Energy Boosting Upgrades and Lifetime Extension

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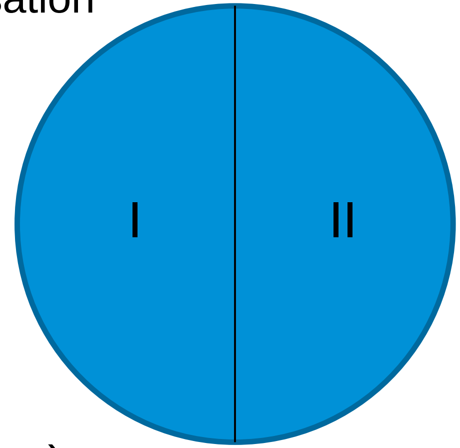
Agenda

Workshop split into two parts

PART I

- Products overview and description (~30 minutes)
  - Power Performance Optimisation
  - Aerodynamic Upgrades
  - Validation
  - Lifetime Extension

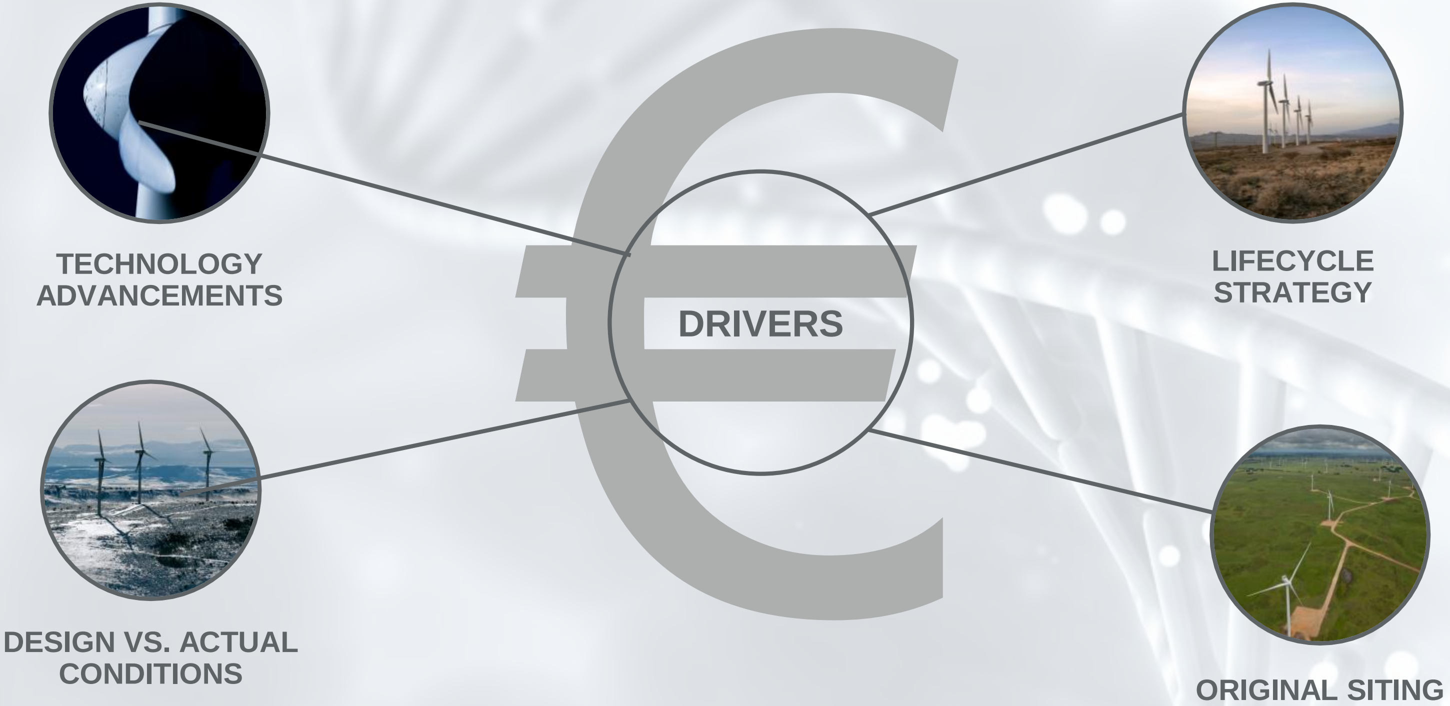


PART II

- Q&A workshop (~30 minutes)

The drivers of turbine upgrades

Technology advancements and better understanding of loads and siting enable upgrades



