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Short version

Decentralization and cellular optimization

Effects on electricity network development

Contracting body
N-ERGIE Aktiengesellschaft

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About Friedrich-Alexander-University/Energie Campus Nürnberg

Energie Campus Nürnberg (EnCN) is an interdisciplinary energy research center that focuses on new technologies for a sustainable energy system and – at the same time – develops energy market models and analytical tools to evaluate the scope of technologies in the future. In an independent research network, six research institutions from the metropolitan area Nuremberg cooperate in the interdisciplinary Think Tank. The **Chair of Economic Theory** and the **Professorship of Industrial Organization and Energy Markets** at **Friedrich-Alexander-University (FAU)** Erlangen-Nürnberg cooperate in the EnCN research unit **Energy Market Design**.

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Background and task

In March 2016 Prognos AG and FAU/EnCN have been commissioned by N-ERGIE Aktiengesellschaft located in Nuremberg to analyse possibilities to further improve the electricity network development procedure in Germany. In the light of the present debate regarding the direction as well as the overall continuation of the energy turnaround in Germany, this study investigates flexibility options as well as alternative framework requirements which could complement or partially substitute the High Voltage Direct Current (HVDC) network expansion. The authors of this study are concerned to contribute to further develop the current network development procedure, focusing on new methodological approaches.

The study design and the model used are based on the expertise submitted to the Monopolies Commission of the Federal government of Germany by FAU/EnCN in 2015. This expertise was the first study of its kind showing an integrated approach to electricity network planning and the future electricity market framework. Furthermore, in this study the optimal spatial allocation of renewable power generating units and the technology choices are not provided exogenously but calculated endogenously within the model. The study provides insights on economic trends and interdependencies that would need to be verified in more detailed electro-technical modelling.

Central findings of the study

The analyses show that – similar to the findings of the German network development plan (NDP) – the current market conditions make an extensive expansion of the network inevitable in order to transport renewable and conventionally produced electricity to the present centres of consumption. However, the usage of certain flexibility options and an appropriate adaptation of market conditions can reduce the necessity for network expansion by high voltage direct current (HVDC) transmission lines as formulated in the NDP by more than 50 %.

These measures include an optimal feed-in management, a more extensive utilization of dispatching procedures (i.e. further intervention in the operation of power plants) as well as the installation of flexible consumers in regions of high renewable power generation. The utilisation of flexibility options has a strong impact on the optimal allocation of renewable power generating units, especially concerning photovoltaics and onshore wind turbines.

Furthermore, the need to expand the current HVDC transmission could be even more reduced by implementation of regional price signals that guide supply and demand. As a corollary, the study shows that the present delay in network expansion in Germany does not necessarily impede the further expansion of renewable electricity production.

In combination with regional price signals, measures that help to adapt conventional production and consumption to the flexible nature of renewable power generation lead to more cost-effectiveness and reduce the need for network expansion. The main findings are listed below:

The present procedure of network expansion planning in Germany accounts insufficiently for the cost interdependencies of power generation, consumption and transmission.

- An adjustment of market conditions and the usage of flexibility options could reduce the need for an expansion of HVDC transmission capacity in Germany by 50%. Scenarios including such measures should be included in the network expansion planning procedure.
- The optimal renewable energy curtailment as well as the spatial allocation of renewable power generating units and flexible power consumers is provided exogenously and rigid in the scenario framework underlying the NDP. Model results based on endogenous calculations of optima show savings of 1.7 bn Euro p.a.
- Even a moderate adaptation of market conditions would lead to additional capacities of 7 GW for photovoltaics and 1.5 GW for wind turbines in southern Germany by 2035. This has a significant impact on the transmission system requirements.
- Enlarging the spectrum of scenarios preceding the NDP could provide impulses to account in a more adequate way for system-wide cost analyses within the NDP.

The regional allocation of renewable power generating units in Germany changes considerably if location is to be cost efficient.

