

Challenges and Costs of Integrating Growing Amounts of Wind Power Capacity into the Grid – Some Experiences Dealing with 12 000 MW in Germany

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Abstract

High annual growth rates over the past years resulted in an installed wind power capacity of 12 000 MW in Germany by the end of 2002 which generated about 17.3 MWh electricity, that is about 3.7 % of the German electricity consumption. This development was made possible by laws introducing feed-in tariffs for wind power generation. Due to the fluctuating nature of wind power generation the feed-in of growing amounts into the grid causes considerable challenges and costs for affected transmission system operators, who have to ensure a safe grid operation, though basically good working wind power prediction tools exist. The owner of wind turbines do not have to deal with these problems since the Renewable Energy Act (EEG) ensures that their generated power is compensated for by fixed feed-in tariffs. In the long run, this is not a sustainable approach: Wind power needs to compete sooner or later fully with other power generating technologies at the market and wind turbine owners need to be able to sell a tradable product. After successfully supporting the development of the wind power technology, an approach is needed for including the owners of wind turbines in the task of realizing other ways than simply providing growing amounts of balancing power for wind power feed-in and gradually face them with the energy economic reality of integrating large amounts of wind power into the grid.

Development of Wind Power in Germany

The installed wind power capacity in Germany has grown at amazing rates over the past ten years: From less than 200 MW in 1992 to 12 000 MW by the end of 2002 with yearly new installed capacity rising from 74 MW to a record high of 3247 MW in 2002. *Figure 1.* 14 500 MW to 15 000 MW are expected by the end of 2003. With over one third of the installed capacity worldwide, Germany is the leading wind power producing country. In 2002 the installed wind power capacity in Germany surpassed 10 % of the existing conventional power plant capacity and accounted with 17.3 TWh for about 3.7 % of the electricity consumption [ewi 2003]; a share that could grow over 5 % this year [BWE 2003]. Wind generated power covers more than 100 % of the consumption in some grid areas at times.

The future development of wind energy in Germany seems to be quite difficult to forecast: For one reason, it is uncertain how much the decreasing quality of available on-land sites effects new

investments in the short run and for another how the offshore generation will develop in the medium-term. Changing terms of credits and insurances are also of relevance.

