Summary of the Essential Results
of the Study

# Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020 (dena Grid study)

by the Project Steering Group

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# Editorial note

The summary with the essential results of the project*:

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

**(dena grid study)**

has been agreed by the Project Steering Group with the following members:

Bundesverband Windenergie e.V., ENOVA GmbH, E.ON Netz GmbH,

EWE AG, Offshore-Bürger-Windpark Butendiek GmbH & Co. KG,

Offshore Forum Windenergie, Plambeck Neue Energien AG,

Projekt GmbH, RWE Transportnetz Strom GmbH,

Vattenfall Europe Transmission GmbH, VDMA Fachverband Power Systems e.V.,

Verband der Elektrizitätswirtschaft e.V., Verband der Netzbetreiber e.V.,

VGB PowerTech e.V., WINKRA-ENERGIE GmbH,

Wirtschaftsverband Windkraftwerke e.V.,

Zentralverband Elektrotechnik und Elektronikindustrie e.V.,

Federal Ministry of Economy and Labor,

Federal Ministry of Environment, Nature Protection and Nuclear Safety (guest).

***This translation has been carried out by dena without official approval of the Project Steering Group. The original version is written in German and can be found at: www.dena.de**

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Berlin, March 15th 2005

## 1. Background of the dena Grid Study

Energy supply is an important location factor for the development of a national economy. In industrialized countries like Germany medium to long-term energy-economy and energy-policy decisions require long-term preparation and planning procedures. Thus a favorable climate for investments for a sustainable economic development can be promoted.

At present, nuclear and fossil energy sources dominate the electric-power generation mix in Germany. In order to reduce global environmental problems and risks connected with power generation from natural gas, coal, oil and nuclear fuels – such as the greenhouse effect, the consumption of finite resources, air pollution, nuclear radiation and final storage of nuclear waste– the energy supply system will have to make fundamental changes. The German Federal Government has set a target for reduction of $CO_2$ emissions from the current 859 million tons per year to 846 million tons by the year 2008/2012. In energy-generation and industry, $CO_2$ emissions will have to drop from the current 503 million tons per year to 495 million tons by the year 2008/2012. One important way to accomplish these $CO_2$ reduction goals is an increased use of renewable energy sources. In Germany, the share in electric power generation from renewable energy sources reached 10% in 2004 and is further increasing. Wind power has attained industrial policy significance due to its enormous growth rates and its prospective further development, onshore and offshore, as well as due to its export potential.

The Federal Government is substantially supporting this development, and aims for the further extension of renewable energies. Till 2010, the share in electric-power generation from renewable energy sources shall rise to at least 12.5%, and by 2020, to at least 20%. Additional major increase of capacity can be achieved by 2050. Wind power will contribute substantially to accomplishing these goals. In accordance with the strategy of the Federal Government for the development of offshore wind power generation in the North and Baltic Seas, an installed wind power capacity of 2 to 3 GW can be expected by 2010, and 20 to 25 GW by 2025/2030. The implementation of this strategy will lead to a very strong geographic concentration of wind power in Northern Germany, a region with low electricity demand. Moreover, wind power is characterized by strong daily and seasonal variations. This creates new challenges for the entire power station park.

The renewal and restructuring process of the German energy economy due to plant age and the phasing-out of nuclear power stations give wider scope for more integration of wind power. Of the 121,000 MW of gross power-generation capacity presently installed in Germany, the plants to be shut down in this process by 2020 account for about 40,000 MW.

Planning for the upcoming replacement investments in fossil power stations are also affected by the increasing share of renewable energy, and by the priority being given to this kind of generation under the Renewable Energy Act (EEG). The technical characteristics of the conventional power plants have to be adapted to the fluctuating feed-in from wind power, which has to be accepted with priority.

The interconnected power system has to synchronize the various power generation and consumption characteristics. The specific demand profiles of single consumers (households/enterprises) and/or regions (urban/rural) have to be balanced with different power stations following various cost and load profiles. An efficient cooperation within the interconnected power system shall lower overall system costs, ensure the reliability of energy supply and further maintain a secure operation of the interconnections to European partners.

The development of the national power system is also affected by the establishment of the European electricity market.

The transmission system operator (TSO) is responsible for the secure and reliable operation of the overall power system. Within his control area he balances both planned and also unexpected load variations, power station failures and bottlenecks in the transmission lines. Reserves for ancillary services ensure customers a high quality of supply with regard to frequency and voltage stability. This is maintained by use of primary-control, secondary-control and minute reserves. To balance more extended power outages or load deviations also hourly reserves are used.

In recent decades the transmission network has been extended to guaranty reliable energy supply and grid stability mainly following technical requirements of fossil and nuclear power station. The ever more powerful generation units have largely shaped the manner of network extension in the past.

## 2. Goals and Framework of the Investigation

For the further development of renewable energy, an efficient integration of onshore and offshore wind energy into the power system is very important. In the medium term, wind power has the greatest potential for increasing the share of renewable energy in electricity generation.

The upcoming changes in energy supply will require capital-intensive investments. First be made, the affects will last over several decades. The prerequisites for optimum solutions include reliable framework for energy-economy planning and agreements on the goals between the stakeholders involved. The German Energy Agency (dena) has commissioned the study “Planning of the Grid Integration of Wind Energy in Germany Onshore and Offshore up to the Year 2020” (dena Grid study). The goal of this study is to enable fundamental and long-term energy-economy planning, supported by as many stakeholders as possible.[1] The dena grid study has been proportionately financed by associations and private companies in the wind-power, power-grid, facility-manufacturing and conventional power-station sectors, as well as by the Federal Ministry of Economy and Labor.[2] They were directly involved in the preparation of the study by help of a Project Steering Group and an Expert Advisory Board, which accompanied the study. All decisions were taken by consensus. Dena initiated the overall project, led the Project Steering Group and the Expert Advisory Board, and was also responsible for project management.

The results of the dena grid study were evaluated by two independent experts[3] who accompanied the study. They gave advice to the Project Steering Group and to the Expert

[1] The German Energy Agency awarded the contract to prepare the study to a consortium headed by the Institute of Energy Economy at the University of Cologne. The consortium also includ the German Wind Energy Institute GmbH, E.ON Netz GmbH, RWE Transportnetz Strom GmbH and Vattenfall Europe Transmission GmbH

[2] The following institutions participated in the study: Bundesverband Windenergie, ENOVA GmbH, E.ON Netz GmbH, EWE AG, Offshore-Bürger-Windpark Butendiek GmbH & Co. KG, Offshore Forum Windenergie, Plambeck Neue Energien AG, Projekt GmbH, RWE Transportnetz Strom GmbH, Vattenfall Europe Transmission GmbH, VDMA Fachverband Power Systems e.V., Verband der Elektrizitätswirtschaft e.V., Verband der Netzbetreiber e.V., VGB PowerTech e.V., WINKRA-ENERGIE GmbH, Wirtschaftsverband Windkraftwerke e.V., Zentralverband Elektrotechnik und Elektronikindustrie e.V., the Federal Ministry of Environment, Nature Protection and Nuclear Safety, and the Federal Ministry of Economy and Labor.