- More renewable power generating units should be installed in southern Germany in order to improve the overall system-wide cost-effectiveness.
- Transmission requirements could be reduced significantly by implementing an optimal feed-in management.
- The regional allocation and the choice of technology are sensitive to the cost developments of individual power generation and transmission technologies. Overall, there would be more wind turbines in southern Germany if, for example, the levelised cost of photovoltaics would not decline as strongly relative to those of wind turbines.
- Model calculations concerning the system optimum result in an increase of installed capacity for wind turbines and photovoltaics by 16.5 GW, which is an increase by 10% as compared to the installed capacity in the scenario framework of the NDP. In the system optimum, the allocation of renewable capacity is determined to a greater extent by the proximity to demand centres rather than by optimal generation efficiency.

A better market design and flexibility options can reduce the need for further network expansion.

- A cost-effective and system-oriented curtailment of renewable energy generation reduces the need for network expansion considerably.
- Model calculations show that an efficient renewable energy curtailment of 5 % leads to a decrease of the necessary network expansion and reductions of the renewable energies act levy by more than 40 % each. This translates to efficiency gains of more than 1.3 billion Euro p.a.
- An improved spatial distribution of flexible consumption units such as power-to-x technologies as well as flexible generation units reduces the need for network expansion only in combination with regional pricing.
- The ambitious expansion of renewable generation capacity can be continued despite the current delay in network expansion due to societal acceptance problems.

Analysed market designs and flexibility options

The market designs and flexibility options considered in this study have been selected based on the present procedure of the German NDP. Those parameters that are – in the view of the authors – too inflexible in the current NDP procedure are varied to assess their possible impact on system performance. Several modified market design elements and flexibility options were tested individually and in combination, resulting in two groups of scenarios. A first group of scenarios, labelled *MG (*Marktgleichgewicht: Market Equilibrium), contains scenarios with a single price zone as in practice today. The second group of scenarios, labelled *FB* (First Best), contains scenarios were parameter variations were tested under a regional pricing regime, allowing for potentially different prices in 16 price zones. The analyses based on this regional pricing regime are to be taken as a benchmark under optimal conditions, thus providing a basis for estimating the maximum welfare gains that could materialise when adapting ideal market conditions and using flexibility options. Both groups, *MG* and *FB,* include model calculations for the following measures and flexibility options:

- **(EM&RD)** Network congestion can be resolved through redispatch procedures (RD) as an alternative to network expansion. An optimal feed-in management (EM) includes curtailment of renewable power to avoid negative prices as well as the curtailment of renewable production in the context of redispatch operations where this is cost efficient. Both measures are anticipated and considered upon network development planning.
- **(EE)** The regional allocation of photovoltaic capacity and wind turbines is chosen as to maximise overall economic welfare. Yield-optimal allocations requiring network expansion are weighed against an allocation of renewable capacity close to demand centres where yields are not as high but that would imply less network expansion. The optimal renewables technology mix which exactly meets the amount of renewable power generation needed is calculated endogenously.
- **(KWK)** An alternative regional allocation of cogeneration plants is tested. In this scenario, cogeneration plants are placed predominantly in southern Germany to reduce the necessity for power transportation to the south from other regions.
- **(P2G)** Power-to-gas units are located in regions of high renewable power generation, creating additional local demand in periods of large supply and thereby reducing the necessity for network expansion.
- **(WP)** Heat pumps are installed in regions of high renewable power generation, with a similar intention as in the scenario above. Heat pumps increase demand for power led by thermal demand of households. Model calculations are carried out with heat pumps being installed predominantly in northern Germany.
- **(EV)** Self-consumption increases due to faster market penetration of PV battery storage solutions, leading especially to a larger self-sufficiency for family homes in southern Germany. The combination of PV systems and battery storage for self-consumption contribute to a smoother feed-in curve.

