

## Dezentralität, Regionalisierung und Stromnetze

Meta-Studie  
über Annahmen, Erkenntnisse und Narrative

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für die  
Renewables Grid Initiative (RGI)

Dr. Felix Chr. Matthes  
Franziska Flachsbarth  
Moritz Vogel  
Vanessa Cook (Übersetzung)

**Geschäftsstelle Freiburg**  
Postfach 17 71  
79017 Freiburg  
**Hausadresse**  
Merzhauser Straße 173  
79100 Freiburg  
Telefon +49 761 45295-0

**Büro Berlin**  
Schicklerstraße 5-7  
10179 Berlin  
Telefon +49 30 405085-0

**Büro Darmstadt**  
Rheinstraße 95  
64295 Darmstadt  
Telefon +49 6151 8191-0

[info@oeko.de](mailto:info@oeko.de)  
[www.oeko.de](http://www.oeko.de)



## Summary

In the discourse about infrastructure expansion that is robust and for which public acceptance is assured, the relationship between decentralization and the future demands on power grid infrastructures is a critical issue. It includes the whole spectrum of applicable interrelationships, the myriad areas of tension and complexities of centrality, decentralization and so-called “cellular” approaches. The issue of decentralization – which is often handled very vaguely and (too) often features rather crude narratives – requires a nuanced, differentiated analysis.

In a first step the present study reviews and analyzes the different dimensions and aspects of decentralization of electricity generation based on literature reviews. This finds, first of all, that a purely technical approach to the relationship between decentralization and grid expansion (small vs. large installations, connected voltage level) is not a viable approach.

A crucial factor in the context of grid expansion is, firstly, the proximity of power generation plants to electricity customers. If a large share of the power generation is decentralized, the pressures on the electricity grid can naturally be reduced. Secondly, the proximity of the flexibility options (e.g. demand flexibility, storage, back-up capacities) to the electricity customers is of major importance, since such flexibility options will play a fundamental role in an electricity system based on renewable energies. All kinds of combinations of decentralized and centralized power generation options on the one hand and decentralized and centralized flexibility options on the other hand can arise and are useful with a view to the large range of flexibility profiles. Decentralized power generation options can only result in a lower need for grid expansion if decentralized flexibility options are also available.

The third aspect, however, is ultimately crucial: the control, coordination and market model, which combines consideration of generation and flexibility options and electricity demand. Within the framework of liberalized markets, i.e. with free decisions about production and supplier choice, large-scale (centralized) markets and prices will emerge and determine the use of flexibility options. Beyond optimization of self-consumption it is only possible to avoid or limit this if very extensive isolation of regional markets, e.g. regional monopolies or very restrictive pricing of infrastructure, is possible. As a result, lower power grid needs can only be reliably assumed if self-consumption concepts combine decentralized power generation and flexibility options or if small-scale “cellular” approaches (whereby electricity is produced and directly consumed without being fed into the grid) are used.

Even if the concrete implementation of “cellular” (market) systems or regional markets designed in other ways has not yet been specified in sufficient detail, a number of reliable statements can be made on a qualitative level about the implications of such models. Small-scale control approaches with high shares of decentralized power generation and flexibility options tend to lead to higher costs for power generation and flexibility options in the overall electricity system if the effects of the large-scale interplay of very different electricity demand and generation profiles (portfolio effects) do not arise.

As a consequence, higher power generation (due to energy losses of the flexibility options, curtailments, etc.) would initially be necessary since (for example) overarching emission reduction targets need to be met. A situation similar to the cost issue also arises with regard to the land requirements for all generation options in the electricity system with the exception of rooftop PV systems.

However, the effort and the implications with regard to the flexibility options would also increase. The additional costs involved could be limited if conventional fossil-fuel technologies (e.g. decentralized gas-fired power plants) are used, which would then lead to higher emission levels in the overall system that should, at the same time, be decarbonized as quickly as possible. If higher emissions are to be avoided, the costs of (decentralized) flexibility options will increase far above the particularly cheap options (which have a limited availability) (if, for instance, not yet matured options like electricity-based fuels would have to be used on a large scale).

From an economic perspective, the costs of the flexibility options should always be compared with the corresponding infrastructure costs. This issue cannot be robustly answered on a purely qualitative level. From an environmental perspective, the significant decrease in power grid capacities does not balance the additional land use and resource consumption described or the higher emission levels that may result.

In addition to the economic and environmental criteria, aspects such as innovation capabilities and acceptance issues are also substantially important. Decentralized technologies and decentralized coordination concepts have indisputable advantages due to their proximity to many relevant actors. However, the question must be raised of whether and to what extent decentralized concepts for power generation and, where applicable, for flexibility options and small-scale control models are needed to a large extent with respect to participation and innovation. Other, selectively designed ways of improving participation and innovation could also be considered.

Lastly, the purely qualitative analysis carried out in the first step also raises the question of whether and when decentralized control models with wide scopes need to be harmonized with the existing regulatory framework for European energy markets.

