

REPORT FROM MEGAVIND  
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Increasing the Owners' Value of Wind Power Plants  
in Energy Systems with Large Shares of Wind Energy

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# 1. Preface

Megavind is Denmark's national partnership for wind energy, and acts as catalyst and initiator of a strengthened strategic agenda for research, development, and demonstration (RD&D). Megavind is the Danish equivalent of the European Technology Platform for Wind Energy; TP Wind.

Established in 2006, Megavind is organized as a public-private cooperation platform, with a broad representation of the wind sector<sup>1</sup> including utilities, wind turbine manufacturers, system and component suppliers, engineering services companies, universities and research institutions, as well as governmental observers.

Megavind delivers RD&D strategies and priorities for key technology areas. The Megavind strategies are intended as agenda-setting for the sector itself and for public funding of RD&D projects.

This present strategy report from Megavind will present and discuss future possible technological innovation related directly to the wind power plant that may increase the value of produced output from wind power plants operating in energy systems with large shares of wind.

The report maintains a strict focus “inside the power plant”. Only value created within a wind power asset is presented and discussed. Following this logic, the report does not discuss broader energy systems innovations and demand side solutions even if these may greatly increase the asset value and society value of wind.

As such, the report primarily contains technological and/or functionality recommendations, and only holds very few recommendations on how European regulation of markets could be designed to make it possible to assign proper value to existing functionality and future advances in functionality of wind power plants.

To deliver the content of this report, a working group was asked to make recommendations on improved wind power plant functionality to deliver security of supply, more flexible production, ancillary and system services, and other services that may increase the produced value and income of wind power plants. The content of this strategy report was developed by a group of selected experts listed as follows:

- Freddie Andreasen, Vestas Wind Systems A/S
- Finn Daugaard Madsen, Siemens Wind Power A/S
- Klaus Baggesen Hilger, DONG Energy
- Kenneth Skaug, Vattenfall Vindkraft A/S
- Preben Nyeng, Energinet.dk
- Poul Sørensen and Nicolaos Cutululis, DTU Wind Energy
- Jakob Lau Holst and Anja Pedersen, Danish Wind Industry Association (Megavind secretariat)

The content of the report has been peer reviewed by national and international stakeholders and experts from E.ON, Mainstream Renewable Power and the Danish Energy Association.

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<sup>1</sup> The list of companies represented on the steering committee can be found on the Megavind web site: [http://windpower.org/da/fakta\\_og\\_analyser/megavind.html](http://windpower.org/da/fakta_og_analyser/megavind.html)

## 2. Introduction to the value of wind energy

Denmark is a nation with green growth ambitions. Successive Danish governments have confirmed the nation's green ambitions to become fully independent of fossil fuels in 2050, and to have a fully renewable electricity supply by 2035 where wind power will be the main production contributor.

The value of wind power for societies lies in utilizing a domestic and abundant renewable resource to power an energy future with a higher degree of energy self-sufficiency and low long-term predictable energy costs in avoiding the harmful effects of emissions from thermal power plants.

The value of wind power for owners is primarily generated from power production. While most owners appreciate the green attributes of the technology, wind power owners are almost always commercial, and their willingness to invest depends upon the projected internal rate of return on the initial investment.

Wind power as an energy source has undergone a remarkable technological development and is considered among the fastest, cheapest and most reliable energy technologies in the market, and the technology benefits from regulated, relatively stable and predictable markets in most developed countries throughout the world. All in all, the value to society as well as owners to owners is generally high.

The recent report from International Energy Agency, "The power of Transformation", shows that "any country can reach high shares of wind cost-effectively" adding that the key to success lies in "transforming the system as a whole, rather than adding wind power on top". Several countries and regions (e.g. North-western Europe, Iberia, South-western USA, Ireland and UK) will before 2020 have relatively high shares of variable renewable electricity according to IEA<sup>2</sup> (see below).

