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Impact of flexibility costs on electricity systems depending on regional wind and PV capacities with an application to France.

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The adequacy of electricity systems is strongly linked to the level of Variable Renewable Energies (VREs) penetration. To ensure supply-demand balance and in the absence of other sources of flexibility, Dispatchable Units (DUs) must be operated in a more flexible manner due to the variability of REs. We expect the DUs schedule to be strongly affected by the flexibility needed from base DUs in response to increasing VREs and taking flexibility into account may lead to using some peak DUs that would be unused in a standard merit order dispatch.

We develop and apply to France a methodology to assess the system cost response to the flexibility costs change due to VREs integration at the regional scale and the impact of the latter on DUs depending on their merit order position.

Changes in the system cost due to flexibility are diagnosed from a residual demand for regional VRE mixes at different penetration levels optimized by the e4clim model. e4clim is a minimal optimal VRE investment model based on the minimization of a system cost assuming that dispatchable costs are a function of the aggregated dispatchable production only. Considering that the standard merit order holds and for prescribed marginal costs of production, the DUs are ranked by loadpoint and defined by their marginal and rental costs. Moreover, at time scales greater than 1 hour, there are few hard flexibility constraints. It is therefore assumed that flexibility can be modeled as costs, for instance because of the extra fatigue and human resources induced by more flexible operation of DUs. Among the different forms of flexibility, we focus on ramps and start-ups. Each producer is assigned a marginal ramp (resp.~ start-up) cost proportional to its fixed cost by a coefficient K_R (resp.~K_{SU}) determined using real data.

The variable costs of flexibility are obtained by multiplying these marginal costs by the ramps and start-ups diagnosed from e4clim.

For the reference value of K_{SU} and 50% penetration of VREs, we find that the variable cost of start-ups contributes to 7% of the system cost and that is 3.6 times larger than the ramps contribution. Secondly, the base DUs have flexibility costs higher than the maximum flexibility cost without VRE. The middle producers see theirs decrease and they completely cancel out for the last producers since they are no longer used. Finally, for large VRE penetration (≥20%), we find that PV induces twice the flexibility need induced by wind and mostly affects base DUs while wind impacts all DUs

more homogeneously.

Although flexibility costs are lower than production costs, considering them in the optimization of DUs could reduce the system cost and result in a dispatch different from the standard merit order. Furthermore, flexibility costs could be significantly reduced by considering them in the optimization of the technological and geographical distribution of VREs. Finally, the sensitivity of our results to the estimates of the coefficients K_{SU} and K_R calls for more empirical studies of the marginal costs of flexibility.