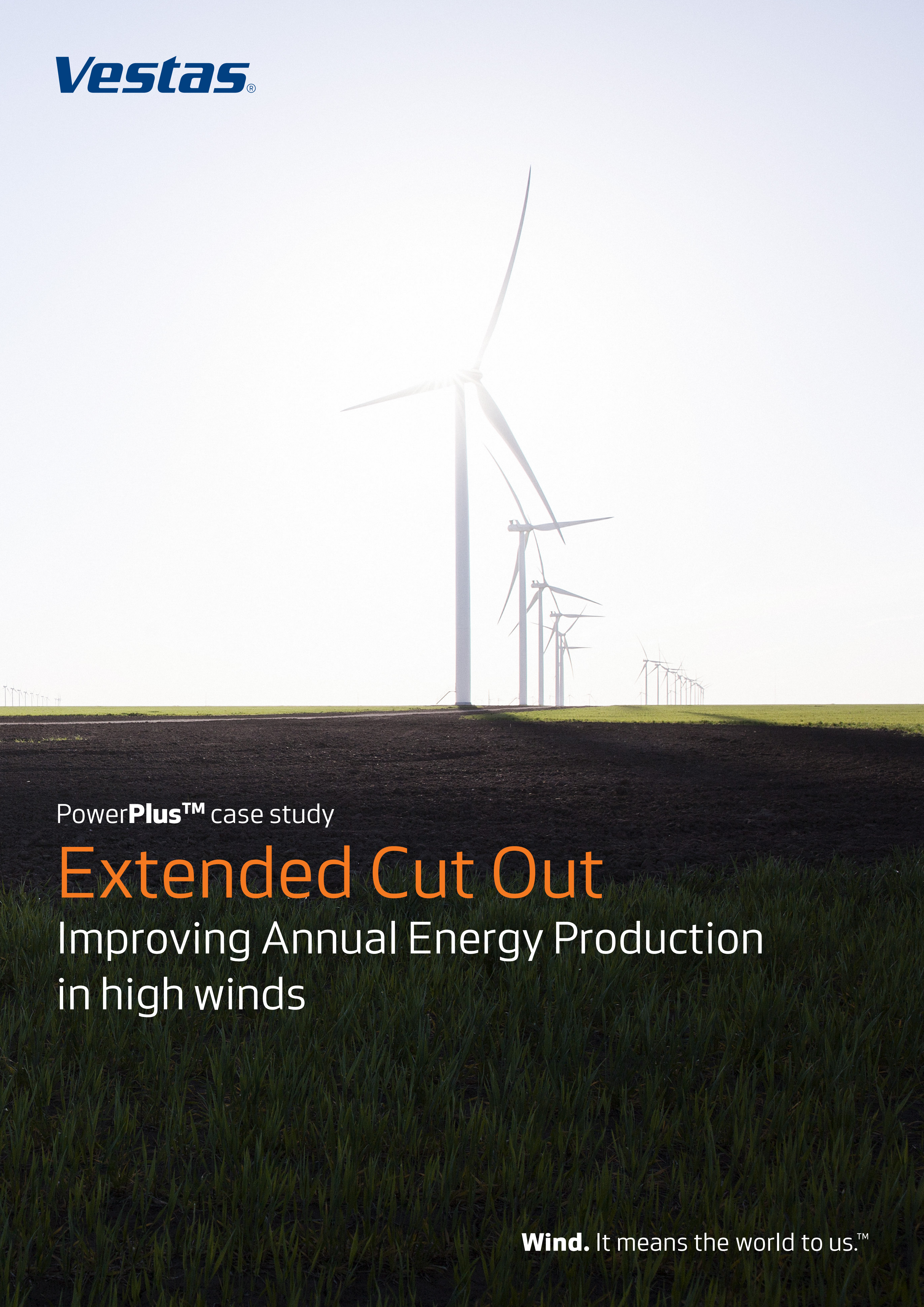

PowerPlus™ case study

Extended Cut Out

Improving Annual Energy Production in high winds

Wind. It means the world to us.™

Introduction

More than 3,000 turbines already reap the benefits of PowerPlus™, a suite of upgrades focusing on optimizing power production for installed turbines, from partial load to post-cut out operation.

Vestas has developed Extended Cut Out, which allows turbines to operate beyond their original cut out speeds to capture the full potential of strong winds. By increasing the cut out wind speed, Extended Cut Out can deliver an AEP improvement of up to 3%, and even up to 5-7% at sites with very advantageous climatic conditions.

This case study presents field results from Extended Cut Out implementations, as well as an introduction to the technology and methodology behind the upgrade.

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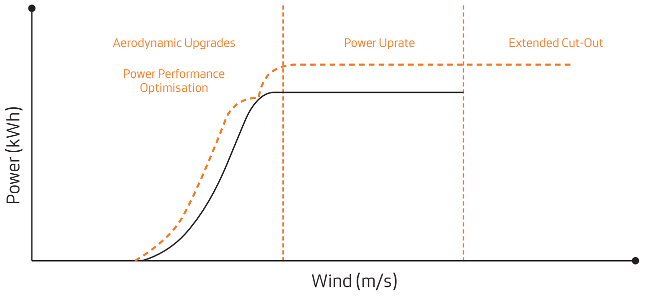
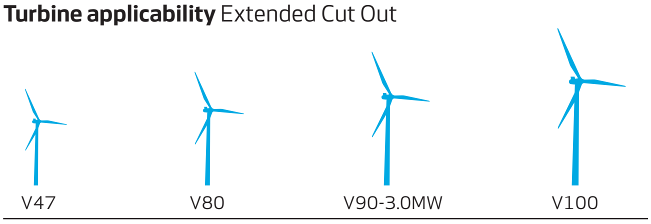
Power**Plus™** solutions and impact on power curve



Turbine applicability Extended Cut Out




Pure. Performance

Case 1: Wind farm gains **4.23% AEP** across +150 WTGs

Reaping the benefits of strong wind resources

To get the most out of strong wind resources, wind farm owners choose turbines that are designed to perform optimally under such climatic conditions. However, even the best suited turbines will not capture the full potential of the available energy unless they are tuned to match the site-specific climate.

As a site-specific upgrade, Extended Cut Out can improve the power capture significantly during high wind speeds. At sites with highly beneficial wind distributions, the AEP gain captured in the power curve can be as high as 5%.