PowerPlus®

Power Performance Optimisation and Aerodynamic upgrades

Vestas

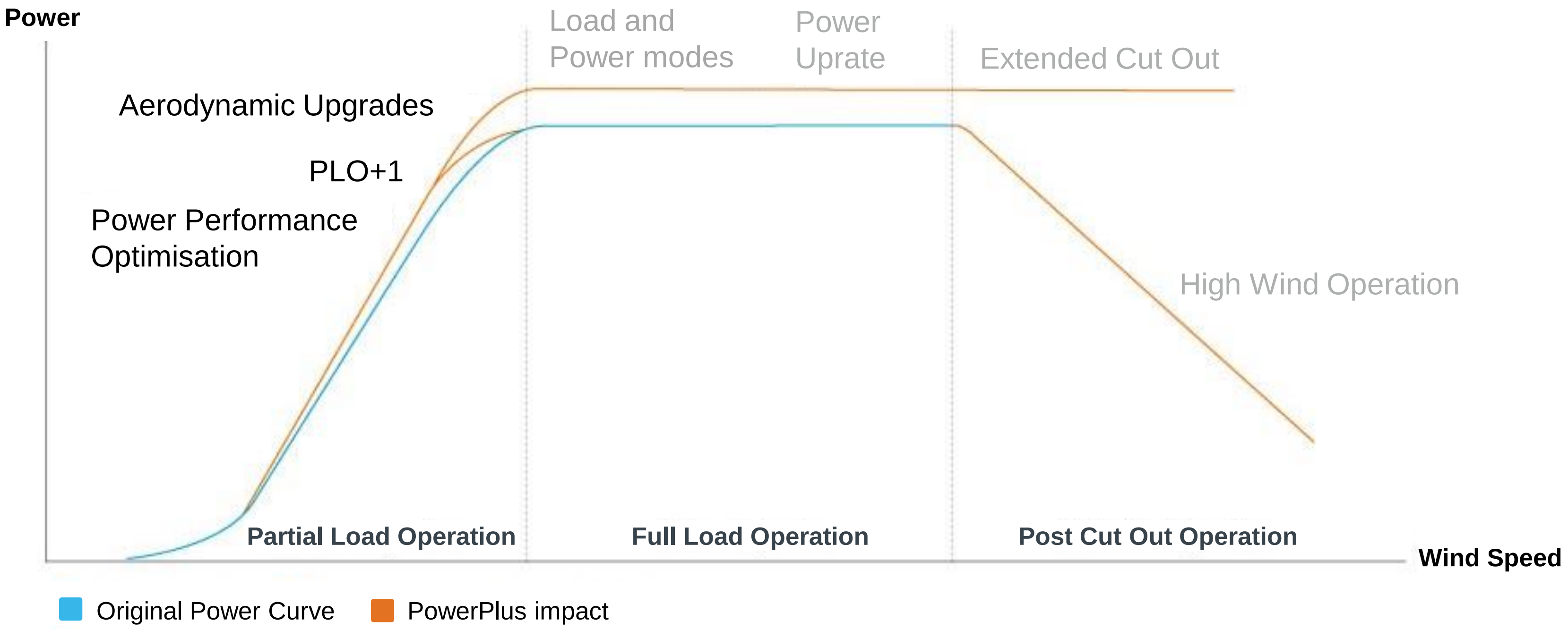
Wind. It means the world to us.™

The Power Performance Optimization (Software algorithms) impact the slope of the power curve by optimizing operational settings such as wind speed, wind direction and thrust to local conditions.

Aerodynamic Upgrades impact the slope of the power curve by lifting up blades' efficiency.

Upgrades for the entire power curve

Products within the PowerPlus® line address different areas of the power curve



Classification: Restricted

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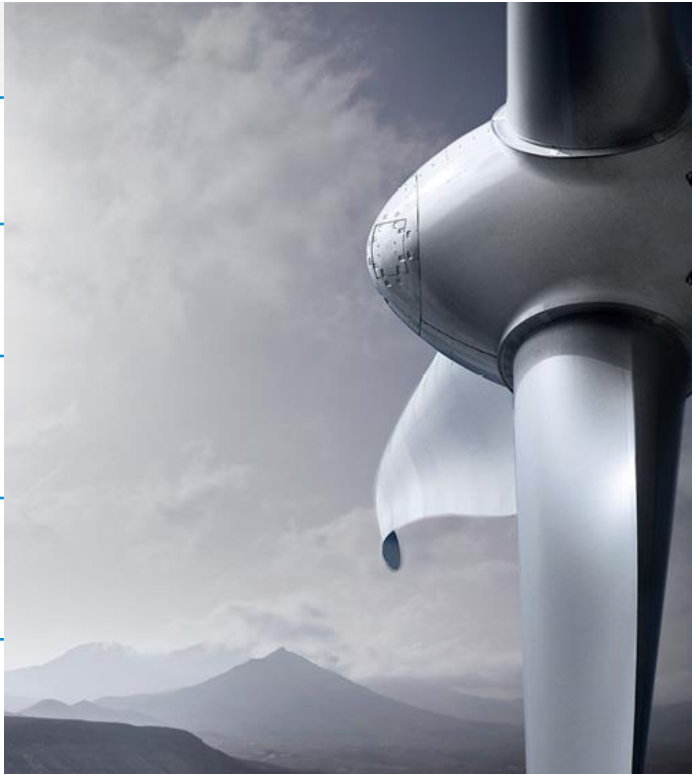
Power Performance Optimisation

Smarter turbines in low wind conditions

Features	Description
Wind Estimator ⚖ *Load Neutral*	Utilizing the entire rotor as an anemometer into to record more accurate wind measurements
Adaptive Wind Sensing ⚖ *Load Neutral*	Continuous self-calibration of optimal yaw position based on maximum power
Extended Power Boost	Sharpens the knee of the power curve by extending the generator boost when entering full load
Variable Thrust Limiter	Improves power performance in partial load operation by enabling an air density-dependent thrust limiter
Partial Load Operation +1	Improves power performance in partial load operation by enabling sector wind direction thrust limiter



