Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020

Concept for a step-by-step extension of the transmission grid in Germany
for the connection and integration of wind turbines onshore and
offshore taking into account the production and
power station developments and the
necessary regulating and reserve power

Consortium

DEWI / E.ON Netz / EWI / RWE Transport Grid, Electricity / VE Transmission

Summary

Cologne, February 2005

Introduction

A reasonably priced and reliable electricity supply is an important location factor for the development of an economy. Against this background, it is necessary to investigate the demands placed on the entire system for the generation and transmission of electrical energy, which in future must again be optimised for the integration of the inevitably increasing amount of electricity generated from wind energy. The economic effects resulting from this must also be determined. Maintaining the current level of reliability of supply must be included here as an important boundary condition.

The Federal Government is significantly promoting the development of renewable energies and is aiming to expand them further. By 2010, the proportion of electricity consumption covered by renewable energies is supposed to rise to at least 12.5%, and to at least 20% by 2020. By 2050, further significant increases are supposed to have taken place. The efficient integration of wind power stations both on- and offshore into the electrical interconnected power system is necessary in order to achieve greater use of renewable energies. This is because in the medium term, wind energy has the greatest potential for increasing the proportion of electricity consumption covered by renewable energies.

The implementation of this strategy will result in a very pronounced spatial concentration of infeed from wind energy in Northern Germany. In this region, there is only a low demand for energy, which means that the regeneratively produced electrical energy has to be transmitted to regions in Western and Southern Germany where demand is high. Electricity generation from wind energy is also strongly characterised by marked daily and seasonal fluctuations and can be forecast only to a limited degree.

This gives rise to new challenges for the entire system and in particular for transmission system operators with regard to their system responsibility as far as a safe and reliable electricity supply is concerned. Firstly, more and more electrical energy must be transported over greater distances. Secondly, it is necessary to at all times guarantee to maintain the equilibrium between the electricity taken from the system by power consumers and electricity generation fed into the grid.. This requires a new method of operating and adaptations in the power stations and the transmission system.

On the basis of the age structure of today’s power plant system and the agreed phase-out of nuclear energy, an estimated 40,000 MW of new installed power plant capacities must be in place by 2020. This power plant renewal process falls in the same period as the planned expansion of wind energy use. This gives rise to both the possibility and the task of adapting the structure of the power plant system to meet the changing conditions that are characterised by an increasing infeed from wind energy that is to be included as a priority and which fluctuates greatly.

For the purpose of deriving solutions to the existing complex tasks, the German Energy Agency ordered this study, which is intended to make possible fundamental assessments and long-term energy management decisions by as many participants as possible.

The findings of the investigations in the dena study for the wind expansion scenario 2020 show that on the basis of the assumptions made and the legal framework conditions, it was not possible to derive a system solution for integration of wind-generated electricity, with further optimisation potentials to be investigated under modified framework conditions.

The study is divided up into three parts, with the following central points:

- Part 1 presents in scenarios the additional spatial expansion over time of wind power capacity both on- and offshore, and at the same time takes into account the planning statuses of the areas of use and the technical development of the WEP.
- Part 2 looks at the necessary network extension and its costs for transmitting the WEP power generated far from the point of consumption based on the scenarios outlined in Part 1 and the dynamic system behaviour in the event of grid problems, and from this derives measures for maintaining supply reliability.
- Part 3 examines the changes to the demands placed on and the effects on conventional power stations, electricity generation costs and cost increases for the end consumer brought about by the expansion of wind energy.

The results of the individual parts of the study are summarised briefly below.

Part 1: Scenarios of the Development of Wind Energy and other Renewable Energies

For the future development of onshore wind energy use both the potential for realisation of new projects by developing new sites and the replacement of older wind turbines by modern and more powerful turbines at locations already in use (the so-called "repowering") are important. For a prognosis of the offshore wind energy use in Germany it is necessary to carry out an independent appraisal of the currently planned projects with a total capacity of more than 40 GW with regard to their feasibility (including the time factor).

Within the scope of the present study, the German Wind Energy Institute (DEWI) has carried out a nationwide survey among the competent authorities in order to determine the areas assigned as suitable areas for the use of wind energy in the regional development programmes of the states (LROP) and in the regions (RROP, regional plans, land development plans). In Germany, wind energy projects are realised almost exclusively on areas assigned for wind energy called priority, conditional or suitable areas – this applies also to repowering projects.

The capacity that can be installed on the areas assigned to wind energy use is determined on the basis of an average area required of 7 ha/MW (1 ha = 2,471 acres). Taking into account the wind turbines already installed by the end of 2003, it is possible to determine the potential still remaining in the suitable areas. Other concrete information available on currently planned projects has also been considered.

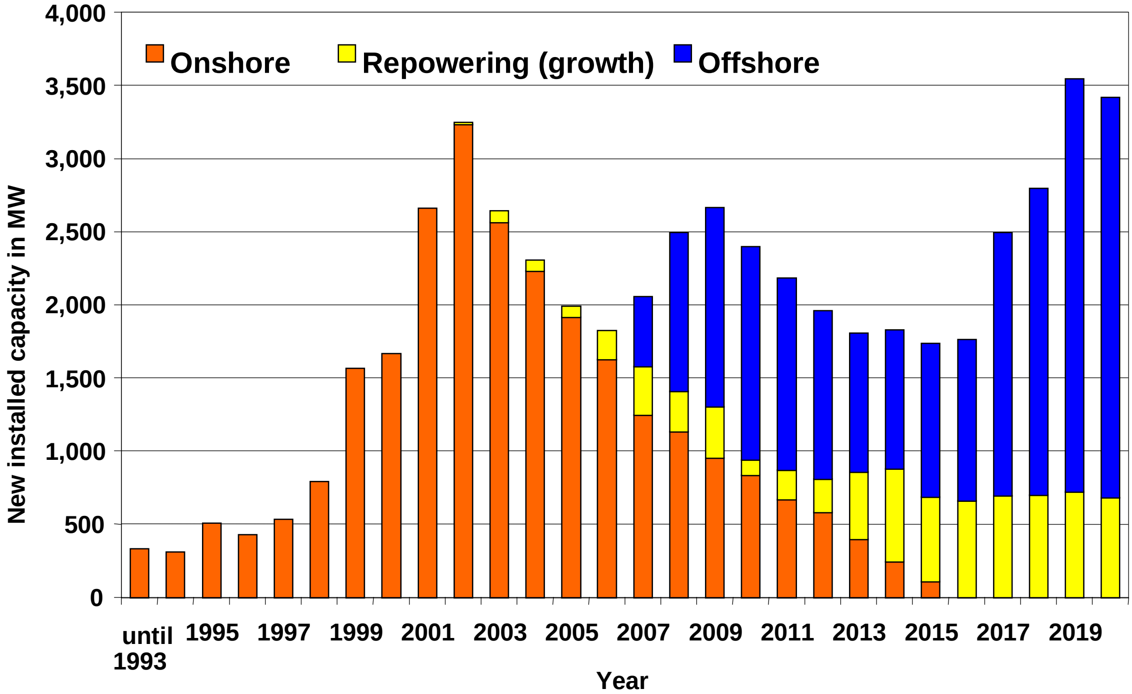
For a prognosis of the wind energy use within the scope of this study the existing incalculabilities with regard to the usability of the areas assigned – e.g. unachievable economic viability, non-existing grid connection and possible problems in the realisation of the project due to approval problems etc., are taken into account by reducing the growth potential determined by a flat rate of 20%.