An example of this scenario is presented here, where a wind farm consisting of more than 150 V100-1.8MW turbines has been upgraded with Extended Cut Out. Based on a wind power plant assessment carried out with Vestas SiteCheck® tools, the cut out speed was increased from 20 m/s to 25 m/s, while the re-cut in speed was increased from 18 m/s to 23 m/s.

AEP gain from energy capture in high wind speeds

In the case at hand, the validated AEP gain is 4.23%. This is a significant AEP gain, which is only achievable at sites with very favorable wind speed distribution. Moreover, the gain is derived from two different, yet related, benefits of the Extended Cut Out upgrade.

Firstly, the increased cut out speed allows the turbine to operate at wind speeds that the original cut out speed would have protected it against. With a propitious wind speed distribution, this increases production relatively more than at a site with lower wind speed averages. A significant amount of additional production hours in the wind speed interval between 20 m/s and 25 m/s was enabled due to the upgrade. This part of the gain is what can be identified in the new power curve.

Specification of upgrade

Turbine model	V100-1.8MW
Number of turbines	+150
Original cut out speed	20 m/s
Original re-cut in speed	18 m/s
Extended Cut Out speed	25 m/s
New re-cut in speed	23 m/s
Validated AEP gain	4.23%
Data training period	Jun 14 - Dec 14
Data testing period	Jun 15 - Dec 15

Climatic conditions at the site

Normal Wind Conditions (annual)	
Weibull A parameter	8.9 m/s
Weibull k parameter	1.9
Site hub height avg. WS	7.9 m/s
Turbulence intensity (TI15) (avg.)	6.3 %
Turbulence intensity (TI15) (std.)	2.7 %
Average wind shear	0.22
Average inflow angle	1°
Extreme Wind Conditions (50 year)	
Extreme WS (10 min. avg.)	39.6 m/s
TI at extreme WS	7.2 %
Survival (2 second gust) WS	48.2 m/s
Temperature and Air Density	
Average temperature	4.9 °C
Min. temp., P1	-22.7 °C
Max. temp., P99	35.4 °C
Avg. air density	1.120 [kg/m3]

Secondly, the gain is achieved by moving the hysteresis gap from 20-18 m/s to 25-23 m/s.

This means that the lost production from the original 20 m/s cut out to the 18 m/s re-cut in is recaptured. Thus, while the Extended Cut Out itself enables production between 20 m/s and 25 m/s, the significant increase in production is captured between 18 m/s and 23 m/s due to the adjusted hysteresis gap.

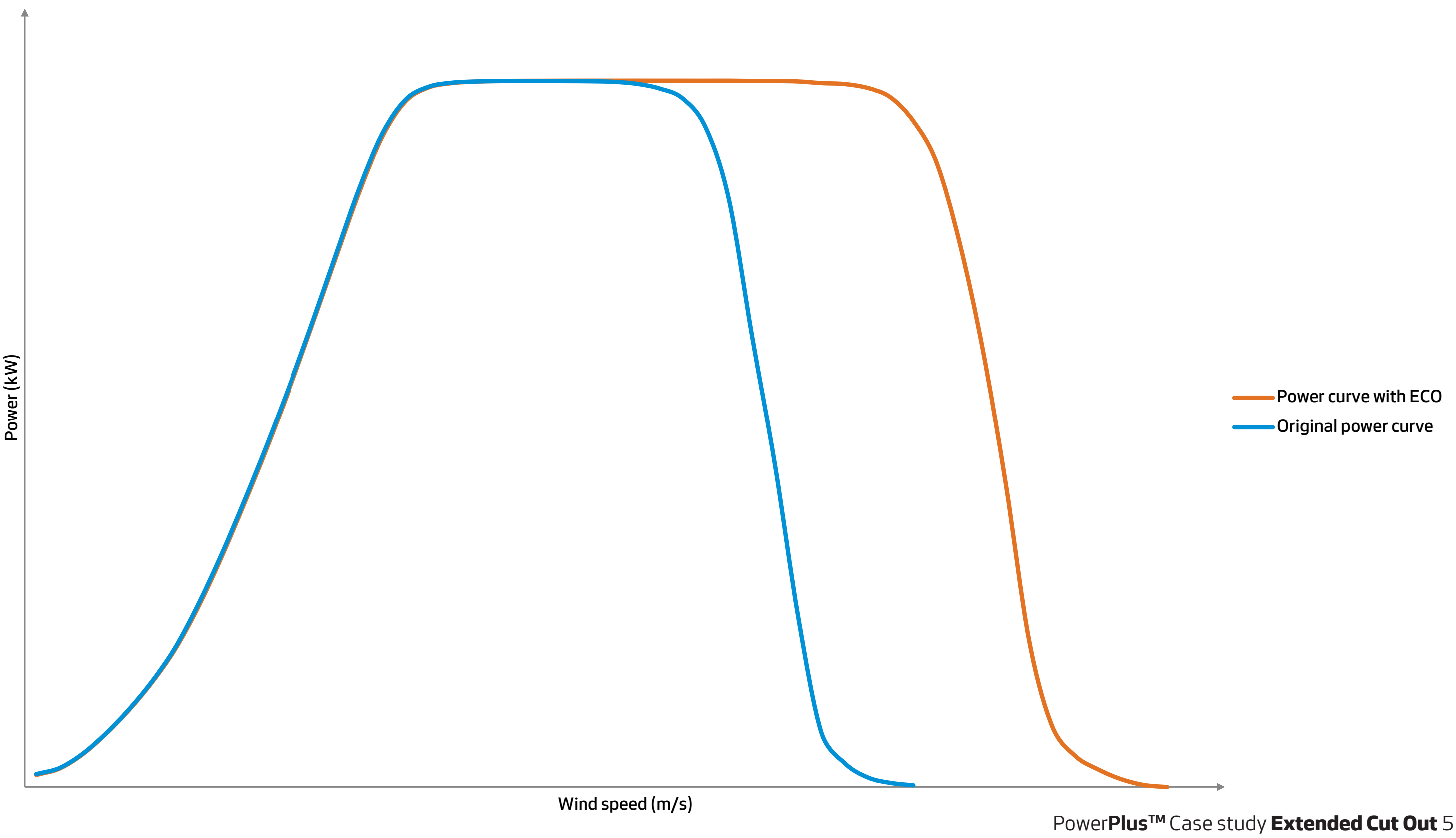
Validating the performance gain

To ensure an accurate pre-post validation of the actual gain, six months of post-implementation data was tested against six months of pre-implementation data. The number of data points from each turbine combined with the large amount of turbines made a strong base for the validation.