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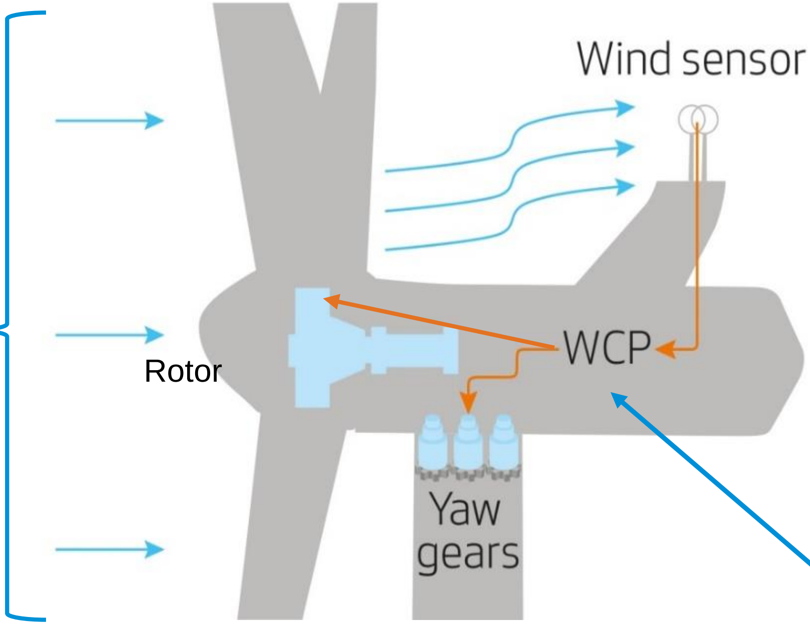
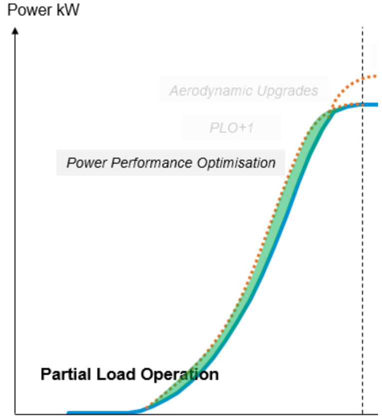
Wind Speed Estimator Technical Description

Optimized wind measurement technique

The algorithm allows Vestas to more accurately measure the wind speed in front of the **entire rotor**





Wind Speed Estimator replaces wind correlation parameters **in partial load operation**, and uses the more accurate wind speed instead

It **reverses the measurement process** by calculating the wind speed from the turbine's pitch, speed, and power readings

+0.2-0.3% AEP

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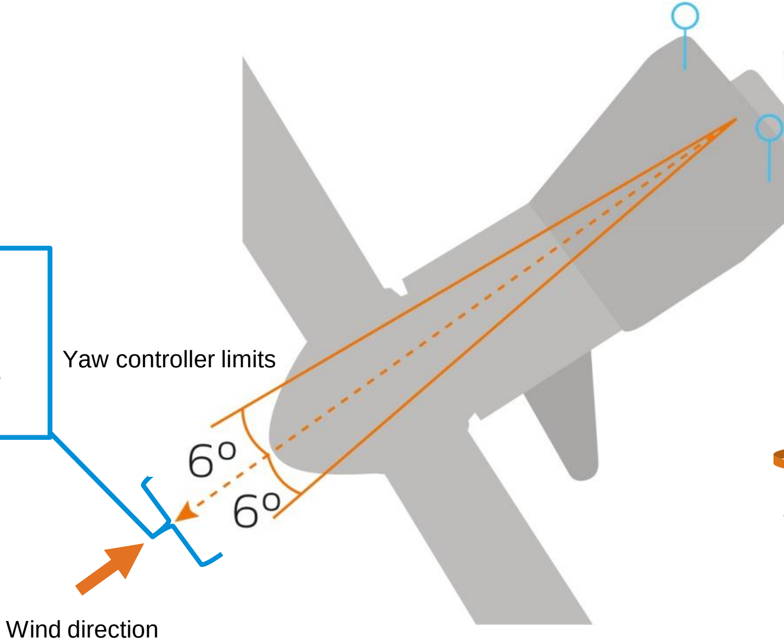
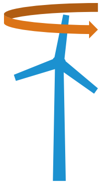
Adaptive Wind Sensing Technical Description

Automatic and continuous self-calibration of optimal yaw position

Adaptive Wind Sensing continuously calibrates its upwind yaw positions, updating the wind correlation parameters for each **individual wind turbine**

The algorithm uses the natural variation in wind direction (+/- 6 degrees) to calculate optimum yaw position based on **average peak power production**





The turbine **will not yaw more than before**, as the improvement is based on the natural variation in wind speed only

