# When “Simple Terrain” Isn’t Simple

Why Advanced Wind Modelling Pays Off — Even on Flat Sites.

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Wind energy projects are built on one critical assumption: that predicted energy production will materialize. Yet industry studies continue to show systematic underperformance. As highlighted in both the 2011 and 2021 surveys referenced in *Designing Profitable Wind Farms* (pp.11-13), European onshore projects have exhibited an average negative bias close to 9% between predicted and actual production. That bias has not materially improved over time. This raises a fundamental question:

Are we improving modelling accuracy — or simply becoming more conservative?

WindSim’s position is clear: the path forward is improved physics, not conservative padding.

You can feel the wind. But can you truly see it? That question sits at the heart of profitable wind farm development. Wind knowledge is wind power — and increasingly, wind modelling determines whether a project delivers on its promise or quietly underperforms for 20 years.

Despite decades of industry experience, European onshore wind projects have shown an average negative bias close to 9% between predicted and actual energy production. In other words: expectations have consistently exceeded reality. The uncomfortable question is why.

## The Amplifier Effect

Wind power is governed by a simple but unforgiving law:

$$E = \frac{1}{2}\rho U^3$$

Energy increases with the cube of wind speed. A modest 10% change in wind speed can result in roughly 30% change in energy production. That cubic sensitivity turns small modelling assumptions into large financial consequences.

A slight overestimation of wind speed does not lead to a slight error in revenue — it leads to amplified risk in AEP forecasts, debt sizing, P90 calculations and ultimately project IRR. In this context, accuracy is not technical perfectionism. It is financial discipline.

## The Comfort of "Simple Terrain"

In practice, many projects classified as "simple terrain" rely on linear modelling tools. The reasoning appears logical:

- Low slopes
- Limited elevation variation
- Uniform land use

If the site looks simple, the wind must behave simply. But the data tells a different story. In one of the case studies presented in *Designing Profitable Wind Farms* (p. 36), a site considered relatively simple revealed something unexpected: the areas with the highest wind speeds did not coincide with the highest elevations. Instead, terrain gradients perpendicular to the prevailing wind direction created localized speed-up effects.

An alternative turbine layout increased AEP by 10%. In a 120 MW example shown in the presentation, a 10% increase in AEP translated into approximately 20 MEUR additional accumulated profit — while wind simulation costs were only 0.05 MEUR (p. 20). That is not incremental optimisation. That is structural value creation.

## The Hidden Nonlinearity of Wind

Wind does not read contour maps. Even in flat or gently rolling landscapes, several physical effects influence flow behaviour:

- Boundary layer development over changing roughness
- Directional gradients relative to terrain slopes
- Local speed-up and sheltering
- Stability and stratification effects
- Flow separation and recirculation in moderate inclines

Linear tools assume small perturbations and steady, attached flow. But real wind is governed by the Navier–Stokes equations — inherently nonlinear (p. 31). This nonlinearity matters.

As terrain inclination increases, even moderately, differences between linear and nonlinear modelling become significant (p. 35). Stability can redirect flow around a hill instead of over it. Boundary layers can interact in unexpected ways (p. 34). Local recirculation zones can create speed deficits invisible to simplified models (p. 29). On paper, the terrain may look simple. In physics, it rarely is.

## "Right for the Wrong Reasons"

One of the most subtle risks in wind modelling is not obvious error — but tuned correctness. When simulations do not match measurements, practitioners sometimes adjust roughness values or other parameters to force agreement (pp. 38–39).

The result appears convincing: model aligns with mast data. But if the underlying physics are incomplete, horizontal extrapolation across the site becomes unreliable. Vertical shear estimates shift. Turbulence predictions distort.

The model becomes "right for the wrong reasons." And this is precisely where uncertainty grows. Total AEP uncertainty is significantly influenced by vertical and horizontal extrapolation (p. 23). Increased uncertainty lowers P90. Lower P90 increases cost of capital. Financing tightens. Risk margins expand. Physics, once again, becomes finance.

## Beyond Energy: Operational Consequences

Accuracy does not only influence production forecasts. Operational costs over 20 years are of the same order of magnitude as initial investment (p. 19). Approximately half of those costs relate to turbine service agreements.

Improper site suitability — turbines placed in high shear or high turbulence zones — can increase fatigue loading, blade wear, gearbox stress and yaw system degradation (p. 21). Advanced flow modelling helps identify these zones before concrete is poured. Reducing maintenance risk is as valuable as increasing AEP.

WindSim's modelling is based on Computational Fluid Dynamics (CFD), solving the Navier–Stokes equations with turbulence and stability physics included (pp. 31–33). Historically, CFD was computationally prohibitive. Today, cloud computing removes that constraint (p. 32). This means:

- Nonlinear flow behaviour can be captured.
- Stability and stratification effects can be modelled.
- Boundary layer development can be resolved.
- Recirculation and speed-up effects can be predicted physically — not assumed.

Importantly, CFD does not rely on tuning to compensate for simplified physics. It aims to reproduce reality.

## The Financial Perspective

From a lender's perspective, exceedance probabilities (P90, P95) are central (pp. 24–26). Higher uncertainty widens the distribution of outcomes. P90 drops. Debt sizing tightens. Cost of capital rises. Reducing modelling uncertainty:

- Improves P90
- Improves DSCR
- Improves financing terms
- Strengthens project valuation

In the presentation's "three ways to increase profit" (p. 42), improved modelling contributes to:

1. Increased AEP
2. Reduced maintenance costs
3. Better financing through reduced uncertainty

Few development activities influence all three simultaneously. Accurate wind modelling does.

## The Real Question

The industry has long asked whether CFD is necessary in complex terrain. The more relevant question today is different: If small modelling errors can reduce lifetime profit by tens of millions — can we justify assuming terrain is simple?

Wind does not behave linearly simply because we label a site "flat." WindSim's approach recognises this reality. By applying validated CFD — even where terrain appears straightforward — developers reduce bias, reduce uncertainty and unlock structural value. In wind development, physics is not optional. It is profit, and even "simple" terrain deserves serious modelling.

## Other resources

📩 Book a Meeting
🔗 Consult our Discovery Hub for validation studies, white papers, customer success stories and other information about our solutions.
🔗 Learn more: Onboarding Portal