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Unravelling the opposing effects of network clustering on electricity system models with high shares of renewables

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Energy systems are typically modeled with a low spatial resolution that is based on administrative boundaries such as countries, which eases data collection and reduces computation times. However, a low spatial resolution can lead to sub-optimal investment decisions for renewable generation, transmission expansion or both. Ignoring power grid bottlenecks within regions tends to underestimate system costs, while combining locations with different renewable capacity factors tends to overestimate costs. We investigate these two competing effects in a capacity expansion model for Europe's future power system that reduces carbon emissions by 95% compared to 1990s levels, taking advantage of newly-available high-resolution data sets and computational advances. We vary the model resolution by changing the number of substations, interpolating between a 37-node model where every country and synchronous zone is modeled with one node respectively, and a 512-node model based on the location of electricity substations. If we focus on the effect of renewable resource resolution and ignore network restrictions, we find that a higher resolution allows the optimal solution to concentrate wind and solar capacity at sites with higher capacity factors and thus reduces system costs by up to 10.5% compared to a low resolution model. This results in a big swing from offshore to onshore wind investment. However, if we introduce grid bottlenecks by raising the network resolution, costs increase by up to 19% as generation has to be sourced more locally where demand is high, typically at sites with worse capacity factors. These effects are most pronounced in scenarios where transmission expansion is limited, for example, by low social acceptance.