As fas as repowering is concerned, the DEWI scenario assumes that of the wind turbines installed after 1998, one third will be replaced after 12, one third after 15 and one third after 20 years, with a factor of 1.4 for the growth in capacity due to repowering. For wind turbines installed before 1998 (e.g. before the revision of the Federal Building Code (BauGB) came into effect), it is assumed that 1/3 of the turbines will be "repowered" and that on average the capacity installed will be trebled.

For a prognosis of the offshore wind energy development, DEWI experts have carried out an independent appraisal of the individual offshore wind energy projects with regard to their feasibility (including the time factor). DEWI estimates that it is possible to install an offshore wind energy capacity of approx. 20,000 MW by the year 2020. Another approx. 16,500 MW already planned can only be realised after 2020 according to this prognosis.

Figure 12 of the study shows the trend of new installations up to the year 2020 according to the DEWI scenario.

Figure 1: Prognosis of wind energy development in Germany onshore and offshore up to 2020 (new installation) - DEWI scenario



For the benchmark figures of the years 2007, 2010, 2015 and 2020 discussed in the study, the following values given in table 1 of the present study have been established for the DEWI scenario.

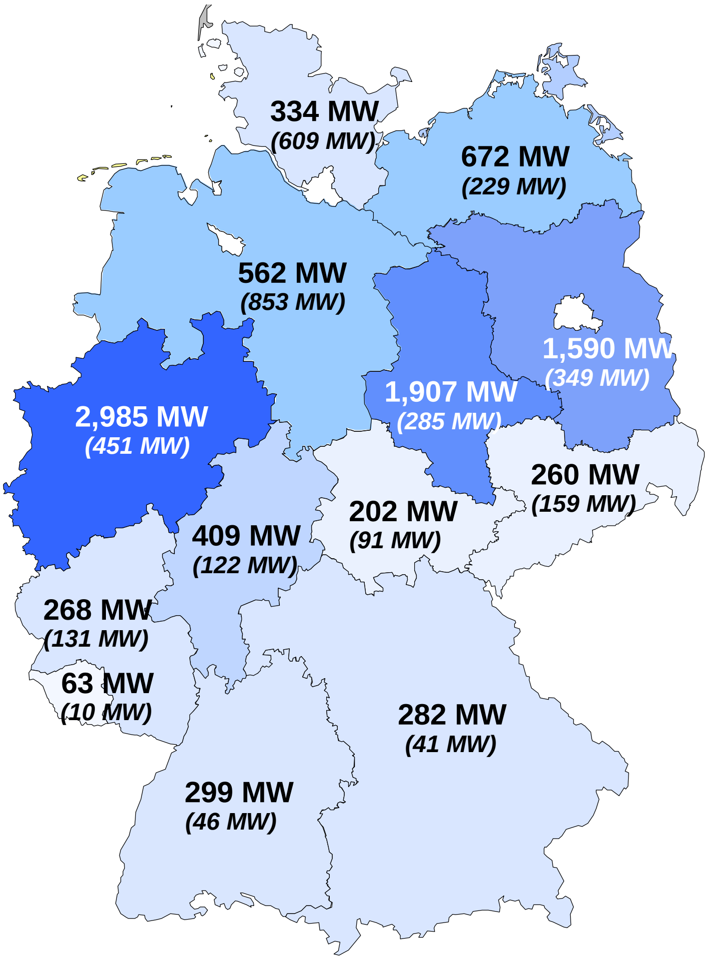
Table 1: Prognosis of the wind energy development for the years 2007, 2010, 2015 and 2020 according to the DEWI scenario (cumulated, figures in MW)

Year	Onshore	Repowering (growth)	Offshore	Sum
2007	21,620	768	476	22,864
2010	24,540	1,503	4,382	30,426
2015	26,544	3,601	9,793	39,938
2020	26,544	7,056	20,358	53,958

The advisory board established for this study has decided to use certain assumptions - differing from the DEWI scenario - for the prognosis of wind energy development in Germany onshore and offshore up to 2020. For Lower Saxony and Brandenburg, for example, an area required per wind turbine of 10 ha/MW instead of 7 ha/MW was determined. For the repowering of wind turbines installed after 1998, the advisory board has decided that one half of the turbines should be replaced after 15, the other half after 20 years, with a growth factor of 1.2. Additionally, certain targets for the offshore wind energy development were decided which in part differ considerably from the DEWI scenario and must be considered as political targets.

