

FROM DUCK TO TURTLE: 2040's SYNCHRONIZED DEMAND RESPONSE RESHAPES DISTRIBUTION GRID LOAD

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Extended Abstract

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Abstract Summary

The decarbonization of the energy sector and the increasing adoption of household energy technologies, such as electric vehicles, heat pumps, photovoltaics, and battery storage, are transforming electricity demand and enabling demand-side flexibility. Dynamic pricing schemes are widely promoted to incentivize such flexibility, yet their implications for local distribution grids remain insufficiently understood, particularly under large-scale adoption. Additionally, most studies assume exogenous electricity prices, ignoring feedback effects whereby aggregate demand responses may distort price signals.

This paper develops a household-level optimization framework to analyze how dynamic pricing interacts with demand-side flexibility and distribution grid load. Using Luxembourg as a case study, we simulate 166 households under 2040 entso-e's TYNDP scenarios, distinguishing between flexible and non-flexible households. We compare a baseline with given prices to an alternative setting with endogenous pricing, in which prices adjust to aggregate demand.

Our results indicate that under exogenous prices, increasing flexibility leads to strong synchronization effects, as households shift consumption toward low-price periods. This transforms the conventional “duck curve” into a “turtle curve” with pronounced midday peaks and induces substantial transformer congestion. When prices are allowed to adjust to aggregate demand, these synchronization effects are expected to be attenuated, as higher demand in low-price periods feeds back into prices and weakens incentives for simultaneous load shifting. As a result, load profiles are expected to become smoother and grid stress may be reduced.

Overall, the findings suggest that demand-side flexibility may shift in time rather than reduce grid stress under fixed price signals. Endogenous pricing is expected to act as a coordination mechanism that can partially mitigate these effects, although additional

measures, such as grid tariffs or curtailment, may still be required under high flexibility penetration.

Presenting Author Biography

Zihan Yang is a PhD researcher at the Interdisciplinary Centre for Security, Reliability and Trust – SnT, University of Luxembourg. She received her master's degree in economics from Bonn University. Her research focuses on the intersection of energy and behavioral economics and applied microeconometrics.