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Published Version

Torriti, J. ORCID: https://orcid.org/0000-0003-0569-039X (2026) Demand turn-up in electricity markets: economic lessons from non-energy sectors. Energy Research & Social Science, 135. 104664. ISSN 2214-6326 doi: 10.1016/j.erss.2026.104664 Available at https://centaur.reading.ac.uk/129052/

To link to this article DOI: http://dx.doi.org/10.1016/j.erss.2026.104664

Publisher: Elsevier

Energy Research & Social Science 135 (2026) 104664

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Perspective

Demand turn-up in electricity markets: Economic lessons from non-energy sectors

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ABSTRACT

Electricity markets with growing shares of variable renewable energy face an increasingly acute challenge in balancing supply and demand. While demand-side flexibility has traditionally been framed in terms of demand reduction or shifting away from peak periods, these approaches need to be revisited to address periods of surplus renewable generation. This perspective paper conceptualises demand turn-up (i.e. mechanisms designed to raise electricity demand at specific moments or locations) as an economically grounded form of flexibility. It situates demand turn-up within the broader economics literature on flexibility, adjustment costs, and uncertainty, showing that flexibility has historically been treated as a supply-side attribute, with demand assumed to respond passively to prices. It then draws on evidence from other sectors, including capital-intensive manufacturing, waste and recycling markets, and shipping, where suppliers pay consumers to absorb surplus output. These cases share common structural features: inflexible supply, high shutdown or disposal costs relative to marginal operating costs, limited storage, and strong network effects. The paper argues that demand turn-up can be framed as a form of recurring economic response to surplus under structural rigidity. Applying this logic to electricity systems with high variable renewable electricity penetration, the paper suggests that explicitly incorporating demand turn-up into market design can improve the marginal utilisation of renewable assets.

1. Introduction: why demand turn-up?

Electricity markets with growing shares of variable renewable energy (VRE) face an increasingly complex balancing challenge. As wind and solar output is characterised by volatility and weather dependence, maintaining real time balance increasingly depends on the flexibility of electricity demand [1]. Traditionally, discussions around demand-side flexibility have focused on demand reduction or demand shifting away from peak periods, typically towards broadly defined off-peak times [2]. The future electricity system will require not only the ability to shift demand away from periods of scarcity, but also mechanisms that can encourage electricity consumption when generation is abundant and marginal system costs are low.

Within-day balancing requirements are already substantial and are expected to grow further. Current estimates by the UK Government suggest that the system requires around 38 TWh of within-day flexibility annually, rising to approximately 50–60 TWh by 2030 [3]. In 2024/25, wind curtailment volumes increased to 13% of hypothetical wind outturn, i.e. wind outturn if no curtailment had taken place [4]. Addressing these imbalances solely through supply-side measures, such as curtailment or storage, risks becoming increasingly inefficient and costly.

Demand turn-up (DTU), which denotes mechanisms designed to raise electricity demand at specific moments or locations, addresses this emerging need by treating demand as an active margin of system adjustment under surplus conditions. DTU is a specific form of demand-side flexibility in which consumers are incentivised or paid to increase electricity consumption during periods of surplus generation. Rather than reallocating existing demand, DTU focuses on activating additional or discretionary load when electricity is system-abundant, either at a national or local network level.

The economic rationale for DTU is compelling in systems with high VRE penetration. Marginal curtailment of additional renewable capacity often far exceeds average curtailment, meaning small increases in surplus absorption can substantially improve utilisation [5]. DTU raises the capacity factor and revenue of existing VRE assets, reducing the effective marginal system cost of integrating additional renewable generation and supporting cost-effective decarbonisation.

DTU can be implemented via two mechanisms that are distinct but closely connected. First, demand shifting involves reallocating the timing of electricity use without necessarily increasing total consumption. Examples include encouraging electric vehicle charging, water heating, or industrial processes to operate during periods of high renewable output. Second, demand creation refers to genuinely additional electricity consumption induced by financial or price signals. For households, this might involve increased heating [6], electric vehicle charging [7], or appliance use during periods of very low prices. For industrial and commercial users, demand creation can take the form of

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https://doi.org/10.1016/j.erss.2026.104664
Received 7 January 2026; Received in revised form 4 March 2026; Accepted 16 March 2026

temporarily expanding electricity-intensive activity when surplus generation is available (e.g. operating electric boilers or chillers in excess of baseline needs to pre-heat or pre-cool buildings) [8]. In these cases, DTU deliberately increases electricity use during surplus periods, reducing curtailment and improving system-wide efficiency when the marginal cost of supply is very low.