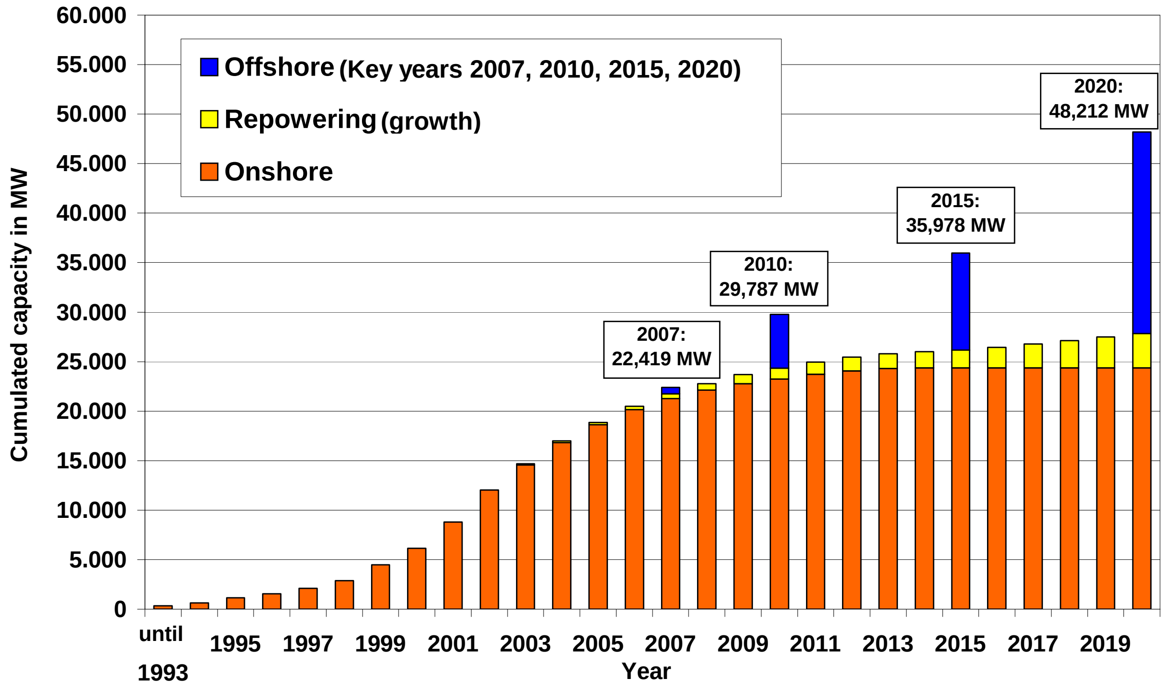
Figure 2 shows the regional distribution of the remaining development potential (onshore new installation and growth by repowering) in the federal states for the scenario "Resolution of the dena Advisory Board".

Figure 2: Regional distribution of the development and repowering potential for the wind energy use up to 2020 - scenario "Resolution of dena Advisory Board“



In figure 3 of the present study the overall prognosis for wind energy development onshore and offshore (only for the key years 2007, 2010, 2015 and 2020) is shown up to 2020 as it would result on the basis of the dena advisory board resolution.

Figure 3: Prognosis of wind energy development in Germany onshore and offshore up to 2020 (cumulated) - scenario "Resolution dena Advisory Board“



For the years 2007, 2010, 2015 and 2020, the following values given in table 2 have been established for the scenario "Resolution dena Advisory Board".

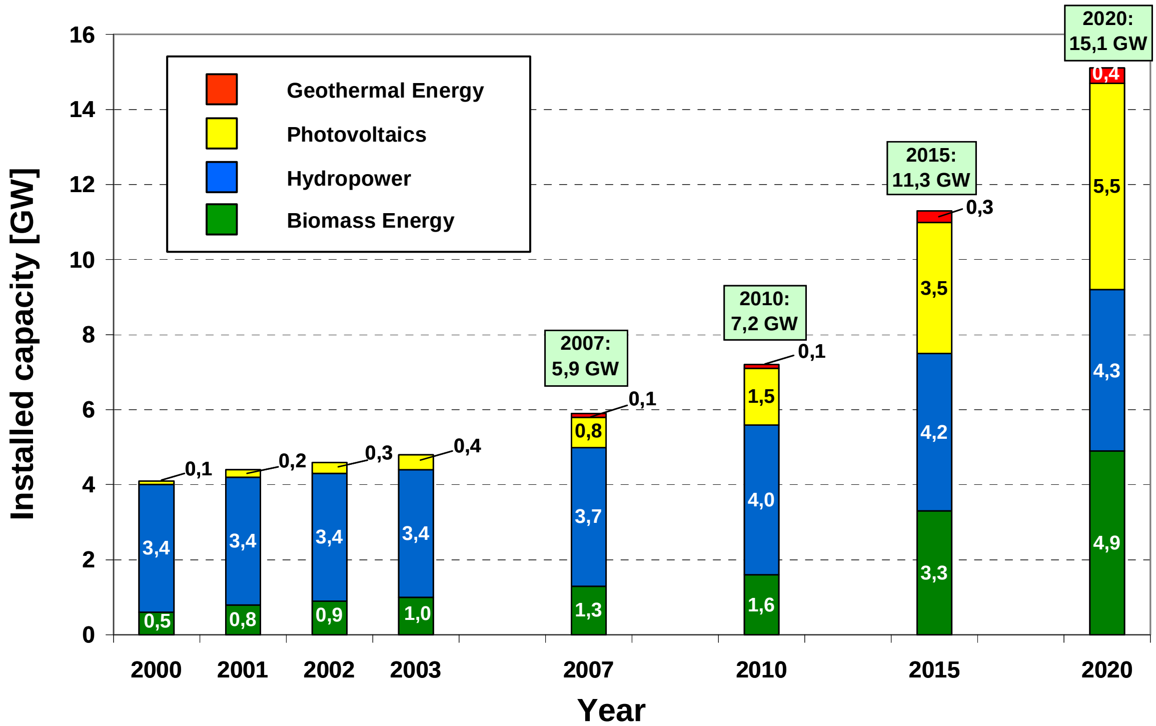
Table 2: Prognosis of wind energy development for the years 2007, 2010, 2015 and 2020 according to the scenario "Resolution dena Advisory Board" (cumulated, figures in MW)

Year	Onshore	Repowering (growth)	Offshore	Sum
2007	21.264	504	651	22.419
2010	23.264	1.083	5.439	29.787
2015	24.386	1.799	9.793	35.978
2020	24.386	3.468	20.358	48.212

Concerning the development of the use of other renewable energies in the period up to 2020, reference is made to the results of the recent study „Ökologisch optimierter Ausbau der Nutzung erneuerbarer Energien in Deutschland“ (Ecologically optimised development of the use of renewable energies in Germany) of the DLR/IFEU/WI consortium.