+0.2-0.3% AEP

Power Performance Optimisation Vestas

Aplicability matrix for Vestas turbines

	V80- 1.8/2.0MW	V90- 1.8/2.0MW	V90- 3.0MW	V100- 1.8/2.0/2.2MW	V110- 2.0/2.2MW	V105/V112/V117/V126- 3.0/3.3/3.45MW
Variable Thrust Limiter (VTL)				•	•	•
Wind Estimator (WE)	•	•	•	•	•	•
Adaptive Wind Sensing (AWS)	•	•	•	•	•	•
Extended Power Boost (EPB)	•	•	•	•	•	•
Partial Load Operation +1 (PLO +1)		•	•			

Vestas Controller Upgrade (for VMP5000/VMP6000)

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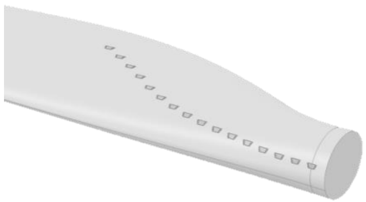
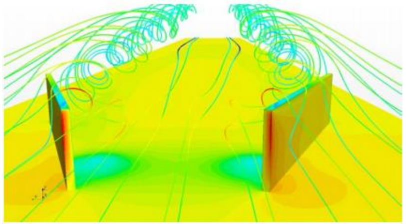
Aerodynamic Upgrades

Improving the aerodynamic performance

- Shape of root region of blade is an aerodynamic compromise for structural performance**:**
- **Vortex Generators**

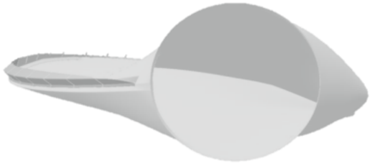
  This delays air flow separation and *increases lift*

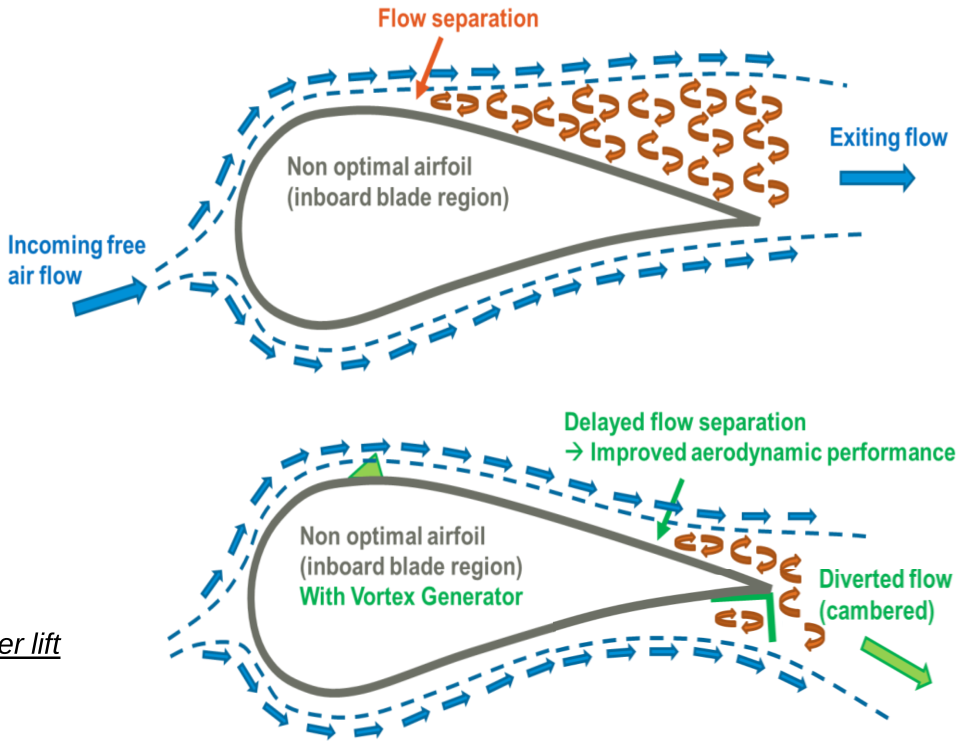




- **Gurney Flaps**

  Increase pressure differential across the aerofoil, producing *greater lift*





Up to 2.0% AEP gain (up to 3.5% for non Vestas turbines)
Aerodynamic benefit is amplified if both upgrades are used together. Both are certified by DNV-GL for load compliance

Vestas

Aerodynamic Upgrades

Aplicability matrix for Vestas turbines

	V80- 1.8/2.0MW	V82- 1.65MW	V90- 1.8/2.0MW	V90- 3.0MW	V100- 1.8/2.0/2.2MW
Vortex Generators	●	●	●	●	●
Gurney Flaps			●	●	●

*Vestas offers Vortex Generators for multiple non Vestas turbine platforms with AEP gains up to 3,5%

Vortex Generators

Aplicability matrix for choosen multibrand platforms where AEP gain falls between 1.5%-3.5%

GE	**2.5xl-2.5MW 1.5sl/s/e-1.5MW 1.6xl/e-1.6MW**
Suzlon	**S88-2.1MW**
Clipper	**CL89,CL93,CL96-2.5MW**
Nordex	**N100-2.5MW**
Acciona	**AW82-1.5MW**
Gamesa	**G80/G87/G90-2.0MW**
Mitsubishi	**MHI102-2.4MW**
GoldWind	**GW82/GW87-1.5MW**
EWT	**DW61-0.9MW**