Despite its growing practical relevance, DTU needs to be articulated in the economics literature under surplus conditions. Situating DTU within the broader economics literature on flexibility, adjustment costs, and uncertainty is necessary for two reasons. First, the conditions under which DTU becomes economically rational need to be examined if electricity demand is to support real-time system balance under such conditions. Second, without an explicit conceptual grounding, DTU risks being treated as an ad hoc policy instrument rather than as a systematic response to structural rigidity. A complementary motivation for this paper is the lack of cross-sectoral perspective in discussions of demand-side flexibility in electricity markets [9].

This paper situates DTU in electricity within a broader cross-sectoral economic context and addresses the following two research questions: (i) under what structural conditions, as identified through the broader economics literature on flexibility, does demand turn-up emerge as an economic mechanism for balancing demand and supply; and (ii) what concepts and sectoral examples illustrate the conditions under which active incentivisation of additional consumption emerges? The paper reviews how flexibility has been conceptualised in economic theory (Section 2) and then draws parallels with industrial production, waste management, and transport markets (Section 3). The conclusions synthesise the theoretical and cross-sectoral arguments to show that recognising DTU as margin of adjustment is essential for electricity systems with high shares of VRE (Section 4).

2. Conceptualising flexibility in the economics literature

In the economics literature, flexibility appears as a diffuse and evolving concept, deployed across multiple subfields with varying meanings and analytical roles. This discussion concerns the economics literature in general, not only work related to energy systems. While flexibility is frequently invoked in applied economic models, it is rarely conceptualised in its own right. Definitions are often inconsistent across contexts, and empirical measures of flexibility tend to be ad hoc, reflecting modelling convenience rather than conceptual uniformity. A feature of the literature is that flexibility is typically examined in conjunction with more firmly established economic constructs—such as uncertainty, prices, and equilibrium—rather than as an independent object of analysis.

2.1. The evolution of flexibility in economics

The meaning of flexibility in economics has shifted significantly over time. Early economic discussions of flexibility emerged from concerns about industries where shutting down or reactivating production entails significant costs. Within the theory of the firm, Stigler [10] characterised a flexible investment as one associated with a relatively flat average cost curve, an idea later refined by Marschak and Nelson [11], who argued that flexibility varies inversely with the slope of the marginal cost curve. This formulation makes explicit the trade-off between flexibility and cost: production technologies that allow output to adjust easily tend to have higher minimum average costs, implying that flexibility is valuable precisely because inflexibility makes adjustment expensive. As Stigler observed, “flexibility will not be a free good.”

Carlsson [12] later described this dimension as “tactical flexibility,” referring to a firm's ability to adjust output in response to exogenous shocks at relatively low cost. Implicit in this notion is the idea that when such adjustment is difficult or costly -because of technological constraints and fixed inputs- firms may seek alternative mechanisms to maintain efficient operation, including influencing demand rather than adjusting supply.

Subsequent contributions broadened the concept further. Mills [13] demonstrated how flexibility could be endogenously determined in competitive markets facing demand fluctuations, while Marschak and Nelson [11] argued that flexibility derives its value from uncertainty and the preservation of future options. Flexibility emerges as the number of feasible alternatives remaining after an initial decision. In this perspective, flexibility functions as a buffer against both internal disturbances (e.g. equipment failures or process delays) and external shocks, including demand volatility and price fluctuations. These disturbances are particularly costly in systems with limited storage or where output must be continuously absorbed, conditions under which demand-side adjustment becomes especially valuable.

Across these contributions, flexibility is overwhelmingly framed as a supply-side attribute, associated with firms, production technologies, or organisational structures. This orientation carries through into energy economics and other applied fields, where flexibility is typically analysed as the ability of producers or system operators to adapt supply to demand conditions, rather than the ability of demand to adapt to -or actively support- the system.