Figure 4 shows the prognosis of the installed gross capacity for renewable energies (without wind energy) up to 2020.

Figure 4: Prognosis of the installed gross capacity of other renewable energies (without wind energy) up to 2020 - based on the scenario „Naturschutz Plus I“ (“nature conservation plus 1”) in [DLR/IFEU/WI (2004)]



The scenarios were developed on the basis of an extensive presentation and discussion of the current situation and of the conditions of wind energy use onshore and offshore in Germany. The results of other recent studies for the future development of wind energy were also discussed in the study.

Part 2: Effects on the grid: Necessary grid extension and extension costs

The bases of the analyses

The technical investigations into the integration of the capacities of wind energy plants (WEPs) into Germany's interconnected transmission system as forecast in Part 1 of the study are based on the premises of unchanged reliability of Germany's electric power system and on maintaining safe and reliable interconnected operation with European partners. The technical criteria, analyses and also the evaluations were made under the agreed framework conditions and assumptions (e.g. a uniform distributed wind energy supply for the whole of Germany) and covered determination of the transmission system extension necessary for (n-1)-secure transmission and the dynamic investigations concerning adherence to reliable limit values in the case of individual system faults.

Necessary system extension over the time horizons 2007, 2010 and 2015

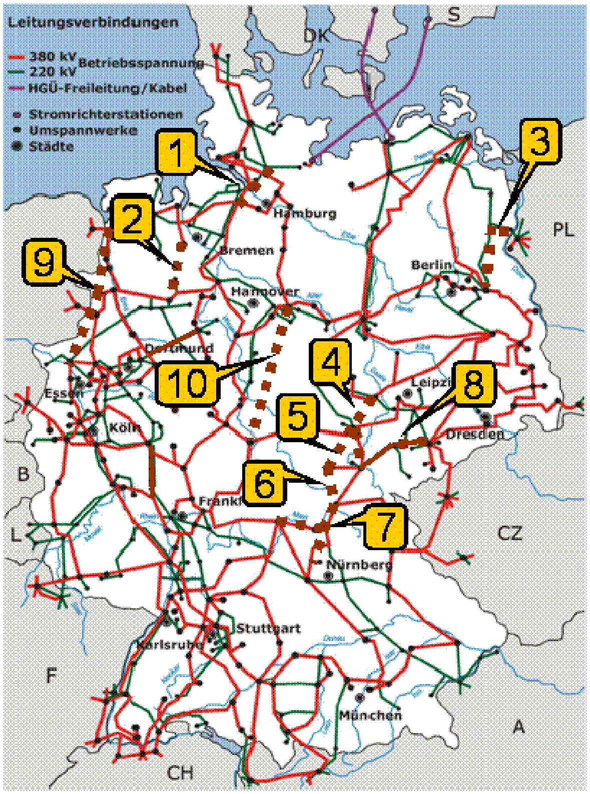
The wind-related transmission tasks of the interconnected system depend crucially on the network regions in which the new WEP capacity is installed and which conventional generation units are freed by the uptake of WEP power. The feed-in situation into the grid was assumed in line with the results from Parts 1 and 3 of the study. As the economic costs of the residual generation have been minimised here in all scenarios, power plants are used in merit order, as described in Part 3. The transmission tasks determined with this optimised generation model form the basis for sizing the transmission system, taking into account the (n-1) criterion. A significant but temporary use of neighbouring foreign transmission systems in heavy-load periods was regarded as tolerable. The individual extension stages have been defined with a view to an optimised final extension stage in 2015 (sustainability principle). These represent an important indication for the development of the transmission system under the agreed framework conditions.

For the time horizon **2007**, various system bottlenecks in normal operation and violations of the (n-1) criterion have been identified as a consequence of the increased wind energy infeed. However, the scope of the line routes to be built in time for eliminating these bottlenecks seems unrealistic from today's point of view, considering the licensing practices of the authorities under public law and the resistance to new line routes among the population. The study therefore assumes that only regional system optimisation is feasible up to this time horizon, to be achieved through the installation of additional conductors and quadrature regulators for power flow control. Even some individual overhead line construction projects, for which the public law licensing procedure has already been started and the realisation of which is planned by 2007, have so far not been covered in this study for the aforementioned reasons.

In windy periods, network bottlenecks can be expected for the 2007 time horizon unless new lines are constructed. These bottlenecks will require intervention in the market in order to maintain system security.

For the following years, a need has been identified for the system extension work shown in the figure below:

Figure 5: 380 kV transmission route requirement up to the time horizons 2010 and 2015



Deutsches Höchstspannungsnetz Stand: 01.01.2003

Until 2010: 460 km

1) Hamburg/Nord – Dollern	45 km
2) Ganderkesee – Wehrendorf	80 km
3) Neuenhagen – Bertikow / Vierraden	110 km
4) Lauchstädt – Vieselbach	80 km
5) Vieselbach – Altenfeld	80 km
6) Altenfeld – Redwitz	60 km
7) Netzverstärkung Franken	
8) Netzverstärkung Thüringen	

Until 2015: Additional 390 km

9) Diele – Niederrhein	200 km
10) Wahle – Mecklar	190 km

Up to the time horizon 2015, there will be a need for approximately 850 km of 380 kV transmission routes in order to transport the WEP power to the load centres. In addition, numerous 380 kV installations will need to be fitted with new components for active power flow control and reactive power generation. Based on the assessed regional distribution, the integration of a total of 36 GW of WEP capacity into the German transmission system will be possible. This WEP power is in line with the target of a 20 per cent share of all renewable energy in the German electricity supply that the Federal Government wants to achieve by 2020 at the latest.

