

dena Grid Study II.

Integration of renewable energy sources into the German power supply system until 2020.

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Outlook and recommendations.

Remodelling the energy system.

Germany and Europe have set the course for a fundamental remodelling of the energy supply system. The focus is on climate protection, security of supply and economic viability within a deregulated European energy market. This is closely related to the accelerated pace of expansion in the use of renewable energy sources.

Expansion of renewable energy sources.

The German Federal Government's Energy Concept published in September 2010 aims to increase the proportion of German gross power consumption accounted for by renewable energy sources to 35 percent in 2020 and to 80 percent in 2050.

Wind and solar energy are intended to make a significant contribution. However, these sources are subject to considerable fluctuations due to climatic conditions and their expansion is focused on specific, generally suitable regions. The power system must be remodelled and made more flexible, if renewable energy sources are to be integrated.

Exploitation of wind energy in north and north-east Germany.

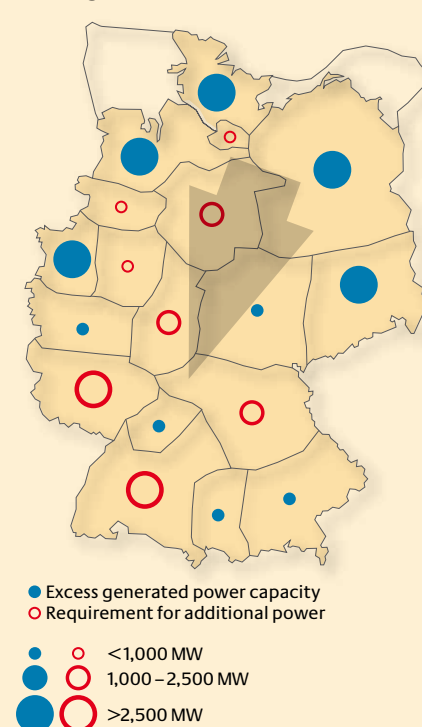
One central challenge for the future power system is the increasing regional concentration of wind power generation in north and north-east Germany. This concentration will increase still further due to the expansion of offshore wind energy exploitation in the North Sea and the Baltic.

The power obtained in these regions must be transported considerable distances to the centres of power demand in the west and south of Germany. Considerable expansion of existing infrastructure, especially of power transmission lines, is required to enable increased levels of power transport and avoid bottlenecks in the power grid.

Conventional power plants and pan-European trading.

Furthermore, cost-optimised operation of conventional power plants and pan-European power trading also require sufficient grid capacity.

Average balance across regions: Power generation and demand in 2020.



dena Grid Study II: Objectives.

The dena Grid Study II investigates the suitability of various system solutions for integrating renewable energy sources into the energy system on the assumption that they will account for 39 percent of German power supply by 2020. The study takes account of the conventional power generation system and deregulated European power trading and indicates the outlook to 2025.

Objectives and assumptions.

The goal of the study is to prepare the ground for upcoming strategic energy policy and economic decisions and to categorise the potential technical solutions correctly.

The study investigations carried out for this purpose are based on defined assumptions, in particular, complete integration of renewable energy sources in accordance with Germany's current Renewable Energy Sources Act (EEG) and the use and development of conventional power stations from an economic standpoint. Furthermore, it is assumed that the European power market is limited solely by the capacity of cross-border links.

Content of the study.

To serve as the basis for the analyses, the study generates accurate wind energy and photovoltaic feed-in time series for the year 2020 and determines the proportion of non-transmittable power in the power transmission grid. Various transmission technologies are investigated with which the necessary grid expansion might be achieved. Possible options for increasing the transmission capacity of existing lines and for making the power supply system more flexible are also investigated.

Drafting.

The study was prepared and funded with cross-sector support. The drafting process was accompanied by a continuous dialogue with stakeholders from the world of politics, business and industry associations in order to arrive at a widely accepted solution. External auditors checked the suitability of the investigatory methodology used and confirmed the plausibility of the results obtained.

Background: dena Grid Study I.