2.2. Demand flexibility in economic theory

The treatment of demand flexibility in economics has followed a markedly different trajectory. In early static models, such as partial equilibrium frameworks, consumers are assumed to adjust instantaneously and fully to changes in prices and income. The Almost Ideal Demand System [14], formalised consumer responsiveness within a rigorous theoretical structure. In these models, demand adjustments arise through income and substitution effects following price changes, implicitly assuming that consumers can absorb changes in supply without frictions or adjustment costs. Even within this tradition, authors acknowledged the limitations of static representations. Subsequent work introduced dynamic demand models to account for empirically observed delays and frictions in adjustment. Habit persistence, adjustment costs, imperfect expectations, and misinterpretation of price signals are sources of divergence between price changes and demand responses [15]. These frictions imply that demand is not infinitely flexible and cannot always respond instantaneously to price signals. Where supply is rigid, reliance on passive price-induced demand adjustment may be insufficient to maintain equilibrium. In such settings, the economic problem shifts from how demand responds to prices to how demand can be actively shaped to accommodate inflexible supply.

Stiglitz [16] provides an important insight into how market structure and supply rigidity can fundamentally alter the relationship between prices and demand responsiveness. In standard competitive models, falling prices are typically assumed to elicit proportionate increases in demand, reflecting a stable elasticity. Stiglitz shows that when supply is rigid and market participation is constrained, effective demand elasticity can itself become endogenous and decline, weakening the price–quantity adjustment mechanism. In an economy dominated by generators who set marginal revenue equal to marginal cost, prices are determined as a markup over marginal cost that depends on the elasticity of demand. As long as demand elasticity remains unchanged, reductions in marginal cost translate into proportional reductions in prices, leaving the markup intact. The elasticity of demand need not be invariant to market conditions, particularly when supply cannot adjust flexibly. To illustrate this point, Stiglitz considers a competitive market with rigid supply, characterised by a fixed number of firms distributed around a circle. When demand is sufficiently strong, equilibrium prices are influenced by both the intensive margin—the responsiveness of existing customers to price changes—and the extensive margin—the expansion of market coverage as lower prices attract new consumers or transactions. Under these conditions, a price reduction increases total demand through both channels, resulting in relatively elastic demand. If demand falls sufficiently, however, the equilibrium may shift to one in which some segments of the market are no longer served at all. Once these extensive margins are exhausted, further price reductions cannot attract new customers or expand coverage. Demand adjustments then occur solely along the intensive margin, which is typically less responsive. As a result, the effective elasticity of demand falls, even as prices decline. This mechanism implies that in markets with rigid supply, falling prices do not necessarily restore balance through increased demand. Instead, demand elasticity itself may contract as participation shrinks, allowing equilibrium prices to remain a higher markup over marginal cost than would otherwise be expected. Price flexibility alone is therefore insufficient to ensure efficient adjustment when supply cannot contract or expand easily. The relevance of this insight extends beyond the specific spatial competition model analysed by Stiglitz. In any system characterised by inflexible supply, limited entry or exit, and constrained participation—such as electricity markets dominated by capital-intensive generators—price reductions during surplus conditions may fail to elicit sufficient increases in demand. When the extensive margin is inactive, lowering prices further yields diminishing demand responses, and surplus persists despite falling prices. Under such conditions, mechanisms that actively stimulate demand, rather than relying solely on price adjustments, may be required to restore equilibrium.

2.3. *Flexibility, prices, and macroeconomic rigidity*

The debate over flexibility is central to Keynesian and post-Keynesian macroeconomics. Keynes' critique of wage flexibility challenged the notion that price adjustments alone could ensure market clearing, warning that excessive nominal flexibility could destabilise prices and undermine economic coordination ([17]). Subsequent Keynesian interpretations emphasised that output fluctuations arise from changes in nominal aggregate demand, with real effects driven by rigid prices [18]. Later contributions softened this position, stating that rejecting instantaneous price clearing does not imply the absence of flexibility in a broader sense, leaving room for adaptive responses within imperfect markets [19]. These debates highlight that when prices cannot fully adjust to clear markets, alternative adjustment mechanisms become necessary. In systems characterised by strong interdependencies and network effects, such mechanisms may include non-price interventions or incentives aimed at stabilising demand rather than forcing supply adjustments.