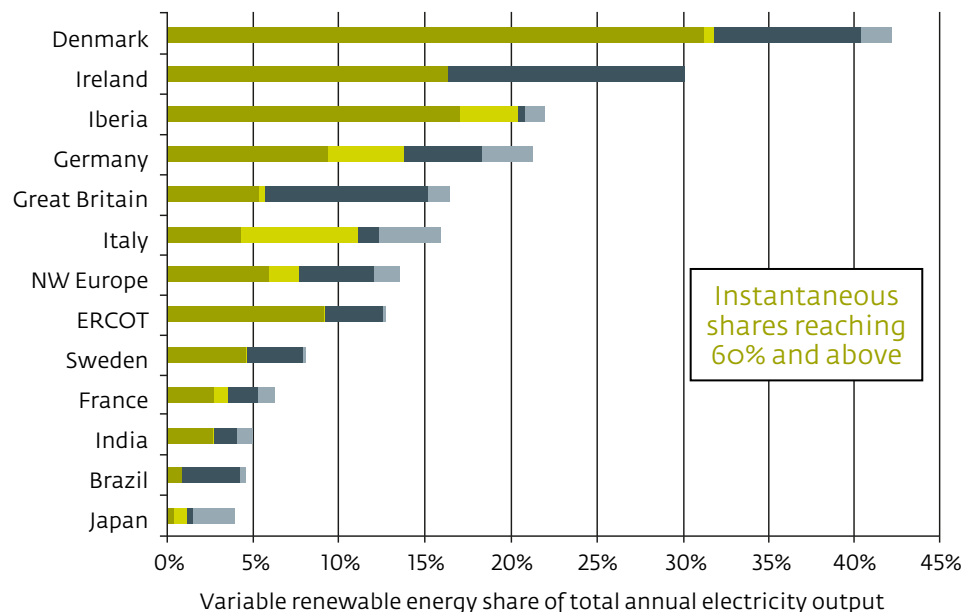
### Current variable renewable electricity shares and mid-term forecasts

**Figure 1.**

- Wind 2012
- PV 2012
- Additional Wind 2012-18
- Additional PV 2012-18

Source: IEA estimates derived in part from IEA Medium-Term Renewable Energy Market Report 2013 [https://www.iea.org/newsroomandevents/speeches/140225\\_GIVAR\\_PC\\_Slides\\_final.pdf](https://www.iea.org/newsroomandevents/speeches/140225_GIVAR_PC_Slides_final.pdf)

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2 IEA, The Power of Transformation, 2014

As has also been shown in several studies, wind power puts a downward pressure on electricity market prices. This is due to the merit order effect, in which electricity production with lower marginal costs are dispatched first to consumers. Simply put, the larger a share of low marginal cost input into a market, the lower your average price will be. Studies show, that in systems with high shares of wind energy, the merit order effect is stronger. Increasing wind energy shares in electricity systems results in more downward pressure on electricity prices.

This may be welcome news to consumers, and there are a number of existing and potential solutions on the demand side to enable society to take advantage of the downward price pressure of merit order effect upon wind power. These include different storage solutions, smart grid technology, improved infrastructure in the way of transnational grid reinforcement etc. All of these measures lie outside the scope of this report.

However, from an investor point of view, the increasing downward pressure of the merit order effect is a challenge. And according to IEA, several regions are becoming markets, where the merit order effect will become a challenge.

For the investor, the value of wind energy boils down to the difference between income and costs. For the investor, the question is then: how may we use technology to counteract the merit order effect? More specifically, how may we increase the value of production from our existing and planned assets in markets with higher wind shares?

Focus in this document is indigenous to the technology, i.e. focus is on what can be done “inside the power plant”. Taking a wind power plant asset perspective, what are the potential technology improvements that could increase production value for the owner and make wind power technology even more competitive compared to other energy sources?

## 2.1. The value of wind energy

In the wind industry, focus has been on decreasing costs of energy for several decades. On average, wind power has decreased its costs by 40% every ten years. This quest is a result of competition between manufacturers to be able to offer turbines with the highest return on investments for potential investors. The competition has always been a race towards still cheaper turbines with still larger annual energy production.

Investors and the industry use Levelised Cost of Energy (LCOE) as a measure to project costs. LCOE is defined as the annualized cost per produced MWh seen over the entire lifetime of the wind power plant. Major components of LCOE are development cost (DEVEX), capital expenditures (CAPEX) and operational expenditures (OPEX) levelised to annual average cost seen over the lifetime of the wind power plant divided by the expected annual energy production (AEP) from the wind power plant.

The drive to reduce LCOE is as strong today as it has ever been. In this report, the working group has attempted to look at potential solutions that may further increase the owners overall value of their wind power assets, in particular when these assets are placed in markets where there is a high wind power penetration.

The value of wind power assets are primarily derived from annual energy production. Total annual energy production and income of a specific asset is therefore highly dependent on the specific wind resource of a given site, and the distribution of this resource over time.

Turbines placed in high penetration markets thus experience longer periods of supplying power at times where total wind production is high. As wind power has low marginal costs, these periods of high instantaneous wind penetration usually mean that obtainable average income for these turbines tend to be lower than on comparable sites where wind power has a lower instantaneous penetration. In these markets with high penetration, it is increasingly relevant to consider whether there is a technological solution to this challenge.