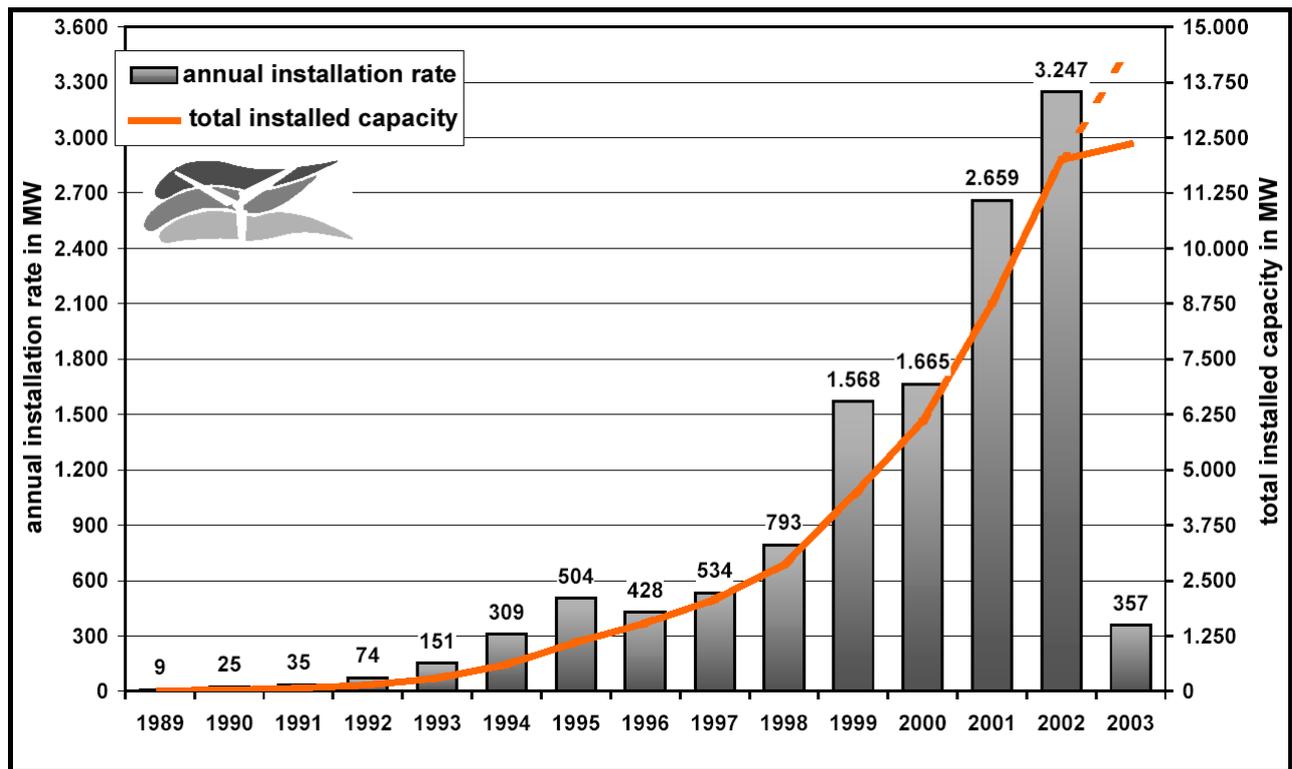
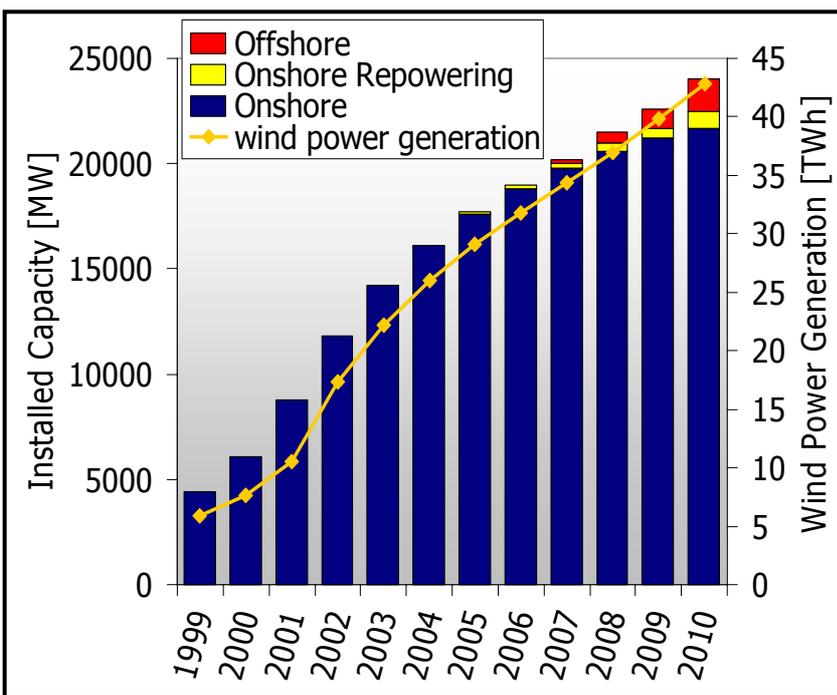


Figure 1: development of installed wind power capacity in Germany [BWE 2003]

Even if experts expected to have seen the climax of newly installed capacity for quite a few years now, annual installation rates have been increasing ever since 1996. But good on-land sites are becoming scarce in Germany and the numbers of the first quarter of 2003 indicate that the rate of new installations is in fact decreasing [BWE 2003]. A survey for planned projects scheduled for the next years indicates that the average wind speed at available sites drops from 5,1 in 2004 to 4,8 m/s (30m) in 2006.



According to a moderate future scenario 24 000 MW of installed wind power capacity are expected in Germany by the end of this decade of which only 1500 MW are expected to be offshore. This would result in an electricity production of 42.8 TWh according to a share of over 8.5 % of the consumer electricity consumption [ewi 2003].