This is a good example of what Vestas can do to prove the impact of our upgrades and assure customers that we deliver on promise. While the case presented here has achieved gains from Extended Cut Out that would be difficult to replicate without similar wind resources, it demonstrates the ability of the upgrade to capture the full potential of high wind speeds.

Pre-post power curve

The validated pre-post power curve for the site



Case 2: Multiple upgrades deliver **2.65% AEP** gain on +40 WTGs

Combining Extended Cut Out with Power Uprate

When wind parks are upgraded with PowerPlus™, different features can be implemented depending on site-specific conditions.

For some sites, it only makes sense to implement one feature, but for others, it might make the most sense to implement the full range of PowerPlus™ suite if the load margins allow it. Vestas SiteCheck® provides an in-depth assessment with the needed input to make a recommendation of which upgrades to implement.

In this case, Power Uprate and Extended Cut Out was implemented based on the assessment from Vestas SiteCheck®. The cut out speed was increased from 20 m/s to 24 m/s, while the re-cut in speed was increased from 18 m/s to 22 m/s, maintaining a hysteresis gap of 2 m/s. Moreover, Power Uprate was applied to the turbines, increasing the maximum power mode from 1.8MW to 1.85MW.

AEP gain from multiple PowerPlus™ features

With the combination of Extended Cut Out and Power Uprate, the validated AEP gain for the site was 2.65% over the one year validation period.

The relatively high AEP gain is mainly derived from the Power Uprate feature, which introduces a new power mode to the turbine, however, the gain from Power Uprate is boosted by the application of Extended Cut Out. The synergy effect from the two upgrade features is captured with production above 1.815MW and 20 m/s, which neither of the features would be able do deliver without the other.

Specification of upgrade

Turbine model	V100-1.8MW
Number of turbines	+40
Original cut out speed	20 m/s
Original re-cut in speed	18 m/s
Extended Cut Out speed	24 m/s
New re-cut in speed	22 m/s
Power Uprate	1.8MW to 1.85MW
Validated AEP gain (combined)	2.65%
Data training period	Dec 13 - Dec 14
Data testing period	Dec 14 - Dec 15

Climatic conditions at the site

Normal Wind Conditions (annual)	
Weibull A parameter	8.0 m/s
Weibull k parameter	1.8
Site hub height avg. WS	7.1 m/s
Turbulence intensity (TI15) (avg.)	7.8 %
Turbulence intensity (TI15) (std.)	2.3 %
Average wind shear	0.20
Average inflow angle	2°
Extreme Wind Conditions (50 year)	
Extreme WS (10 min. avg.)	34.3 m/s
TI at extreme WS	7.3 %
Survival (2 second gust) WS	41.8 m/s
Temperature and Air Density	
Average temperature	8.1 °C
Min. temp., P1	-16.1 °C
Max. temp., P99	44.8 °C
Avg. air density	1.054 [kg/m3]

Validation of gain
The pre-and-post validation of the AEP gain was based on one year pre-implementation data and one year post-implementation data. The two data sets were tested against each other, and the validated gain was 2.65%.

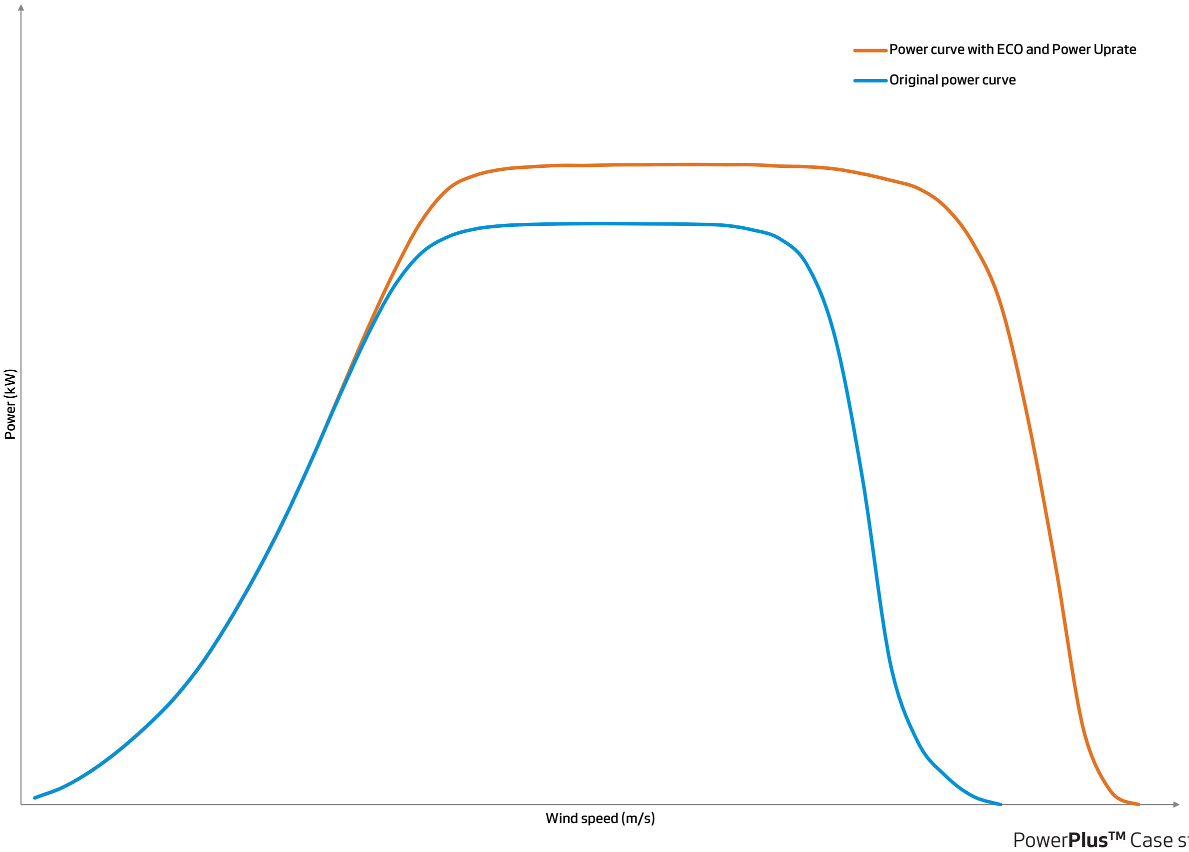
This is an example of value capture through a combination of PowerPlus™ features, and how they together can increase production significantly.