In energy markets, nominal wholesale prices vary significantly over time, reflecting changing supply conditions, yet end-users have historically faced smoothed or averaged prices. This insulation limits consumers' exposure to real-time system conditions and constrains their ability to respond through standard price signals alone. Whether real-time pricing is welfare-improving depends critically on assumptions about demand flexibility and on the costs imposed by supply inflexibility, including the costs of curtailment or shutdown.

2.4. *Flexibility in applied economics*

Applied economics research has largely reinforced the supply-centric view of flexibility. In supply chain management, flexibility -often equated with agility- is treated as a firm's ability to align production with uncertain demand or to respond to disruptions. Operations management literature similarly conceptualises flexibility as a reactive capability, enabling adaptive responses to environmental variability [20]. These models implicitly assume that maintaining throughput and avoiding costly interruptions is central to system performance, particularly where storage is limited.

In finance, flexibility appears as financial flexibility: a firm's capacity to respond optimally to unexpected changes in cash flows or investment opportunities [21]. Health economics provides another example, where models of medicine and vaccine supply chains prioritise flexible supply responses to crises, typically treating demand as exogenous and passive [22]. Here, too, the emphasis reflects the high costs of supply disruption and the difficulty of storing or rapidly reallocating capacity.

A partial exception arises in agricultural economics, where the separability of household and firm decisions complicates the treatment of flexibility [23]. Contractual arrangements, such as sharecropping, have been analysed as mechanisms for sharing risks arising from environmental uncertainty. Braverman and Stiglitz [24] conceptualise flexibility as the ability to renegotiate contracts in response to changes in production conditions, with costs and risks shared between parties. This approach recognises that when production cannot be easily adjusted, reallocating risk and incentives across agents may be more efficient than relying on price adjustments alone.

2.5. *Who pays for flexibility?*

Across much of the economics literature, flexibility is implicitly assumed to be supplied by firms and paid for by consumers, either directly or through higher prices. Labour economics exemplifies this pattern: employers demand flexibility, while workers bear the costs through variable hours, insecure contracts, or performance-based pay [25]. Flexibility is thus treated as a productive attribute, priced into contractual arrangements to offset adjustment costs and preserve system functionality.

Examples where demand is paid for flexibility are comparatively rare. Where they exist, as in certain agricultural contracts, flexibility is embedded in shared-cost or risk-sharing arrangements rather than explicit payments to stimulate consumption changes [24]. The relative absence of such mechanisms in mainstream economic theory helps explain why demand turn-up remains conceptually underdeveloped, despite its presence in practice in sectors characterised by inflexible supply, high shutdown costs, limited storage, and strong network effects. There is, however, empirical evidence of demand turn-up in sectors beyond electricity, as discussed in Section 3.

Table 1 summarises how flexibility is conceptualised across major strands of the economics literature, highlighting the dominant supply-side framing and the corresponding locus of adjustment.

3. Demand turn-up in non-energy sectors

While DTU has received limited explicit attention in the economics literature, a common structural logic appears across multiple sectors: supply is highly inflexible, marginal operating costs are lower than shutdown or disposal costs, storage options are limited, and network or system-level effects amplify the value of maintaining throughput. Under such conditions, suppliers may rationally pay consumers to absorb output, either directly or indirectly.

3.1. *Industrial overcapacity of steel, cement, and chemicals*

Industries characterised by capital-intensive production technologies—such as steel, cement, and bulk chemicals—provide some of the clearest examples of DTU. These sectors exhibit extreme supply inflexibility, with high costs associated with shutting down and restarting production [26]. Blast furnaces, cement kilns, and chemical crackers often incur substantial fixed costs, long restart times, and equipment degradation when idled [27].

As a result, marginal operating costs frequently fall below shutdown costs, particularly during periods of weak demand. In such circumstances, firms may prefer to continue production even at prices below average cost, or even below marginal revenue, rather than incur the irreversible or quasi-irreversible costs of stopping production. Empirical studies of the steel and cement industries document sustained periods of output persistence despite low or negative profitability, driven by these technological rigidities [28].