Figure 2: future scenario for development of installed wind power capacity in Germany; data source [ewi 2003]

Political Support for Wind Power in Germany

The rapid development of wind power in Germany is mainly due to laws introducing feed-in tariffs for wind generated power. The first law was passed in 1991 and guaranteed a fixed price for wind generated power fed into the grid and made wind turbines at good sites economically feasible, which initiated the first push for increasing installations of wind power capacity. The law forced the regional grid operators to buy the wind power from owners of wind turbines, but only to a cap of 5 % of the total amount of electricity distributed within their grid. After a few years, this cap became a significant problem for new installations of wind turbines in areas with good wind conditions.

The Renewable Energy Act (Erneuerbare-Energien-Gesetz – EEG) came into effect in April 2000 and did not only remove the 5 % cap but also introduced a system which made investments at inland sites with lower wind speeds economically feasible: A high feed-in tariff is paid for new turbines for at least 5 years. The high tariff started at 9.1 Euro ct/kWh until the end of 2001 and decreases since then at a rate of 1.5 % being at 8.9 Euro ct/kWh for wind turbines set in operation during 2003. If a certain turbine at a certain site produces at least as much electricity during the first five years as it would produce at a standard site with standard (good) wind conditions, the owner will receive a reduced feed-in tariff afterwards. It started out at 6.19 Euro ct/kWh and is also subject to a decrease of 1.5 % being at 6.0 Euro ct/kWh at the moment. If a turbine produces less electricity during the first five years compared to an amount at a standard site, the owner receives the high tariff for a longer time. The additional time span is calculated by a formula that takes the difference between the production at the actual site and the standard site into account. That way, turbines at sites with lower wind speeds receive the high feed-in tariff for a longer time than those at sites with high wind speeds, which makes turbines economically feasible even at inland sites. For wind turbines that were in operation before the EEG came into effect, the time span in which the high compensation is paid is reduced by 50 % of their operational time prior to the EEG, but not below four years. Owners of wind turbines are compensated by the EEG mechanism to a maximum of 20 years.

The nearest suitable grid operator has to connect the wind turbines to his grid, accept wind power with priority, and compensate the owner according to tariffs of the EEG. He can forward the amount of wind power that is fed in his grid to the grid operator he is connected to and is compensated for that. This way, the wind power eventually reaches one of the four German transmission system operators (TSOs), who exchange amounts of wind energy among each other to reach equal shares of wind power within their distributed electricity. This percentage of wind power has to be accepted by all power distributors who deliver electricity to customers. They finally equally pay the fed in wind power that was compensated for by the EEG mechanism with every consumed kWh, though exceptions for businesses with a high electricity demand are under negotiation and will be introduced soon.

Energy Economic Value of Wind Power

The feed-in tariff systems made the tremendous development of wind power possible in Germany. In a system of about 100 000 MW of conventional power plant capacity 12 000 MW of wind power at the end of 2002 no longer represent a negligible part of the German electricity sector. Assuming normal wind conditions, wind power could have a share of over 5 % of the electricity consumption this year, but in many past years the wind conditions were under

average. Even in those with good conditions wind obviously does not blow constantly strong all the time; not at good costal sites and especially not at in-land sites. That raises the question how much conventional power plant capacity can be substituted by the installed wind power capacity. Results from the Scientific Measurement and Evaluation Programme (WMEP), which was carried out by the ISET during the years 1990–1999, are shown in *Figure 3*. They indicate that the monthly average capacity factors (percentage of generation compared to nominal capacity) vary considerably with the site quality. Values for average wind energy production in Germany are 2200–2400 full load hours at costal locations and 1300–1500 full load hours at in-land sites [ISET 2000]. Full load hours is a value for the annual energy yield of a wind turbine broken down to hours of operation at its nominal power.

