

Regulatory approaches to the challenges posed by the energy and digital transitions: global lessons from 20 leading electricity distribution system operators (DSOs)

Michael G. Pollitt, Daniel Duma, Andrei Covatariu, Paul Nillesen

Electricity distribution system operators (DSOs) are at the centre of the energy and digital transitions. As the segment of the power system where most new technologies connect, from rooftop solar panels to electric vehicle (EV) chargers, heat pumps and data centres, DSOs are being asked to do more, faster and at greater scale than ever before. Meeting these demands requires them to shift from network managers to active system operators, managing complex and variable power flows while keeping costs under control.

This paper focuses on four specific challenges, referred to as the "4Cs", that are currently placing strain on distribution networks. The first is the growth in distributed energy resources (C1), especially rooftop photovoltaic (PV) solar, which can cause reverse power flows and congestion. The second is the electrification of transport (C2), as rising numbers of electric vehicles create concentrated and potentially simultaneous peaks in demand. The third is the electrification of heating and cooling (C3) through heat pumps, which increase winter peak demand. The fourth is the rapid growth of data centres (C4), which create localised grid stress, connection backlogs and significant planning uncertainty. The first three are products of the energy transition; the fourth is driven by the digital transition and stands apart due to its scale, pace and specific technical requirements.

To study how DSOs and their regulators are responding to these pressures, the paper selects 20 DSOs from Europe, North America and Asia-Pacific that are among the most exposed to the 4Cs. The selection draws on country-level rankings for each challenge: decentralised solar capacity per capita for C1, the share of electric vehicles in the passenger car fleet for C2, heat pumps per thousand households for C3, and data centre electricity consumption as a share of total consumption for C4. The paper then examines official DSO annual reports to assess whether the 4Cs are acknowledged as sources of strain, and regulator reports to identify new policy instruments and regulatory reforms being introduced in response.

Distributed solar generation emerges as the most widely recognised source of stress, acknowledged by DSOs across all regions examined. Data centres are already highly disruptive

but concentrated in a small number of systems, most notably in Ireland, the Netherlands and Virginia in the United States. Heat pump electrification is recognised as a medium-term challenge in cold-climate countries, while EVs, despite high penetration in leading markets, are notably not yet reported as a major source of immediate operational strain, even in countries like Norway with the highest share of EVs in the world.

Across the 20 regulators examined, a convergence in regulatory direction is visible. Regulators are moving away from a "reinforcement-first" model toward active system management. Seven broad types of regulatory response are identified: redesigning network tariffs to be more time- and capacity-based so as to reduce peak demand; reforming connection regimes to offer faster, conditional or shared access; developing flexibility markets in which DSOs procure services such as demand response and battery storage as alternatives to grid expansion; introducing direct operational controls that allow curtailment or load management; strengthening planning transparency and stakeholder engagement; overhauling regulatory incentives to remove the bias toward capital expenditure; and mandatory governance arrangements such as the separation of system operation from network management.

The paper interprets these developments through the concept of the "learning regulator", one whose approach is dynamic, adaptive and responsive. Regulatory frameworks are being updated in light of new information about technology uptake and DSO behaviour. Regulators are designing frameworks that can be revised by design, for example through more frequent network planning updates or trial-based approaches to flexible connections. And many are seeking a middle ground between rigid rules and discretion for network companies, combining incentives, market mechanisms and operational tools to fit national context.

The findings suggest that flexibility, buying time and making the most of existing assets through markets, tariff design and connection reforms, is emerging as an essential complement to physical grid investment. For regulators in jurisdictions not yet facing acute pressures from the 4Cs, the experience of more exposed systems offers practical lessons on what reforms are effective and in what sequence they tend to emerge. The emergence of the active DSO, this paper concludes, is inseparable from the development of a learning regulator.

Contact	m.pollitt@jbs.cam.ac.uk
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