Grid Study II builds on the results of 2005's dena Grid Study I.

dena Grid Study I had identified a need for 850 km of new power routes within the extra-high voltage grid in order to integrate wind energy into the power grid by 2015 and the necessity of measures to expand the power transmission grid such as the addition of conductors to existing routes.

The specific requirement for route expansion in the extra-high voltage grid identified in the study was included as a high priority project in the German Power Line Expansion Act (EnLAG 2009). According to the results of dena Grid Study I, 850 km of new routes must be erected by 2015. In dena Grid Study II investigations, these routes are assumed to have been completed in their entirety.



Power grid expansion requirements.

dena Grid Study II focuses on identifying German power grid expansion requirements in the years to 2020/2025 as a result of increased use of renewable energy sources, taking conventional power plants and European power trading into account.

Future energy feed-in.

As a basis for identifying additional construction requirements, the study predicts future renewable energy feed-in for the year 2020 and shows how the conventional power plant fleet will develop to that point.

Use of nuclear energy.

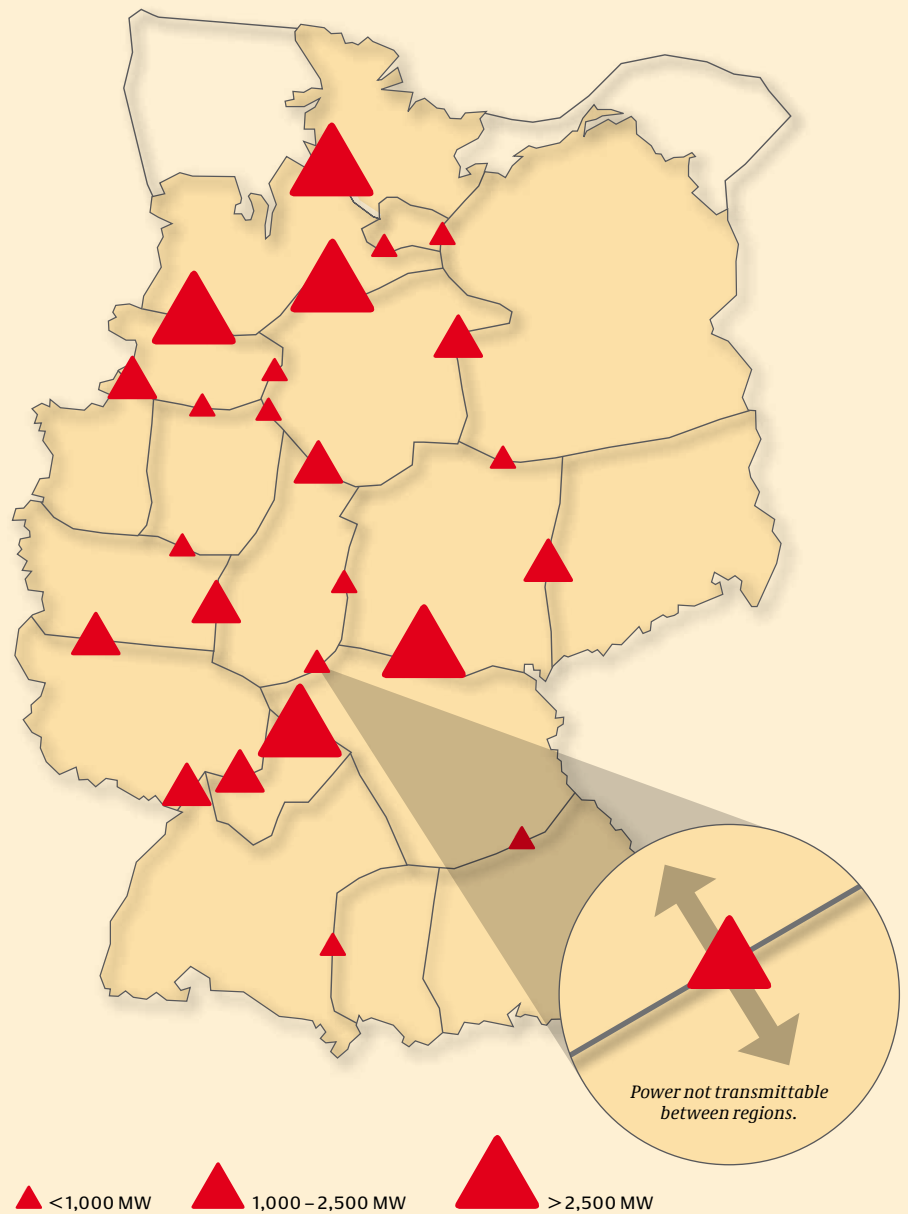
dena Grid Study II assumes the phase-out of nuclear energy as adopted in 2000. An investigation for the study has shown that the extension to the service lives of nuclear power stations adopted in 2010 will not, however, have any fundamental impact on identified power grid expansion needs, but regional changes in the extent and sequence of grid extension requirements may arise.