[3] Dr. Schmieg (DIgSILENT GmbH, Gomaringen) and Prof. Schmid (ISET, Kassel).

Advisory Board, and also evaluated the intermediate and the final report. They finally documented the results of their evaluations in written statements. The Project Steering Group has formulated this summary taking into account these statements and criticisms. The further-reaching suggestions formulated by the independent experts have also been used for the formulation and task-assignment for a part II of the dena grid study.

First of all, the dena grid study drafted scenarios for the increased use of renewable energy sources for the years 2007, 2010, 2015 and 2020. The primary aspect here was a geographically differentiated scenario for wind-power development onshore and offshore, with the assignment of wind-power feed-in to particular network nodes. Based upon these scenarios, the effects of wind power feed-in on the transmission network and on the power station park were investigated. Weak points in the power system have been identified and solutions developed.

The proposed infrastructural measures for the overall system, particularly regarding the conventional power station park and in the transmission network, are to contribute to the sustainable development of the energy supply and to the implementation of the recommendations of the Council for Sustainable Development of the German Parliament.

For methodological reasons, the external costs connected with energy generation, i.e., the effects on the environment and nature, were not included in the cost calculation of the study.

During the preparation of the study it became clear that within the given framework conditions of the study it would only be possible to draft technical solutions for the integration of renewable energy sources  into the existing power system up to a share of approx. 20% in electric power generation (5% offshore-wind, 7.5% onshore-wind, and 7.5% other renewable sources). A further major increase in geographically concentrated offshore wind farms in Northern Germany, as it is planned after 2015, would require a more extensive investigation to develop viable technical solutions.

The results from this part I of the dena grid study show that for the scenarios of wind power development from 2015 to the year 2020, considering the assumptions and framework conditions put forward by the Project Steering Group, no system solution for the integration of wind power could be found. Technical solutions are to be investigated under new, modified framework conditions. Additional investigations must be carried out on fundamental technical and energy-economy issues in order to allow for the preparation of viable statements. The dena grid study has therefore been modified in terms of the time horizon to be investigated, and has been split into two parts: The present report on part I covers the time period up to 2015, with a share of renewable energy sources in power generation of 20%, while the planned part II of the dena grid study will examine the time period up to 2025.

The following aspects are to be examined in part II:

- Extension of the existing integrated grid system as a transmission network: For this purpose, the various options for an overlay network must be compared, and technically and economically solution found;
- Implementation and effects of power output control systems for wind farms,
- Demand site management,
- Application of new storage capacities and adopted supervisory control schemes for already available storage systems in the interconnected power system,
- Investigations on the resilience of overhead lines on different environmental conditions,

- Frequency assessment and general evaluation of grid bottlenecks.

Part II of the study will also take a more thorough look at issues raised in part I of the study, and examine additional issues to allow an analysis of the entire time period up to the year 2025.

These investigations could not be carried out within the constraints of the projected schedule and budget of dena grid study part I. The Project Steering Group has therefore unanimously approved the preparation of a part II, and has contracted dena to make the necessary preparations.

In the following, the essential results of part I of the dena grid study are summarized from the point of view of the Project Steering Group. The results are applicable only within the stated framework conditions and under the stated assumptions. In this summary, the results are presented only cursorily, and can be investigated in more detail in the original study, which is some 500 pages long.

## 3. Development of Wind Energy

The further development of installed wind energy capacity is forecasted geographically differentiated for various regions for the years 2007, 2010 and 2015, and 2020. The compiled data allow for a distinction between the German states, between new turbines and "repowered plants" (replacement of old wind turbines by more efficient plants), and also between onshore and offshore wind farms in the North and Baltic Seas.

An increase of installed wind energy capacity of 26.2 GW onshore and of 9.8 GW offshore is forecasted up to 2015. By 2020, it is expected that there will be 27.9 GW onshore and 20.4 GW offshore. A breakdown of wind energy capacity for the years 2007, 2010, 2015 and 2020, differentiated in onshore, offshore Baltic Sea and offshore North Sea, is shown in Table 1.

The schedule of the forecasted offshore wind power development in the dena grid study is ambitious in terms of:

- Availability of offshore technology for specific conditions in the North and Baltic Seas,
- Handling under the maritime zoning regulations as of January 1st 2006,
- Availability of the infrastructure for the construction and operation of offshore wind farms,
- Insurance and financing concepts for offshore wind farms,
- Increase of efficiency of wind turbines to compensate the decreasing feed-in tariffs fixed by the Renewable Energies Act (EEG),
- Time-frames for grid enforcement and grid extension measures.

The onshore and offshore wind power development scenarios have been drafted under the assumptions of largely positive political and economical framework conditions. If these conditions should remain valid only in parts, the assumed 20% share of renewable energy sources in power generation already expected for the year 2015 could only be realized with a delay of some years. The development of onshore wind power has however been estimated under the limiting condition of a larger specific area needed per installed kW of wind power capacity. By this, possible new legal regulations regarding minimum distances to buildings have already been taken into account. Thus, a conservative approach has been used as the basis for future onshore wind energy development.

By 2015, a total capacity of 47.3 GW of renewable energy sources should be installed, raising the share of renewable energies in total electric power generation from today's 10% to some 20%.

The average full-load-hour figure for wind turbines is calculated to be 1650 h/a in 2007, rising to 1960 h/a in 2010, and to 2150 h/a in 2015. The reason for the increase by about 30% is increasing replacement of old by more efficient wind turbines, and the use of productive sites in the North and Baltic Seas.

With the onshore and offshore extension of wind power under the EEG, the average energy production is projected to rise from 23.5 TWh in 2003 to 77.2 TWh in 2015. In 2015, some 42% of that should come from offshore wind farms.

Due to the further decrease of feed-in tariff under the EEG and an assumed inflation rate of 1.5% per year, the average real tariff per kWh under the EEG will drop from 8.3 ct€/ kWh in 2007 to 7.0 ct€/ kWh in 2015.