To sustain throughput, firms have employed a range of DTU mechanisms, including price rebates, extended payment terms, bundled services, or side payments unrelated to the core product. These practices

Table 1
Conceptualisations of flexibility in the economics literature.

Strand of economics literature	How flexibility is framed	Core assumptions/ mechanisms	Locus of adjustment
Early theory of the firm [10]	Flexibility as a supply-side attribute embodied in production technologies	Adjustment costs arise from steep cost curves; flexibility trades off against higher minimum costs; value derives from uncertainty and preserved options	Supply (firms, capital, technologies)
Tactical/ operational flexibility [12]	Ability to adjust output in response to shocks at low cost	Fixed inputs and technological constraints limit adjustment; firms seek system-preserving responses	Supply, with implicit attention to demand conditions
Static demand theory [14]	Demand as fully price-responsive	Instantaneous adjustment via income and substitution effects; no adjustment costs	Demand (passive, price-driven)
Dynamic demand models [15]	Demand flexibility as limited and frictional	Habit persistence, adjustment costs, imperfect expectations delay response	Demand, but constrained
Market structure & spatial competition [16]	Demand elasticity as endogenous under rigid supply	When extensive margins are exhausted, elasticity declines even as prices fall	Supply-determined pricing with constrained demand response
Macroeconomics (Keynesian & post-Keynesian) [17,19]	Excessive price flexibility can be destabilising	Nominal rigidities, coordination failures, network effects	System-wide (prices vs quantities)
Applied economics (supply chains, operations) [20]	Flexibility as agility	Maintaining throughput and avoiding costly interruptions; limited storage	Supply and organisational structures
Finance and health economics [21,22]	Flexibility as capacity to respond to shocks	High costs of disruption; demand treated as exogenous	Supply and financial structure
Agricultural & contract economics [24]	Flexibility via risk-sharing	Inflexible production; uncertainty shared across agents	Shared between supply and demand
Labour economics [25]	Flexibility as a productive attribute	Employers demand flexibility; workers bear adjustment costs	Supply of labour

are documented in analyses of industrial dumping, cyclical pricing [29], and excess capacity management [30]. Although often framed as price discrimination or strategic pricing, these mechanisms effectively function as incentives for buyers to increase or maintain demand in periods of surplus supply. Storage constraints further reinforce these dynamics. Bulk industrial outputs are costly or impractical to store at scale, meaning that continued production requires continued off-take. In such contexts, maintaining demand becomes a system-preserving objective rather than a profit-maximising one in the short run.

3.2. *Paying consumers to take waste*

A more explicit form of DTU appears in waste, recycling, and by-product markets, where consumers are directly paid to “consume” unwanted outputs. Examples include scrap metal, used cooking oil, industrial by-products, and beverage container deposit schemes. In these cases, disposal costs are high, and waste often has residual downstream value if collected and processed efficiently.

The economics of waste management highlights that when disposal costs exceed the marginal value of processing or recycling, negative prices can emerge [31]. Consumers or intermediaries are paid to accept waste because doing so reduces the supplier's net cost relative to landfill, incineration, or regulatory penalties. Scrap metal markets, for instance, have exhibited negative pricing during periods of excess supply or low recycling capacity, particularly for low-grade materials [32].

Used cooking oil markets exhibit similar dynamics. Restaurants are paid to supply waste oil to collectors because the alternative—safe disposal—entails compliance costs and environmental liability. Beverage container deposit-refund schemes institutionalise this logic: consumers receive explicit payments to return empty containers, thereby increasing collection rates and reducing system-wide waste management costs [33].

These cases satisfy all four structural conditions for DTU. Supply (waste generation) is largely inflexible in the short run, storage is limited or costly, disposal costs exceed marginal processing costs, and network effects arise because high participation improves the efficiency of collection, sorting, and recycling systems.