Table 3: Overview of major system extensions (cumulative figures)

	By 2007	by 2010	by 2015	by 2020*
Construction of new 380 kV routes	5 km	460 km	850 km	1,900 km
System reinforcement of existing routes	270 km	370 km	400 km	850 km
Quadrature regulators (1400 MVA in each case)	3	3	3	4
Reactive power compensation	5,600 Mvar	6,600 Mvar	7,350 Mvar	10,850 Mvar

*Provisional results

The total costs for the transmission system extension necessary up to the time horizon 2015 are approximately 1.1 billion €. The investigated solutions for the time horizon 2020 are restricted to stationary observations for determining the necessary transmission line cross sections. The estimated cost of extending the transmission system up to 2020 amount to approximately 3 billion € in total.

The **specific installation costs** (excluding system connection costs) for installed WEP power of between 20 and 40 GW are approximately **50 € / kW**. This does not include the land and marine cable connections to the offshore WEP. The costs of these connections for connecting approximately 10 GW in the North Sea and the Baltic Sea up to the time horizon 2015 are estimated at approximately 5 billion € in total. These are classed as system connection costs to be added to be included under construction costs for the WEP and hence funded by the EC infeed payments.

In view of the high speed of expansion in wind energy use, the requirement for transmission routes as determined in the study has resulted in ambitious targets being set for completing the approvals procedure on time. Due to the geographical conditions and also conservation and landscape protection concerns, we can expect complex deliberations about the routes and a lengthy legal approvals procedure. Realising the necessary new transmission routes in line with requirements will require the responsible authorities to deal more quickly with the procedural steps demanded by law.

The impact on supply reliability

The results of the study show that even today and particularly in conditions of strong wind, German transmission system operators are forced to operate their grids close to the permissible operating limits. Even grids in neighbouring countries are massively and adversely affected by the electrical energy generated in WEPs in Germany. The grid-related problems arise in particular because wind energy is available to the extent required neither in the right location nor at the right time.

Due to the high expansion speed of wind energy, it has so far not been possible to incorporate at the right time the results already available from existing studies and operational experience into the technological further development of WEPs. The result of this is that because of the large number of obsolete plants, the UCTE rules that serve to maintain system reliability can be violated. The reason for this is that existing WEPs connected to the high-voltage and medium-voltage grids are immediately disconnected from the grid in the event of grid faults in order to prevent damage to the WEP and to observe the safety criteria in the distribution systems. In contrast, conventional generation units are obligated to maintain their supply and to support system stability in line with the system connection conditions even in problem situations.

For WEPs, this problem can be solved for new plants with the aid of advanced technology and more complex integration into the grids. The improved system support from new plants and replacement of the old plants by re-powering will therefore result in a continuous reduction in the WEP outage capacity in the event of grid problems for the time horizons 2007 and 2010. However, by the time horizon 2015, this positive effect will be partially cancelled out again by the shutdown and the wind-related output reduction of conventional power station capacity, with the result that the problem will again become more acute for the time horizon 2015 due to the remaining large number of older plants, which do not contribute to voltage support. These high levels of generation outage caused by simple line faults can put at risk European interconnected operation. It remains to be investigated to what extent the upgrading of obsolete plants and additional installations for supporting the transmission system can improve the situation in the event of faults.

The Outlook

According to the targets of the Federal Government, the expansion of wind energy, particularly offshore, is to be pushed ahead after 2015. The total WEP capacity of 48 GW forecast as being feasible by 2020 according to Part 1 of the study will require a further significant extension of the transmission systems for transporting the WEP power to distant load centres. Alternatively, 380 kV three-phase lines with series compensation or HVDC links can be used for this purpose. Determining the best technical and economic alternative will require examination of the individual cases, with particular attention needing to be paid to an in-depth investigation of the effects on stability under the prevailing grid conditions.

The replacement of conventional power stations by high WEP infeed under conditions of strong wind will increase more markedly after 2015. The result of this will be that during periods of strong wind and low electricity demand, the grid load will be lower than the fed-in WEP power, including that other from other regenerative systems, with the result that in terms of the power balance as defined by the EC priority rule, the conventional generation units would even have to be completely disconnected from the grid. The extent to which a reduction in conventional generation capacity in such situations is permissible while maintaining the present supply reliability will require detained extensive investigations.

This means that a series of technical, organisational and economic questions must be answered before any further significant expansion of wind energy after 2015. Determining the necessary measures for maintaining the present level of supply reliability requires further research and investigations, the most important content of which is listed and justified in the study. These include, among other things, the system-related incorporation into the interconnected system of the transmission technology for offshore power, the technical and legal necessities and requirements for WEP infeed management (obtaining the fed-in power levels, a manageable control mechanism), the possibilities and limits of future WEP technologies for supporting system stability and the future demands placed on the remaining conventional generation and its technical limitations. In future examinations, it will be necessary to consider both the effects on the European interconnected system of increasing wind energy use in Germany and the associated developments in neighbouring European grids. The present efforts on the political level in the European Commission must also be examined. These also promote the expansion of European electricity trading over longer transport distances, while at the same time there is a demand for an unchanged level of supply reliability.

Part 3: Effects on conventional power stations and electricity generation costs

The task and method

Part 3 of the study investigates the effects of the further expansion of wind energy up to 2015 on the demands placed on conventional power plants, on electricity generation and on the costs of electricity generation.

The Institute of Energy Economics at the University of Cologne (EWI) will use model-based analyses for the years 2007, 2010 and 2015 to determine the changes caused by the expansion of wind energy: The increase in statistically guaranteed capacity through installed wind energy plants (WEP), the necessary additional provision of regulating and reserve power capacities as well as their additional dispatch, and the residual load to be covered by conventional power plants. Afterwards an optimisation model will be applied to determine the cost-minimizing developments of power plant capacities, electricity generation, fuel consumption and resulting CO_2 emissions in the conventional power plant system. Two scenarios will be examined in each case here: In the expansion scenario, the development of the WEP capacity is assumed as outlined in part 1 of the study. In the comparison scenario, the installed WEP capacities and WEP electricity generation up to 2015 are fixed at the level at the end of 2003.