These forecasts and calculations up to 2015 form the basis for the investigations in the section of the study titled "Grids" and "Power Stations". The forecast up to 2020 is to be investigated and examined in detail in the context of the projected part II of the dena grid study.

## 4. Grid Upgrade and Grid Extension

For the further integration of renewable energy sources into the interconnected power system, an extension of the extra high voltage transmission network will be necessary. This will include an upgrading of existing overhead lines, the construction of new extra high voltage lines, the implementation of quadrature-regulators to control power flows, and the implementation of units to provide reactive power. In order not to endanger the further development of wind power, implementation of these measures within the near future will be a prerequisite.

Although the identified grid extension measures account for only about 5% of the existing transmission network,[4] there are various bottlenecks to rapid implementation. Compared with the new construction of recent years, the timeframe for necessary network extension is very ambitious.

In order not to endanger the further development of wind power, not only the immediate ongoing implementation of planning and investment decisions, but also in particular the legal approval procedures for network extension must be accelerated.

In the future, a denser network of extra high voltage transmission lines could also be used for additional activities in energy trading. However, this issue has not been examined.

The further extension of the transmission network will decisively affect the speed of growth of renewable energy sources, and also power generation by very efficient conventional power plants. This particularly applies to wind energy use in the North Sea.

With regard to grid extension, the dena grid study shows the following detailed results:

[4] The stock of extra high voltage lines (380/220 kV) in Germany amounts to a length of approx. 18,000 km.

## Onshore Network Extension

The necessary new grid constructions up to 2015 will extend the existing transmission network by a total of 850 km. This corresponds to a share of 5% of the currently existing extra high voltage line tracks.

- Onshore grid upgrading and extension up to 2007: Three existing overhead line sections in Thuringia and Franconia will have to be upgraded to a total length of 269 km. Two overhead line sections with a total length of 5 km will have to be built.
- Onshore grid extension up to 2010: In addition to the measures mentioned above, another 455 km of new 380-kV double overhead lines must be built. Moreover, 97 km of existing lines must be upgraded.
- Onshore grid extension up to 2015: In addition to the above-mentioned measures, another 390 km of new 380 kV double overhead lines must be built, especially to enable transmission of wind power from the North Sea. Also, 26 km of existing lines must be upgraded.

Onshore grid extension beyond 2015: Further extension of offshore wind power, as expected beyond 2015, would require massive grid extension measures to transmit the power from geographically concentrated offshore wind farms and regions with low energy consumption to the German regions with high energy consumption. Three approaches for grid extension measures between 2015 and 2020 were evaluated in terms of their fundamental advantages and disadvantages. They principally show how wind power could be transmitted from the North Sea to Germany’s centers of high electricity consumption. A thorough investigation of the technical realization and an economical optimization of further grid extension measures beyond 2015 (approximately 1,000 km) will be necessary. Both will be addressed in part II of the dena grid study. It will only be possible to make conclusive statements about these aspects when part II has been finished.

## Offshore Network Extension

Technical solutions are available for power transmission from offshore wind farms in the North and Baltic Seas to the onshore points of grid connection. The transmission of huge amounts of wind power over long distances is considered as technically feasible.

For the period beyond 2015 a system model has been developed for the further expansion of wind farms in the North Sea which avoids a large number of parallel submarine cables. This system model should be implemented as soon as possible. It consists of four offshore collection stations, to which several wind farms could be hooked. Wind power could then be transmitted to shore from these collection stations by use of only one common submarine cable (see Figure 4). Due to the investigations required (part II of the dena grid study), no conclusive statement can yet be made on this issue.

## Reliability of the Extra High Voltage Transmission Network

Dena grid study has been comprehensively investigated the reliability and stability of the extra high voltage transmission network up to the year 2015. Critical grid conditions were identified, possible effects were described and approaches for technical solutions were developed.

For 2003, the dena grid study found that safety criteria of the UCTE (Union of the European Transmission System Operators) would have been violated: Assuming that under strong wind conditions, certain faults will occur in the transmission network (three-pole short circuit of a power line or busbar), or that major conventional power stations could fail, there would have been large-scale regional voltage sags and critical grid situations. The voltage sags could have continued and caused so called “fault-run through” situations. If the voltage had dropped by more than 20% in a network segment, “older” wind turbines which went into operation before 2003/04 would have disconnected themselves from the grid, in accordance with the relevant grid codes in force at that time. These additional outages would possibly have worsened the critical grid situation considerably and led to risks for the security of energy supply in Germany and the European interconnected network (transgression of the 3,000 MW reserve capacity level maintained by all UCTE members).

The “old” grid codes were already supplemented by improved codes in 2003: New wind turbines shall now disconnect themselves from the grid only in case of voltage sags far below 80%, or only with a time delay. The dena grid study shows, that the new grid codes and enhanced technical performance of wind turbines will improve system security by 2015 in the Northeast grid area and by 2010 in the Northwest grid area. The critical grid situations found for 2003 would not remain. In 2015 however, the situation in the Northwest grid area would worsen again, because major shut-downs of power plants are to be expected due to age or to the phasing-out of nuclear power stations. Without countermeasures in place, serious grid failures and resulting power station outages can be expected. To solve these problems technical solutions in the grid and for wind turbines principally exist and could further ensure system stability. Only if the technical solutions are implemented on time the forecasted wind power development up to 2015 can be realized without raising the mentioned “fault-run through” problem. This study has not investigated the costs connected with these measures, their concrete realization, or the time needed for the complete implementation.

It is to be expected that in addition to the use of phase shifters and the adoption of improved shut-down criteria for older wind turbines (following new grid codes), an increased “Repowering” (replacement of old wind energy converters by new ones) will considerably improve the situation.

The implementation and optimization of proposals for technical solutions must be further examined.

In certain situations (strong wind and low load), Germany sees a surplus in power generation on a few days a year. In such situations, huge power flows to neighbored countries can be observed. Further solutions, such as additional storage facilities, demand site management and reduced power output from wind energy converters are to be examined in the planned part II of the dena grid study.

Large scale power generation from wind energy converters in Germany impairs considerably the reliable operation of the grids in neighboring countries. Particularly during weekends with strong wind conditions and during low load nighttime hours, the cross-border interconnectors and the transmission lines in frontier areas are operated close to the (n-1) limit.