Boosting AEP with Power Uprate
Power Uprate is a PowerPlus™ upgrade that equips the turbine with a new power mode, enabling it to produce above its original rated power under certain circumstances.

Depending on site-specific wind and topographical conditions, the new power mode can optimize the energy output and increase AEP by up to 5%.

The upgrade is available for:
V47-660kW
V82-1.65MW
V90-1.8MW
V100-1.8MW
V112-3.0MW
V117-3.3MW
V126-3.3MW

Pre-post power curve
The validated pre-post power curve for the site



Case 3: +60MW wind farm gains **0.96% AEP** in high wind speeds

Optimizing production beyond 25 m/s

In cases 1 and 2, we show examples where Extended Cut Out is implemented to increase the wind speed to 25 and 24 m/s respectively, however, the upgrade feature also applies to turbines that are already designed to operate in these conditions. Sites where a cut out speed of 25 m/s is not sufficient to capture the full value of the high winds are eligible for cut out speed extensions up to 30 m/s.

Here, the cut out wind speed was increased from the original 25 m/s to 29 m/s, while the re-cut in speed was increased from 20 m/s to 24 m/s. This enables the wind park to optimize the energy capture when the wind speeds are at their highest, and the result is an AEP gain of 0.96% over a 1 year validation period.

Lower, but significant AEP gain

While cases 1 and 2 show very high AEP gains due to favorable climatic conditions and additional PowerPlus™ upgrades, not all wind parks can expect gains in that range. Nonetheless, this does not mean that there are not significant upsides to be achieved through Extended Cut Out.

The 0.96% AEP gain validated in this case is a strong example of the ability of Extended Cut Out to capture significant value that otherwise would be lost.

It also serves as proof to the applicability across turbine models, as the AEP gain here is achieved on V90-3.0MW turbines opposed to the V100-1.8MW in cases 1 and 2. The versatility of Extended Cut Out makes a strong-case for fleet-wide implementation.

Specification of upgrade

Turbine model	V90-3.0MW
Number of turbines	+20
Original cut out speed	25 m/s
Original re-cut in speed	20 m/s
Extended Cut Out speed	29 m/s
New re-cut in speed	24 m/s
Validated AEP gain	0.96 %
Data training period	Jun 14 - Jun 15
Data testing period	Jun 15 - Jun 16

Climatic conditions at the site

Normal Wind Conditions (annual)	
Weibull A parameter	8.9 m/s
Weibull k parameter	2.2
Site hub height avg. WS	7.9 m/s
Turbulence intensity (TI15) (avg.)	7.3 %
Turbulence intensity (TI15) (std.)	1.7 %
Average wind shear	0.19
Average inflow angle	0°
Extreme Wind Conditions (50 year)	
Extreme WS (10 min. avg.)	40.0 m/s
TI at extreme WS	11.0 %
Survival (2 second gust) WS	53.2 m/s
Temperature and Air Density	
Average temperature	7.0 °C
Min. temp., P1	-3.0 °C
Max. temp., P99	20.0 °C
Avg. air density	1.250 [kg/m3]

Validation of lower AEP gains

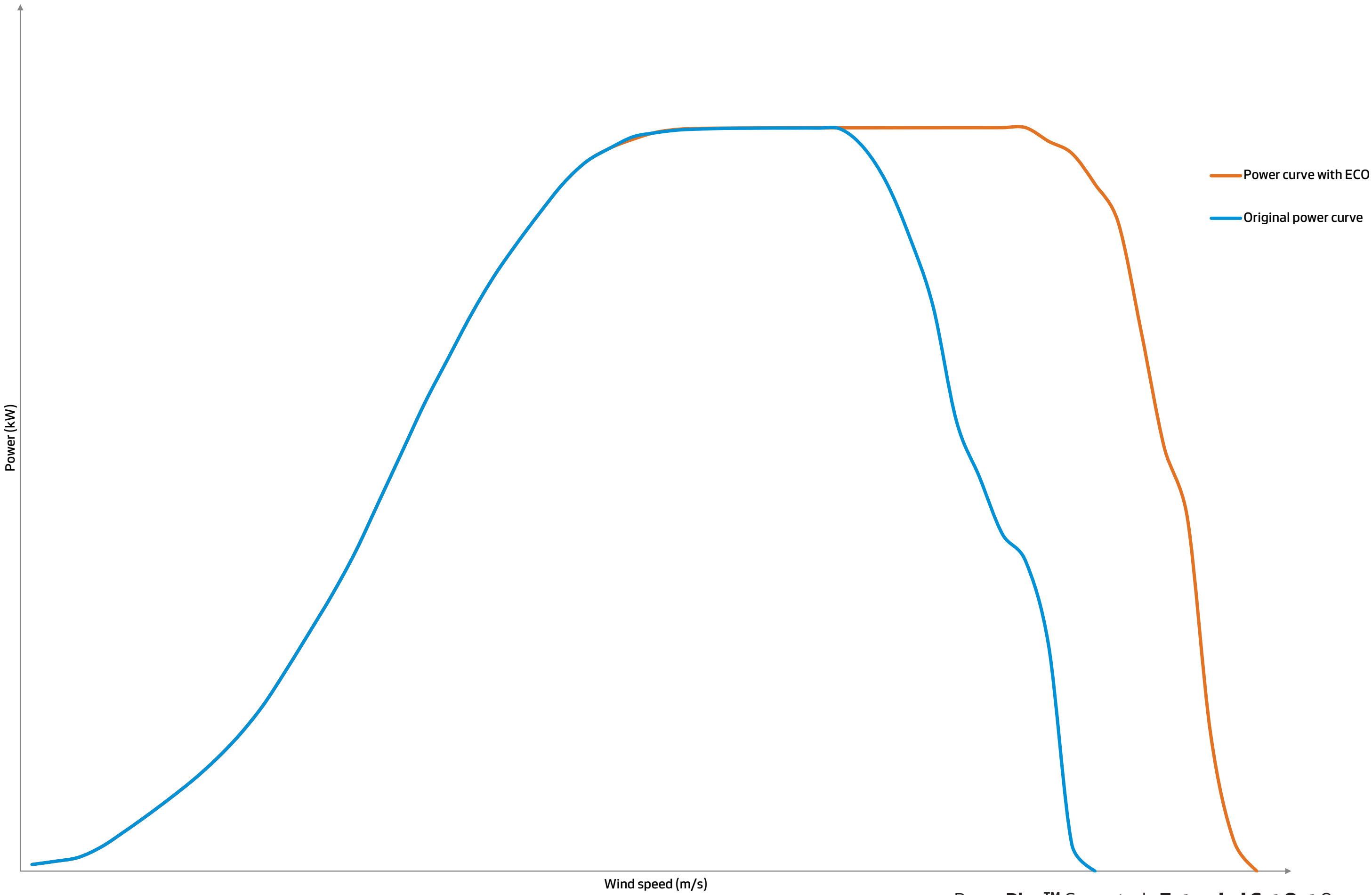
This case features a lower AEP gain and fewer turbines than cases 1 and 2. Generally, this combination would make the validation procedure more complicated and less accurate due to the smaller sample size.