The bases are the predicted WEP capacities of the DEWI (‘Resolution dena Advisory Board’) for 2007, 2010 and 2015 (Part 1 of the study) and the WEP electricity generation in these years as determined in a special ISET investigation (Table 4).

Table 4: Forecasts of the development of installed WEP capacity and WEP full load hours up to 2015 with wind energy expansion

		2003	2007	2010	2015
Installed WEP-Capacities in GW	Onshore	14,5	21,7	24,2	26,1
	Offshore	-	0,7	5,5	9,8
	Total	**14,5**	**22,3**	**29,7**	**35,9**
Annual Full Load Hours in TWh/a	Onshore	23,7	34,9	40,3	44,7
	Offshore	-	1,9	18,0	32,5
	Total	**23,7**	**36,8**	**58,4**	**77,2**

The difference between the two model runs (expansion vs. constant WEP capacity) shows the effects of wind energy expansion on the conventional power plant system and its operation assuming a cost-optimised adaptation of the conventional power system.

It must be noted in this context that adaptations will be made to the entire conventional power plant system.as a result of the great amounts of additional wind energy generated in the expansion scenario. This will determine not only the direct effects on electricity generation of wind energy feed-in. In addition indirect effects arising from conversion of the conventional power plant system are also considered, such as the level of cogeneration, the total time required for power plant overhauls and the foreign trade balance. Therefore the differences of the two model runs do not exclusively represent the effects on the conventional power plant system arising directly from wind power. Rather, they should be regarded as an overlap of various effects that arise in the conventional power plant system when cost minimisation aspects are examined.

Both model runs are based on the same fundamental assumptions. These particularly include the conventional power plants that are currently in operation in Germany, the available conventional power plant technologies, the shutdown of nuclear power plants based on the resolution to abandon nuclear energy, the maximum transmission capacities to neighbouring countries and the electricity feed-in from other renewable energy sources (in addition to wind energy). In addition some institutional and organisational framework-conditions are assumed which do not fully correspond to the present situation of the electricity supply system in Germany. For example, there is no separate examination of the four German transmission system operators, and the present separation of responsibility to compensate for power plant outages between transmission system operators and power plant operators is not taken into account.

Depending on the assumptions made about the fuel prices and the burdens of CO_2 prices, we obtain different optimum-cost adaptations to the expansion of wind energy for conventional power plants and how they are dispatched. All calculations were therefore made on the basis of three scenarios:

- ***Basic scenario***
  The basic scenario assumes a moderate price rise for natural gas, oil and hard coal (compared to 2000), and a real constant lignite price based on the total costs of the extraction of lignite. It is also assumed that the CO_2 emission allowances under the national allocation plan will be issued for both existing and new plants in line with requirements (“ex post“ adaptation) and free of charge, and that the CO_2 price will therefore not be included in the companies’ cost and price calculations.

- ***Basic scenario with CO2 surcharge***
  This scenario assumes the same fuel-price developments as in the basic scenario. Unlike in the basic scenario, the CO_2 emission allowances will be auctioned and the CO_2 prices (2007: 5 €/t CO_2/; 2010: 10 €/t CO_2/; 2015: 12.5 €/t CO_2) will be fully included in the companies’ cost and price calculations.

- ***Alternative scenario***
  This scenario assumes a significantly sharper rise in natural gas and oil prices and combines this with the assumption that the CO_2 prices (2007: 5 €/t CO_2/; 2010: 10 €/t CO_2/; 2015: 12.5 €/t CO_2) will be fully included in the companies’ cost and price calculations.

Effects on the demands placed on the conventional power plant system

Increase in statistically guaranteed capacity from wind power plants

The increase in (statistically) guaranteed capacity provided by WEPs is approximately the same as the capacity in the conventional power plant system, which can be completely given up without restricting supply reliability thanks to the installed WEP capacity. However, due to the dependence of the electricity supply from wind power plants on the very changeable wind availability, only a small proportion of the installed WEP capacity can contribute to the reliable capacity among a conventional and regenerative power plant mix. Depending on the time of year, the gain in guaranteed capacity from WEP as a proportion of the total installed WEP capacity is between 6 and 8 % in the case of an installed WEP capacity of around 14.5 GW (in 2003) and between 5 and 6 % in the case of an installed WEP capacity of around 36 GW (in 2015).

Additional requirements for regulating and reserve power capacities

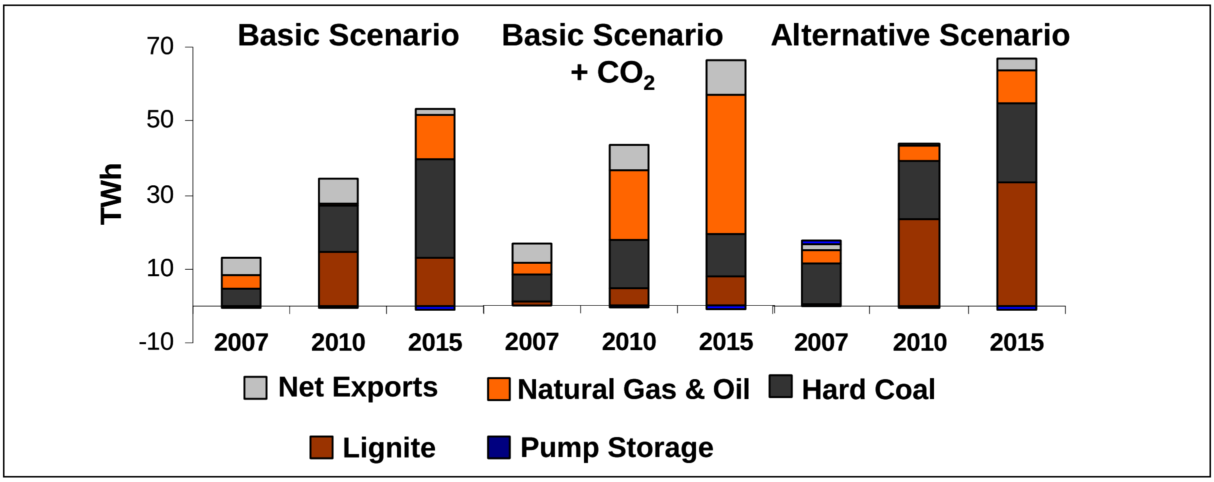
The forecast errors for the WEP feed-in give rise to an additional requirement for regulating and reserve power capacity provision so as to guarantee the balance between infeeds into the grid and tapping from the grid, which is crucial in the power supply at all times. Despite an assumed improvement in the predictability for the WEP infeeds, the required regulating and reserve power capacity increases disproportionately as the installed WEP capacity increases. Due to the dependency of the wind-related regulating and reserve power capacity requirement on the level of the predicted wind infeed, the regulating and reserve power capacity required for the following day can here be defined as a function of the forecasted WEP infeed level, taking into account optimisation aspects. This provides an average “day ahead“ regulating and reserve power capacity. However, the power stations must be collectively configured in order to provide the required maximum regulating and reserve power capacity at all times.