Implementation

Occupancy times

Features	Description
Aerodynamic Upgrades	1 day for installation per blade (optimum conditions)
Power Performance Optimisation	1-2 hours for remote software upgrade and activation of PPO per turbine
Controller Upgrade	4 hours for controller upgrade per turbine (only if needed)

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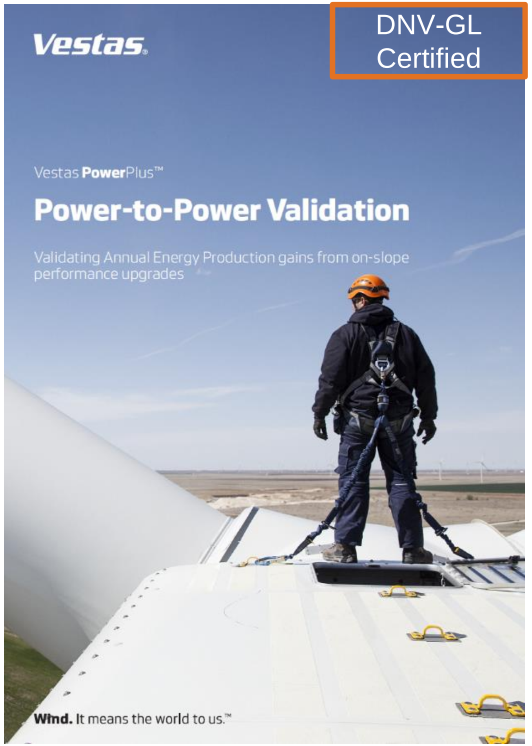
VALIDATION METHODS

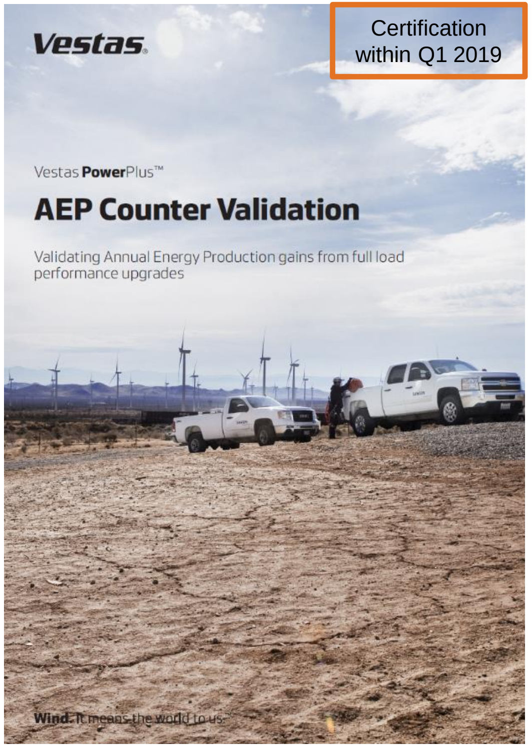
- DNV-GL Certified validation methods allow are used to validate the AEP gain

DNV-GL Certified

DNV-GL Certified



Certification within Q1 2019



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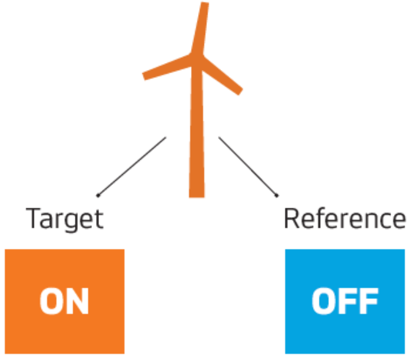
Upgrade Validation

Measuring expected gains

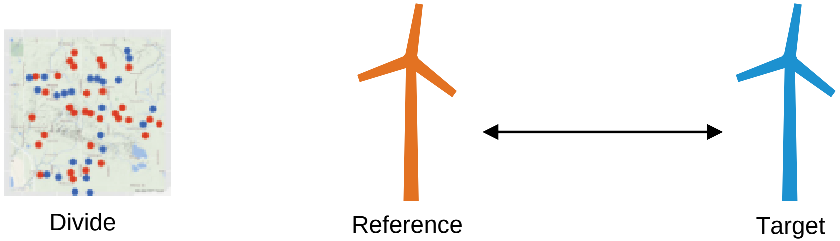
- Difficult to validate gains from a power curve comparison
- DNV GL Certified validation methods decrease uncertainty from **5% to 0.2%**

Toggle Validation (PPO)



- All turbines upgraded
- 3-6 months validation period

Power to Power (AU)

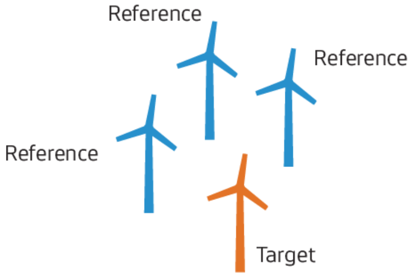


- 50% of turbines upgraded initially
- 12 month validation period

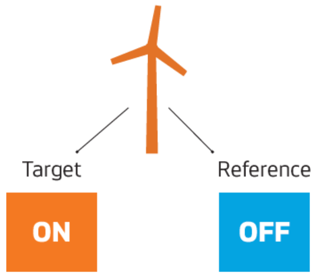
Toggle Validation **Description**

Shifting from multiple turbine target-reference data to single turbine target-reference drastically improves the validation set-up

