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Renewable energy sources to secure the base load in electricity supply

Summary

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SUMMARY

Irrespective of their precise origin, methodology and objective, all the currently available scenarios, projections and prognoses on the long-term development of electricity supplies in Germany come to the conclusion that there will be a fundamental change or even a radical revolution in the decades ahead.

The drivers for this are, on the one hand, the liberalisation and advancing European integration of the electricity markets and, on the other hand, challenging objectives in terms of climate policy and the expansion of the use of renewable energies for electricity supply purposes (RES-E). Although the rise in the proportion of RES-E is not the only lever acting on structural change in respect of electricity supply, it nevertheless plays a prominent role in the debate in experts' circles.

The starting point for this report is the question of how the base load can be secured in an electricity supply system that is already based to a substantial degree – approx. 20% – on renewable energies, about half of which is in the form of fluctuating energies, particularly wind power and photovoltaics, and which is planned to be converted to be (almost) fully dependent on renewable energies in Germany by 2050. This question can only be addressed with integrated systemic perspective, in which it therefore becomes an – albeit important – aspect of the higher issue of how a secured supply can be organised overall.

In the summer of 2008 the Committee for Education, Research and Technology Assessment of the German Bundestag commissioned the Office of Technology Assessment at the German Bundestag (TAB) to address this issue by means of a literature review and model-based analyses and to identify options for action as to how a reliable electricity supply can be designed in the face of ambitious targets for expanding the use of renewable energies.

BASE LOAD AND SECURED SUPPLY

Electricity demand is usually sub-divided into the segments of base, intermediate and peak load. Base load is the term for that amount of electricity for which there is a constant demand and which must be supplied as a minimum in the course of a day or year. In a conventional electricity system the load segments are covered by power plants which are particularly suited to that purpose: base-load power plants (mainly using hydropower, lignite and nuclear power) are characterised by high capital costs and low operating costs and must be run at high capacity utilisation (e.g. more than 7,000 full-load hours a year) in order to operate cost-efficiently. Peak-load power plants (e.g. gas turbines) can be profitable even at relatively low capacity utilisation (e.g. 2,000 full-load hours) (low capital costs and high operating costs). Between these lie the intermediate-load power plants (e.g. coal).

To ensure a secured power supply the amount of electricity fed into the grid must be exactly the same as the electricity demand. If the feed-in from renewable energies is deducted from the electricity demand, the resulting figure is termed the »residual load« which has to be covered by dispatchable power plants. A characteristic feature of residual load is that it can change significantly faster than demand and that, where renewable energies are a large part of the energy mix, it can become very small – even negative under certain circumstances (i.e. there is a surplus of electricity).

This means that the differentiation into load segments becomes increasingly obsolete as the system becomes more dependent on fluctuating feed-in from renewable energies. Similarly, increasing blurring will occur in future in the assignment of certain power plant types (base-load, intermediate-load and peak-load power plants) to individual load ranges. The options for operating power plants which are designed for very long periods of full-load operation are diminishing. There is a need for flexible power plants with short start-up and shut-down times and dynamic regulatability.

To guarantee secured operation of the energy supply system, a substantial proportion of the nominal output of the RES-E plants (e.g. for wind power) must be covered by dispatchable plants whose actual period of operation, however, is only short. One of the consequences of this is that new operating strategies will have to be developed. For example, the »system services« (especially the primary and secondary regulation) are currently mainly provided by large fossil-fuel or nuclear power plants. If the intention is to integrate a high RES-E proportion (50% or more) into the system in the long term, it is of crucial importance that RES-E plants also increasingly take on responsibility for securing system services.

ELECTRICITY GRIDS

The electricity grids play a key role in integrating a dynamically rising proportion of renewable energies. Congestion of high-voltage and ultra-high-voltage grids already occurs regularly in certain regions of Germany. This will further increase in future unless appropriate expansion measures are implemented.

Some players foresee a risk that the grids could become a bottleneck in the expansion of RES-E. All the more so, since it appears that grid expansion has so far been unable to keep pace with the expansion of RES-E capacities.

The performance capability of the transmission grids can be increased by *optimising grid operations*, enhancing and expanding grids, with the costs of the measures increasing in the order cited.

One means of optimising grid operations is what is termed »power cable monitoring«. This involves monitoring the operating temperature of the cables so that more efficient use can be made of their transmission capacity. *Existing grids can be strengthened,* for example, by converting transmission routes to a higher transmission voltage or fitting them with high-temperature cables . Since existing transmission routes are used in these measures, it would be possible to effectively accelerate the expansion of grid capacity in this way.