- In 2015, an <u>additional</u> maximum 7,064 MW of positive regulating and reserve power capacity is needed, of which on average 3,227 MW has to be contracted “day ahead”. In 2003, the corresponding values were 2,077 MW maximum and 1,178 MW on average.
- In 2015, an additional maximum 5,480 MW of negative regulating and reserve power capacity is needed, of which on average 2,822 MW has to be contracted “day ahead”. In 2003, the corresponding values were 1,871 MW maximum and 753 MW on average.

Effects of the additional WEP infeed on conventional electricity generation

In the short term, the conventional power plant system will be adapted to the additional WEP feed-in by using the power plants differently, and in the long term by an altered make-up of the power plant system and its use. The additional WEP feed-in will replace electricity generation from power plants fired by fossil fuels and therefore will change the foreign trade balance. The displacement of electricity generation from conventional power plants (based on different fossil fuels) due to additional WEP feed-in depends on the assumed fuel price developments. In Figure 6 the differences in electricity generation with and without the expansion of wind energy are shown by fuel type.

Figure 6: Conventional electricity generation avoided by additional WEP infeed, by fuel type; 2007 - 2015

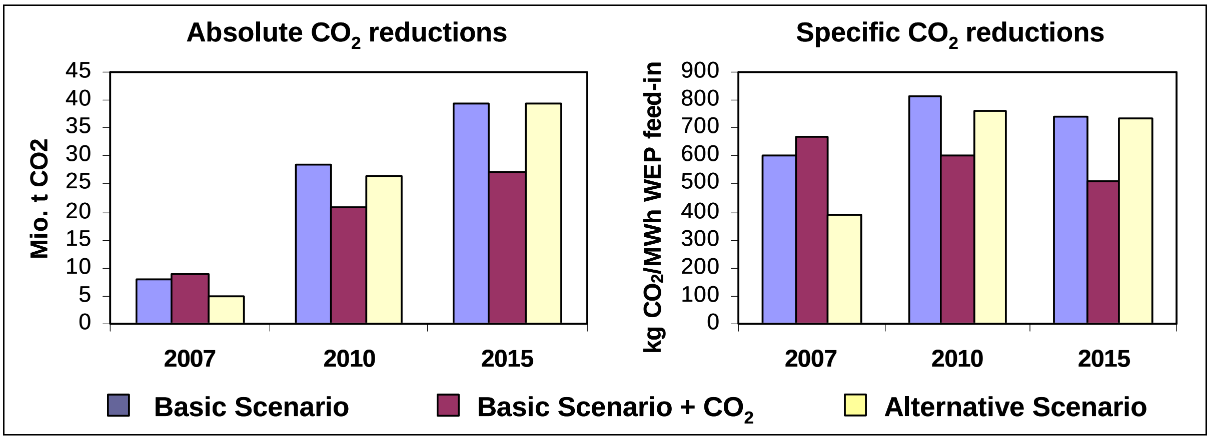


In 2007, mostly electricity generation from natural gas and hard coal power plants, which have higher generation costs with lignite and nuclear power plants, will be displaced. In all scenarios, net exports will increase as wind energy continues to expand. In 2010 and 2015, the electricity generation that has been displaced by additional WEP generation will depend significantly on the (expected) fuel price development, since power plant shutdowns and necessary new constructions will play an increasingly important role. As a result of the volatile wind power generation and the associated reduction in the average capacity utilisation of conventional power plants, the new construction of capital-intensive power plant technologies to cover base and lower medium load will be less cost-effective. In the basic scenario and the alternative scenario, in which coal-fired power stations are the economical alternative in these load ranges, this will primarily affect lignite and hard coal power stations. In contrast, in the basic scenario + CO_2, in which the base and lower medium loads are to an increasing extent also being covered by natural gas-fired CCGT plants and natural gas-based cogeneration power plants, mainly electricity generation based on natural gas will be substituted. In all fuel price scenarios, net exports and the use of pumped storage power plants will increase moderately. Flexible peak load power plants such as gas turbines, of which an increasing number will be built due to the expansion of wind energy, mainly serve to cover the additional short-term and long-term regulating and reserve requirement and hardly change electricity generation based on fossil fuels.

Effects of the additional WEP infeed on CO_2 emissions in electricity generation

The additional WEP feed-in substitutes electricity generation in fossil-fired power plants and thereby reduces the consumption of fossil fuels and CO_2 emission. Depending on fuel price developments (including costs of CO_2 allowances), varying amounts of CO_2 emissions will be saved due to the different CO_2 factors of the fuels and the varying efficiencies of the power stations based on their technologies. In 2007, the absolute CO_2 savings resulting from the additional WEP infeed will be between about 5 million tons and just under 9 million tons of CO_2 and by 2015, this will increase to about 27 to 39 million tons of CO_2, mainly as a result of the further increase of the WEP infeed – depending on the assumed fuel price development (Figure 7).

Figure 7: CO_2 emissions avoided by additional WEP infeed; 2007 - 2015; absolute and specific



The specific CO_2 emission reductions per additional MWh of WEP feed-in also increase in the basic and alternative scenarios, since wind energy will increasingly displace coal-based electricity generation. In contrast, in the basic scenario + CO_2, the specific CO_2 emission savings fall because it is mainly electricity generation from modern gas-fired power plants (CCGT and gas-fired CHP plants) that is displaced.