Traditional target-reference set up



Toggle Validation set up



Benefits

- All turbines can be upgraded
- Shorter validation periods
- No complex transfer functions
- Limited use of historical data

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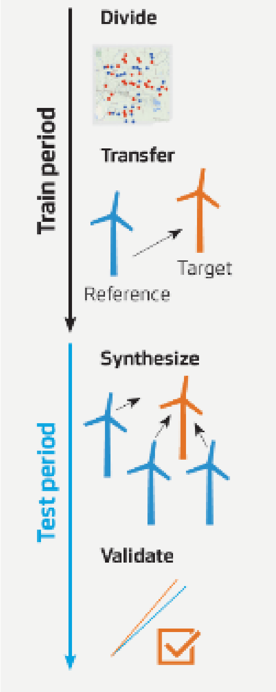
Power-to-Power Method **Methodology**

Target reference method for validating gains in the Partial load operation region of the power curve



1. Vestas' Power-to-Power method is based on standard ten-minute average values obtained from the turbine's Supervisory Control and Data Acquisition (SCADA) unit.
2. It utilizes actual power performance as derived from the SCADA data points
3. Park is divided into reference and target turbines where each upgraded turbine (target) is compared to a set of unmodified control turbines (reference).
4. Data is split into wind sectors, to accommodate wake effects.
5. Transfer function for transferring actual power performance measurements between targets and references is calculated
6. Synthesize target turbine power measurements based on all reference turbines using a weighted average approach.
7. Percentual yield difference (AEP gain) is computed based upon direct comparison of Target and Reference power curves using synthesized power measurements to Reference turbine power.

Validation Examples

Three most recent sites in Northern Europe for Power Performance Optimization

Country	Turbine type	Estimated % AEP gain	Delta	Measured % AEP gain
Sweden	V112 3.3MW	0,60	+0,23	0,83
Great Britain	V90 2MW	0,36	+0,31	0,67
Sweden	V112 3.3MW	0,60	+0,18	0,78

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Validation Examples

Four most recent sites in Europe for Aerodynamic Upgrades

Country	Turbine type	Estimated % AEP gain	Delta	Measured % AEP gain
Italy	V100 1.8MW	1,10	+0,38	1,48
Germany	V90 2MW	0,80	+0,12	0,92
Italy	V90 2MW	1,16	+0,70	1,86
Spain	V90 3MW	1,10	+0,66	1,76

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Upgrade Payment Options

Flexible payment methods for your business case

Payment Method	Benefit
Full Amount Upfront	• Low transactional cost • No recurring payments • Simple contact structure
Split Payment (Over X years)	• Annual payment – option to postpone first payment until 1 year after implementation • Cost of product is aligned with wind park revenue increase • Price increase (~5 %/year) to minimize negative cash flow
Included in AOM contract	• Similar to Split Payment, but contract length equal to AOM contract • Relevant if AOM contract is being renegotiated
Annual Revenue Sharing (Over X years)	• Vestas shares gain revenue • Reduced electricity spot price risk

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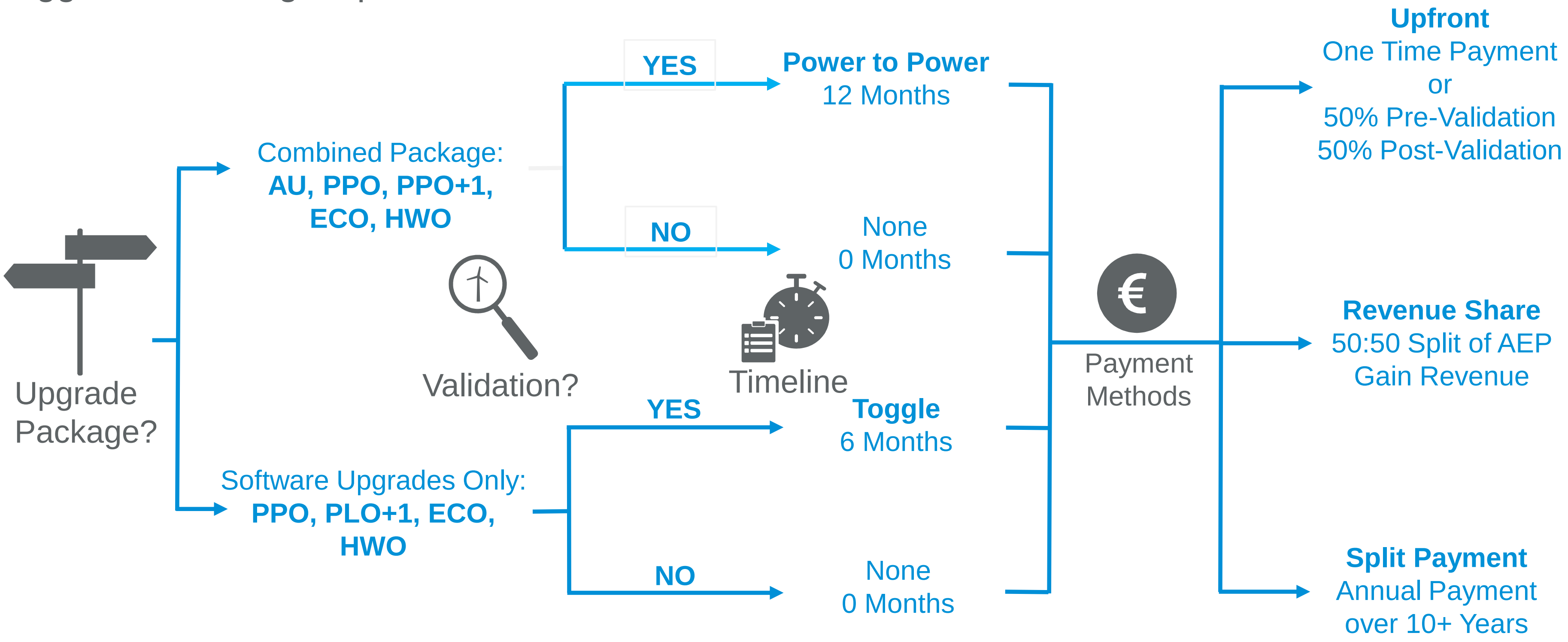
Route Map to Implementation