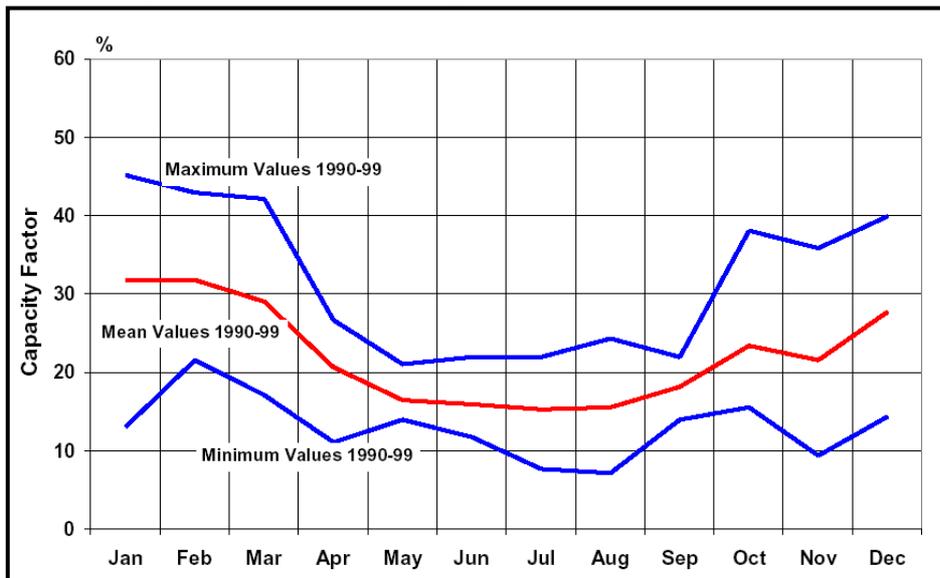


Figure 3: average monthly capacity factor of wind turbines as determined by ISET over a period of time from 1990-99, based on 125 000 monthly energy delivery reports [ISET 2000]

When evaluating the energy economic value of wind energy one has not only to think about an average capacity factor but also

consider that wind power feed-in can vary strongly in relatively short periods of time. *Figure 4* shows the wind power feed-in into the grid of E.ON Netz (one of the German TSOs) over a period of time in December 2001 in which the total installed wind power capacity within the grid of E.ON Netz was 3 500 MW.

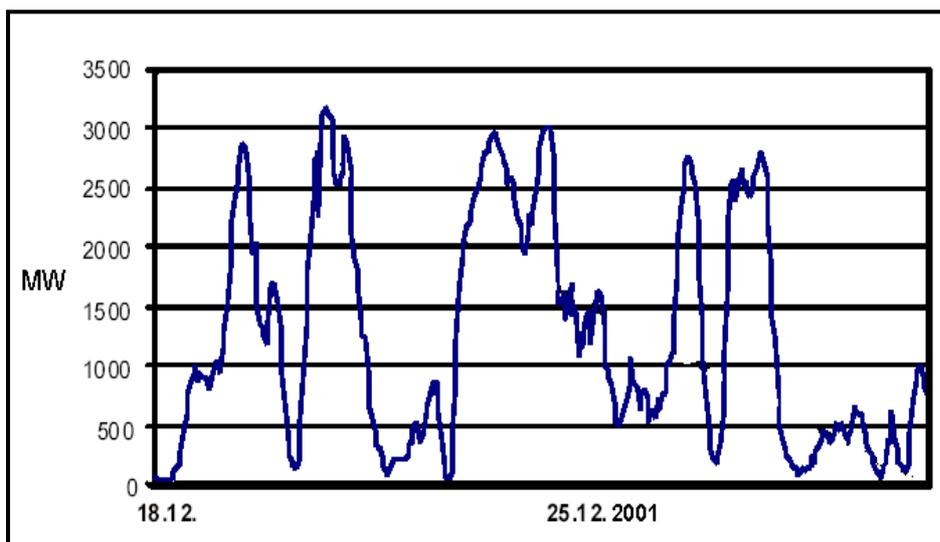


Figure 4: fluctuating wind power feed-in into the grid of E.ON Netz [Schneller 2002]

The TSOs are responsible for ensuring a save grid operation. To do so, they have to provide system services like online regulation and planning of regulation power for balancing

power feed-in and load (consumer demand). The generation schedules from conventional power plants are known a day ahead and the load schedule can be predicted with high accuracy, leaving stochastic load variations, unexpected power plant down-time, and the wind power feed-in, of course. The better the prediction of the wind power is the less regulation power is needed,

which requires power plants running in partial load, thus not producing power very economically, for example. Some power plants might need to be running in stand-by, that way not producing power at all. Improved prediction and integration of wind power into the electrical energy supply system increases the energy economic value of wind power.