Non-transmittable power.

Based on the predicted feed-in of renewable energies and conventional generation structures, the power which needs to be transmitted between different regions of Germany is calculated in accordance with the breakdown used by the transmission grid operators. Grid bottlenecks at 70 percent of regional borders mean a large proportion of power cannot be transmitted, in places as much as four gigawatts.

These figures are used as the basis for calculating how much the transmission grid needs to be expanded between the regions to equalise non-transmittable power. The study analyses and compares various technical alternatives with regard to the construction of new power routes within the extra-high voltage grid.

Power not transmittable between regions of Germany.



Regional borders according to the breakdown used by the transmission grid operators with non-transmittable power based on the transmission grid planned for 2015.



Technical alternatives and associated expansion requirements.

dena Grid Study II's investigation focuses on three basic scenarios using AC overhead lines and taking account of possible ways of increasing their transmission capacity.

BAS (basic) scenario: Expansion of grid using technology already in use.

In this scenario, the grid is expanded using 380 kV AC overhead lines with standard transmission capacity. Result: around 3,600 km of new overhead power lines would have to be erected, at annual costs of approx. EUR 950 million.

TAL scenario: use of high temperature conductors (TAL).

Conductors made from high temperature resistant aluminium have a 50 percent higher load capacity than standard conductors. They can therefore transmit more power. Using them thus reduces the need for the erection of new routes to 1,700 km. At the same time, however, 5,700 km of existing routes would have to be upgraded to high temperature conductors, including mast modifications. This solution will cost around EUR 1.6 billion per year.

FLM scenario: use of flexible line management (FLM).

In this solution, the operating temperature of the conductors is continuously monitored, so as to be able to load the conductors more heavily under appropriate weather conditions (e.g. wind) and thus transmit more power. Such a monitoring system is capable of significantly increasing the transmission capacities of overhead power lines, in particular at times of high wind energy feed-in. Since the benefit is only temporary, however, using FLM reduces the need for new routes only insignificantly to 3,500 km, and in addition 3,000 km of existing overhead power line routes would have to be equipped with FLM. The costs would run to EUR 985 million per year.

All stated costs include annualised capital and operating costs and the connection of offshore wind farms.

Evaluation model for comparing transmission technologies.

In addition, the study investigates alternative transmission technologies for their suitability and development potential for use in the future power system. These include:

- Conventional 380 kV AC overhead lines
- 800 kV AC overhead lines
- 380 kV AC underground cables
- High voltage direct-current transmission (HVDC) based on overhead power lines
- Underground HVDC cables
- Gas-insulated conductors (GIL)

The study has consequently developed a model for structured evaluation of the use of various transmission technologies and applied this to four abstract transmission tasks, i.e. tasks not falling under specific projects.