# 3. Recommended actions to add value of wind

Megavind has identified a list of actions that can contribute to increasing the value of wind power within the scope of this report. This means that primarily technological and/or functionality initiatives within the wind power plant has been included. Broader energy systems innovations and demand side solutions even if these may greatly increase the asset value and society value of wind lie outside the scope of this report.

The identified actions are grouped into the following categories:

- Higher market revenues
- Lower costs
- New revenue streams

## 3.1 Higher market revenues

### 3.1.1 Participate in balancing and intraday markets today

Depending on the power prices, it is occasionally feasible for wind power to participate in the existing balancing markets [1]. For wind power, downregulation is generally a much more attractive option than upregulation, because provision of upregulation capacity requires prior reduction of wind power plants below possible wind power production, and thus is usually very costly in terms of lost production revenues. In the future, more and longer periods with zero or negative prices are expected due to the impact of wind power penetration on the merit order described in the introduction. Depending on support schemes, including subsidy period, some wind power plants may choose to run curtailed in the spot market in low or negative price periods, hoping to make better earnings on the balancing markets for upregulation.

### 3.1.2 Trading optimisation using probabilistic forecasts in existing markets

The present balancing markets are very dominated by day-ahead spot markets. This long horizon is challenging for wind power trading because of the increased uncertainty with the horizon of forecasts.

Better wind power forecasts and better tools to use the wind power forecasts in probabilistic wind power plant control and market trading provide substantial potentials to increase the market revenues of wind power.

Improved wind power forecasts has the potential to improve the decisions of the power traders to increase market revenues and support the TSOs to ensure that sufficient but not unnecessary reserves are available at any time. However, this calls for advanced, probabilistic decision tools.

There is also a potential to use wind power forecasts automatically in advanced control of wind power plants or wind power clusters. A special case is storm control, where there is a trade-off between power production and the loading of the wind turbines, depending on power prices and the value of reserves. Thus, during periods with storm forecasts, up-regulation reserves from wind power plant could be made available in real-time reserve

markets at a high price ensuring that this reserve will only be activated if the price for reserves is sufficiently high to counterbalance the increased lifetime reduction of the wind turbines.

### 3.1.3 Retrofit of wind turbine components.

According to Wind Power Monthly [2], wind farm owners “struggle to raise financing for new projects, or simply seek to avoid the risk of making a major investment in an uncertain economic climate”, and therefore they “are instead looking to the less risky and less capital-intensive process of upgrading their existing turbines through retrofitting”.

Retrofit of selected wind turbine components can be driven by an expectation of increased wind turbine lifetime. This includes critical mechanical components, control systems and sensors.

Finally, retrofit of rotors is obviously a very costly option, but in certain cases it is still viable because the expected increase in production is accordingly high.

### 3.1.4 Power tuning apps and flexible power limitation of individual wind turbines

The power tuning apps included in this measure can be implemented as changes in the control system, and the apps will usually not require any retrofit of wind turbine components.

Wind turbines are traditionally designed to maximise power production in the lower wind speed range, limit the production to a nominal value in an adjacent higher wind speed range, and finally the wind turbine protection system shuts the wind turbine down during storms.

Some modern wind turbines stay connected to the grid and generate reduced power during storms, and will only disconnect during strong storms or hurricanes [3],[4]. The value of such extended storm operation was demonstrated in the EU TWENTIES project [5]. The Danish Technical Regulations [6] require that wind power plants are equipped with an automatic downward regulation function at wind speeds. This may be implemented in the control of the individual wind turbines or by coordinated shut-down at the plant level.

There is also a potential for wind turbines to provide temporary overproduction, i.e. production above the nominal power value. The possible overproduction will mainly be limited by the drive train including the generator and the converter. The converter is designed to be able to provide the required reactive power capability at nominal active power. Therefore, a higher overpower can be delivered through the converter if the grid codes will allow active power priority at the cost of reactive power capability in case of overproduction.

The power tuning apps of wind turbines provide very valuable features to ensure a more stable balance in the power system. The ability to continue wind power generation during storms will reduce the requirement for reserves during storms significantly, and the temporary overproduction capability will make it possible to offer temporary frequency support even when the wind turbines are operated at nominal power.

The wind turbine power tuning apps are also not only contributing positively to the power system balancing, but are also affecting the total yield in terms of annual energy production. Results from TWENTIES show that modern wind turbine storm controls can increase the annual energy production by more than 1% [7].