Monitoring and Prediction of Wind Power in Germany

Integrating wind power into the electrical energy supply system is supported by a tool developed at the ISET within a framework of governmental and EU funded projects and in cooperation with the German TSOs E.ON Netz, RWE Net, and Vattenfall Europe Transmission. The Wind Power Management System (WPMS) provides online monitoring of the wind generated power feed-in as well as the prediction of the wind power generation from 1 hour up to 72 hours [ISET 2003].

An accurate method of monitoring the wind generated power feed-in within a certain area would be obtaining the power output of all wind turbines. Equipping all wind turbines with monitoring systems is, however, not a feasible approach considering the number and wide spread distribution of wind turbines in Germany. Based on the long term experience and the measurement data gained during the “250 MW Wind” program, ISET developed in cooperation with E.ON Netz a model which allows to monitor online the power output of all the wind turbines within the TSO’s grid area by taking the measured power output from only some representative wind farms into account. That way, with data from the measurement network of 50 representative wind farms with a net capacity of 1953 MW, wind power generation from a capacity of about 5000 MW is calculated. The model has been used in the load dispatcher of E.ON Netz since mid 1999, since January 2003 also in that of RWE Net, and is being adapted for Vattenfall Europe Transmission [ISET 2003].

The prediction model for wind power delivers forecasts for 1 to 72 hours with a one-hour resolution and is based on three essential foundations [ISET 2003]:

- prediction of wind speed and direction as well as other meteorological parameters for selected representative locations based on the local model (LM) of the Deutsche Wetterdienst (DWD)
- determination of the corresponding wind power utilizing artificial neural networks
- extrapolation of the wind power on the total feed-in in the control area with the online transformation model

The forecast for representative wind farms by the DWD delivers meteorological parameters in one-hour intervals for a period up to 72 hours. The forecast model has a resolution of 7x7 km horizontally by 35 vertical layers with 106 000 grid points per layer and delivers new forecasts twice a day. The artificial neural networks calculate the corresponding power output of a wind farm. They are constantly trained with predicted meteorological data and measured power output from the past to improve their calculations of wind power output from wind speeds. The measurement equipment at those representative locations also allows to feed current power data into the artificial neural networks, which helps to reduce influences of errors of the weather forecast thus improving the short-term prediction for the power output of the wind farm. The

predicted output of the representative wind farms is then transformed by the online model to forecast the total wind power generation of the complete grid area or sub regions.

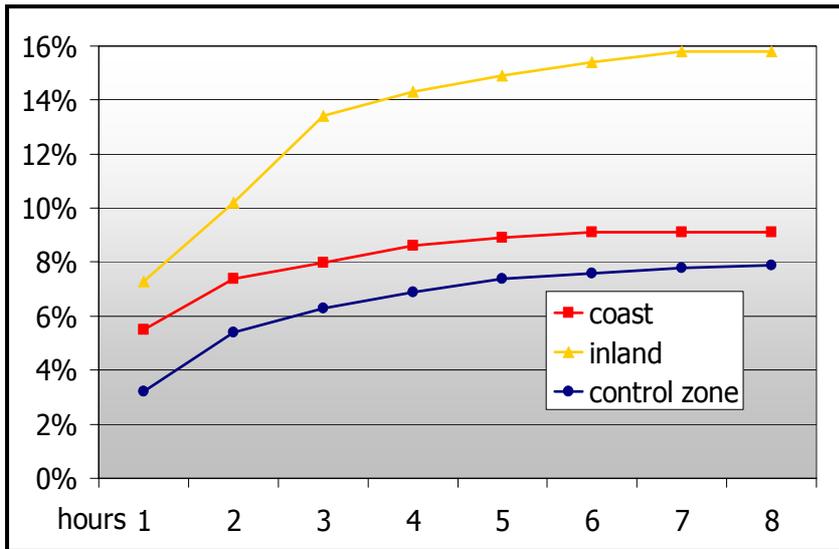


Figure 5: error of short-term prediction by WMPS; data source [ISET 2003]

