Environmental Impact of Load Shifting Agent

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Overview

Decarbonizing the electricity sector leads to a substantial increase in the share of variable energy sources (VRES) such as solar and wind power in the energy mix. To reach net zero by 2050, VRES should supply 70% of the electricity generation [1]. Replacing conventional reliable fossil-based generators with uncertain and variable renewables can disrupt supply and demand matching. Thus, as the share of renewable increases, demand shortages and supply surpluses become more frequent and more extreme. Such cases lead to more frequent extreme electricity prices. Also, an increasing share of VRES might lead to a reduction of baseload generation (generally low CO2 emitting), and an increase of peak load generation (generally high CO2 emitting). The remedy to integrate a large share of uncertain supply (here, VRES) is similar to any other commodity: to introduce flexibility to the market. This is to add storage or any type of buffer that can shift supply and demand in time and absorb short-term mispredictions. This historical reason suggests that flexibility is primarily added to the market to facilitate green energy (VRES) integration into the market by absorbing the variability and uncertainty of VRES. Yet, this is important to ensure that the introduction of this flexibility does not by itself increase the emission as otherwise, it is detrimental and contradictory with the concept of VRES integration in the first place. In this work, we generalize the concept of flexibility by defining the notion of load-shifting agents (LSA), which can buy (sell) energy at a certain point and sell (buy) the same amount back at another time. Obviously, an LSA includes storage operators as a special case. However, it is broader than storage and can also include the concept of demand response. Together, storage and large-scale demand response are considered the major and promising sources of flexibility for future electricity markets. As such, the capacity of LSAs in electricity markets is expected to grow exponentially fast in the next years to come. We, therefore, raise the question that whether their large-scale presence in the market while helping the integration of VRES, is indeed harmless to the emission, and if not what are the conditions to ensure and the solutions to make it harmless to CO2 emissions? We focus on the day-ahead market; as this is the main trading stage and the largest among all stages and hence, has the largest influence on the overall emission of the electricity sector.

Previous studies have shown that in some cases, the integration of large-scale LSA increases the amount of CO2 emission of the electricity procurement while in others it reduces it [2-4]. Therefore it is primordial to understand the relation between the market characteristics and the LSA characteristics that lead to one result or another. This is our first contribution: formulating and analyzing the impact of the LSA on the CO2 emission of the day ahead markets by constructing and analyzing a stylized model. By understanding this relation, we are therefore able to make a second contribution which is different policy recommendations to avoid and/or control the amount of CO2 emission from an LSA. Finally, our last key contribution is to use real-world data and optimize the behavior of an LSA to evaluate the CO2 impact of different LSA in various practical market scenarios.

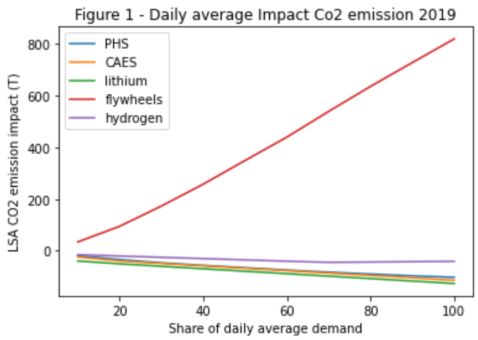
Method

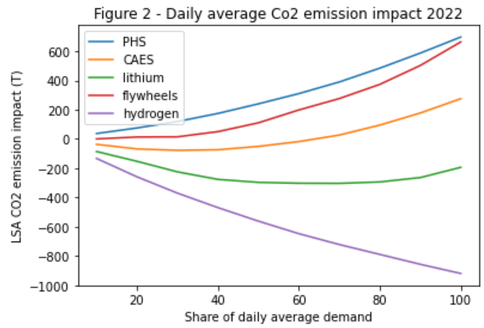
First, we build a stylized model to analyze analytically the LSA environmental impact on a day-ahead market. We assume an electricity market with an inelastic demand, exogenous renewable energy sources, conventional fossil-based energy resources with linear cost and CO2 emissions function. Then, we optimize the behavior of both a strategic and a non-strategic LSA and characterize the equilibrium at optimality. By doing so, we can derive the condition of a market in which the LSA does not pollute and we can make some policy recommendations to avoid LSA pollution. In the second part, we use data from the Dutch day-ahead market from 2019 and 2022 and we formulate an ex-post cost minimization dispatch, subject to serving the inelastic demand. We cast this problem as a Mixed Integer Linear Programming (MILP). The objective function is either to minimize the total cost of energy procurement (non-strategic) or to maximize the profit of the LSA (strategic) on a daily horizon. In addition to our stylized model, more constraints are applied to this optimization including non-convex constraints for fossil fuel generators and self-discharge parameters for LSAs. Then, we can evaluate what will be the impact of the introduction of different LSA in the dutch day-ahead market depending on the market conditions. We also propose an evaluation of the solutions described in our analytical model.

Results

Analytically, we decompose a full arbitrage period in a special set of two-period transactions. Thus, we find that, for ensuring that an LSA does not pollute for any of these two-period transactions, it is sufficient to have a market in which conventional generators are ordered by marginal emission coefficient in the merit order curve and that the LSA does not clear a quantity for which the difference between the marginal emission of the two clearing generators (buy and sell period) is not high enough to compensate the inefficiency of the LSA.
Knowing this, we propose three solutions to avoid any pollution from an LSA which are, by order of efficiency, a CO2 tax, a transaction tax, and a capacity cap.

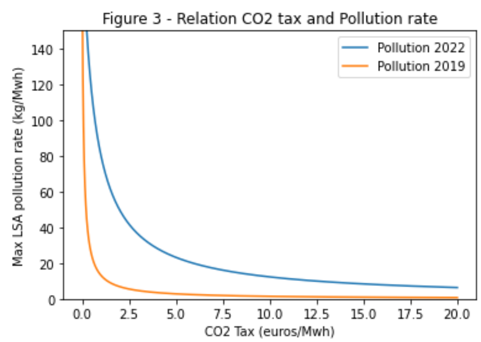
Numerically on a 30 days sample, we find the impact for different LSA depending on their capacity. This is represented by figures 1 and 2.





Additionally, we find that a strategic LSA versus a non-strategic one does more arbitrage and thus increases the Co2 emission in 2022 while in 2019 it reduces the CO2 impact of flywheels.

We apply our solutions for limiting LSA pollution in the dutch day ahead market in 2019 and 2022 and we find that with the real ETS price, the theoretical maximum pollution rate for an LSA would have been, for every Mwh sold back to the market, 155.6 kg/Mwh in 2019 and 186.3 kg/Mwh in 2022. Otherwise, we find that a cap between 0 and 1GWh should have been implemented depending on the efficiency and the day. Finally, for the transaction tax, we find that the maximum tax that should be applied to ensure any LSA to not pollute would have been 393 euros/Mwh in 2019 and 289 euros/Mwh in 2022. For all these solutions, there is an arbitrage between the maximum pollution rate and the policy implemented. Figure 3 shows this arbitrage for the CO2 tax.



Conclusion

This study shows the potential environmental impact of an LSA depending on its own characteristics and the day-ahead market characteristics. This understanding is essential if large scale storage and demand response capabilities are introduced into the day-ahead markets. Moreover, this study makes policy recommendations to introduce safely LSA in a day-ahead market.

References

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