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Inverting spatially low resolved electricity system modeling results: How feasible are they when disaggregated into high resolution?

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Electricity system optimisation models should have a high spatial resolution, because mixing locations with high renewable yield and locations with high electricity demand while ignoring power lines underestimates transmission constraints that can cause congestion. This can result in an infeasible model and is particularly true for configurations with high renewable penetration because the infrastructure of today's transmission grid is not designed for an uncertain and geographically scattered generation. But spatially high resolved models are computationally intractable, therefore researchers have developed methods to simplify their models on a spatial scale. Common approaches include modeling every country by a single node, or clustering spatially high resolved models using selected clustering methods. Nevertheless, it was not investigated if results obtained from such low resolution or clustered models are feasible when dis-aggregating the results back into a higher resolution. Moreover, no evaluated dis-aggregation method exists to the author's knowledge. This is a challenging task as the clustering process typically is not bijective and finding a suitable inverse is not intuitive.

Here, we propose a first method to dis-aggregate spatially low resolution model results into higher resolution. The proposed dis-aggregation is a local optimisation problem that minimises the excess of renewable energy for every node within the cluster while respecting land-use restrictions. We define excess as the available renewable energy per node minus local electricity demand minus all transmission capacity that is connected to the node. Electricity storage is distributed proportional to the resulting renewable capacity. Then, the spatially high resolved model is solved as an operational problem where no further capacity expansion is allowed. We investigate if the cost-optimal low resolution investment results of a fully renewable system that consists of wind and solar energy and storage (hydrogen and battery) is feasible when dis-aggregated into a spatially high resolved model of 1250 nodes. Results of our novel approach are benchmarked against the intuitive Ansatz to uniformly dis-aggregate the low resolution modeling results, i.e. distributing the capacity of a clustered node evenly among the nodes in the high-resolution model.

Our results for dis-aggregating a low resolution model of Europe where every country is modeled as a single node are that 12.8% of total demand can not be met with renewable energy

(benchmark: 15.3%). If this gap is compensated with gas, carbon emissions would rise by 5% of 1990 emissions (benchmark: 6%) and total annual system costs would increase by 24 billion euros (benchmark: 29 billion). When modelling Europe with 100 nodes, our dis-aggregtion method yields 5.6% of unmet demand (benchmark: 7.3%). This means that carbon emissions would rise by 2.2% (benchmark: 2.7%) compared to 1990s level in case the unmet demand is satisfied with gas and would increase the total system costs by additional 10.6 billion euros (benchmark: 13.2 billion). This result supports other research which shows the importance of modelling at higher resolution than country boundaries in order to avoid unwanted infeasibilities. Approximately one half of unmet demand can be avoided by raising the model resolution in Europe to 100 nodes.