The WMPS has been utilized in the load dispatcher of E.ON Netz since July 2001 and supports establishing the load schedule and power plant planning. The forecast error of the model is 8.8 % for the day-ahead forecast and 6 % for the short-term prediction from 1 to 8 hours. *Figure 5*

shows the error of the short term prediction for the calculated intervals. Even if the average quality of the forecast is very good, the problem that remains are the times when the forecast is off by more than the average. *Figure 6* shows the frequency distribution of the forecast error of an earlier version of the model for the day-ahead forecast calculated at 9 a.m. for the following day. By that time the installed capacity within the E.ON Netz grid area amounted to 3500 MW. 90 % of the forecast error is within a range of ± 500 MW, but there are times when forecast is off by up to -1400 MW. Since the TSOs have to ensure a safe grid operation within their grid area (control zone), they have to be prepared for these worst cases. They claim to have noticeable additional costs for integrating wind power into the grid.

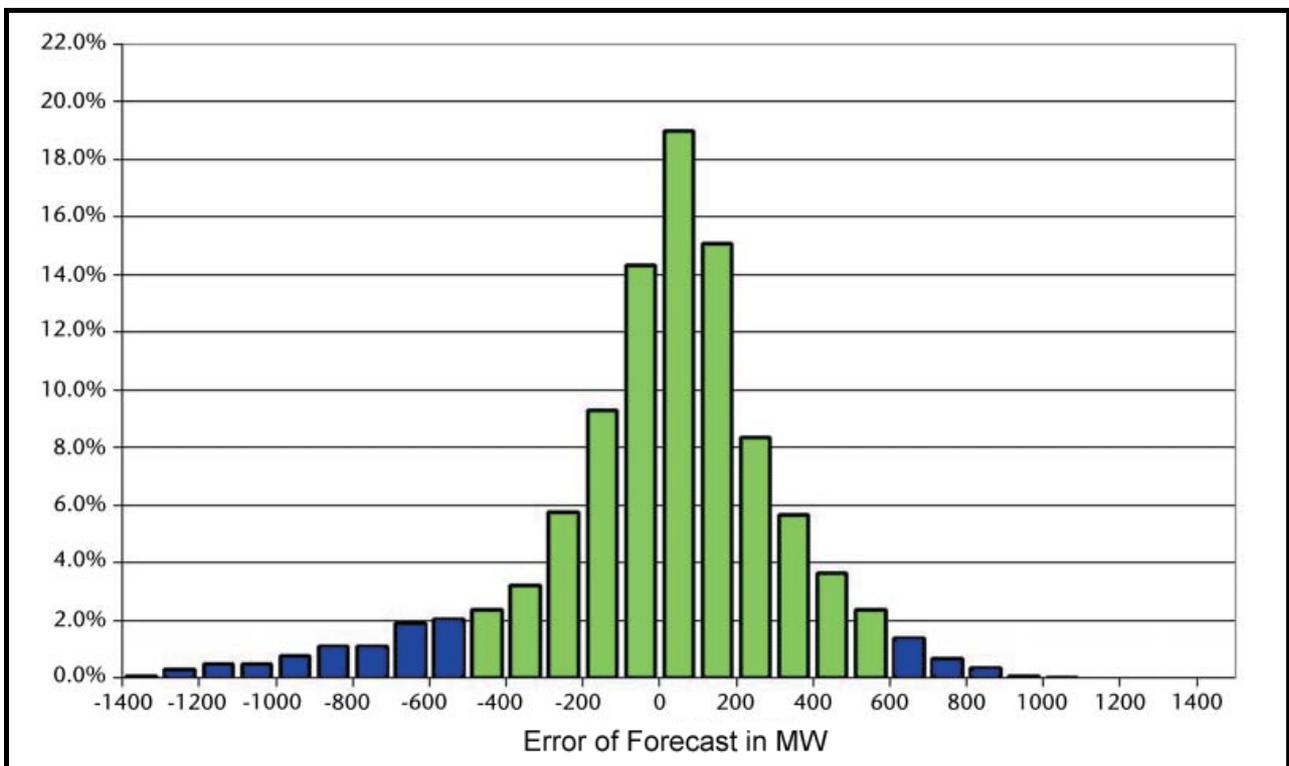
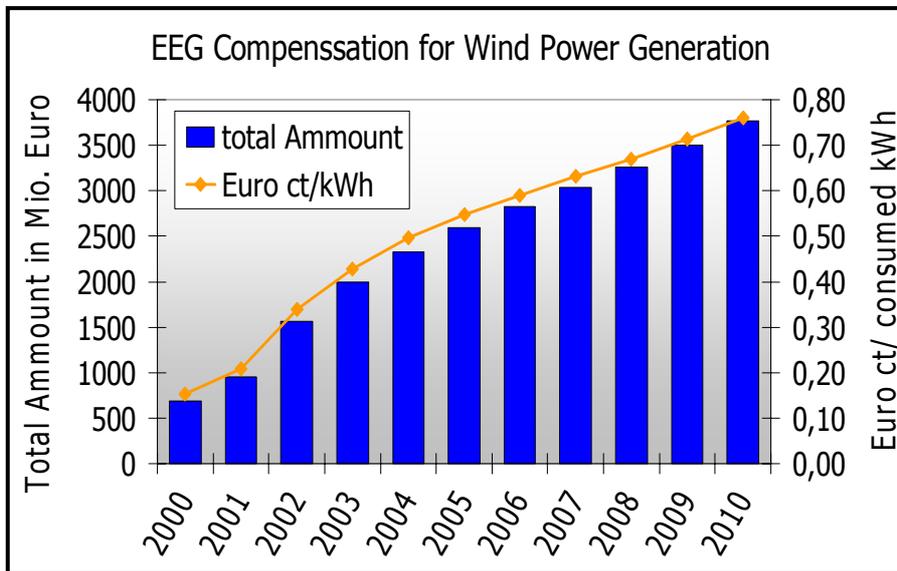