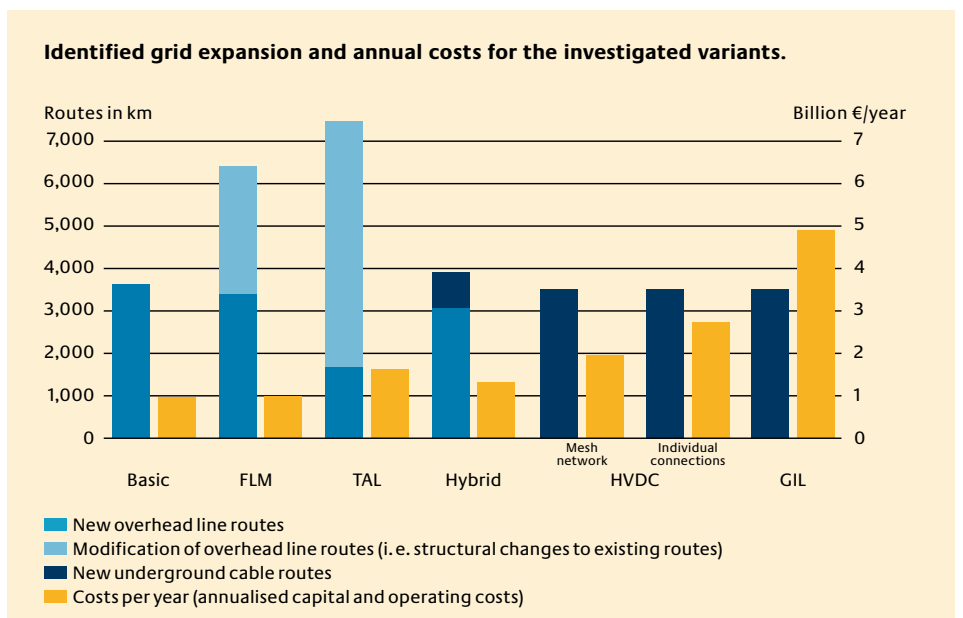
Overhead power line technologies have proven to be the more suitable solutions for all the transmission tasks looked at. For small transmission capacities (1,000 MW) and relatively short routes (100 km), the conventional 380 kV AC overhead line comes out best. For three tasks, several transmission technologies tend to be almost equally good, while for routes longer than 400 km or for higher powers the advantages of high voltage direct-current transmission (HVDC) become increasingly evident.

The sample evaluations of the technologies are not suitable for generalisation. For plans of specific routes the respective conditions must be analysed with the evaluation criteria to determine the most suitable transmission technology.

Grid expansion options using alternative technologies.

dena Grid Study II examines three of the available technology options in detail to see what the grid expansion requirements would be if they were used:

- HVDC: overlay DC voltage grid based on underground cables. This solution gives rise to the need for 3,400 km of new routes and, at a cost of around EUR 2 billion per year, is twice as expensive as the basic scenario. If the routes are not constructed as a mesh network, but instead as individual point-to-point connections, the costs are EUR 2.4 billion.
- Hybrid solution: 800 km, 4,400 MW power DC voltage route for long-distance transmission from Schleswig-Holstein to Baden-Württemberg. An additional 3,100 km of overhead routes are needed for the remaining transmission tasks. Total costs are around EUR 1.3 billion per year.
- GIL: universal use of underground gas insulated 380 kV lines. For this option 3,400 km of route would be necessary, at an annual cost of around EUR 4.9 billion.





Making the power system more flexible.

In order to develop measures for optimising the overall system, dena Grid Study II assessed the potential of the various options for increasing flexibility and took them into account in calculating the requirement for expansion in the German extra-high voltage grid.

Power storage systems.

Power storage systems assist the integration of renewable energy sources by absorbing non-integratable generating capacity, smoothing residual load and providing flexible balancing power.

dena Grid Study II investigates the extent to which power storage systems are also suitable for reducing transmission grid expansion requirements. This is achieved by additionally evaluating the various scenarios, BAS, FLM and TAL, with construction of extra storage capacity in the regions with anticipated grid bottlenecks. Market-based use of power storage systems is being found to modify generation and power flows in the grid. As a consequence, non-

transmittable power is again arising at regional borders. Overall, storage systems thus do not bring about a substantial reduction in grid expansion requirements.

Moreover, the investigation demonstrates that, over the period to 2020, construction of extra pumped-storage plants is the only economically viable option. Other power storage technologies such as compressed air and hydrogen storage systems are not yet sufficiently well developed for economically viable use on a large industrial scale.

Demand-Side Management.