## 5. Effects on Conventional Power Stations

For the future development of the conventional power station park, two options are compared, in order to extract the effects caused by wind power use. For the first option the installed wind power capacity in 2007, 2010 and 2015 is assumed to be the same as in the year 2003. Under the second option, the installed wind capacity is increased in several stages up to 2015 according the scenarios developed in chapter 3. Differences between the two options regarding the configuration of the conventional power station park and the related costs were then extracted. Both options were investigated under three different scenarios (*the basic scenario with no $CO_2$ surcharge; the basic scenario with a $CO_2$ surcharge; and the alternative scenario with a $CO_2$ surcharge).*

The development of fuel prices assumed for this study reflects a long-term development (see Table 3.) In view of the experiences of the past years, even higher fuel prices are possible. They can be examined in the context of the planned part II of the dena grid study. No external costs related with energy generation were taken into account in any of the three scenarios.

### Basic Scenario without $CO_2$ Surcharge

This scenario assumes no significant change in the prices of natural gas, oil or hard coal. Furthermore, a constant real price of brown coal was assumed, based on the full costs of brown-coal excavation. The $CO_2$ certificates are assumed to be allocated both for existing and for new plants under the National Allocation Plan, in accordance with need, and free of charge. It is assumed that the $CO_2$ price will not affect the cost and price calculations of the companies. Under these conditions, brown-coal and hard-coal power stations used as base- and medium-load power stations have a competitive advantage compared with natural-gas-fueled power stations.

Under the *Basic Scenario without $CO_2$ Surcharge* the extension of wind energy use up to 2015 will stabilize $CO_2$ emissions at today's level. That would compensate for the additional emissions connected with the phasing-out of nuclear power stations. Without wind power extension, emissions would increase by 39 million tons of $CO_2$ (see Table 4).

By 2015, electricity generation by hard-coal power stations will increase in comparison with that of 2003 by 15 TWh, and generation by brown-coal power stations by 17 TWh.

In view of the fact that emissions trading have already been introduced in Germany, this scenario merely serves as a standard for comparisons.

### Basic Scenario with $CO_2$ Surcharge

This scenario assumes the same fuel prices as the basic scenario without a $CO_2$ surcharge. The $CO_2$ certificates would here be auctioned and resulting prices would increase (2007: 5 €/t of $CO_2$; 2010: 10 €/t of $CO_2$; 2015: 12.5 €/t of $CO_2$; 2020: 12.5 €/t $CO_2$). $CO_2$ costs would be completely incorporated into the cost and price calculation of the companies. As a result, between 2003 and 2015, the following price changes would take place: brown coal: +170%; hard coal: +69%; natural gas: +14%; light fuel oil: +6%; and heavy fuel oil: +12%. This would considerably worsen the competitive position of the $CO_2$-intensive energy sources brown coal and hard coal, particularly for medium-load power stations.

Under the *Basic Scenario with a $CO_2$ Surcharge,* with wind-power extension, $CO_2$ emissions would drop from 251 million tons of $CO_2$ to 228 million tons of $CO_2$ by 2015 (see Table 4).

By 2015, electric power generation by hard-coal power stations would drop by 44 TWh, compared with 2003. Power generation by brown-coal power stations would drop by 35 TWh. The drop in electric power generation by hard-coal power stations due to wind power would be around 9 TWh, and for brown-coal power stations by 6 TWh.

## Alternative Scenario with $CO_2$ Surcharge

This scenario assumes an increase in the natural gas and oil prices, connected with the assumption that the increased $CO_2$ prices would be fully incorporated into the cost and price calculation of companies. Between 2003 and 2015, the following price changes would result: brown coal: +170%; hard coal: +69%; natural gas: +33%; light fuel oil: +20%; and heavy fuel oil: +18%. The competitive advantage which natural gas enjoys in case of rising $CO_2$ prices over such $CO_2$-intensive sources as brown- and hard-coal is partially offset under this scenario. This is due to the increasing fuel prices for natural-gas. The higher gas prices would lead to a development which is like that under the basic scenario.

Under the *Alternative Scenario with a $CO_2$ Surcharge*, with wind power extension, $CO_2$ emissions would drop from 302 million tons of $CO_2$ to 264 million tons of $CO_2$ by 2015 (see Table 4).

Electricity generation by hard-coal power stations would increase by 16 TWh by 2015 over 2003, and that of brown-coal power stations by 3 TWh.

## Regulation and Reserve Power Requirements

The guarantied capacity of wind power describes how much of the total installed wind power capacity can be considered as statistically guarantied for the coverage of maximum seasonal load, at a given level of reliability of energy supply. From this result, it is possible to derive how much of the conventional power plant capacity does not have to be maintained as long term reserve, in order to guarantee reliability of energy supply.

The guarantied capacity of wind energy (capacity credit) clearly changes with the season, since wind conditions vary over the course of the year (see Table 5). From the total installed wind power capacity of 36,000 MW in 2015, the capacity of approx. 1,820 MW to 2,300 MW can be considered as guarantied for the coverage of maximum seasonal load (at a level of reliability of energy supply of 99%). This corresponds to a share of approx. 6% of installed wind power capacity.

In 2003, the guarantied capacity was between 890 MW and 1,250 MW, rising to between 1,190 MW and 1,600 MW in 2007, and to between 1,600 MW and 2,050 MW in 2010.

The needed amount of wind-related regulation and reserve power, directly dependents on the quality of short term wind power prediction and the resulting deviation between predicted and actual values of wind power feed-in. In the dena grid study, an further improvement of wind power prediction quality has been assumed.

To balance unforeseen variations in wind power feed-in immediately, minute and hourly reserves must be provided as positive and negative regulation capacities: Positive reserve capacity is needed to compensate for unexpectedly low wind power feed-in. Negative reserve capacity is needed to compensate for unexpectedly high wind power feed-in. These capacities must be maintained in operational readiness. Due to the priority regulation under the Renewable Energy Act (EEG), negative reserve capacity has to be maintained.

In 2003, an average of 1,200 MW and a maximum of 2,000 MW of wind-related positive regulation power had to be available one day ahead in Germany. By 2015, that amount would rise to an average of 3,200 MW and a maximum of 7,000 MW. The mean value corresponds to 9% of the installed wind power capacity and the maximum to 19.4%. These capacities have to be available as positive minute and hourly reserves.

In 2003, an average of 750 MW and a maximum of 1,900 MW of wind-related negative regulation power had to be available one day ahead. By 2015, that amount would rise to an average of 2,800 MW and a maximum of 5,500 MW. The mean value corresponds to about 8% of the installed wind power capacity, and the maximum to 15.3%.

The wind-related regulation and reserve capacities can be covered by the conventional power station park and its operating method as developed in this study. No additional power stations need to be installed or operated for this purpose.