Suggested Package Options



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Lifetime Extension with Vestas LifePlus™

Overview of Vestas' approach to Lifetime Extension

Vestas applies a proven lifetime extension assessment methodology that is based on proprietary and certified tools

Data collection	Lifetime extension assessment			Implementation

Data collection

- Basic site and turbine information
- Operational settings
- SCADA data
- Maintenance and inspection reports
- Site permissions

Lifetime extension assessment

Load modelling & analysis[1]

Calculating consumed life and remaining lifetime of the wind turbine's structural components in Vestas SiteCheck®

End-of-life inspections

Assessing the current condition and structural integrity of your wind turbines through thorough inspections

Report & Certification[2]

Documenting and certifying of findings and formulating life extension strategy to maximize your business case

Implementation

- **Fleet Optimization**
- **Maintenance Partnering**
- **Parts & Repair**

[1] *Applicability of load analysis depends on availability and type of load models and accurate climatic data*
[2] *Certification of life extension by a third party is optional in most countries*

Load analysis

Vestas SiteCheck® is a certified tool used to calculate the expected remaining lifetime and define the end-of-life inspection scope

- Climatic data
- Turbulence data
- Weibull parameters
- Turbine coordinates
- Topography
- Inflow angles

Vestas **SiteCheck®**

- Climatic data
- Turbulence data
- Weibull parameters
- Turbine coordinates
- Topography

Life extension **implementation**

- Fleet Optimization
- Maintenance Partnering
- Parts and Repairs

+ GWh per year

CFD for Power Plus

Computational fluid dynamics

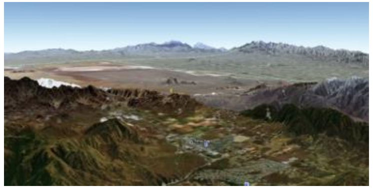
- For projects which are complex in nature – Complexity due to terrain, complexity due to wind flow or a combination of both CFD is used for the analysis of the projects.
- 36-sector analysis is performed. Helps in accurately estimating wind shear, inflow angle, wind veer etc.

<u>CFD tool – Vestas FOAM</u>

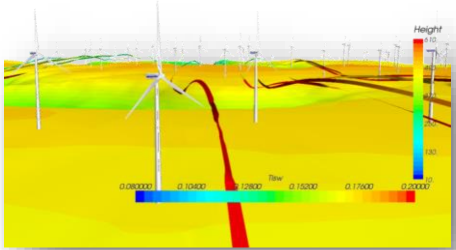
- Integrated package developed by Vestas CFD Group based on Open FOAM CFD toolkit
- Body-fitted mesh over the terrain surface - terrain geometries are directly resolved.
- Particularly well-suited for highly complex terrains, e.g. steep slope with hills, mountains, cliffs, forests, etc.
- Improved prediction of flow separation - outperforms the linearized WAsP model.
- Different turbulence methods & different level of CFD analysis is available to solve highly complex wind flow phenomenon.

> CFD is used for all the projects with complex terrain. The results from the CFD analysis is also used in the load analysis (wind shear, turbulence, inflow angles – used as an input for load analysis)