Figure 6: frequency distribution of forecast error earlier version of the WMPS over a period from Sept. 2000 until July 2001; 90% of forecast error within ± 500 MW range [ISET 2001]

Costs of Wind Power and its Integration into the Grid

The wind generated power, which is compensated by the EEG mechanism, is equally paid by all consumers with every consumed kWh so far. The following considerations assume that this will continue to be so. For wind energy they amounted to 1565 Mio. Euro in 2002 and will rise, according to the earlier mentioned future scenario, to 3764 Mio. Euro in 2010. *Figure 7*. Broken



down to one kWh of consumed electricity this value will increase from 0.34 Euro ct/kWh in 2002 to 0.76 Euro ct/kWh in 2010 [ewi 2003].

Figure 7: future scenario for wind generated power feed-in and EEG compensation paid per consumed kWh; data source [ewi 2003]

These numbers do not consider the effects of the feed in wind generated power on the conventional power generation: It saves variable and fix costs in conventional power plants as well as generating extra costs by additional need for balancing power and grid enforcements. The feed in wind power replaces conventional generation which saves variable costs given by the variable power generation costs of the most expensive generating power plant in operation at that time. But the fluctuating feed-in of wind generated power also leads to rising fuel cost due to various reasons: In general, conventional power plants running at partial load generate electricity less efficiently as running at full load. Also, power plants which are able to shift load more flexibly and are designed for less operation hours a year have lower fix costs but higher variable (fuel) cost. E.ON claims that wind power feed-in replaces conventional power generation especially in coastal regions where fuel cost are lower due to shorter transportation routes from the coast. They also say operating power plants not in the way they were designed for, i.e. more load shifts and power up and down cycles, wears them out sooner as planned [Tauber 2002]. Future investments in the conventional power generation capacity is affected by growing wind generated power feed-in by the fact that a share of the installed wind power capacity can replace conventional power plant capacity (according to E.ON to a maximum of 15 % [Tauber 2002]) and more flexible power plants of the before mentioned type are needed. Furthermore additional back-up and balancing capacity is needed as well as grid enforcements in the northern part of Germany: Most of the wind power is generated in areas with a low population density and needs to be transferred to urban and industrial areas further south. This problem will become even more urgent when (if?) the planned offshore wind power generation capacity will be operational. Some of the decentralized generation of wind power is closer to consumer in terms of distance and voltage, but according to [ewi 2003] the transmission capacity cannot be reduced considerably due to this fact and cost savings by avoided transportation losses are negligible.