## 6. Cost Development

The development of the cost of electric power has been calculated in the dena grid study for the three scenarios: *basic scenario without $CO_2$ surcharge, basic scenario with $CO_2$ surcharge, and alternative scenario with $CO_2$ surcharge.* The total costs will be presented below, and a distinction made between the area of conventional power station park including regulation and reserve power demand on the one hand, and the area of electrical grid on the other. All costs are real costs related to the year 2003.

The development of wind power shifts the structure of the power station park in the direction of more flexible power stations with lower capital costs and higher fuel costs. A further extension of wind power thus implies a reduction of capital costs in the area of conventional power stations, in addition to an overall saving of fuel costs. This savings have to be balanced with the additional costs from feed-in tariffs. The costs for regulation and reserve power demand are contained in the total costs, and are not listed separately in the study, for methodological reasons.

The cost savings in the conventional power station park are less than the compensation for additional wind-power feed-in in all scenarios examined. However, that gap narrows between 2007 and 2015 in all the scenarios. This is due on the one hand to the rise in the level of savings, and on the other to the reduction in the average feed-in tariff for wind power. A rate of inflation of 1.5% per year was assumed for the calculation up to 2015. In 2007 according to this study, the real cost of every additionally generated kWh of wind energy would amount to 6.3 to 6.5 ct€, depending on the scenario. By 2015, that cost would be reduced to 4.3 and 3.0 ct€/kWh. It must be taken into account that the total amount of energy, generated by wind turbines will more than triple between 2003 and 2015 (see Table 2). The total additional net costs for the generated energy by wind turbines between 2003 and 2015 amounts to €1.6 to €2.3 billion, depending on the scenario (see Table 6).

Changes in costs for privileged and non-privileged consumers, $CO_2$ avoidance costs of wind power, grid extension costs, and changes in use of system charges are presented below.

### Change of Costs for Non-Privileged Consumers (Private Households)

The further extension of all renewable energy sources (including wind energy) in the period from 2003 to 2015 will increase the cost for non-privileged consumers by 0.905 to 1.105 ct€ per kWh, depending on the scenario. These costs cover the poor energy costs and the use of system charges. They also incorporate the costs for the feed-in tariffs (EEG) for all renewable energy sources. However, to evaluate this costs figures, it has to be considered, that no optimization potentials were investigated regarding the implementation of renewable energy sources other than wind power.

The further extension of wind energy capacities in the period from 2003 to 2015 would rise the costs for non-privileged consumers by 0.385 to 0.475 ct€ per kWh depending on the scenario. The total cost breaks down into the following components:

- 0.36 to 0.45 ct/ kWh of wind-related cost increase in the power station park, including costs for regulation and reserve power, minus savings for fuel and capital costs. The costs of EEG compensation are also included.
- 0.025 ct/ kWh for the extension of the extra high voltage transmission network (220/380 kV).

### Change of Costs for Privileged Consumers (Industry)

The energy costs for privileged consumers under the hardship clause of the EEG would increase by 0.03 to 0.04 ct€ per kWh by 2007 due to wind power extension, depending on the scenario. By 2015, the increase would be 0.15 ct€/ kWh in all scenarios. The energy costs cover wind-related cost increases in the power station park, including those for regulation and reserve power, minus the savings for fuel and capital costs. The corresponding costs for a reduced purchase of energy under EEG hardship clause are also included in the figures.

### $CO_2$ Avoidance Costs

The $CO_2$ avoidance costs of wind power drop in all scenarios investigated. Based on the 2007 figures, with $CO_2$ avoidance costs of € 95 to € 168 per ton $CO_2$, they drop to € 77 and € 41 per ton $CO_2$ by 2015.

These figures are in reference to the international climate-protection debate. No possible cost increases for fossil fuels or external costs of power generation were taken into account.

## Grid Extension Costs and Changes in Use of System Charges

The extension of the onshore extra high voltage transmission network (380/220 kV) up to 2007 will cost approx. € 280 million, from 2007 to 2010 approx. € 490 million and from 2010 to 2015 approx. € 350 million. This will yield a total of € 1.1 billion.

Costs to the distribution grid for the connection of wind farms were not within the scope of the present investigations, nor were upgrades of the 110 kV grids.

The investment costs for submarine cables to connect the offshore wind farms in the North and Baltic Seas with the points of grid connection onshore up to the year 2010 will amount to approx. € 2.6 billion and to about € 5 billion up to 2015. The costs of the submarine cable connection up to the point of grid connection on the shore are covered by the wind farm developers from the revenues from feed-in tariff under the Renewable Energy Act (EEG).

The investment costs for the connection of the wind farms in the North Sea (extension level of 2020) are estimated at approx. € 11 -12 billion. These costs are also covered by the wind farm developers from the revenues from feed-in tariff under the Renewable Energy Act (EEG). Due to the investigations still required in part II of the dena grid study no conclusive statement can be made yet. The schedule of financing will in any case be closely linked with the actual construction of offshore wind farms. A step by step realization is possible.

Compared with 2003, the use of system charges will increase up to 2007 by 0.05 ct€ per kWh, up to 2010 by 0.015 ct€ per kWh and by 0.025 ct€ per kWh up to 2015. This is only due to grid extension costs. The additional costs caused by wind-related regulation energy are contained in the assessments of the power station park. However, they are prorated through the use of system charges.

## Appendix with Tables and Figures

**Table 1: Development of installed wind capacity in Germany up to 2020 in GW**

| | Installed wind capacity in Germany, in GW | | | | |
|---|---|---|---|---|---|
| **Year** | **2003** | **2007** | **2010** | **2015** | **2020** |
| Onshore | 14.5 | 21.8 | 24.4 | 26.2 | 27.9 |
| North Sea | 0 | 0.4 | 4.4 | 8.4/8.1 | 18.7 |
| Baltic Sea | 0 | 0.2 | 1.0 | 1.4/1.7 | 1.7 |
| Total | 14.5 | 22.4 | 29.8 | 36.0 | 48.2 |

**Table 2: Development of wind energy (W.E.) production up to 2015 in GWh**

| | Wind-power feed-in, in GWh | | | |
|---|---|---|---|---|
| **Year** | **2003** | **2007** | **2010** | **2015** |
| W.E. onshore | 23,500 | 34,900 | 40,300 | 44,700 |
| W.E. offshore | 0 | 1,900 | 18,000 | 32,500 |
| Total | 23,500 | 36,800 | 58,300 | 77,200 |