However, operating the turbines in this way will impact the mechanical and electric loads on the wind turbines, and thus have an impact on operation and maintenance (O&M) and lifetime of the individual wind turbine. This may cause conflicts of interests between manufacturer's warranty risk and owners' income, which may be an obstacle towards an optimal solution over the complete lifetime of the wind turbine.



### 3.1.5 New power tuning apps at plant level

The power tuning apps used today are based in the individual wind turbine controllers. There is a potential to coordinate the power dispatch between the wind turbines in an optimal way, taking into account the capabilities and impacts on the individual wind turbines. Such coordination should also take into account the current power prices.

Increased production measures usually also increase the loads on the wind turbines. An optimal plant level coordination and dispatch will therefore require mechanical load analysis to quantify the impact of different operational strategies on the life-time of the asset.

The necessary information regarding lifetime consumption of the asset is not accessible to the owners today, but proprietary to the wind turbine manufacturers. As for the individual wind turbine power tuning apps (4.1.4), this may cause conflicts of interests between the manufacturer's warranty risk and owner's income.

### 3.1.6 Reducing lost production via diagnostics

A remarkable amount of expertise has been accumulated on the design of wind turbines and wind farms, onshore and offshore, based on experience and the use of engineering models. However, due to various reasons such as limited access to measurement data and the relative infancy of wind turbine technology, the models used to design and predict the performance of wind turbines are often derived and calibrated based on small subsets of the available data. The measured condition and environmental data from several wind farms allows the development and validation of novel analysis methods to increase prediction accuracy and reduce uncertainty. Improved predictive capabilities of wind farm performance and component damage will facilitate the implementation of operation and maintenance strategies such as decisions on preventive maintenance, corrective actions on control systems, and resetting of faults, to maximize power output, availability, and mean time between failures (MTBF).

With the rise of Data Analytics (e.g. 'big data'), machine learning and data mining methods can be systematically employed to adequately process extensive data reflecting the conditions of wind turbines, wind farms and their environment. They can be combined with existing design and operational tools, to further extend the capabilities of both types. There is a great advantage in the use of these methods to process large operational data in wind farms to probabilistically assess the confidence with which power production prediction can be made and the near term occurrence of component failure, given an observed probability of occurrence of certain events and environmental conditions. Such operational and failure prediction models based on measurements in several wind farms will enable the development and verification of new cost effective O&M strategies and concepts.

### 3.1.7 Repowering

Repowering differs from retrofit (4.1.3), because repowering refers to the replacement of existing older wind turbines with completely new wind turbines on the same site.

Potentially, repowering can save planning and development costs compared to the development of a completely new wind power plant. For offshore wind power plants, there may be very high benefits in reusing the best sites and the existing grid infrastructure.

A major driver for repowering is that it offers the opportunity to use new wind turbines with larger rotors per nominal capacity, which improves the power performance in the lower wind speed range. Besides the local wind conditions and the corresponding value of changing to a larger rotor ratio, economic viability of repowering a specific site depends on the history of O&M cost of the wind turbines and other wind turbines of the same type.

Another driver for repowering is that a new wind power plant can offer ancillary services to the power system which were not delivered by the original wind turbines. New wind power plants will also potentially provide a better power quality.

### 3.1.8 Overplanting

Overplanting means to install more wind turbine capacity than the allowed maximum power. The additional power can be used to compensate for losses in the power collection grid and for unavailability, mainly of wind turbines but possibly also of parts of the collection grid.

A certain degree of overplanting will be feasible in large offshore wind power clusters taking into account the current availability of wind turbines, the dynamic line rating, forced cooling of transformers, and the current power market prices.

Dynamic line rating takes advantage of the dependency of the line capacity on the current ambient conditions. Thus, the capacity of overhead transmission lines depends on the wind speed and temperature, while capacity of underground cables depends on the ambient temperature.

Dynamic line rating is in focus, especially by TSOs with high present or future wind power penetration, because of the increased transmission capacity in windy periods. Likewise, the capacity of offshore cables varies with the water temperature, and this has also a positive correlation with the wind power generation which is highest in the cold periods.

Dynamic line rating has been demonstrated and analysed in the EU TWENTIES project [8], and presently, and a new CIGRÉ working group is formed on the subject. The use of forced cooling to optimise the rating of transformers for offshore wind power plants is also investigated by plant owners [9], and this approach can also be applied to optimise overplanting.

## 3.2 Lower costs

### 3.2.1 Reactive power CAPEX reduction

There is a potential to reduce the investment costs (CAPEX) if some of the absolute connection requirements in grid codes were replaced by more flexible means, for instance by markets.