However, with one year's worth of both pre-and-post data and the Vestas' statistical methodologies, the validation can be drawn with high statistical certainty.

The 95% confidence interval of the validated gain is 0.74-1.21%. This means that even if a small-to-mid sized wind farm is estimated to achieve lower production gains, Vestas is able to isolate and validate the gain, and ensure that there is an actual upgrade of the performance.

Pre-post power curve

The validated pre-post power curve for the site



Case 4: **1.64% AEP** gain at +30MW wind farm

Extended Cut Out with hysteresis gap reduction

As described in some of the other cases, the hysteresis gap has a significant influence on the production gain from Extended Cut Out. In the previous examples, the hysteresis gap has simply been moved, which means that the production loss from the original hysteresis gap is converted into full energy capture.

However, in addition to moving the hysteresis gap, it is also possible to reduce it and thereby enable the turbine to re-cut in faster. In short, the hysteresis gap is the gap between the cut out speed and the re-cut in speed, where the turbine is not producing, even though the wind speed is at an acceptable level.

In this case, the cut out speed is increased from 25 m/s to 29 m/s, but the re-cut in speed is increased from 20 m/s to 27 m/s. This actively reduces the hysteresis gap from 5 m/s to 2 m/s, meaning that the turbine returns to operation quicker than before.

This is possible because the climatic conditions at the site provide stable wind speeds in the higher wind speed ranges. If this was not the case, the hysteresis gap reduction would mean that the turbine would cut in and out more often. As a result, the increased wear from cutting in and out would negate the AEP gain from the reduced gap.

Significant, validated AEP gain

The combination of the increased cut out speed and the hysteresis gap reduction resulted in a 1.64% AEP gain over the one year validation period.

The gain is captured both through the elimination of the hysteresis gap between 20 m/s and 25 m/s, the enabled production above 25 m/s, and the gap reduction from 5 m/s to 2 m/s.

Specification of upgrade

Turbine model	V90-3.0MW
Number of turbines	+10
Original cut out speed	25 m/s
Original re-cut in speed	20 m/s
Extended Cut Out speed	29 m/s
New re-cut in speed	27 m/s
Validated AEP gain (combined)	1.64 %
Data training period	May 14 - May 15
Data testing period	May 15 - May 16

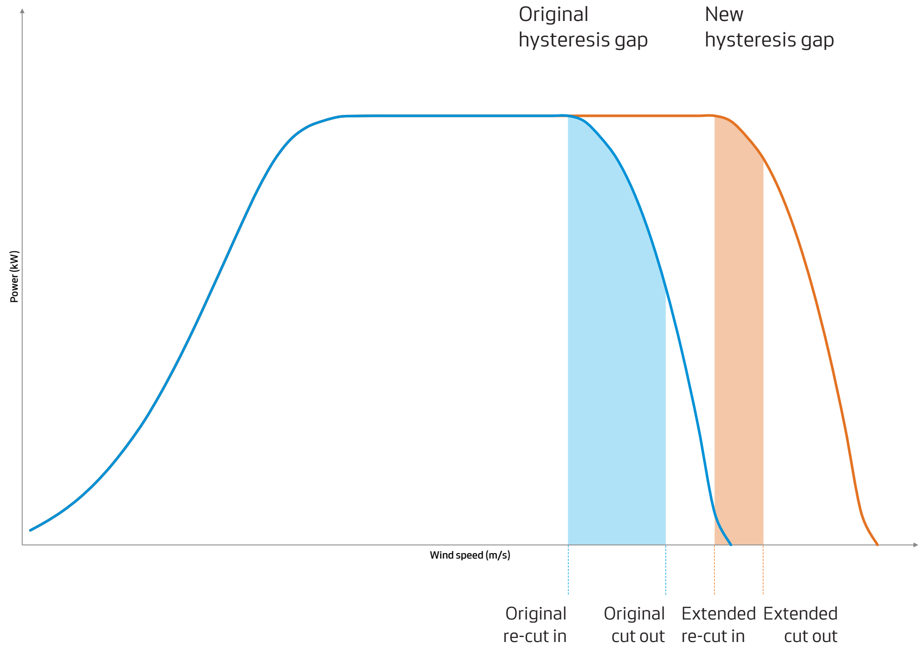
Climatic conditions in case

Normal Wind Conditions (annual)	
Weibull A parameter	10.2 m/s
Weibull k parameter	2.0
Site hub height avg. WS	9.04 m/s
Turbulence intensity (TI15) (avg.)	9.7 %
Turbulence intensity (TI15) (std.)	2.6 %
Average wind shear	0.09
Average inflow angle	n/a
Extreme Wind Conditions (50 year)	
Extreme WS (10 min. avg.)	39.4 m/s
TI at extreme WS	8.8 %
Survival (2 second gust) WS	49.8 m/s
Temperature and Air Density	
Average temperature	7.6 °C
Min. temp., P1	-6.9 °C
Max. temp., P99	18.2 °C
Avg. air density	1.150 [kg/m3]