**Table 3: Long-term development of real fuel prices (free power station)**

| **Year** | **2003** | **2007** | **2010** | **2015** | **2020** |
|---|---|---|---|---|---|
| **Basic scenario without $CO_2$ surcharge<br>€ / MWh thermic (NCV)** | | | | | |
| Brown coal | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Hard coal | 6.1 | 5.8 | 5.9 | 6.1 | 6.4 |
| Natural gas | 14.6 | 13.2 | 13.6 | 14.2 | 14.7 |
| Light fuel oil | 25.4 | 23.4 | 23.5 | 23.6 | 23.8 |
| Heavy fuel oil | 15.4 | 12.6 | 12.6 | 13.6 | 14.2 |
| **Basic scenario with $CO_2$ surcharge<br>€ / MWh thermic (NCV)** | | | | | |
| Brown coal | 3.0 | 5.0 | 7.1 | 8.1 | 8.1 |
| Hard coal | 6.1 | 7.5 | 9.2 | 10.3 | 10.6 |
| Natural gas | 14.6 | 14.2 | 15.6 | 16.7 | 17.2 |
| Light fuel oil | 25.4 | 24.7 | 26.2 | 26.9 | 27.1 |
| Heavy fuel oil | 15.4 | 14.0 | 15.4 | 17.2 | 17.8 |
| **Alternative scenario with $CO_2$ surcharge<br>€ / MWh thermic (NCV)** | | | | | |
| Brown coal | 3.0 | 5.0 | 7.1 | 8.1 | 8.1 |
| Hard coal | 6.1 | 7.5 | 9.2 | 10.3 | 10.6 |
| Natural gas | 14.6 | 15.5 | 17.7 | 19.4 | 20.4 |
| Light fuel oil | 25.4 | 24.7 | 27.9 | 30.6 | 32.3 |
| Heavy fuel oil | 15.4 | 14.0 | 16.4 | 18.2 | 19.1 |

Abbreviation: NCV = Net Calorific Value (lower heating value)

**Table 4: Development of $CO_2$ emissions with and without further extension of wind energy, given in million tons per year**

| | 2003 | 2007 | | 2010 | | 2015 | |
|---|---|---|---|---|---|---|---|
| | | W.E. f.e. | W.E. 2003 | W.E. f.e. | W.E. 2003 | W.E. f.e. | W.E. 2003 |
| Basic scenario without $CO_2$ surcharge ($CO_2$ emissions in million t) | 279 | 287 | 292 | 293 | 317 | 279 | 318 |
| Basic scenario with $CO_2$ surcharge ($CO_2$ emissions in million t) | 279 | 282 | 289 | 258 | 276 | 228 | 251 |
| Alternative scenario with $CO_2$ surcharge ($CO_2$ emissions in million t) | 279 | 280 | 284 | 281 | 307 | 264 | 302 |

Abbreviations: W.E. f.e.= with further extension of wind energy; W.E. 2003= wind energy use as of the year 2003

**Table 5: Statistically guaranteed power from total installed wind power capacity**

| | **Year 2003 in MW** | **Year 2007 in MW** | **Year 2010 in MW** | **Year 2015 in MW** |
|---|---:|---:|---:|---:|
| Winter | 1,199 | 1,542 | 1,941 | 2,163 |
| Spring | 1,245 | 1,605 | 2,057 | 2,289 |
| Summer | 889 | 1,187 | 1,599 | 1,824 |
| Fall | 1,040 | 1,352 | 1,750 | 1,970 |

**Table 6: Real cost savings in the conventional power station park through the extension of wind power (vs. wind energy use as of 2003)**

| | Basic scenario | | | Basic scenario + $CO_2$ | | | Alternative scenario + $CO_2$ | | |
|---|---|---|---|---|---|---|---|---|---|
| **Year** | **2007** | **2010** | **2015** | **2007** | **2010** | **2015** | **2007** | **2010** | **2015** |
| Additional W.E. production compared with 2003 in GWh | 13,267 | 34,810 | 53,675 | 13,267 | 34,810 | 53,675 | 13,267 | 34,810 | 53,675 |
| Saved production-related costs in ct€/kWh of wind power | 1.32 | 0.9 | 1.55 | 1.32 | 2.1 | 2.26 | 0.83 | 1.69 | 1.96 |
| Saved fixed maintenance costs in ct€/kWh of wind power | 0.1 | 0.18 | 0.14 | 0.11 | 0.07 | 0.11 | 0.12 | 0.31 | 0.24 |
| Saved capital costs | 0.33 | 0.6 | 0.87 | 0.32 | 0.3 | 0.66 | 0.64 | 1.38 | 1.73 |
| Total cost savings in convent. power stations per add. produced kWh, in ct€/kWh of wind power | 1.76 | 1.68 | 2.57 | 1.75 | 2.47 | 3.03 | 1.59 | 3.38 | 3.93 |
| Average feed-in tariff for the additional W.E. feed-in, in ct€/kWh of wind power | 8.1 | 7.67 | 6.92 | 8.1 | 7.67 | 6.92 | 8.1 | 7.67 | 6.92 |
| Specific additional costs of additional W.E. feed-in, in ct€/kWh of wind power (feed-in tariff minus cost savings) | 6.34 | 5.99 | 4.35 | 6.35 | 5.2 | 3.89 | 6.51 | 4.29 | 2.99 |
| Costs of the additional W.E. feed-in, in million € (2003) | 834 | 2.079 | 2.332 | 835 | 1.806 | 2.085 | 856 | 1.489 | 1.603 |

**Table 7: Development of the $CO_2$ avoidance costs with extension of wind power**
(vs. W.E. production as of 2003):

| **Year** | | **2007** | **2010** | **2015** |
|---|---|---|---|---|
| Basic scenario without $CO_2$ surcharge | $CO_2$ reduction in million t | 8.0 | 28.3 | 39.5 |
| | $CO_2$ reduction in million t, in kg per add. MWh of W.E. feed-in | 605 | 817 | 738 |
| | $CO_2$ prevention costs in € / t | 104.7 | 73.4 | 58.9 |
| Basic scenario with$CO_2$ surcharge | $CO_2$ reduction in million t | 8.8 | 20.8 | 27.2 |
| | $CO_2$ reduction in million t, in kg per add. MWh of W.E. feed-in | 667 | 600 | 508 |
| | $CO_2$ prevention costs in € / t | 95.1 | 86.8 | 76.6 |
| Alternative scenario + $CO_2$ surcharge | $CO_2$ reduction in million t | 5.1 | 26.3 | 39.4 |
| | $CO_2$ reduction in million t, in kg per add. MWh of W.E. feed-in | 387 | 758 | 735 |
| | $CO_2$ prevention costs in € / t | 168.0 | 56.6 | 40.6 |