An example of this is that the requirements to reactive power capability are the same for connection to HVDC converter as to HVAC networks. The result is an unnecessarily high and costly reactive power capacity.

Another example is the requirement to provide the reactive power at the point of connection can result in additional investment costs compared to the case if the compensation is positioned in the power grid outside the wind plant connection point.

In those cases, there is a potential to save costs if we convert from generic grid connection requirements to individual assessments of the need for volume and position of reactive power capability. However, the ongoing development of a new joint European grid code pulls towards standardised assessments rather than individual assessment. Such a standardised assessment is a barrier for an optimal individual design of the reactive power capability.

### 3.2.2 Joint optimisation of O&M services

The costs of O&M services can potentially be reduced considering the entire value chain from silo to clusters, to portfolio in a joint optimisation. An example of this is to share port and jacking between different wind power plants, not just by single owners but also across owners.



### 3.2.3 Technology shift (evolution) to low frequency AC

Low frequency (LF) AC is an interesting alternative to HVDC for long offshore transmission distances. The main advantage of LFAC compared to HVDC is to remove the need for a large HVDC converter offshore and replace it by a back-to-back LF to nominal frequency converter onshore.

The main disadvantage of the LFAC concept is that the LF transformers are substantially larger and heavier than corresponding 50Hz transformers, and consequently require larger platforms. However, if the concept can replace offshore HVDC converters, then it may still be cost efficient in terms of platform size, and in terms of reliability.

### 3.2.4 Technology paradigm change to DC WTGs

The few offshore projects which are using HVDC transmission also use standard wind turbines, which often have full scale back-to-back converters in each wind turbine. This overall concept uses power electronics intensively, and there is a potential to reduce the volume of power electronics significantly and thus save investment costs and maintenance costs.

DC wind turbines replace the full back-to-back converter with a rectifier, but it will also require a DC transformer instead of AC/DC converter on the platform in order to obtain a feasible voltage level in the DC collection grid. Such DC transformers are not available on the market today with the required rating. Besides, DC transformers will be based on power electronics, and therefore reduce or even remove the potential investment and maintenance benefit. Alternatively, the wind turbine DC terminals may be connected in series [10], but this solution will increase the voltage in the wind turbines, which will be a safety issue.

In any case, the change to DC wind turbines is a major technology shift for the electrical design of wind turbine as well as transformer station. Such a technology shift will have a considerable (low to medium) risk, which could be minimised by proving the concept in a full scale onshore wind power plant before it goes offshore.

### 3.2.5 Increased voltage levels in power collection grids

Higher voltage levels in the power collection grids have a potential to lower the costs of wind power plants, especially in the power collection grids of very large (GW) offshore wind power plants using large wind turbines. Thus, higher voltage levels will enable transformer stations to service wind farms over larger areas than what is possible with the present 33-36 kV limit, with which it is difficult to handle more than 4-5 wind turbines in the 7-8 MW range. Still, there is a trade-off between the benefit to the power collection grid and the added costs associated with an increased voltage level in the wind turbine transformers and protection system. Increased voltage levels will reduce the costs of cables in the power collection grid, and fewer but larger breakers will be needed on the offshore substation.

### 3.2.6 Improved power quality performance and assessment procedures

There is also a potential cost saving in development of new advanced filter solutions based on combinations of passive filters and active filters [11]. Development of such solutions requires a better understanding of the harmonic sources and frequency dependent impedances in the grid. This understanding can also contribute to the development of new methods to test the harmonic emission of a wind turbine type, and subsequently use such type tests to and assess the harmonic emission from a wind power plant using the tested wind turbine type.

The harmonic emission from the wind turbine converters in wind power plants is usually overestimated because of inaccurate state-of-the-art in the methods to test and assess harmonics. This often results in investments in unnecessary harmonic filters to ensure

that the power quality is not violated. The existing standard method for assessment of harmonic emission was developed at a time with much less power electronics in the grid, but the fast growth of wind power and PV in the grids makes the need for more accurate methods increasingly urgent.

The power converters in modern wind turbines often provide active damping of harmonics, and also provide the possibility to dampen voltage flicker originating from other costumers in the grid. In order to verify such power quality improvements from wind power plants, it is necessary to develop new test procedures which can quantify such features. The present test procedures penalise such active power quality improvements.

### 3.2.7 Push OPEX to CAPEX

There is a potential benefit in increasing specific investment costs (CAPEX) which will be paid back in terms of reduced operation costs (OPEX). Thus, the overall costs can be reduced by smart investments at the construction stage. One example is to reserve space for possible need of auxiliary equipment in the design phase to avoid very high additional costs if the need for auxiliary equipment appears after commissioning.