Hysteresis gap reduction

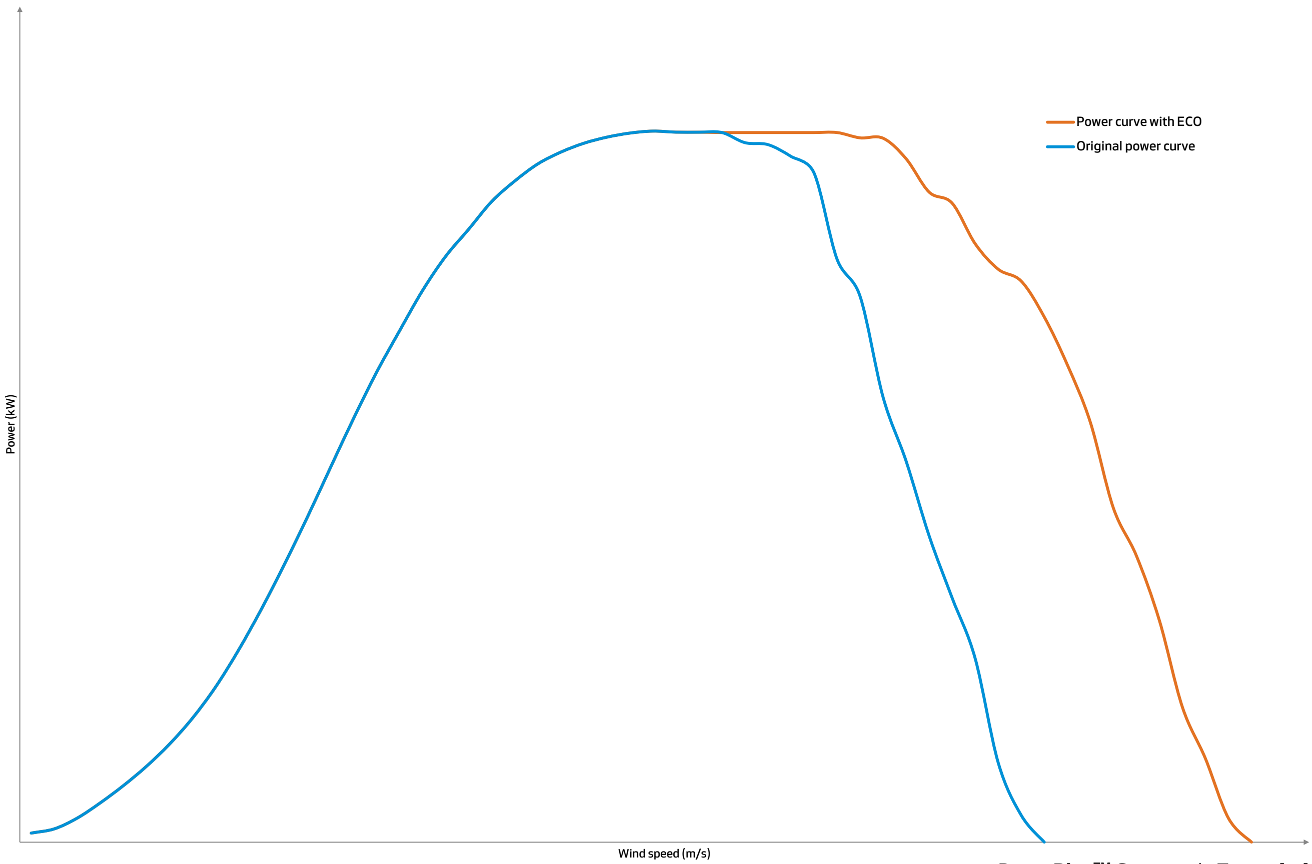
The visualisation on the right depicts a reduced hysteresis gap as a result of extending the re-cut in speed relatively more than the cut out speed.

The marked areas are the wind speed ranges where the turbine does not produce any power until the wind speed reaches the defined re-cut in speed as an average over a 100 second interval. By reducing the gap between cut out and re-cut in, the lost production caused by the hysteresis gap is reduced.