**Table 8: Development of energy costs, by customer groups (cost increases in €$_{(2003)}$ per MWh)**

| | For Non-Privileged Consumers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2007 | | | 2010 | | | 2015 | | |
| | **W.E. f. e.** | **W.E. 2003** | **Difference** | **W.E. f. e.** | **W.E. 2003** | **Difference** | **W.E.-Additional construction** | **W.E. 2003** | **Difference** |
| Basic scenario | 37.5 | 35.9 | **1.6** | 41.6 | 37.3 | **4.4** | 46.1 | 41.6 | **4.6** |
| Basic scenario+ $CO_2$ | 40.9 | 39.4 | **1.5** | 47.2 | 44.0 | **3.2** | 51.0 | 47.1 | **3.9** |
| Alternative scenario | 40.6 | 39.2 | **1.4** | 49.2 | 45.8 | **3.5** | 53.4 | 49.8 | **3.6** |
| | **For Privileged Consumers (EEG hardship clause)** | | | | | | | | |
| | **2007** | | | **2010** | | | **2015** | | |
| | **W.E. f. e.** | **W.E. 2003** | **Difference** | **W.E. f. e.** | **W.E. 2003** | **Difference** | **W.E.-Additional construction** | **W.E. 2003** | **Difference** |
| Basic scenario | 32.6 | 32.1 | **0.4** | 35.1 | 33.3 | **1.8** | 38.3 | 36.8 | **1.5** |
| Basic scenario+ $CO_2$ | 36.2 | 35.8 | **0.4** | 41.5 | 40.6 | **1.0** | 44.4 | 42.9 | **1.5** |
| Alternative scenario | 36.0 | 35.6 | **0.3** | 43.9 | 42.4 | **1.5** | 47.3 | 45.8 | **1.5** |

Abbreviations:W.E. f.e.. = with further extension of wind power; W.E. 2003 = no further extension of wind power after 2003

