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Research Brief

Long-term Equilibrium in Electricity Markets with Renewables and Energy Storage Only

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Spot power markets for electricity have supported the development and operation of electricity generation systems for years in many regions of the world. There are, however, several well-known challenges regarding spot markets, and these challenges are likely to exacerbate as wind and solar generation continues to expand. One of the main challenges is that wind and solar generators have low or zero variable costs, and these in turn contribute to determine prices in the spot market. In this paper, we analyze a simplified 100% renewable system, with therefore zero variable costs, and evaluate analytically how the concept of market prices still exists.

In many regions of the world, the economic dispatch of electricity, and the corresponding financial arrangements, are organized using spot markets. This is for example the case in most European countries and in North America. In the simplest form of those markets, the wholesale price of electricity is determined at each time step, typically one hour, with the price equal to the variable cost of the marginal generation unit. The use of spot markets is often combined with other mechanisms to ensure revenue sufficiency for each generator. Existing or new power purchase agreements (PPAs), capacity and balancing remuneration mechanisms, and various environmental support mechanisms (such as zero emission credits) are other sources of revenue. It remains true, however, that one cornerstone of price formation in modern electricity markets is a variable cost or, to make it simple as in the traditional case, the product of the heat rate of generation technologies by their fuel costs, such as natural gas, coal, fuel-oil, uranium etc. Overall, spot markets have shown a high degree of efficiency in delivering large amounts of electricity, even though they exhibit limitations, such as the difficulty to adequately support peak generators and concerns regarding the market power of large generation owners. On top of that, their ability to function adequately in the presence of renewable energy sources (VRE) that have zero variable costs (e.g. wind, solar PV) is still a question of debate. To summarize this issue, VRE may reduce Spot prices through the merit order effect, which in turn impacts other generators by increasing the "missing money problem".

VRE are undoubtedly a key element of future power systems: this is because they are deemed to answer three major concerns. Firstly, they support an economical generation system (since their per MWh generation costs have decreased rapidly in the past decades). Secondly, they provide security of supply for many countries by reducing the reliance of power systems on imports of primary energy, typically in the form of fossil fuels. And, finally, they contribute to meet climate targets since their greenhouse gas emissions are low, both in absolute and in life-cycle analysis terms. This overall attractivity explains why many regions of the world now plan for a very large increase of VRE capacities. The fact that VRE will operate within spot markets, where prices traditionally were based on the variable costs of generators, is a sort of paradox that is the motivation for our research. More precisely, we address the question of price formation in power markets in which only VRE and electricity storage are present, that is in the absence of any variable

costs except for load shedding represented using value-of-lost-load (in $/MWh). We use an analytical formulation developed in our previous work [Korpås, M., & Botterud, A. (2020)], i.e. we solve a simple optimization problem in which optimal capacities of wind and storage technologies lead to the least cost of generation. We show that, under certain conditions, a price structure that is based, in part, on the fixed capital costs of generation sources (VRE and storage) is compatible with cost recovery for market players and overall cost minimization. This result is in contrast to earlier work with thermal generators as part of the resource mix, where prices in equilibrium depend on variable costs only.

Our results can be interpreted in various ways, keeping in mind that they are based on a simplified model. On the one hand, one could see the results as proof that spot markets cannot work with VRE only, since market operators could not possibly ensure that all generators and storage operators are bidding their right price. However, on the other hand one can argue that the supervision and mitigation of market power in electricity markets already exists. For example, "economic withholding" is defined in NYISO tariffs as "submitting Bids for an Electric Facility that are unjustifiably high" [NYISO]. In a case of economic withholding, NYISO "imposes a default bid on the Market Party" [NYISO]. One could therefore see our result as a change to existing spot markets, in which additional supervision rules need to be created that allows market participants to reflect capital costs in their offers. Our result is therefore an additional element indicating that future VRE-based spot markets will likely be more complex to monitor and to operate. Overall, we do not claim to propose an actual market design based on our simplified model and case study. However, our results illustrates that more research is needed to better understand price formation in future low-carbon electricity markets, including studying the impact of having more markets participants, demand side management, capacity constraints, uncertainty, and more.

References

Korpås, M., & Botterud, A. (2020). "Optimality Conditions and Cost Recovery in Electricity Markets with Variable Renewable Energy and Energy Storage," MIT CEEPR Working Paper 2020-005, March 2020.

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