Sustainability trade-offs in the spatial allocation of future onshore wind generation capacity – an empiric case study for Germany

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Abstract
The expansion of renewable energies is a key requirement to the global climate protection efforts. However, renewables themselves can be associated with negative local effects. A prominent example is the deployment of wind energy. Different sustainability criteria – e.g. the mitigation of adverse impacts on human health and ecosystems and the generation costs for renewable electricity from wind power, may call for different spatial allocations of wind turbines. As the optimal siting of wind turbines differs with regard to the individual sustainability criteria, this can imply trade-offs between the different sustainability criteria. Therefore we developed an approach to identify and quantify how significant these trade-offs potentially are and to what extent they depend on the spatial allocation of wind turbines as well as on the overall level of wind power deployment.

Based on a spatially explicit GIS modelling using high resolution wind speed, settlement and ecological data for Germany, we calculate the potential trade-offs. Using a set of more than 100,000 technically and legally potential sites for modern wind turbines across Germany in a greenfield approach, the numerical optimization of these data identifies on the one hand optimal sites for each sustainability criteria in an expansion scenario for 2030. These different optimal spatial allocations can then be compared against each other for a basic trade-off analysis. Additionally, the trade-off analysis can be elaborated by the calculation of pareto-frontiers as well as a Gini-like coefficient that quantifies the potential trade-off between sustainability criteria in a paired comparison of sustainability criteria.

The results show that trade-offs are inevitable giving the required and projected capacity expansion for onshore wind power. But the potential trade-offs among the different sustainability criteria differ significantly with Gini-like coefficients ranging from 0.13 up to 0.69 for depending on the selected criteria in a paired comparison. This underlines that the approach and the obtained results are highly relevant for the management of sustainability trade-offs in future.

In general, the developed approach covers multiple relevant criteria and provides a framework for the empirical analysis and assessment of trade-offs associated with any spatially relevant energy-
infrastructure and sustainability criteria. The approach can also be transferred to other application
where trade-offs between different sustainability criteria have to be investigated and managed.
And finally, as performed for the case study region of Germany, the obtained results can likewise
be reintroduced and visualized using GIS in order to verify and further assess the spatially explicit
results.

Index Terms: spatial planning, trade-offs, wind energy, GIS applications, integrated assessment,
allocation optimization