<u>Example of a complex terrain</u>

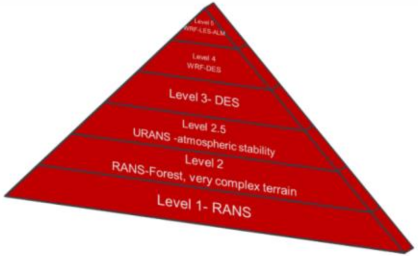


<u>CFD result visualization</u>



<u>CFD support pyramid.</u>

The abbreviation is for the main CFD methods used at each level

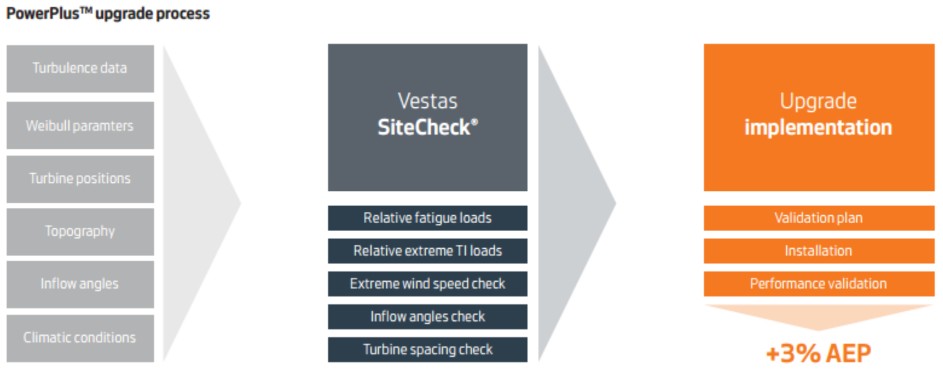


Classification:

Load data analysis

Utilizing Vestas SiteCheck®

- To identify the site-specific potential of PowerPlus® features ASVE team utilises SiteCheck® certified by DNV-GL
- Vestas SiteCheck® is a set of tools and processes used to analyse the conditions at a given site and determine the load margins that allow increased production
- Vestas SiteCheck® receives six main data inputs from the given site
- These data points are then used to approve the site for upgrades based on five parameters
- The evaluation of the structural safety is performed according to IEC 61400-1, edition 3



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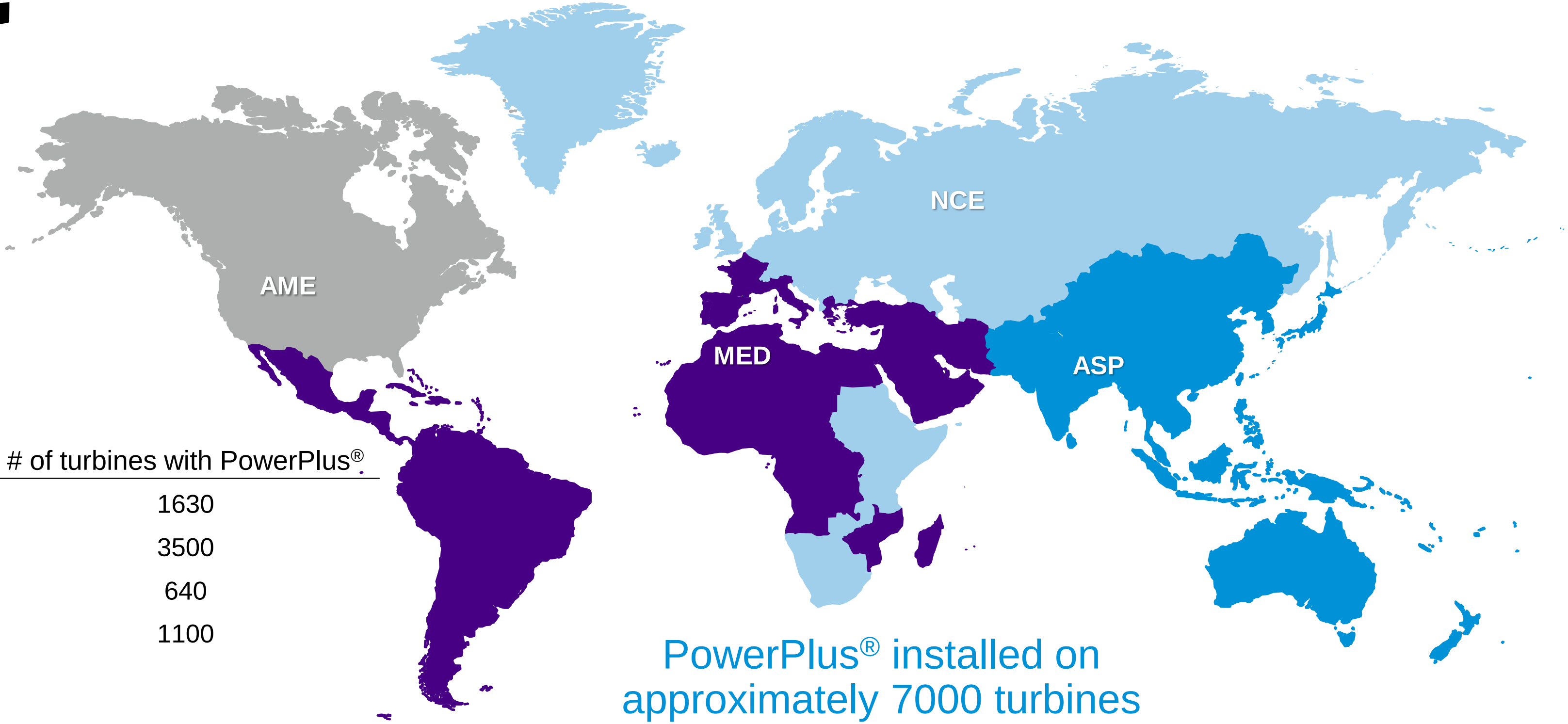
Q&A



SBU	# of turbines with PowerPlus®
NCE	1630
AME	3500
ASP	640
MED	1100

PowerPlus® installed on approximately 7000 turbines across the globe

* Includes retrofit and factory installations

Vestas

How to get **more** from your assets?

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