Controlling power demand is known as demand-side management (DSM). DSM may contribute to equalising fluctuating feed-in from renewable energy sources, for example, by also reducing power demand at times of low wind power generation. This may suitably be achieved, for example, with industrial processes (such as chlor-alkali electrolysis) and applications in private households (e.g. circulating pumps).

The economically usable potential of DSM over the period to 2020 is capable of satisfying approx. 60 percent of requirements for positive balancing power, but only approx. two percent of requirements for negative balancing power. However, due to its elevated unit price, actual usage of balancing power will amount to less than 0.1 percent of German gross power demand. DSM's contribution to load smoothing reduces the peak load requirement, for example from gas-fired power stations, by approx. 800 MW. As a result, the costs of power generation to the economy will drop by some EUR 0.5 billion over the period to 2020.

Improved quality of forecasting of wind power feed-in.

The study shows that wind forecasts can be improved by 45 percent over the period to 2020, for instance, by using higher resolution weather models. As a consequence, the requirement for balancing power caused by the uncertainty of forecasting wind energy feed-in may be considerably reduced.



Contribution of renewable energy sources to system security.

As a result of the increasing proportion of power supply accounted for by renewable energy sources, generation by conventional power stations simultaneously falls. However, the conventional power generation system has previously provided important system services, such as balancing power, short-circuit and reactive power together with islanding and black start capability during grid restoration. System services are needed to maintain power system stability and to ensure security of supply. dena Grid Study II investigates the extent to which renewable energy sources and in particular wind turbines can contribute to providing system services.

Short-circuit and reactive power.

Feed-in of short-circuit and reactive power into the transmission grid will decline as a result of expanding renewable energy sources, as these sources feed into the grid for the most part, at relatively low voltage levels.

The reduction in short-circuit power is offset by close links with foreign transmission grids with their predominantly conventional power generation and, as requirements increase, can be balanced by further compensating devices in the transmission grid.

Reduced availability of reactive power combined at the same time with increased demand due to heavier loads on transport lines must be balanced by additional reactive power compensating devices in the transmission grid.

Provision of balancing power.

The current tendering procedure with lead times of up to a month and requirements for the provision of balancing power limits the possibilities for renewable energy sources to participate in balancing power markets.

Wind turbines are capable of providing positive balancing power if they are initially throttled down. However, this approach is cost-effective in only very infrequent situations over the year. Considerable negative balancing power, on the other hand, may be provided in 2020 by down regulating wind turbines in the event of frequency fluctuations in the grid.

Biomass power plants have the ability to achieve steep power gradients and are in principle, very well suited to providing balancing power. Pooling biomass power plants makes it possible to provide both secondary balancing power and tertiary control.

Connecting offshore wind energy to the grid.

In future a significant proportion of Germany's wind energy will come from offshore wind farms in the North Sea and the Baltic. These have to be connected to the land-based power grid, to bring power to consumers. dena Grid Study II investigates various technical grid connection options.

Cluster connections.

A commercial and technical analysis of the available technologies shows that connection of the planned offshore wind farms in the North Sea is best achieved using self-commutated VSC-HVDC technology (direct current connections) and "bundled" connection of wind farms in clusters. Such "cluster connections" reduce the cost of grid connection and also minimise environmental impact.

For lower power offshore wind farms in the Baltic, at shorter distances from the coast, the most suitable solution may also be individual connections using AC cables.

Multi-terminal operation.

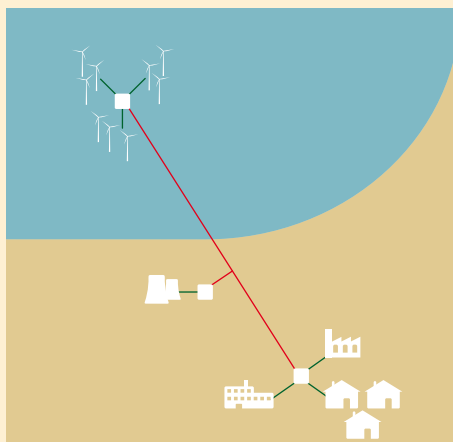
"Multi-terminal" solutions offer the possibility of connecting several converters to one DC voltage circuit, so producing more than two connections to an AC network. Multi-terminal operation is advantageous, for example, for linking together various cluster connections of offshore wind farms or connecting them by cable links (interconnectors) to neighbouring countries. Further development of technical concepts for multiterminal solutions and the standardisation of direct current technologies at a European level are necessary, before implementation can go ahead.