Electronic systems for controlling power flows termed »FACTS« (flexible alternating current transmission systems), which permit transmission bottlenecks to be resolved at least temporarily, are regarded as a technology of the future. To date, FACTS have not gained widespread acceptance particularly for reasons of cost. However, experts foresee in them a major growth potential.

A number of analyses have already been carried out into the *need to expand the transmission grid*, including the two »Grid Studies« by DENA, the German Energy Agency. »Grid Study I« identified a need for expansion to the tune of 850 km of new transmission routes; building on this, »Grid Study II« concluded there was a need for an additional 3,600 km of new routes, including 1,550 km of underwater cabling for connecting offshore wind farms. The approach and outcomes of the DENA Grid Studies are not entirely uncontroversial; for instance, critics feel that technological alternatives to conventional overhead power transmission lines (e.g. use of high-temperature cables, underground cables or high-voltage direct current transmission) are not given sufficient recognition. Nonetheless, they form a hook for the debate about the level of expansion needed for the ultra-high-voltage grids in Germany.

Robust estimates of the demand for expansion are not currently available for the *distribution grids*, though these are currently being drawn up. A shift of large parts of electricity production to the distribution grid level as a result of small decentralised systems (for example, photovoltaic systems) is a very recent trend which poses considerable challenges for grid operations.

The appropriate expansion of the distribution grids is therefore a key area if the electricity system is to be successfully transformed. More intelligent distribution grids (»smart grids«) will enable the demand side to make a more active contribution than hitherto to energy savings and strengthen the flexibility and stability of the system as a whole. Overall, the need for expansion could be reduced at both the transport and the distribution grid level.

European perspective

From the point of view of electricity generation from fluctuating renewable energy sources a European perspective is particularly beneficial since taking a large geographic area into account results in a more constant supply and therefore makes it easier to balance supply and demand. The prerequisite for this, however, is an effective trans-European grid.

In its »Ten Year Network Development Plan« (TYNDP) ENTSO-E (European Network of Transmission System Operators for Electricity) puts the demand for new or upgrades of cables of significance at a European level at 42,100 km by 2020 (of which 9,600 km will be mostly underwater high-voltage d.c. cables). The three drivers for this demand – security of supply, completion of the European internal market and integration of RES-E – play approximately equal roles in ENTSO-E's view.

The prospect is that ever larger amounts of electricity will have to be transported over ever greater distances. In order, for instance, to transport electricity from the sunny areas of Southern Europe or North Africa and the windy areas of Northern Europe to the centres of consumption in Central Europe, a new infrastructure, known as the »super grid«, would have to be built.

STORAGE SYSTEMS AND OTHER FLEXIBILISATION OPTIONS

A dynamically advancing expansion of electricity generation using fluctuating renewable energies means that it is absolutely essential for the electricity system to be capable of responding significantly more flexibly than in the past to different feed-in and demand situations to ensure that the security of supply is maintained.

Storage systems are just one of many options available for making the electricity system more flexible. The tasks which storage systems can handle can always also be achieved in other ways. In addition to the already mentioned grid expansion, the flexibilisation of electricity generation and load management are key options. These options can complement each other, but also to a certain degree replace each other.

What is important overall is to identify from the available portfolio of enhanced flexibility options the combination of measures which guarantees the long-term security of supply at the lowest financial cost with the highest possible environmental and social compatibility. This means organising a social search process with scientific support.

A central outcome of the analyses is that, when integrating renewable energies, it is substantially more efficient to use the available flexibilisation options to level out the (residual) overall demand. This strategy will enable both the remaining demand for conventional power plants to be significantly reduced and also the limitation of renewable energies to be minimised. The alternative approach, i.e. only striving to level out the feed-in from renewable energies (e.g. by installing decentralised storage systems on wind farms), results in inefficient solutions.

Storage systems

Overall, the role to be played by storage systems in Germany's electricity system in the next 10 to 15 years is likely to be somewhat limited, seen from today's viewpoint. In the debate among the public, experts and policy-makers, this role tends to be overestimated rather than underestimated at present. Depending on how the framework conditions are developed, there could be a demand for short-term storage of the order of 1 to 2 GW; over this time horizon no additional storage demand is expected in order to achieve a weekly or seasonal balance.