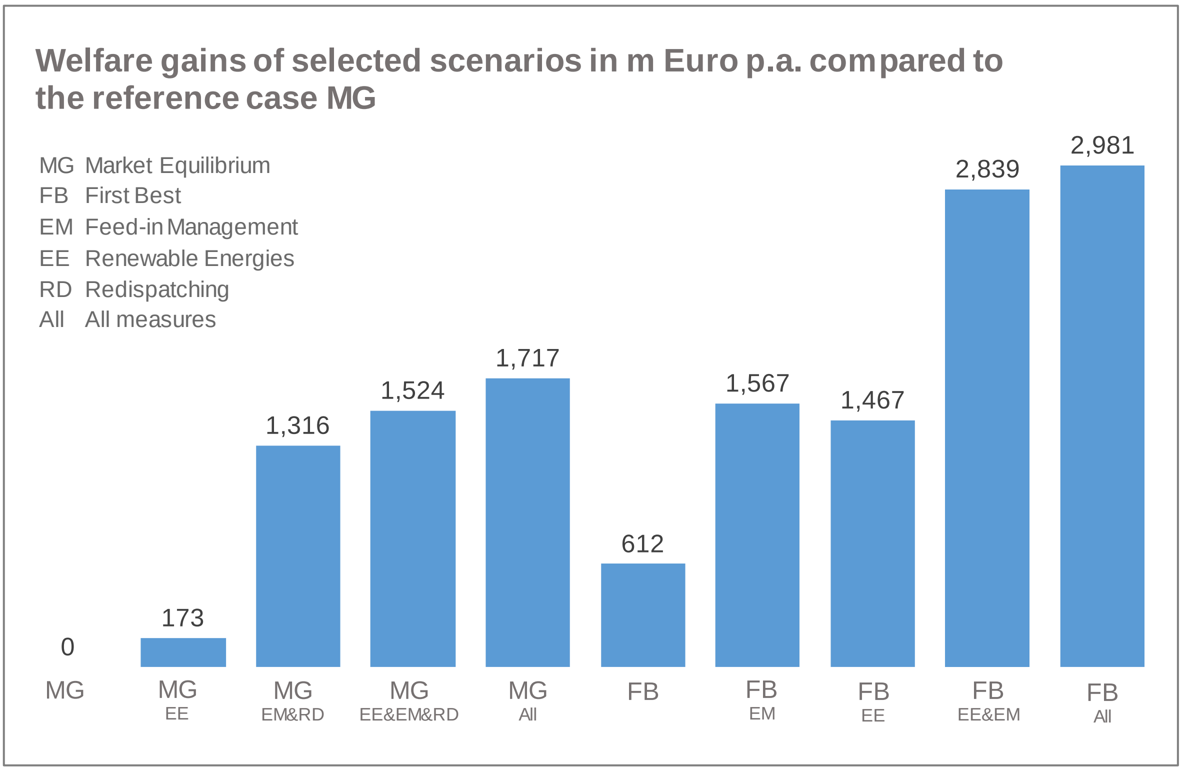
The findings in detail

The study demonstrates that the current network development procedure leaves room for improvement. Next to significant welfare gains, the above-mentioned scenarios are characterised by large savings in network expansion, a different regional allocation of renewable power systems and as a consequence potentially significant price reductions for final consumers.

The alternative scenarios presented above show significant efficiency gains compared to the reference case (scenario MG) even without a regional pricing regime. The scenarios, labelled “All”, consider all flexibility options. The welfare gains of all these measures under the single price zone (MG_{All}) amount to 1.7 billion Euro p.a. (see figure 1). The largest singular effect is ascribed to an optimal feed-in management in combination with redispatch ($MG_{EM\&RD}$).

Introduction of **regional pricing** leads to further significant increases in welfare gains. The combination of all measures under a regional pricing regime (scenario FB_{All}) leads to efficiency gains of nearly 3 bn Euro p.a., of which 2.8 bn Euro p.a. can be attributed to an optimal feed-in management in combination with an optimal regional allocation of renewable production ($FB_{EE\&EM}$).

Figure 1: Welfare gains in selected scenarios in million Euro p.a. compared to the reference case MG, which reflects the current conditions of the NDP framework.



