



FROM BETTER WIND MODELS TO BETTER DECISIONS

POLICY RECOMMENDATIONS FOR RELIABLE WIND ENERGY
MODELLING, DEPLOYMENT AND DECISION MAKING

SEPTEMBER 2026



Funded by
the European Union

ABOUT MERIDIONAL

MERIDIONAL is a Horizon Europe project **advancing multiscale modelling for wind farm design, performance assessment and loading, helping make wind energy deployment more reliable, efficient and decision-ready.** Its results provide practical guidance for researchers, industry and policymakers on how better modelling can support safer turbines and smarter wind farms, reduce investment risk and promote faster uptake of innovative wind energy solutions.

MERIDIONAL shows that credible wind energy design and operational decisions depend on credible modelling. As turbines grow in size, wind farms become larger, sites become more complex and innovative solutions move closer to demonstration, **modelling choices** increasingly shape expectations on energy production, structural loads, wake effects, control strategies and operational risk. The central lesson is not that every decision needs the most complex model. It is that **each decision needs a model that is fit for purpose**, validated, and transparent about uncertainty.

This brief recommends a practical shift: **treat modelling evidence as a shared requirement across planning, funding, permitting, procurement and demonstration**. Better modelling governance can reduce uncertainty, strengthen trust in project evidence and help MERIDIONAL results be used across regions, technologies and institutions.



Wind energy is moving into a new phase. Future deployment will rely on larger turbines, denser wind farm clusters, offshore expansion, complex-terrain projects, active wake control and emerging airborne wind energy systems. While these developments offer major opportunities, they also make performance and load assessment more demanding. Decisions that once relied on simplified assumptions now need a **clearer understanding of turbulence, atmospheric stability, terrain effects, wake interaction and system-level behavior**.

The MERIDIONAL project contributes to this challenge **by advancing multiscale modelling for wind farm design, performance assessment and loading**. Its findings point to a simple principle: **modelling should be matched to the situation and the requirements**. Fast engineering models can support early screening and comparison. More dynamic, load-aware or high-fidelity approaches are needed when the decision concerns fatigue, extreme loading, complex wakes, neighbouring wind farms, advanced control or safety-critical claims. The objective is to make evidence clearer, more comparable and more useful.



RESEARCH FINDINGS

Wind energy modelling is decision infrastructure for faster, safer and more trusted deployment

Model choice changes the decision

Different modelling approaches answer different questions. A model that performs well for average annual energy production may not be sufficient for fatigue loads, extreme events, active control or farm-to-farm wake interactions. **Treating all modelling outputs as equivalent can create false confidence.**

Inflow matters from the start

Wind turbines and wind farms are sensitive to atmospheric inflow. Turbulence, shear, veer, stability, low-level jets, gravity waves, wind ramps and large-scale structures can influence loads and performance. Synthetic turbulence generation remains essential because it is fast and supports many simulations, but its assumptions must be understood. **Higher-fidelity atmospheric simulations can capture more physics. They are more computationally intensive, but may be required where very detailed and accurate information is required.**

Wake effects are a system issue

Wakes influence production, loads and the performance of neighbouring turbines and wind farms. The right wake model depends on the requirements: quick layout screening, control design, dynamic load assessment and cluster-level interaction require different levels of detail. As offshore build-out increases, **wake-aware planning becomes more important for efficient use of space and fair assessment of impacts.**