In a second step, data analyses (with a high spatial resolution) were conducted on the limits of potentials for absolute solar and wind power generation and on the corresponding demand structures (in both cases on a district level). These analyses initially completely exclude the cost or availability issues of flexibility options and contain only quantity balances with a high spatial resolution. They show that, firstly, there is a substantial concentration of demand in the industrial regions in the west and south and in the metropolitan regions of Germany. Secondly, very profitable solar power generation can come about particularly in southern Germany and with the roof potentials in metropolitan regions. Thirdly, very profitable wind power generation is available in north and northeast Germany and offshore. Fourthly and finally, challenges concerning the public acceptance of onshore wind power plants will have a restrictive effect on actionable potentials, especially in regions that are densely populated and have a high electricity demand.

On the level of federal states (*Länder*) these restrictions decrease but remain clearly evident. Even at the next aggregation level – a total of six regional areas (zones) – the role of electricity imports and exports remains important even if criteria such as costs, land use, emissions, etc., are excluded from the analysis.

Consistently small-scale (“cellular”) concepts were analysed on a district level. These could only be implemented without substantially increasing use of grid infrastructure when flexibility options are applied very widely, which would entail the above-mentioned implications (costs, emissions, etc.). The quantitative analysis also shows that the portfolio effects become stronger, the larger the cells are defined, i.e. larger cells decrease the need for flexibility options and the associated negative effects. It follows that even with cellular ap-

proaches applied to larger areas it must be assumed that, regardless of the technological requirements and the costs involved, transregional electricity imports and exports would arise to a significant extent. In any case it should be noted that aside from optimization of self-consumption, no practicable proposals have been made yet for consistently implemented small-scale market concepts.

In a third step, a comparative analysis is conducted for a wide range of models of the German electricity system that have different designs and use very different methodologies. Scenarios that calculate a 20% to 50% lower need for grid expansion have the following characteristics:

- The scenarios assume or determine a strong expansion of onshore wind energy in the “South” zone. The scope of the additional grid expansion resulting for 2030 and 2035 is three to four times, and in extreme cases six times, higher than the values assumed in the network development plans.
- A disproportionate expansion of onshore wind energy in the “West” zone is predominantly assumed or calculated. The additional grid expansion amounts to a factor of 2 to 3, and in two extreme cases to a factor of 7, higher than that assumed in the network development plans.
- Largely, albeit not consistently, a very strong expansion of solar power generation is assumed in the “South” zone. The capacities of PV systems in the “South” zone exceed that of the network development plans for 2030 and 2035 by a factor of 2 to 3.
- For 2030 the relationships between the remaining coal-fired power plant capacities and the necessary grid expansion depend to a great extent on how (additional) renewable power generation is regionalized. For 2035 the amount of coal-fired power generation no longer shapes the dimensions of electricity grid expansion.

The different assumptions of the potentials in the relevant literature were compared, with the result that assumptions for the expansion of onshore wind power generation and partly also for PV power generation for 2030/2035 in the “South” and “West” the zones may bring into question the limits of the potentials or that the modelling is conducted using questionable assumptions for the expansion of renewable power generation, at least for the period under discussion.

A review of scenarios with more ambitious expansion paths for power generation based on renewable energies in Germany shows that the decreased need for grid expansion is temporary and that grid expansion would nevertheless be necessary in the long term.

With a view to the contributions that decentralized control models make to decreases in grid expansion needs, the model simulations show that regional distribution of renewable power generation remains paramount for the differences in grid expansion needs. Regionalization is clearly the most influential parameter, especially with a view to onshore wind power capacities.

With regard to the overall cost effects of different regionalization or control approaches, no reliable quantitative conclusions can be drawn from the available literature since the studies analyzed do not examine these aspects to the extent necessary and do not use comparable approaches. The same applies to environmental factors such as land use or the impact on CO<sub>2</sub> emissions.

Viewing the three steps of the analysis overall, a number of recommendations for action can be derived in addition to the above-mentioned conclusions. Firstly, a structured discourse is needed to clarify whether and in which model or at what times decentralized (“cellular”) control approaches – aside from optimization of self-consumption – could be implemented or considered as a variant for grid expansion planning. Secondly, the assumptions for expansion limits of renewable power generation need to be validated. This is the case for onshore and offshore wind power capacities as well as PV power generation in high spatial resolution, at least for the zones and particularly the “South” and “West” zones in Germany. The real land potentiality and acceptance should receive special attention. Thirdly, there is an urgent need to develop a uniform assessment criteria for calculating all the costs and land requirements (for electricity generation plants, flexibility options and infrastructures) in order to enable comparability in future analyses. Fourthly, to improve the comparability of future studies, it would be helpful to develop a pragmatic metric that can be used to compare the grid expansion needs and take into account the different modeling approaches.

The present metastudy is the first comprehensive attempt to analyze the complex fields of tension between decentralization and grid expansion, which have been shaped by different narratives and present many conceptual and data challenges. Further research needs to be conducted on these aspects.

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