**Figure 1: Grid upgrades of the extra high voltage transmission network up to 2007**

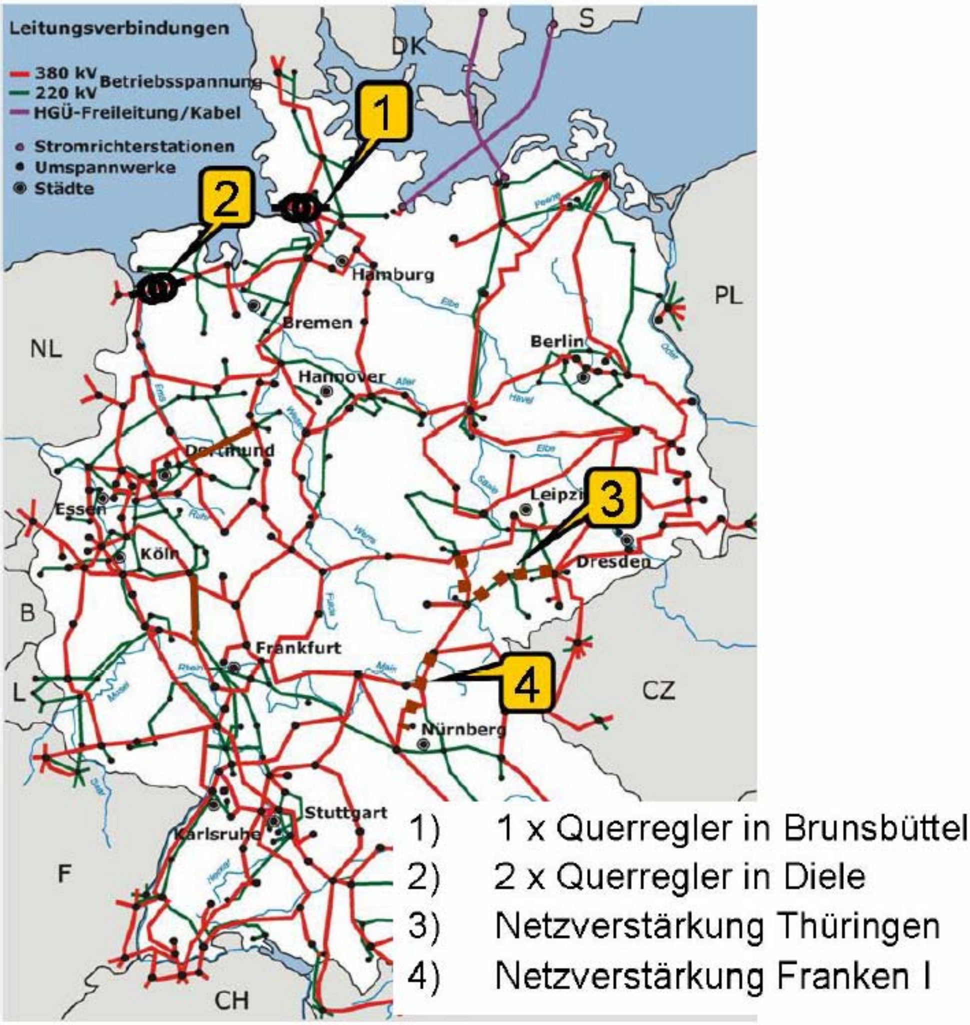

**Figure 2: Grid upgrades and network extension of the extra high voltage transmission network between 2007 and 2010**

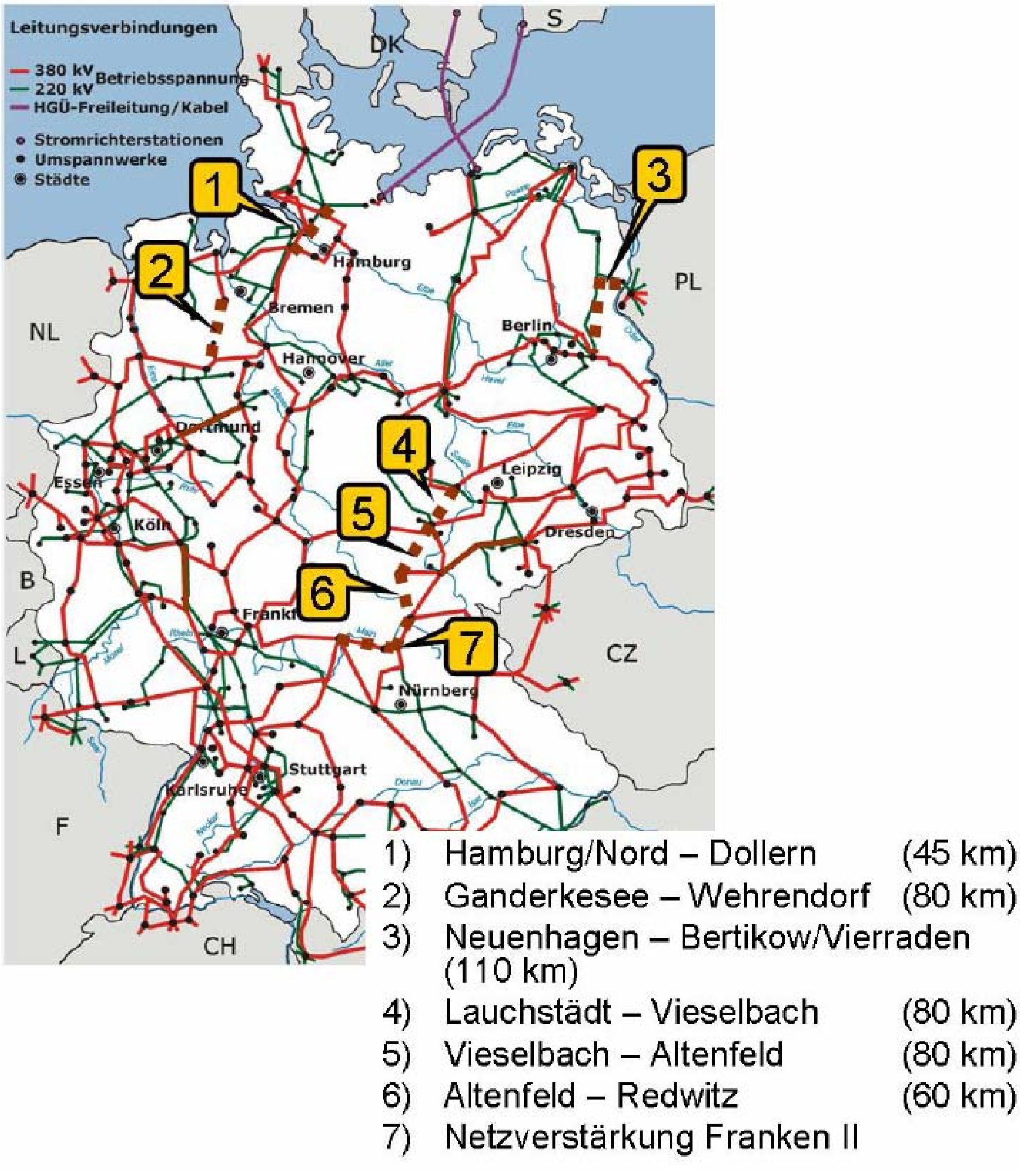

**Figure 3: Grid upgrades and network extension between 2010 and 2015**

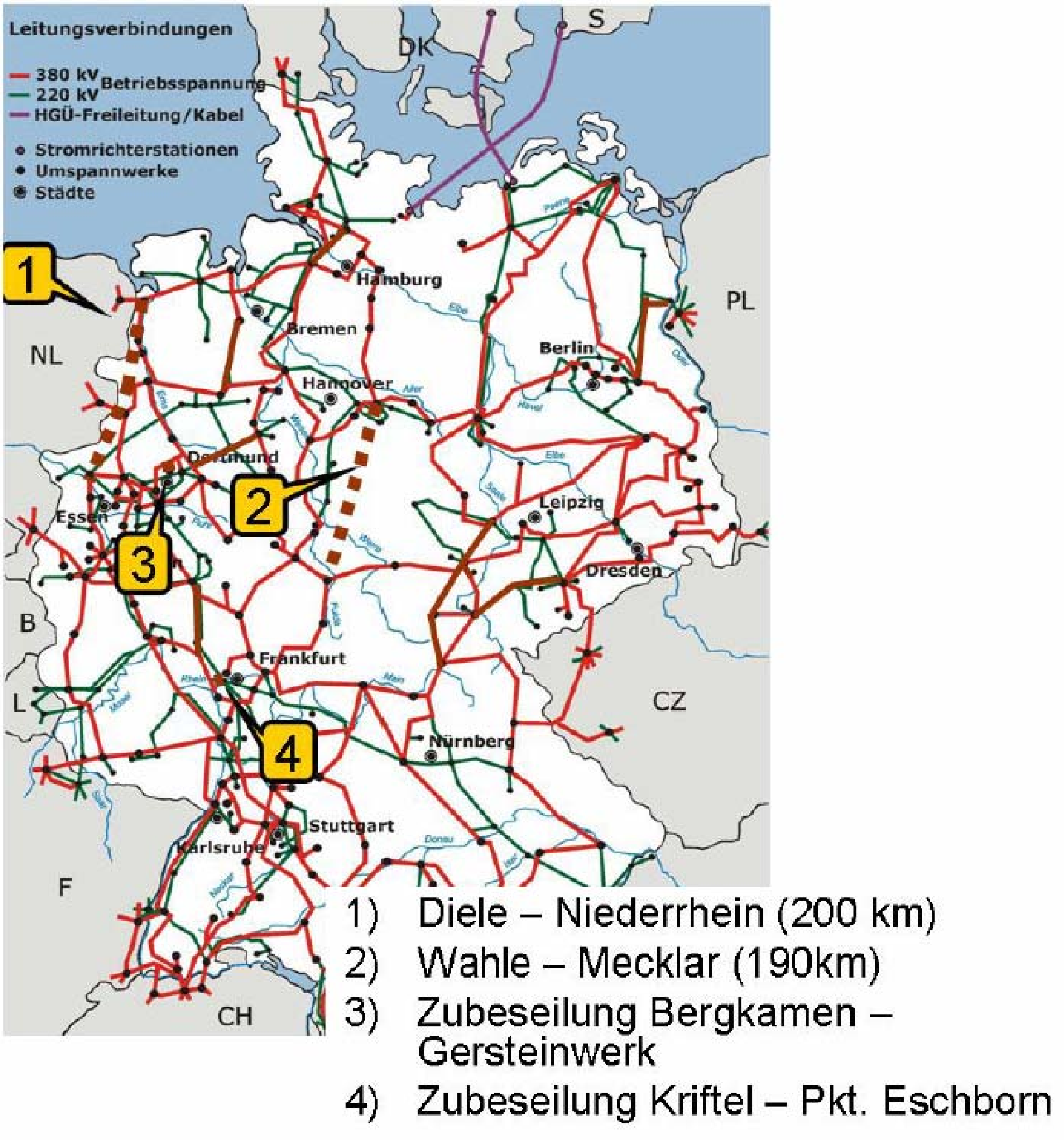

**Figure 4: System model for the grid connection of offshore wind farms in the North Sea and grouping of the submarine cables in the coastal area**