A survey analyzing the actual fuel savings in the conventional power plants within the E.ON control zone due to wind power feed-in for a week in April of 2001 (3500 MW installed wind power capacity by that time) concluded that about 28 % of expected savings were lost due to “regulation losses” [Leonhard, Müller].

The [ewi 2003] expert opinion estimated avoided costs of the fed in EEG compensated power, which besides wind power also includes power generated by photovoltaic, biomass, and small water power. They estimated that every kWh of fed in EEG compensated power avoids costs in conventional power generation to an amount of 2.7 Euro cents per kWh in 2005 and 3 Euro cents per kWh in 2010. Even though the EEG power feed-in is dominated by wind generated power by about 75 % applying this number to the fed in wind power is not quite correct, since water power and power generated by biomass are not as fluctuating as wind generated power. Thus that installed capacity has a higher energy economic value and is able to replace more conventional generation capacity than wind power. If still applying that number to wind power to get an estimation of the future costs of wind power generation in Germany, it will avoid costs to an amount of 790 Mio. Euro in 2005 and 1260 Mio. Euro in 2010. Thus the total costs of the wind generated power feed-in compensated by the EEG mechanism would sum up to 1800 Mio. Euro (0.4 Euro ct/consumed kWh) in 2005 and 2500 Mio. Euro (0.5 Euro ct/kWh) in 2010 which is about 15 % of the total power generation costs in Germany.

E.ON claims to have additional costs for every kWh fed in wind power, which consist of the following shares:

• costs for balancing power	0.7 Euro ct/kWh
• higher generation cost of existing conventional power plants	1.5 Euro ct/kWh
• necessary grid enforcement	0.2 Euro ct/kWh
<hr/>	
<u>additional cost for wind generated power feed-in</u>	<u>2.4 Euro ct/kWh</u>

According to those numbers and assuming a market price of about 2.5 Euro ct/kWh the market price basically covers the additional costs leaving the complete EEG compensations for wind generated power feed-in as its total costs.

Conclusions

What ever the correct numbers may be, the compensation and integration into the grid of the growing amounts of wind generated power causes considerable costs. So far, the owners of wind turbines receive a granted compensation and do not have to think about the value of their product at all. This way of subsidizing the technology of wind power generation has very successfully supported the installation of an energy economically considerable generation capacity and advanced its technology tremendously. The question is, if continuing with unchanged policy is sustainable in the long run. Sooner or later wind power has to compete fully with other generation technologies at the market and owners of wind turbines will need to sell a product. Right now, they do not have to develop this skill, since the TSOs take care of handling the fed in wind generated power. The decrease of the feed-in tariffs provided for in the EEG will not lead to competitive prices of wind power in the near future and the amount of EEG compen-

sation paid for wind power is rising every year reaching considerable sums without any cap. The energy economic consequences of integrating large amounts of wind power into the grid are not addressed at all. Taking away the feed-in tariffs wind power, will have no future in Germany for a long time if continuing business as usual. How could a gradual shift be done to an in the long run sustainable wind power generation? Even though there have been some bad experiences with a bonus system in Germany (support of combined heat and power generation), such a system (possibly optional) is an idea to face this shift. Owners of wind turbines could be responsible for selling their wind generated power at the market and receive a bonus to make up for the difference between the market value of the power and the now paid EEG compensation. If owners of wind turbines want to sell a tradable product, they have to think of their own measures to balance their fluctuating power feed-in or find someone, who buys their power the way it is fed in. Either way, the TSOs would not have to pay for balancing power and the wind turbine owner could also receive at least part of the additional costs for the wind power feed-in E.ON claims to have. New ways of dealing with the fluctuating wind power generation would also be interesting to owners of wind turbines this way encouraging the development of new technologies.

In the future, balancing fluctuations of wind power feed-in can not be addressed only by supplying more and more balancing power. Besides more power plants that are capable of generating power more flexibly are needed, new ways of facing this task include:

- enlarging control zones: fluctuations of wind power is smoothed over larger catchment areas making grid enforcements necessary to prevent congestion
- demand side management: adjusting power consumption of certain consumers instead of power generation
- power storage technologies: so far not economically feasible, but of course possible by producing hydrogen from wind power, for example

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