Another example is the trend for large wind turbines towards higher ratios between the rotor area and the rated power, which used to be considered feasible only for low wind areas. However, taking into account the influence of wind power on the power prices in areas with high wind penetration, larger rotors become feasible also on high wind sites. For offshore plants, this is particularly relevant, taking into account the high costs for transformer stations and transmission lines.

## 3.3 New revenue streams

### 3.3.1 Participate in ancillary service markets

The frequency stability in the present power systems is ensured by a combination of primary and secondary reserve services, where the purpose of the fast primary reserves is to respond fast and thus contain the frequency within an acceptable range, while the purpose of the secondary reserves is to bring the frequency back to the normal operation range and thus replace the primary reserves so that they are available in case of another frequency disturbance. Therefore, the primary reserves must have a short response time (often 10-30 seconds), while secondary reserves must have a longer response time (typically up to 15 minutes) [12].

The idea with this measure is for wind power to participate in these markets as they are today. This already happens to some extent as part of the portfolio control by balancing responsible utilities. Thus, in high wind – low load cases, it can be feasible to provide the contracted secondary down regulation services from wind power as an alternative to running thermal plants above minimum load.

The product lifetimes in existing markets for ancillary services are barriers for the participation of wind power. This is because the wind power forecasts get increasingly uncertain with increased product lifetimes, and as a consequence, the lost production needed to ensure the reserves is too high. For example, a study in EU TWENTIES project [13] show that the potential volume for wind power plant contribution to the balancing markets in Germany will double if the product lifetime is reduced from 24 hours to 4 hours.

### 3.3.2 Offer ramping services to conventional assets

Due to the slow power control in some conventional assets and the fast power control in wind power plants, it may be feasible to offer ramping services from wind power plants to conventional assets. For instance, the ramp up needed to follow the morning peak load



can be achieved by a scheduled sequence where the conventional plant starts ramping up in due time *before* the load ramps while the wind power plant ramps down to balance the . Subsequently, the wind power plant can contribute to a joint fast ramp up when the load starts to ramp up.

This option is to some extent working in the internal balancing of the balancing responsible utilities that own and operate both thermal power plants and wind power plants. There are no market mechanisms which support the use of the service across utilities.

There is a need to advance market models enabling them support the assessment of future value of such ramping services, taking into account the expected growth in wind power generation and the corresponding higher frequency of shutdowns and startups of thermal power plants.

### 3.3.3 New ancillary services

In addition to the existing ancillary services, the transition of the power systems towards increased levels of penetration of inverter-connected renewable generation calls for new ancillary services from the inverter-connected generation to be able to replace the synchronous generators. Such services are needed to allow the system to be operated with a minimum of synchronous generators without jeopardising the system stability.

Virtual inertia [14] and fast frequency response [15] are the most developed and demonstrated types of the new ancillary services. The idea of those services is to replace the effect which the inertia of power plants with synchronous generators has on the frequency stability.

Power system oscillation damping [16] is needed to stabilise the power swings between groups of synchronous generators connected through long transmission lines. This service is today implemented in the Automatic Voltage Regulators (AVR) of synchronous generators.

Finally, the synchronizing torque, which is essential to ensure angular stability of the power system can be emulated by synchronizing power [17] from inverter-connected wind power plants.

Those new ancillary services are probably going to be implemented as technical requirements for grid connection rather than markets for the services. In that case, the services will not add any direct value to the owners. Still, allowing the system to operate with less online synchronous generation will reduce wind power curtailment and increase the market value of wind power in periods with high instantaneous penetration due to favourable wind conditions.

### 3.3.4 Reactive power payments

Wind power plants are usually running in constant power factor or constant reactive power modes, but they are also capable to contribute actively to voltage control. This is relevant when wind power is displacing conventional power plants, and also to control the voltage in rural areas with high wind power penetration. Traditionally, wind power plants were only able to support the voltage control when wind speeds were high enough to produce active power, but this constraint has been removed, so wind power can provide a continuous voltage support.

Reactive power and voltage control are usually ensured by technical requirements rather than markets. A major barrier for introduction of reactive power and voltage control markets is that the services are needed locally, and therefore the markets will be relatively small and difficult to operate.

Another aspect of the reactive power and voltage support is that when the TSOs require these capabilities today, it is to facilitate a high level of security in the system. It is not because the TSOs rely on these services to be provided by wind turbines in normal operation, but in critical situations these capabilities may be decisive to ensure the voltage stability.