Complex terrain and large projects need more detailed modelling

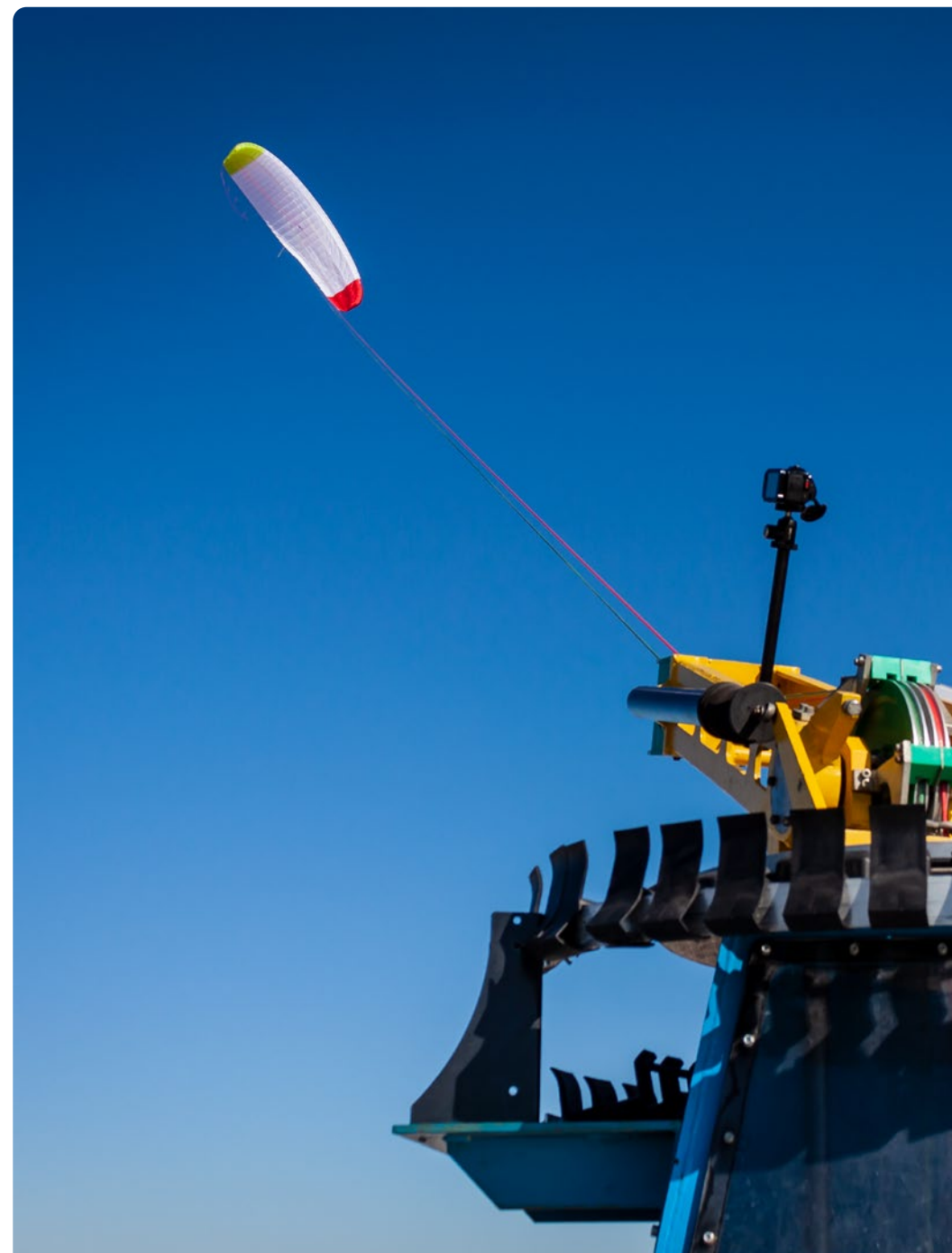
Terrain, forests, surface roughness and atmospheric stability can significantly affect wind conditions. For complex sites, simplified assumptions may be inaccurate unless they are calibrated or checked. **MERIDIONAL points to the value of benchmark cases, open data where possible and protected data-sharing routes where commercial information is sensitive.**

Data-driven and hybrid models can accelerate uptake, but they need guardrails

Surrogate and machine-learning approaches can make advanced modelling faster and more usable. They are valuable for design exploration and operational decision support, but only when their training data, validation range, input features and extrapolation limits are documented. **Any model used outside its evidence base can become a fast route to poor decisions.**

Innovation needs staged confidence

Airborne wind energy and advanced control strategies should be enabled through demonstration and learning. Early modelling can support screening and comparison, **while stronger experimental and high-fidelity evidence is needed for loads, control, tether dynamics, take-off, landing and safety-critical claims.**



POLICY RECOMMENDATIONS

Ensure fitness-for-purpose

Every modelling submission should state the decision it supports, why the model is suitable, what assumptions it uses and where its results should not be applied.