Source: own representation

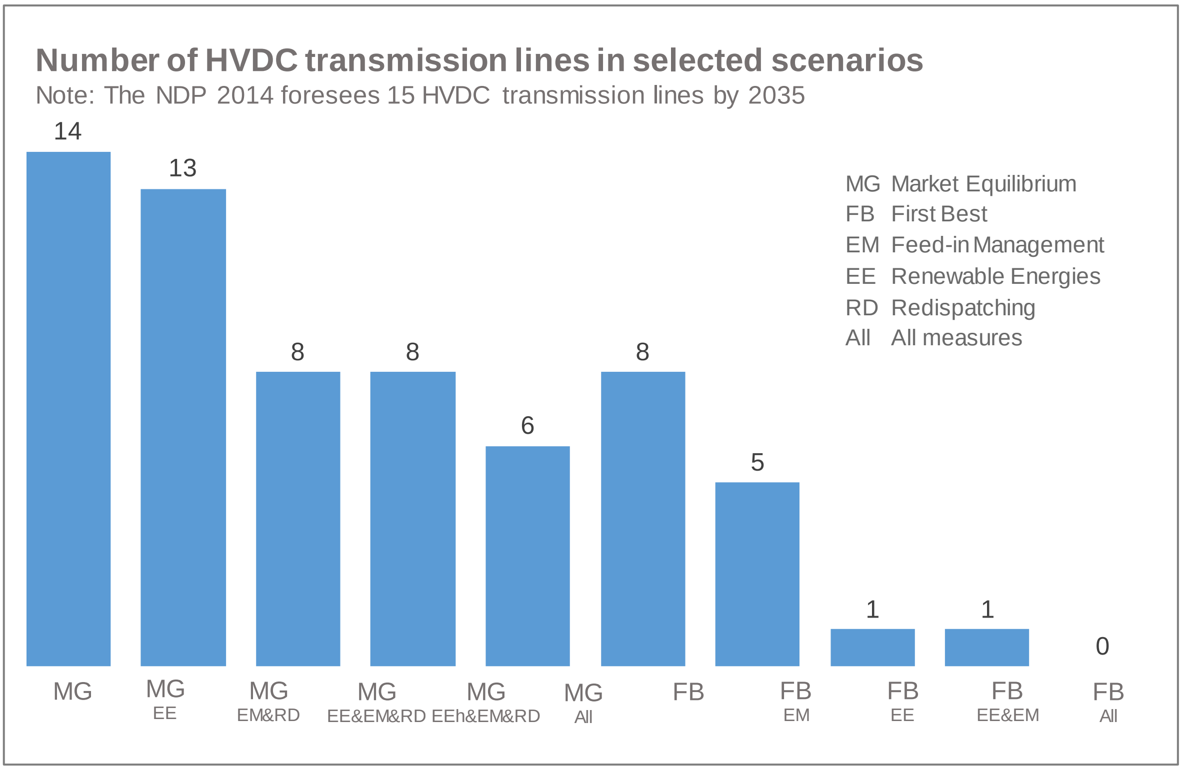
The **number of HVDC transmission lines** could be reduced significantly by adopting a combination of different flexibility measures. By introducing all measures (feed-in management, redispatch, optimal renewables allocation, cogeneration predominantly in southern Germany and installation of additional power-to-gas units in northern Germany) under current market conditions with a single price zone (MG_{All}) the need for a network expansion could be reduced by more than 50% (see figure 2).

The largest singular effect introduced under current market conditions can be attributed to the measures ‘optimal feed-in management’ in combination with ‘redispatch’ ($MG_{EM\&RD}$). This finding underlines that the current procedures of the NDP – allowing a curtailment of renewable power generation system of only 3 % of their annual generation output – need to be reconsidered.

A scenario with regional prices and all presented flexibility measures (FB_{All}) results in an optimal system configuration without additional HVDC transmission lines. Furthermore, in a regime with regional pricing (FB_{EE}) the ‘system-optimal renewables allocation’ has a much stronger effect than under current market conditions (MG_{EE}).

Policy conclusions concerning the comparison of a single price zone as compared to a regional pricing regime was not in the focus of this study. It would need to be addressed in a separate study in more detail.

Figure 2: Number of HVDC transmission lines in 2035 in selected scenarios, compared to the reference case MG, which reflects the current conditions of the NDP framework.