### 3.3.5 Capitalising meteorology data

The development of wind power has not only resulted in an increased wind power production, but also in the construction of a widely spread network of meteorology stations associated with each wind farm or cluster. The information from these meteorology stations is not just used by the individual wind turbines, but also available externally through SCADA systems and other communication networks. This meteorological data has a value which is already capitalised by the owner in terms of rebates on wind power forecast systems.

This available data is already used to some extent in meteorology forecast models, but a possible new revenue stream adding more value to the data could include exploiting available data on a larger scale (regionally), which could be achieved if access to data across regions and sharing of data between owners (in some way) was agreed. Because of the enormous amount of available data, data mining is essential to extract the useful information from the raw data.

The joint meteorological data from wind turbines is not only valuable for wind power trading, but it has a general value for meteorological forecasts.







# 4. Analysis

## 4.1 Product – market matrix

As mentioned in the introduction, the implementation of some of the measures depends on changes in markets. Recommendations regarding market design are outside the scope of the present strategy, but for clarification, the dependency of the individual measures on new market structures is shown in Figure 2 together with the novelty of the product or service.

**Figure 2.**  
Mapping of novelty and dependency of new markets of the individual measures

Market	New	Reactive power payments	New ancillary services Overplanting
	Existing	Participate in balancing and intraday markets today Trading optimisation using probabilistic forecasts in existing markets Retrofit of wind turbine components Power tuning apps and flexible power limitation of individual wind turbines Repowering Reactive power CAPEX reduction Participate in ancillary service markets Offer ramping services to conventional assets Capitalising meteorology data	New power tuning apps at plant level Reducing lost production via diagnostics Joint optimisation of O&M services Technology shift (evolution) to low frequency AC Technology paradigm change to DC WTGs Increasing voltage level in power collection grids Improved power quality performance and assessment procedures Push OPEX to CAPEX
		Existing	New
		Product or service	

## 4.2 Feasibility – value matrix

In order to prioritise the measures, the potential value plays an important role, but also the feasibility is decisive. Figure 3 shows a qualitative assessment of feasibility and value of the individual measures.

Value	HIGH	<ul style="list-style-type: none"> <li>New power tuning apps at plant level</li> <li>Joint optimisation of O&amp;M services</li> <li>Technology paradigm change to DC on WTG</li> </ul>	<ul style="list-style-type: none"> <li>Retrofit of wind turbine components</li> <li>Power tuning apps and flexible power limitation of individual wind turbines</li> <li>Reducing lost production via diagnostics</li> <li>Reactive power CAPEX reduction</li> <li>Increased voltage levels in power collection grids</li> <li>New ancillary services</li> </ul>
	LOW	<ul style="list-style-type: none"> <li>Trading optimisation using probabilistic forecasts in existing markets</li> </ul>	<ul style="list-style-type: none"> <li>Participate in balancing and intraday markets today</li> <li>Repowering</li> <li>Overplanting</li> <li>Technology shift (evolution) to low frequency AC</li> <li>Improved power quality performance and assessment procedures</li> <li>Participate in ancillary service markets</li> <li>Offer ramping services to conventional assets</li> <li>Reactive power payments</li> <li>Capitalising meteorology data</li> </ul>
		LOW	HIGH
Feasibility			

**Figure 3.** Quantitative assessment of the value versus the feasibility of the individual measures







# 5. Conclusions and recommendations

## 5.1 Action recommendation

The most obvious measures are the ones which have high value as well as high feasibility. Besides these measures, it is also recommended to participate in existing markets although the potential value is not expected to be very high because this will only be feasible in cases with very low or negative prices. Repowering is also included, but limited to the cases where the O&M of existing plants is high due to the age of the plants. Finally, the potential value of joint optimisation of O&M services is very high offshore, but it is not straight forward to establish the necessary cooperation between competing owners.

Value	HIGH	<ul style="list-style-type: none"> <li>New power tuning apps at plant level</li> <li>Joint optimisation of O&amp;M services</li> </ul>	<ul style="list-style-type: none"> <li>Retrofit of wind turbine components</li> <li>Power tuning apps and flexible power limitation of individual wind turbines</li> <li>Reducing lost production via diagnostics</li> <li>Reactive power CAPEX reduction</li> <li>Increased voltage levels in power collection grids</li> <li>New ancillary services</li> </ul>
	LOW		<ul style="list-style-type: none"> <li>Participate in balancing and intraday markets today</li> <li>Repowering</li> <li>Improved power quality performance and assessment procedures</li> <li>Participate in ancillary service markets know today (primary and secondary)</li> </ul>
		LOW	HIGH
Feasibility			

**Figure 4.** Recommended measures organised according to value and feasibility

## 5.2 Quantification of potential value

The quantification of the potential value of the individual measures is not straight forward because it will require dedicated studies to provide credible estimates.