Marine grid expansion.

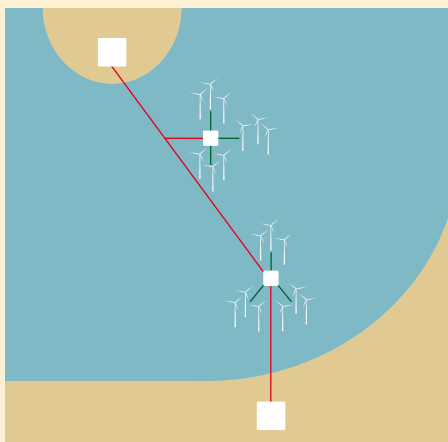
To connect up Germany's offshore wind farms by 2020, marine cables extending to a total length of 1,550 km are needed, resulting in annual costs of EUR 340 million. All in all, the study reveals useful synergies between cluster connections and solutions based on multi-terminal operation. Since these can only be exploited as part of an overall strategy, it is important when planning grid connections for offshore wind farms to develop long-term strategic plans.



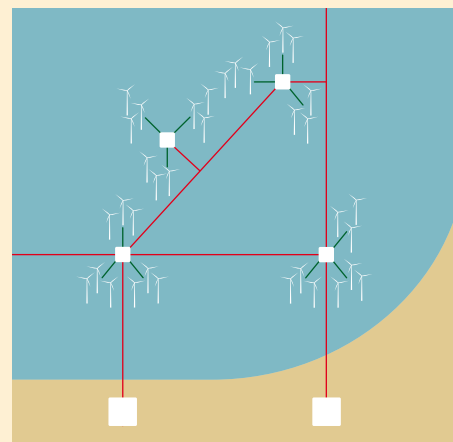
Multiterminal operation opens up the following possibilities:



Continuation of on-land connection into load centres through the connection of further generating capacity.



Construction of cross-border lines between Germany and other Northern-European countries with simultaneous grid connection of offshore wind farms.



Exploitation of synergies in the grid connection of scattered offshore wind farm clusters by linking and bringing together the grid connections, ultimately forming an offshore grid.

Outlook and recommendations.

With its broad system approach, dena Grid Study II describes new ways of developing Germany's integrated grid with regard to the expansion of renewable energy sources and taking not only an economically optimised conventional power generation system but also European power trading into account.

Basis for detailed grid planning.

Having investigated many different transmission technologies, grid management measures and options for increasing flexibility on both the supply and demand side, the study does much more than simply identify grid expansion requirements, it shows the path towards overall optimisation of the energy supply system.

In addition to robustly identifying grid expansion requirements, dena Grid Study II provides a very sound basis for further detailed grid planning and the identification of specific power routes in the German power transmission grid.

Increasing grid expansion requirements.

dena Grid Study II investigates the expansion of electricity generation from renewable energy sources to 39 percent by 2020. However, this is just an interim goal. By as soon as 2030, the German Federal Government is planning to raise the proportion of renewable electricity generation to 50 percent. This shows that even after 2020, further adaptation of grid infrastructure will still be necessary.

Practical action required.

If the grid expansion required to integrate renewable energy sources is to be achieved rapidly, there is an urgent need to back up the grid expansion scenarios presented in dena Grid Study II with practical action.

Study also downloadable from:

www.dena.de/netzstudie

Recommended actions from the study:

- Rapid and complete construction of the routes from dena Grid Study I
- Further investigations for determining line-specific grid expansion measures
- Implementation of pilot projects for trialling selected innovative technologies
- Consideration of all available options for future grid planning (topological alternatives, transmission technologies, grid management measures etc.)
- Acceleration of approval procedures for grid expansion measures, including an examination of further development of the legal framework
- Information campaigns to increase public acceptance of grid expansion in Germany



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