What is true for all storage technologies is that they usually represent the more expensive option when compared with other flexibilisation options. From an economic viewpoint, therefore, the potentials which are less costly to develop should be exhausted first. In particular, storage systems are not an alternative to grid expansion because of their significantly higher capital costs. The current development on the electricity markets where, particularly on days with high feed-in from photovoltaic systems, the price spread between peak-load and base-load electricity falls sharply, even puts a question mark over the cost effectiveness of new pumped-storage power plants, the least expensive of all storage technologies.

However, a purely economic analysis of the electricity system is an inadequate means of assessing the future development of storage systems. It cannot, for example, be ruled out that (expensive) storage systems would have to be built if, for instance, further grid expansion proves unacceptable to society. Decentralised storage systems could also increasingly be built, although they are usually inefficient in energy economics terms and with reference to the overall system if, for example, grid parity (electricity generation costs are at or below the level of the end customer electricity price for domestic customers) is achieved for photovoltaic systems with storage systems (this is expected from about 2019).

Against this, the *long-term challenges from 2025 onward* with the target of achieving (more or less) complete supply with RES-E by about 2050 are huge. Even in this long-term perspective, however, the challenges can also be overcome in ways other than just a massive expansion of storage capacities.

Flexibilisation of electricity supply

The expansion of renewable energies has significant impacts on *conventional power plants*. Although conventional power plants which cover the residual proportion of the electricity demand will still be required in future, both the output demand and the capacity utilisation of these power plants will fall substantially. In the scenario studied, the demand for base-load power plants will fall from the current level of approx. 29 GW (installed power output of lignite and nuclear power plants) to just 6 GW by 2030. Because of the significant reduction in the achievable capacity utilisation, the economic efficiency of new power plants with high capital costs will be reduced compared with power plants with lower capital costs.

Also if the *electricity production from renewables* can be matched to actual demand, this will also increase the flexibility of the generation. Biomass power plants are well suited to this from a technical viewpoint, as are hydroelectric plants and geothermal systems. Biomass plants, in particular, could make a substantial contribution to the flexibility of the power plant fleet since, according to the »National Action Plan for Renewable Energy« 8.8 GW of biomass power plants are to be connected to the grid by 2020.

Load management/flexibilisation of demand

By enhancing the flexibility of demand, it is possible to reduce the differential between electricity generation from renewables and electricity consumption. Industrial and large industrial consumers in particular (e.g. chlor-alkali electrolysis, aluminium production, large refrigerated warehouses) offer attractive potentials in overall financial terms where the cost of saving electricity at peak-load periods (or saving balancing energy) is lower than the cost of additional electricity production.

By contrast, the load management potentials in the domestic sector (and in large sections of the trade, industry and service sector), for example by means of household appliances which can be switched on or off intelligently or load management of electric vehicles, require closer study before coming to a definitive assessment. In particular, the extent to which the potential savings can justify investments in smart grid infrastructures needs to be determined.

ACTION FIELDS AND OPTIONS

Based on the analyses, eight action fields can be identified where the government and/or the executive and legislative energy policy players can design framework conditions which can assist in ensuring that the upcoming restructuring of the electricity supply system succeeds. In accordance with the criteria for sustainable development, the success of this restructuring should be measured against the standard that it delivers the best possible outcomes, both economically and also in environmental and social terms.

As the TAB report shows, enhanced flexibility in the overall electricity system is a necessary prerequisite for successfully incorporating a high proportion of renewable energies in the system at the lowest possible cost and guaranteeing a secure power supply even at times of low energy production from renewables. Although the analysis shows that the existing and concretely planned options for enhancing flexibility will be more or less adequate up to 2030 at least, provided no grid bottlenecks occur, government can nonetheless contribute towards further improving the system integration of renewable electricity generation, particularly in the long term, by providing additional flexibilisation options.

Fundamentally, when optimising the strategy for increasing the flexibility of the electricity system, it is important to carefully weigh up the costs, benefits and efficiency of the individual options. The moment at which any policy intervention is indicated should also be given thorough consideration.

Grid bottlenecks and expansion

There is an extensive need for action by government in this field since otherwise, in light of the long lead times for planning and approval, grid expansion could prove to be a stumbling block for the restructuring of the electricity supply system.

The Grid Expansion Acceleration Act (NABEG) passed by the German Bundestag and the European Commission's »Guidelines for the implementation of trans-European energy infrastructure priorities« are important steps in implementing the necessary expansion of the transmission grids. However, further measures could prove necessary. One possibility would be to make the investment conditions for grid expansion more attractive, for example by strengthening the regulatory framework in order to reduce the risk for investors.