However, there are some studies with results which are relevant in this context, although most published studies of economic impact provide results regarding the value for the society as a whole rather than the value for the owners of plants. Another challenge in quantification of the value is the different market structures, especially for ancillary services, which makes it difficult to compare results across borders.

The following results are identified as relevant to the present strategy:

- In the EU TWENTIES project, EDF estimated that with 25 GW wind power in France in 2020, it will be feasible to provide 2% of the reserves in the French system from wind power, and this will reduce the costs of producing electricity in France by 2.3 MEuro/y [18].
- In the EU TWENTIES project, IWES Fraunhofer has estimated that if a proposed available active power proof is applied then wind power participation in the secondary control reserve market can provide cost reductions for secondary reserves of up to 24 % [13].
- In the EU TWENTIES project, DTU has estimated that a power tuning app for High Wind Extended Production will increase the energy production of offshore wind power plants with more than 1% [7].
- In the EU REserviceS project, the benefits of providing reserves from renewables have been studied in three cases representing different types of systems: The island system of Ireland [19], the “end-of-line” peninsula Iberia [20], and a large North European case including Germany, Poland, Netherlands, Belgium, France, Great Britain, Denmark, Norway, Sweden and Finland [21]. The results clearly show that the benefits of services from renewables increase significantly with increased penetration. As an example, in the 42% renewable penetration case for Iberia, the additional annualised investment costs of making services available from renewables were estimated to approximately 240 MEuro/y and the corresponding benefits were estimated to approximately 660 MEuro/y. The results also indicate that the benefits are highest in island systems (Ireland) and lowest in larger strongly interconnected systems (The North European case)<sup>3</sup>.

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<sup>3</sup> One interpretation of the REserviceS case study results is that the benefits get significant in high penetration cases with significant wind curtailment, which can be mitigated by the use of wind power to provide reserves.

## 5.3 Key messages to policy makers

Below follows a list of key messages to policy makers. The understanding of policy maker in this context includes politicians, energy system development planners, regulators and transmission system operators.

- There is a need to continue the development towards more international and larger energy markets.
- Well functioning energy markets will also require further development of the transmission grids.
- There is a need for economic incentives to promote the integration of energy systems, hereunder to transfer demand from other energy systems to electricity. An example of this is to replace fossil fuels by electricity in the transportation sector.
- There is a need to shape the markets so that it becomes more attractive for wind power to participate to all power system services.
- There is a need to continue public funding of new CAPEX projects as is done by PSO resources in Denmark today.
- Policy makers should consider to change tax on electricity to increase demand flexibility.
- Policy makers should consider larger tenders to accelerate value chain maturation.
- Policy makers should reduce the regulatory risks which are presently disproportionately high compared to the market risks.

## 5.4 Key messages to industry

The following key messages address to industry companies including owners, wind turbine manufacturers and sub-suppliers

- It is important to have clear strategies and roadmaps on how to reduce the cost of electricity produced by wind power plants.
- There is a potentially very high value in utilising portfolio and cluster synergies, especially if the industry will cooperate.
- The industry should aim to collaborate across the value chain.
- The industry should communicate to potential investors that wind power is a sound long term investment in order to mitigate capital sourcing challenges.



## 5.5 Key messages to research

There is a need for R&D to support the development of the measures identified in this strategy:

- Development of data mining techniques to handle the “big data” for the purpose of diagnostics and condition monitoring.
- Studies of the technical and economic feasibility of
  - a. Wind power joining markets (frequency control, balancing, ramping)
  - b. Use of probabilistic forecasts
  - c. New market designs
- Development of new tools for economic assessment with special focus on higher resolution market models enabling studies of real-time balancing.
- Technical studies of ancillary services from wind power plants
  - a. Uncertainties and values of ancillary services depending on service lifetime
  - b. New ancillary services from wind power plants allowing higher instantaneous penetration of wind power plants.
  - c. Dynamic modelling of ancillary services from wind power plants
- Cost reductions of O&M
  - a. Use of condition monitoring (diagnostics)
  - b. Development of optimisation tool(s)
- Technical and economic feasibility studies of new electrical concepts:
  - a. DC wind turbines and collection grids
  - b. Low Frequency AC transmission
- Power quality and harmonics
  - a. Development of new test and assessment procedures to reduce costs for ensuring the necessary power quality
  - b. Development of converter technologies and active control to mitigate the harmonic emission







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