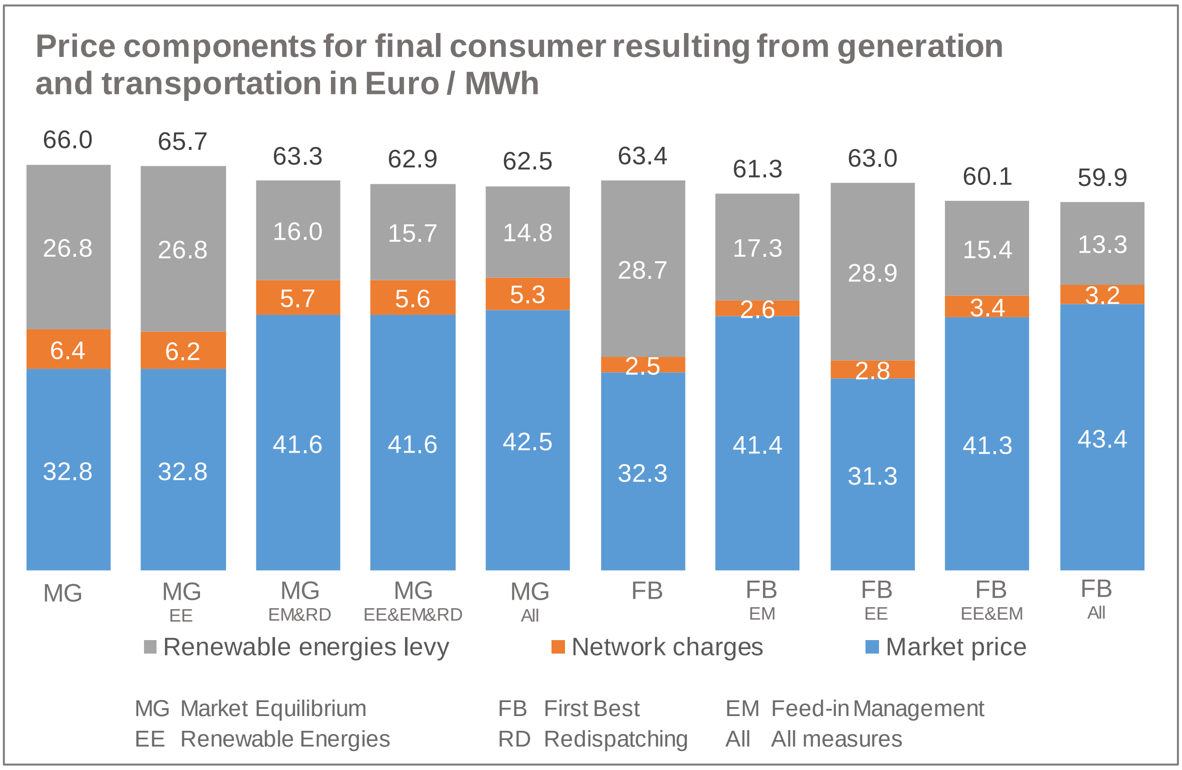
Source: own representation

Efficiency gains and savings in network expansion result in **benefits for the average final electricity consumer** in Germany. Final consumers pay in sum less for electricity (given the price components looked at in this study) in the alternative scenarios than in the reference case (MG). Regional differences in terms of electricity prices, which are relevant in all scenarios containing a regional pricing regime (FB…), are not depicted in detail.

The structural changes among the price components become clear in the findings. While network charges would reduce significantly – due to savings in network expansion – costs for power generation would increase. Moreover, the introduction of regional price signals (FB) reduces network charges even further due to savings in redispatch costs.

Scenarios with higher average market prices (which result due to avoidance of negative prices) imply a reduction in subsidies for renewable power generation which are necessary cover investment cost for renewables. Especially scenarios with a system-optimal curtailment of renewable power generating units show this effect.

Figure 3: Price components for final consumers resulting from generation and transportation in selected scenarios (without taxes, concession fees, distribution network charges and cogeneration levies)



