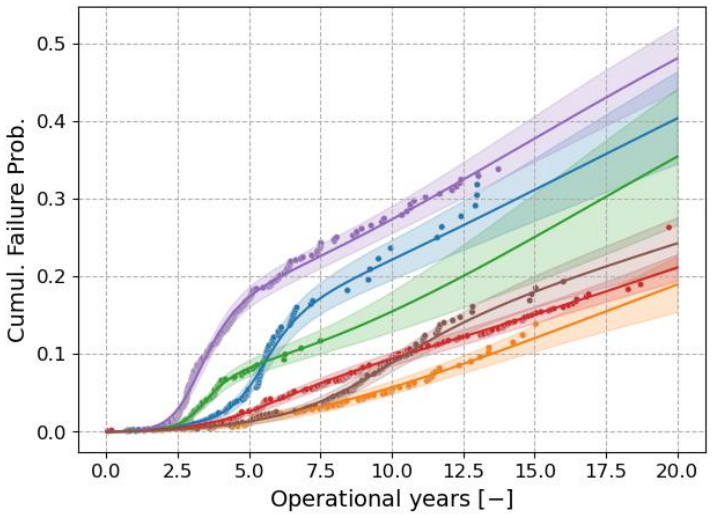
Concluding remarks

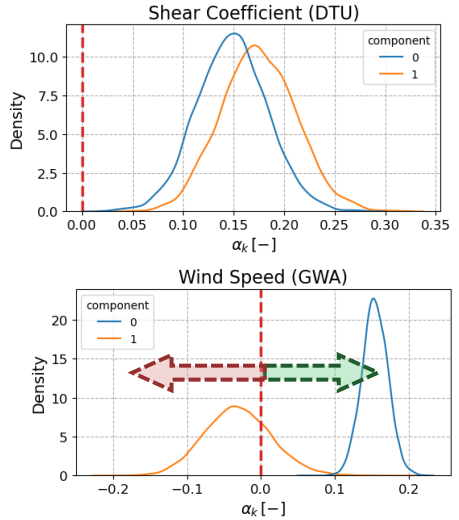
Key takeaways

- **Site conditions are not a second-order effect for main bearings:** Shear alone can halve the 15-year failure probability.
- **Neither design nor site alone tells the full story:** Model #3.2 at a high-shear site (30%) outperforms Model #2.2 at a low-shear site (31%)
- **Reliability modelling must account for both:** A fleet benchmark that ignores site heterogeneity will systematically misattribute reliability differences between assets.

Next steps:

- ❑ Include additional feature (e.g., number of hours in production).
- ❑ Include operation history (using SCADA data).
- ❑ Expand to other components (generators, transformers…)





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Thank you for your attention

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Check our paper

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