Match model complexity to decision risk

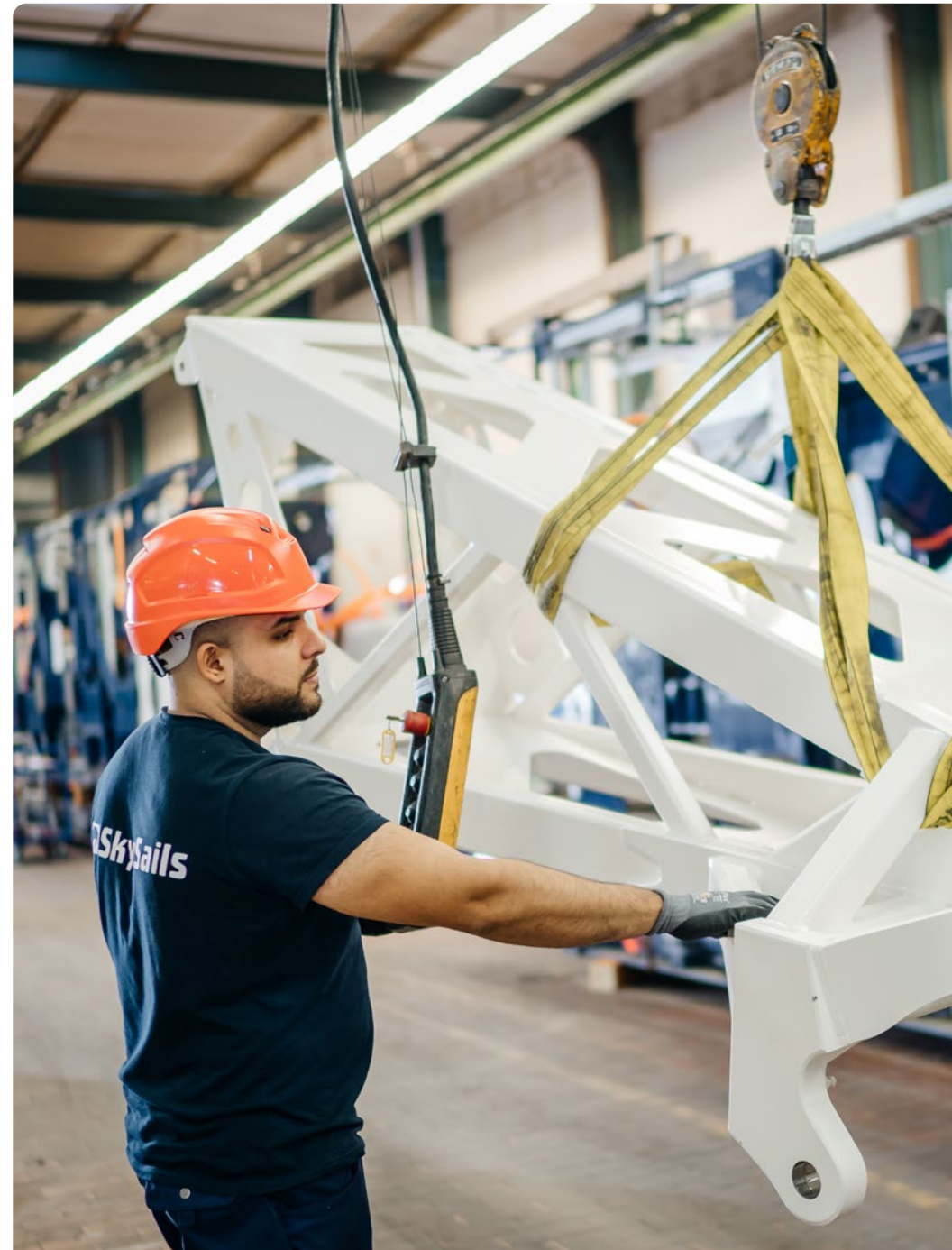
Use fast engineering models for early screening, layout comparison and average production estimates. Use stronger dynamic, load-aware or high-fidelity evidence for fatigue, extreme loads, complex terrain, active control, complex atmospheric conditions, and neighbouring wind-farm effects.

Demand uncertainty, not just single numbers

Modelling results should include sensitivity checks for key assumptions such as turbulence, atmospheric stability, terrain representation, grid resolution, stochastic seeds, wake parameters and operating conditions.

Make validation a normal requirement

Funding calls, tenders and demonstration projects should include validation plans, benchmark cases or comparison against measurements and accepted reference models. Validation data should be treated as shared and essential information, not as an afterthought.



Set guardrails for data-driven tools

Surrogate and machine-learning models should document training data, validation data, intended use, uncertainty and extrapolation limits. Hybrid workflows should be encouraged: measurements and simulations build the evidence base, fast models support exploration, and selected cases are checked with higher-fidelity methods.

Support protected data sharing

Create routes for using SCADA, LiDAR, met-mast, terrain and operational data without exposing sensitive commercial information. Better data access will improve calibration, benchmarking and trust.

Use staged evidence for emerging technologies

Airborne wind energy and advanced controls should progress through clear demonstration steps. Simplified models are useful early on, but safety-critical claims require stronger validation and experimental support.

Turn project results into guidance

MERIDIONAL outputs should feed practical templates for reporting assumptions, limitations, validation status and uncertainty. This will help regions and institutions replicate good practice without needing to become modelling experts.

Better modelling should help make decisions faster, not slower. The goal is clear evidence, proportionate requirements and stronger trust in wind energy deployment.





This policy brief builds on the MERIDIONAL D4.2 - Final report on best practice guidelines for modelling loads and performance and translates its main insights into actionable guidance. To shape the policy brief, the content of the deliverable was reworked by ICONS foundation with the support of AI and the supervision of TU Delft and TUM.

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 **meridional.eu**

 **info@meridional.eu**



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