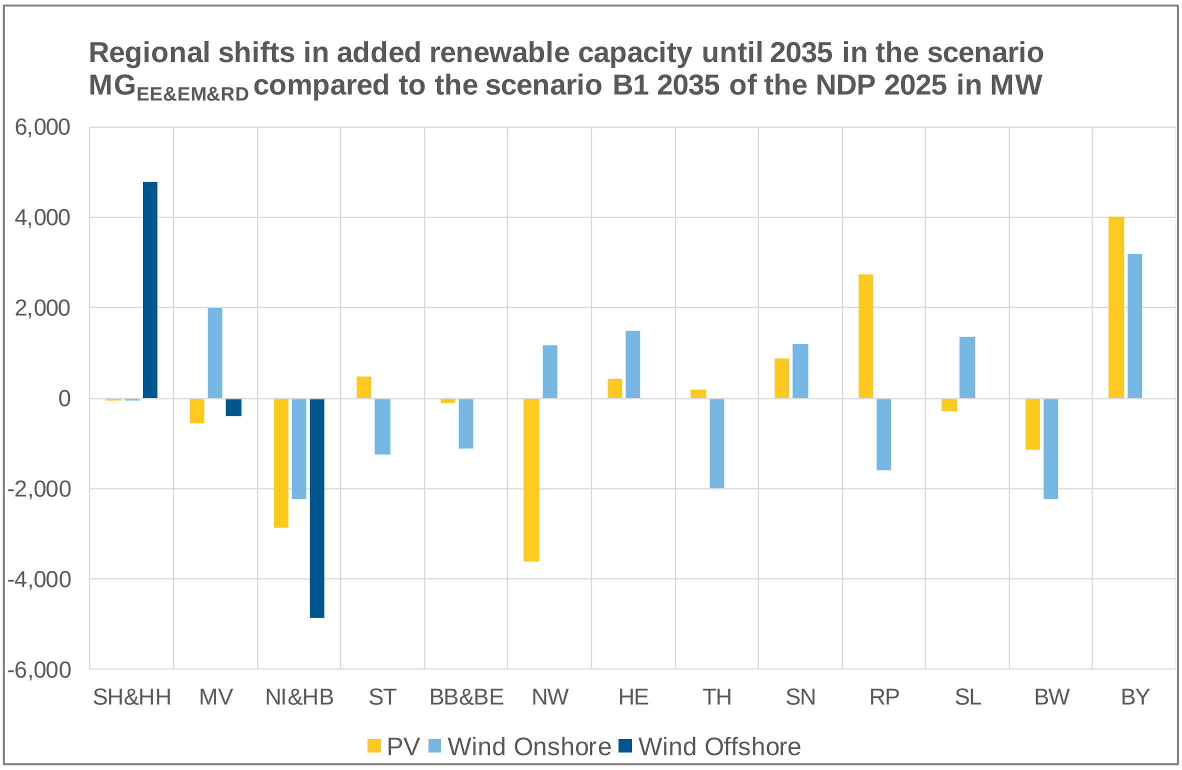
Source: own representation

The **spatial distribution of renewable power** generation units throughout Germany changes significantly in the considered scenarios compared to the NDP-based reference case (see figure 4), leading to savings in network expansion. In calculations, considering system-optimality implies a stronger increase of renewable capacities in southern Germany as compared to yield-optimality. The effect on the technology mix of renewable power generation is negligible compared to the spatial distribution effect. Spatial allocation has been calculated based on surface potentials only. Transaction costs that may result from questions related to acceptance (and which may vary among regions) are omitted.

The shift concerning offshore wind power between Lower Saxony and Schleswig-Holstein results from assigning useable areas in the German Bight to federal states without taking into account actual landing places of the network connections. However, there are no shifts between the Baltic and North Sea.

At federal state level, the overall expansion of renewable power generation capacity is reduced especially in Lower Saxony. The expansion of photovoltaic capacity is reduced in Northrhine-Westfalia, whereas the expansion of wind capacity is reduced in Thuringia, Rhineland-Palatinate and Baden-Wuerttemberg. An increase in renewable capacity expansion takes place especially in Saxony and Bavaria. However, these regional shifts of renewable power generation contradict the political orientation of most federal states. An implementation of the proposed measures would require a harmonisation of federal state politics.

Figure 4: Regional shifts in added renewable capacity until 2035 in the scenario $MG_{EE\&EM\&RD}$ compared to the scenario B1 2035 of the NDP 2025.



Source: own representation

Note: SH&HH - Schleswig-Holstein & Hamburg; MV- Mecklenburg Western Pomerania; NI&HB – Lower Saxony & Bremen; ST – Saxony Anhalt; BB&BE – Brandenburg & Berlin; NW – Northrhine Westphalia; HE – Hesse; TH – Thuringia; SN – Saxony; RP – Rhineland-Palatinate; SL – Saarland; BW – Baden-Württemberg; BY – Bavaria.