Pre-post power curve

The validated pre-post power curve for the site



Extended Cut Out

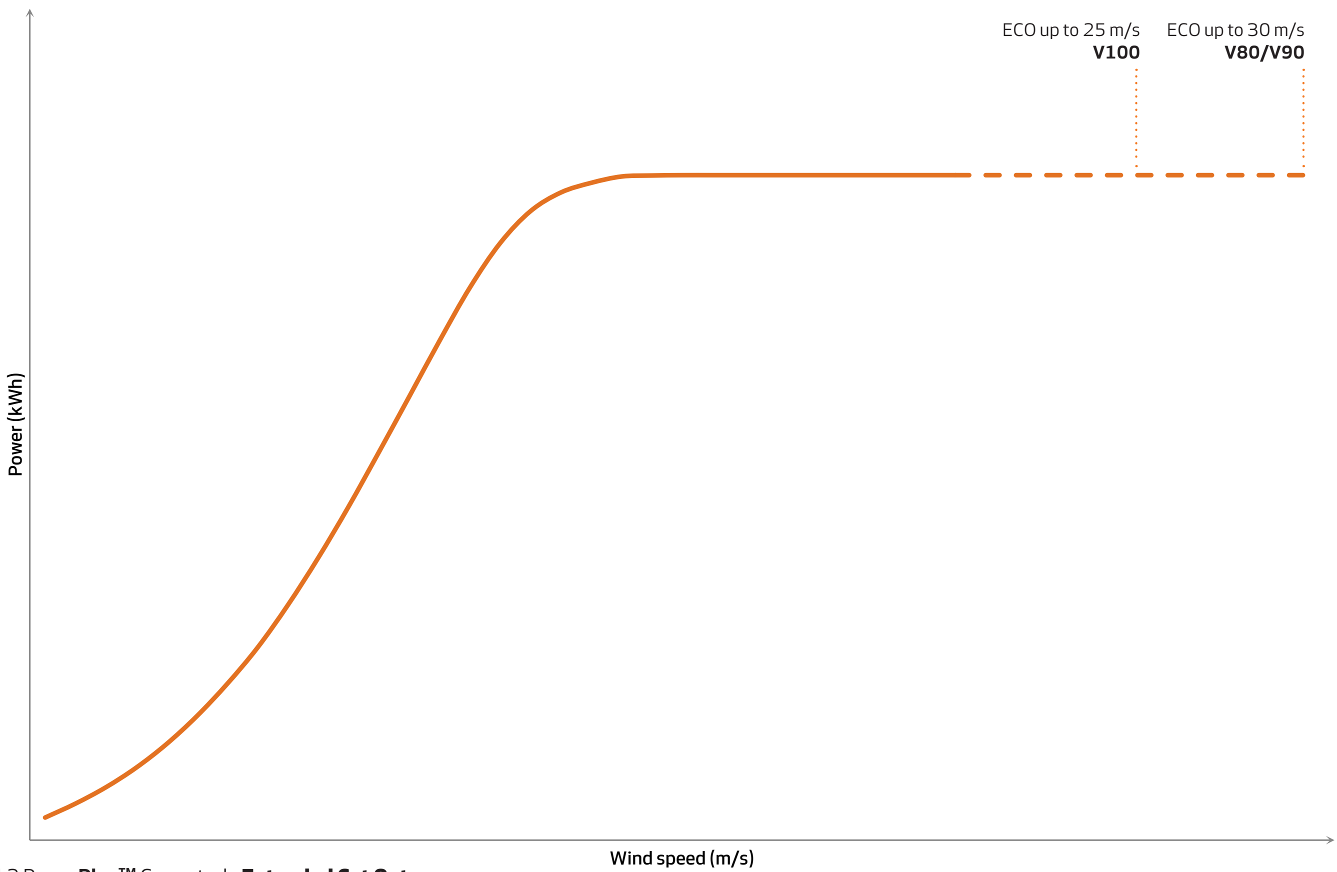
Technical description

Every Vestas turbine is installed with settings that instruct the machine to cut out of the wind when the wind reaches a certain speed. This limit has a high impact on the turbine's overall performance over time, both in terms of its production levels and its load exposure.

At high wind speeds, the turbine is operating at rated power, and the longer the turbine can operate at this level, the more power it produces. However, the turbine is also experiencing the most extreme loads exposure as the wind speed increases. At a certain point it is not longer advantageous to operate, as the wear and tear from the extreme loads outweighs the production gain.

Vestas has become experts in finding the exact point where the cut out wind speed optimally balances energy capture with loads exposure, thus ensuring that our customers are realising the full potential of their turbines.

The cut out in a Vestas turbine is determined by a 100 second exponential average of the windspeed. If the average exceeds the set cut out speed, the turbine increases the pitch angle and simultaneuously reduces speed and power until the turbine is fully stopped. Once a new 100 second exponential average shows a value below the set re-cut in wind speed, the turbine initiates start-up.



Optimising site-specific cut out speeds

Despite our expertise in forecasting the optimal cut out wind speed, some sites experience benign climatic conditions, which results in less structural loads exposure than in the design conditions. Common examples are lower-than-expected air density or turbulence levels.

The margin between design load exposure and actual load exposure creates a potential to extend the cut out wind speed and thereby allow the turbine to operate at rated power for longer intervals.

By identifying the turbine-specific structural load exposure over the operational life-time, Vestas can determine the potential for an extended cut out speed on each turbine in a given wind farm. With load margins available, a new optimal cut out speed can be identified to maximise production without exceeding load limits.

Generally, a new and extended cut out speed can deliver an AEP gain of up to 3%. However, sites with very favorable climatic conditions can potentially achieve production gains of 5-7%.

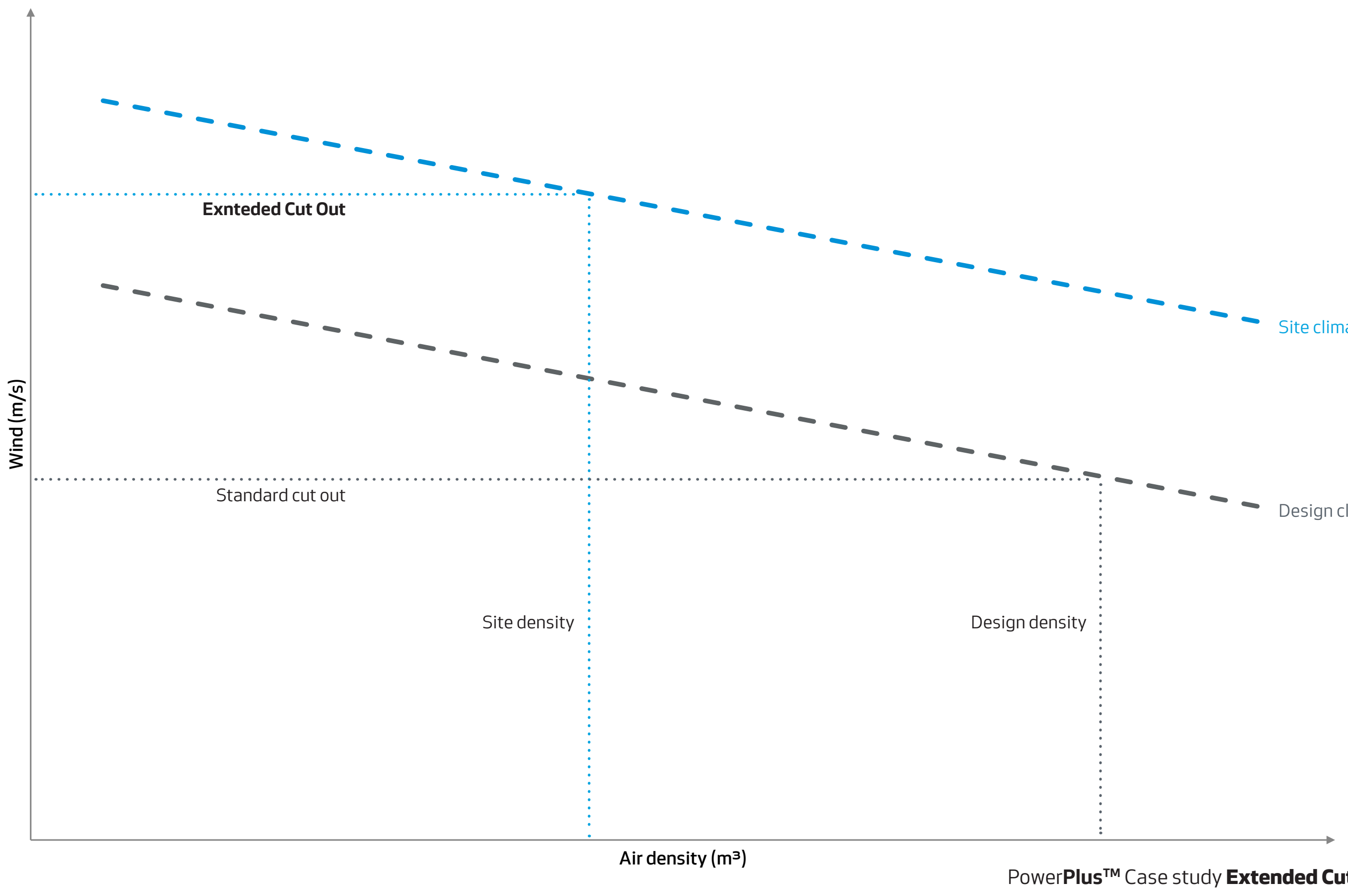
Additional benefits of Extended Cut Out

In addition to the obvious benefits of more production in full load operation, implementation of Extended Cut Out offers other operational advantages.

