

Valuation of digital twins in wind energy through a common classification system

Yuriy Marykovskiy¹, Avni Jain² and Sarah Barber¹
¹Eastern Switzerland University of Applied Sciences (OST), Switzerland
²Delft University of Technology, The Netherlands

A Digital Twin or just a Simulation?
“Duality and Similarity” via “Connectivity and Integration” delivers higher value.

Digital Twins (DTs) in Wind Energy

High Potential Value

Low Adoption

- Wind-energy digitalisation barriers: Reusable data frameworks, access to data, and cross-organisation collaboration.
- Systems-engineering burden: Developing, validating, deploying, and maintaining DTs for complex, coupled assets and fleets.
- Inconsistent terminology (hindering maturity benchmarking and ROI valuation) & a technology “trough of disillusionment” phase.

What do we propose?

- Adopt a common DT definition and a shared classification system (Digital Twin Taxonomy).
- Connect DT functional capability levels to concrete use cases (e.g. Table 1) and a value - complexity decision matrix (e.g. Table 2).

For more information, check out:

Joint Best Practices for the Classification and Valuation of Digital Twins in Wind Energy by IEA Wind Task 43

Role	Activity	Digital twin use case				
		Supervisory	Operational	Simulation / Prediction	Intelligent / Learning	Autonomous / Management
Examples: Project Developer	Turbine siting and layout	Ingest and store wind simulation or on-site measurement data. Collect and display historical wind resource data or seabed baseline planning data.	Estimate energy production at different sites. Assess subsea and seabed turbine placement.	Enhance weather or measurement data with regional simulations to enable optimised turbine placement.	Evaluate the accuracy of simulations and update models accordingly using AI/ML. Make site layout decisions.	Automatically optimise measurement system positioning, e.g. through autonomous drone measurements.

Operator	Energy production optimisation	Track and store turbine availability and energy production data.	Perform operational analysis to derive turbine efficiency information.	Simulate and predict turbine operations under various conditions / control strategies. Perform proxy measurements by combining available data with simulation outputs.	Dynamically improve models via model updating. Learn optimal operational strategies from historical performance.	Automatically adjust control strategies for maximum energy production.

Table 1. Digital twin use cases. Descriptions reflect best-practice capability targets; autonomous functions assume predefined constraints and appropriate human oversight.

	Supervisory	Operational	Simulation / Prediction	Intelligent / Learning	Autonomous / Management
Potential relative complexity (yellow → purple = low → high)					
Physical system	The asset and sensors, wind measurement devices	+ Sensor measurement uncertainty and calibration information			+Access to wind turbine controller +Controllable actuators +Autonomous drones
Connection system	Data stream from sensors		+Data fed into simulation models, one-way automated or manual coupling	+Results feed back into simulation set-up	+Near real-time data stream, two-way coupling, on-edge compute, wind turbine controller connection
Digital system model	Assets / component identifiers	+Geometrical models, geospatial models	+Physics models, surrogate models	+Data driven models, Bayesian models	+Behaviour models +Rule models
Digital system data	Sensor data storage, integration of multiple sources	+Storage of analysis results	+Defined metadata	+Standard semantics	
Digital system services	Dashboards	+Analysis code/tools	+Physics-based, data-driven, or hybrid solvers, UIQ, V&V, simulation visualisation	+DSS, model updating +Dashboards, alarms, anomaly detection	+Control algorithms, grid control
Potential value (purple → yellow = low → high)					
Reduced OPEX	Improved operating diagnostics	+Less down-time	+Improved prediction accuracy	+Improved operating decisions	+Improved wind farm control or automation
Reduced CAPEX	Improved design diagnostics	+Improved wind turbine design	+Improved wind farm layout	+Improved design decisions	+Improved wind farm control
Increased revenue	Improved turbine availability	+Improved turbine performance		+Reduced risks	
Improved community impact	Transparent monitoring of community-relevant indicators (e.g. noise, visibility)	+Assessment of monitored indicators against agreed thresholds	+Simulation of visual, acoustic, and environmental impact scenarios	+Learning from impact data & stakeholder feedback to recommend mitigation options	+Automated generation and evaluation of mitigation options under constraints
Improved environmental impact	Improved environmental indicators	+Assessment against regulatory or ecological limits	+Simulation of environmental impacts and mitigation scenarios	+Improved policies based on learned environmental response patterns	+Improved wind farm control
Improved energy security	System-level visibility of availability and production status.		+Simulation of stress and disruption scenarios affecting supply.	+Improved resilience planning, reduce risks	
Improved supply chain	Improved tracking of components	+Improved supply chain planning		+Learning supplier and logistics patterns to improve planning decisions	+Automated optimisation of inventory, logistics, and scheduling under constraints
Workforce benefits	Improved situational awareness for operators and engineers	+Improved use of staff skills	+Use of simulated scenarios for training and safety analysis	+Optimal deployment of crews based on intelligent DSS	+Improved scheduling, safer operations

Table 2. System functionality value matrix template (with representative examples of increasing complexity and value).

Excerpts from the Digital Twin Taxonomy