Effects of the additional WEP infeed on electricity generation costs

Increased electricity feed-in from WEPs and other supported renewable energies will result in additional electricity generation costs in the form of the infeed payments (remunerations) made to the plant operators (gross costs).

The increased electricity feed-in from renewable energies avoids the need for electricity generation in conventional power plants and thereby also avoids fuel costs related to generation. It also results in a change to the power plant mix, thereby also altering the fixed maintenance costs and capital costs. The sum of the cost changes arising from these effects can be regarded as cost reductions in the conventional power plant system.

The remunerations minus the cost savings in the conventional power plant system give the total additional electricity generation costs (net costs) arising from increasing the electricity infeed from WEPs. The gross and net costs are shown as the monetary value for 2003 [€ (2003)].

Gross costs of WEP infeed and other renewable energies

The gross costs of the electricity infeed from WEP and other renewable energies correspond to the annual payments to the plant operators (Table 5).

Table 5: Absolute and average remunerations (real) for wind energy and other renewable energies in accordance with EC – 2007 to 2015 in million €(2003)

		2007	2010	2015
Wind Energy (Onshore)	Remuneration in Mio. €(2003)	2,901	3,132	3,092
	Average Remuneration in €(2003)/MWh	83.2	77.6	69.2
Wind Energy (Offshore)	Remuneration in Mio. €(2003)	165	1,417	2,296
	Average Remuneration in €(2003)/MWh	85.7	78.7	70.6
Wind Energy (Total)	**Remuneration in Mio. €(2003)**	**3,066**	**4,550**	**5,388**
	Average Remuneration in €(2003)/MWh	**83.3**	**78.0**	**69.8**
other REGs (total)	**Remuneration in Mio. €(2003)**	**1,346**	**1,667**	**2,911**
	Average Remuneration in €(2003)/MWh	**99.4**	**105.9**	**103.4**
REG (total)	**Remuneration in Mio. €(2003)**	**4,412**	**6,217**	**8,299**
	Average Remuneration in €(2003)/MWh	**87.6**	**83.9**	**78.8**

While the average remuneration for all renewable energies will fall as a result of the annual degression of the real remunerations for new plants stipulated under the renewable energy source act, (RES Act) the total payments will increase to around 8.3 billion € (2003) in 2015 as a result of an increase in the volume of energy fed into the grid. Of this, approximately 65% of the payments will be accounted for the promotion of wind power – around 5.4 billion € (2003) in 2015.

If the remunerations required for the further expansion of wind energy (excluding remunerations for the other renewable energies and the support for the WEP inventory installed at the end of 2003) are determined, in 2015 there will be an additional required volume of subsidies amounting to around 3.7 billion € (2003) arising from increasing electricity generation based on wind power by 53.7 TWh (Table 6).. Here, the real average remuneration rate will fall by around 30% from about 90 € (2003) / MWh in 2003 to approximately 70 € (2003) / MWh in 2015.

Table 6: Real remunerations (gross costs) for additional WEP infeed with the expansion of wind energy, 2007 -2015

		2007	2010	2015
Additional WEP-Generation	Generation in GWh	13,267	34,810	53,675
	Remuneration in Mio. €(2003)	1,074	2,670	3,712
	Average Remuneration in €(2003)/MWh	81.0	76.7	69.2

Net costs of the additional WEP infeed

Cost savings achieved through the additional WEP infeed in the conventional power plant system can be deducted from the gross costs.

Table 7: Cost savings in the conventional power plant system through expanding wind energy and net costs of the additional WEP infeed up to 2015

	Basic Scenario			Basic Scenario + CO_2			Alternative Scenario		
	2007	2010	2015	2007	2010	2015	2007	2010	2015
	€(2003) per additional MWh WEP feed-in								
Average Remuneration for additional WEP-Generation	81.0	76.7	69.2	81.0	76.7	69.2	81.0	76.7	69.2
Cost savings in conventional power plants	17.6	16.8	25.7	17.5	24.7	30.3	15.9	33.8	39.3
Remunerations minus Cost Savings	63.4	59.9	43.5	63.4	52.1	38.9	65.1	42.9	29.9
Total Net Costs of the additional WEP-Generation in Mio. €(2003)	**834**	**2,079**	**2,330**	**834**	**1,806**	**2,082**	**856**	**1,489**	**1,601**

Between 2007 and 2015, the specific net costs of the additional WEP feed-in will fall in all fuel price scenarios, firstly due to a fall in the average feed-in remunerations for wind energy and secondly through risen cost savings in conventional power plants. While the specific net costs will amount between 63 and 65 € (2003) in 2007, in 2015 they only will be between about 30 and 43 € (2003) for each additional MWh of WEA infeed. In each case additional costs caused by the need for extra balance power are already included in the cost savings in conventional power stations.

However, the absolute net costs will continue to expand between 2007 and 2015 because wind power-based electricity generation will increase significantly. While in 2007 between about 830 and just under 860 million € (2003) will be incurred in net costs for the expansion of wind energy, the additional net costs will rise in 2015 – depending on the assumed fuel price development – to 1.6 to 2.3 billion € (2003).

CO_2 avoidance costs

In Table 8 are the specific CO_2 avoidance costs per additional MWh of WEA infeed for 2007, 2010 and 2015, shown as a function of the fuel price development.

Table 8: Specific CO_2 avoidance costs through expanding wind power electricity generation in € (2003) per t of CO_2

	2007	2010	2015
Basic Scenario	104.7	73.4	58.9
Basic Scenario + CO_2	95.1	86.8	76.6
Alternative Scenario	168.0	56.6	40.6

Compared with alternative saving-possibilities, the specific CO_2 avoidance costs are relatively high as a result of the expansion of wind energy. Although the specific CO_2 avoidance costs will fall from 2007 to 2015, in 2015 they still will amount significantly higher than alternative saving-possibilities for CO_2 emissions, such as power plants retrofits or replacements or increasing energy efficiency on the demand side.