By extending the cut out wind speed, the number of shut down cycles due to high wind speeds is automatically reduced. This will reduce the stress on drivetrain components and ensure grid stability.

Moreover, Vestas also has a feature that adresses the hysteresis gap occuring between the extended cut out speed and the re-cut in speed. In this gap, production is lost during accepted wind speeds to ensure that the turbine does not cut in and out of the wind too frequently and thereby negate the benefit described above.

With hysteresis gap reduction, Vestas analyses the wind speed variance at the site to determine whether or not it would be beneficial to increase the re-cut in wind speed and thereby reduce the hysteresis gap. Usually, a low variance in wind speeds during high winds make a good case for reducing the hysteresis gap without negating the benefit from fewer shut down cycles.



Assessing potential with Vestas SiteCheck®

Many wind farms around the world can benefit from Extended Cut Out, but the potential production gains will vary from site to site.

Site-specific conditions, such as turbulence intensity, wind speed distribution and air density, have impact on the potential production benefit a wind farm could realise by extending the cut out speed on the turbines.

Upgrade within the design envelope

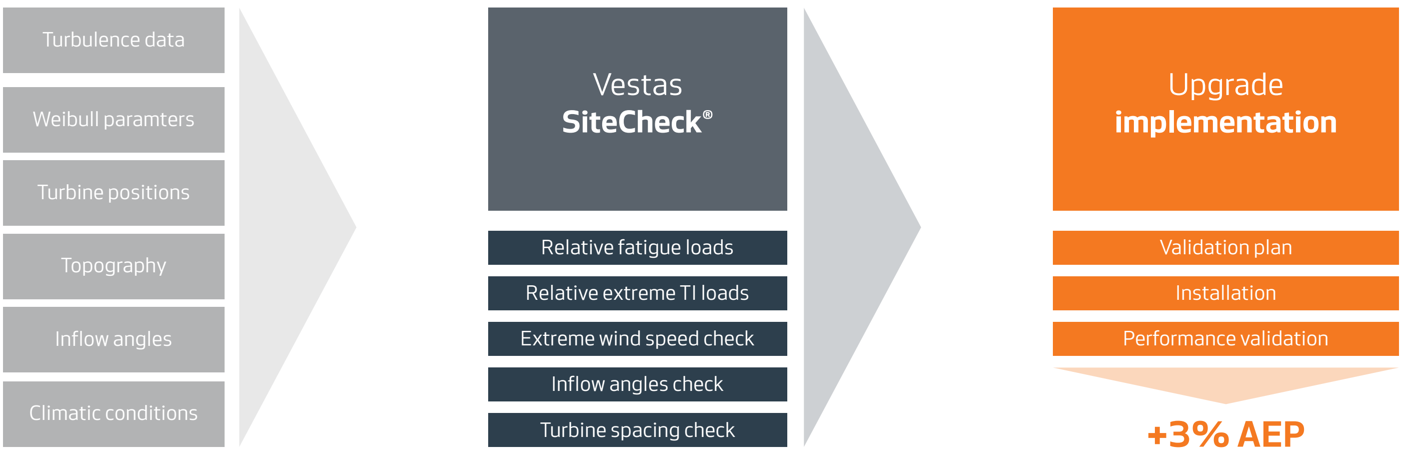
To identify the site-specific potential of PowerPlus™ features such as Extended Cut Out, Vestas utilises SiteCheck®. Certified by DNV-GL, Vestas SiteCheck® is a set of tools and processes used to analyse the conditions at a given site and determine the load margins that allow increased production.

Vestas SiteCheck® receives six main data inputs from the given site (turbulence data, Weibull parameters, turbine positions, topography, inflow angles, and climatic conditions). These data points are then used to approve the site for upgrades based on five parameters:

- Relative fatigue loads
- Relative extreme TI loads
- Extreme wind speed check
- Inflow angles check
- Turbine spacing check

The conclusion of the analysis is the degree to which the turbines can be upgraded without exceeding the load margins and which upgrade features that would be best suited to do so. This is delivered in a report, which highlights the key findings and recommends which upgrades to implement to achieve the optimal production gain.

PowerPlus™ upgrade process



Validating AEP gains with proven methods

The primary objective with Extended Cut Out and the PowerPlus™ suite is to provide owners with more production from their assets. In doing so, it is essential to offer business case certainty and clear visibility of the actual production gains.

Vestas' proven validation methodologies has been developed to confirm the production gains and thereby scientifically prove the value of the upgrades.

Full load upgrade validation

When the applied upgrade solution increases the full loads exposure of the turbine, Vestas applies a pre-post method to validate the production gain.

The method relies on power curve measurement using wind speed sensors from the nacelle, and the outcome is a direct comparison of the actual power curve before and after implementation of the upgrade.

The power curves are calculated by applying a weighted bin-wise power gain test, which increases in accuracy as the sample size grows. Additionally, the validation certainty is impacted by the size of the production gain. A smaller production gain would need a larger data-set to be validated and vice versa.

Ensuring value for money

The transparency achieved by validating the performance gains with certified methods enables you to identify the return on your PowerPlus™ investment.

Protecting and proving your return on investment is our biggest concern, and validated production gains ensure that you realise the full potential of your wind assets.

Upgrade your wind farm today

To know more about how PowerPlus™ can boost your wind assets, reach out to your local Vestas representative to get a tailored upgrade plan.

PowerPlus™ has already improved the productivity for more than 3,000 turbines around the world, and our dedicated specialists are ready to do the same for you and your business.