A pan-European approach when expanding the grid should be the target since in this way the balancing effects could be used over a large geographic area and potentials for generating and storage could be optimally incorporated. Projects such as DESERTEC and the European Offshore Grid could help to seed an intensified trans-European grid expansion.

Measures for optimising grid operation may be more suitable than grid expansion in managing short- to medium-term grid bottlenecks since they can be implemented considerably faster. Such measures include, for instance, temperature monitoring of cables.

At the market organisation level so-called »nodal prices« could be a suitable means of reducing grid bottlenecks. In this approach the electricity price is individually determined on the basis of the grid bottlenecks occurring for each grid node. Positive experience with nodal prices is available from the US. However, the introduction and management of such a system represents a break with the pricing system used to date. The advantages and disadvantages should therefore be thoroughly examined and weighed up in advance.

A key challenge lies in promoting acceptance by society and especially by those affected. At present, grid expansion projects are frequently delayed or even prevented by protests by residents. It is important here to build trust by means of open communication and a transparent planning process and to concentrate on convincing those involved that grid expansion is indispensable to the transformation to a sustainable electricity system.

Because of their special importance to the restructuring of electricity supplies, innovative technologies for grid infrastructure and operation (e.g. connection concepts and transmission technologies with high-voltage direct current, flexible alternating current systems [FACTS], superconducting components etc.) should continue to be priorities for research funding.

Conventional power plants

As described, the conventional power plants required for backing up electricity production from renewables must expect to have a significantly lower capacity utilisation than now and must respond flexibly to the production of renewable energies.

There are two conclusions to this. On the one hand, the construction of new power plants which are designed (technically and/or economically) for base-load operation must be examined critically. In light of the long investment cycles and technical service life of 40 years and more the fear would be – depending on the design of the framework conditions – either of being tied in to a technology path which is inefficient in terms of climate and energy policy (termed the lock-in effect), or that these investments would prove to be unprofitable in the long term (»stranded investments«).

On the other hand, flexible conventional power plants will be needed to maintain the security of supply. A debate is currently under way as to whether the construction of new (or even the retention of existing) such power plants also needs additional support – in the form of so-called »capacity mechanisms« - to ensure that the market players do so to a sufficient extent.

There is intensive discussion at present about the provision of a »strategic reserve« as one of the many possible capacity mechanism options. This involves a central body keeping a certain number of power plants available which are then only to be used if the power plants available on the market are unable to meet demand. If this is considered, careful attention should be paid during the actual specification to ensuring that the impact on the electricity market is kept as low as possible.

No urgent need for action in the next few years is identifiable since, according to our current level of knowledge, the capacities of (existing or currently under construction) conventional power plants in Germany are sufficient to reliably cover demand until at least 2020 or so. In the longer term (from about 2020) capacity mechanisms could nonetheless become necessary to back up flexible gas power plants, storage systems and demand management. However, these represent a very extensive intervention in the electricity markets, and their impacts should be precisely analysed before any implementation.

Flexibilisation of electricity supply from renewables

If at all possible, regulatable RES-E systems should not be incentivised by a subsidy system to operate continuously, as is currently the case with the fixed feed-in tariff-system.

The introduction of the optional market bonus in the Renewable Energy Sources Act (EEG) is one way of making electricity production from RES-E plants more flexible. These operate directly in the electricity market and can yield higher revenues if they produce electricity at periods of high demand. The optional market bonus also empowers the RES-E generators to operate in other markets, e.g. in balancing energy markets and futures markets. The introduction of the flexibility bonus for biomass power plants also contributes to making electricity generation more flexible.

It remains to be seen, however, to what extent this new support scheme will actually result in a change in the feed-in behaviour of renewable energies and thus to greater flexibility in the electricity, thereby justifying the initial additional expenditure and the administrative effort.

Storage systems

The model-based analyses carried out here emphatically show that the strategy of using storage systems to level out electricity generation from renewables is not ideal from an efficiency standpoint. Instead, using the storage systems to level out the residual load, i.e. optimising the overall electricity system, is clearly preferable. This argument should not be overlooked when drawing up policy measures. For example, supporting virtual power plants, a hybrid power plant bonus or supporting local consumption of photovoltaically generated electricity is inefficient from a system viewpoint. These measures could only be justified nonetheless under certain circumstances, e.g. in the event of local grid bottlenecks which cannot be resolved in any other way.

Pumped-storage systems are currently the most commonly used energy storage means at a system level. However, the construction of new pumped-storage systems involves substantial interventions in the landscape which, like other major infrastructure projects, frequently encounter problems in the planning process and generate concern among affected members of the public. Government may be able to provide assistance in this regard. The challenge lies mainly in resolving the trade-off seen by many between simplification and acceleration of approval processes, on the one hand, and strengthening public involvement and creating transparency, on the other.

Until recently, pumped-storage systems represented a profitable business model in the deregulated electricity market. If, however, the recent trend continues, which has seen the price spread between off-peak and peak-load electricity shrink, this business model will find itself under ever greater pressure. If no other more efficient measures for enhancing flexibility are available, consideration may have to be given in this case to support measures which go beyond the current exemption from the network charges and from the apportionment scheme of Germany's Renewable Energy Sources Act (EEG).

Many of the other potential storage technologies are still in the development stage. Storage systems should therefore remain a priority for research funding, as already set out, for example, in the »Joint Energy Storage Promotion Scheme« of the German Federal Ministries of Economics and Technology (BMWi), the Environment (BMU) and Education and Research (BMBF).

Furthermore, storage systems which link with other sectors – particularly the heating sector and also, in the longer term, the gas and fuel sectors – could open up attractive options and offer synergies.

A link to the heating sector could be created, for instance, by fitting CHP (Combined Heat and Power) plants with heat storage systems which enable their electricity generation to be matched to electricity demand. The heat demand can then be met from the storage systems, if required. This also permits the base load to be reduced to which the CHP systems contribute when operated for heat. A second option is to use surplus electricity for heat generation, for example by means of immersion heaters or heat pumps.

A link to the gas sector is provided by the option of generating methane (wind gas) or hydrogen using electricity (by means of electrolysis). Although these processes are still far from economically viable, they could in the long term represent sensible options in the transport sector, for example, depending on future developments in the cost structure, the demand for long-term storage systems and potential applications.

At present it is not possible to reliably quantify the level of long-term storage which is economically and technically feasible. It is therefore recommended that the relevant knowledge base be expanded and that a detailed study be conducted into whether and, if so, what sort of, political support in addition to research grants is appropriate before taking any action – for instance, in the form of large-scale subsidy schemes for constructing storage systems.

Load management/flexibilisation of demand

In the short to medium term it makes undoubted sense to increase the flexibility of the major electricity consumers. Suitable means of doing so include further opening-up of the balancing power markets, but also a greater emphasis on the introduction of electricity tariffs in which the electricity price fluctuates with the power exchange price.

In Germany the discussion to date has centred on greater inclusion of industrial electricity consumers in the market for balancing energy. Some companies are already involved in the balancing energy market. In parts of Germany demand management is also being used to reduce strain on the grid (e.g. by means of contractual agreements between companies and grid operators).

The »Load Shedding Ordinance« drafted by the Federal Ministry of Economics and Technology is currently under discussion as a means of opening up a greater potential for load management by industry. The ordinance is designed to encourage grid operators and industrial companies to conclude load-shedding contracts to stabilise grid operations. However, this is proving controversial. Among other things, critics point out that the specification is non-market-compliant and that the level of the payment rates is far above the prices for balancing energy.

Market for balancing power output

Conventional power plants, which provide system services or balancing energy and are thus needed to maintain system stability (known as must-run power plants), form a baseline for generation which can restrict the the electricity system's ability to take up renewable energies. To reduce this constraint it is essential to open up the balancing markets for renewable energies and the demand side. The first key steps in this have already been taken, though further dismantling of access barriers to the balancing market is necessary in order to increase the number of players in the market and to diversify them.

In addition, greater cooperation at a European level would be desirable since larger balancing zones require a smaller proportion of the balancing power. However, this presupposes an effective trans-European grid. Another option is to focus more strongly on intraday electricity trading. Positive examples of this can be found abroad (e.g. in Spain).

European coorperation

Cooperation at a European level is sensible in many areas to promote the integration of renewables. Trans-European grid expansion and market integration can significantly increase the flexibility of the system.

Cooperation at a European level can also reduce the need for regulation and potentially lower costs, e.g. if the availability of resources and the integration costs are addressed holistically when deciding on the location for investments in renewable systems.

Germany’s active role both at an EU level and also within multilateral project partnerships (DESERTEC, North Sea Offshore Initiative) and direct bilateral talks (e.g. German-Norwegian energy partnership) is welcomed.

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