3.3. *Oversupply and negative freight rates*

The shipping and freight sector provides another instructive example of DTU driven by inflexible capacity and network effects. Maritime shipping is characterised by high fixed costs, long-lived capital assets, and limited short-run adjustability of supply. Once vessels are deployed, the marginal cost of carrying additional cargo is often low relative to the cost of idling ships or withdrawing capacity from service [34].

During periods of global overcapacity -such as those following demand shocks or fleet expansions-freight rates can collapse, occasionally turning negative on specific routes. Empirical studies document instances where carriers offer very low or even negative ‘base’ rates on backhauls have been observed to induce shippers to move goods that would otherwise not be transported [35].

These pricing practices reflect the fact that marginal revenue from additional cargo can be negative but still preferable to sailing empty, given the fixed costs of crew, fuel, port access, and network coordination. Storage of shipping capacity is effectively impossible, and network effects are central: maintaining route frequency, port presence, and contractual relationships can be more valuable than short-run profitability. In this context, paying demand to remain active helps preserve the integrity of the shipping network and avoids longer-term losses associated with route exit and re-entry. DTU thus operates as a

Table 2
Demand turn-up mechanisms in non-energy sectors.

Sector	Nature of supply inflexibility	Demand turn-up mechanism	Economic rationale
Capital-intensive manufacturing (steel, cement, chemicals)	High shutdown and restart costs; long-lived capital; limited storage	Rebates, bundled services, extended payment terms, side payments	Marginal operating cost < shutdown cost; maintaining output minimises total loss
Waste, recycling, and by-product markets	Waste generation inflexible in short run; storage and disposal costly or regulated	Direct payments to accept waste; deposit-refund schemes	Paying consumers reduces net system costs relative to disposal
Shipping and freight networks	Fixed fleet capacity; high fixed operating costs; capacity cannot be stored	Negative or near-zero backhaul rates; inducements to ship	Carrying cargo is cheaper than sailing empty; preserves network presence

stabilising mechanism in the face of cyclical volatility.

Table 2 illustrates how structural supply inflexibilities have prompted firms in non-electricity sectors to actively incentivise additional consumption.

4. Conclusions

This paper has argued that DTU should be recognised as a legitimate and economically grounded form of flexibility in electricity systems with high shares of VRE. As the penetration of wind and solar generation increases, surplus conditions are becoming more frequent and more costly to manage [36]. Under these conditions, the operation of the system increasingly depends on mechanisms that can actively encourage demand to rise when supply is abundant.

By revisiting the economics literature on flexibility, the paper has shown that DTU occupies a conceptually underdeveloped space. Flexibility has traditionally been framed as a supply-side attribute, valued for its ability to accommodate uncertainty, demand fluctuations, and shocks. Where demand enters the analysis, it is typically assumed to respond passively to prices, with limited attention paid to the structural conditions that constrain adjustment. Recognising demand as an active margin of adjustment under surplus conditions therefore extends, rather than contradicts, established economic reasoning.

The cross-sectoral evidence reviewed in the paper reinforces this interpretation. In capital-intensive industries facing overcapacity, in waste and recycling markets characterised by costly disposal, and in shipping networks with inflexible capacity and strong network effects, suppliers revert to incentivising demand to absorb surplus output. These practices are responses to asymmetries between marginal operating costs and the costs of shutdown, disposal, or capacity withdrawal. Across these sectors, paying for demand emerges as a system-preserving strategy that minimises total costs when supply cannot easily adjust.

Electricity systems with high VRE penetration increasingly exhibit the same structural features. Generation is capital-intensive and weather-dependent, storage remains limited and costly at scale, and network constraints create strong interdependencies across time and space. This suggests that DTU is particularly relevant for system operators and market designers seeking to manage marginal integration costs as renewable deployment continues to expand.

The implications of DTU extend beyond system efficiency to questions of distribution and social welfare. Much of the demand-side flexibility currently available in electricity systems is tied to ownership of capital-intensive low-carbon technologies, such as electric vehicles, heat pumps, or advanced home energy management systems [37]. Access to flexibility revenues or low-cost electricity is therefore unevenly distributed, often favouring higher-income households [38]. DTU may differ in this respect. Participation in DTU may be more broadly accessible to households and small commercial users able to adjust discretionary consumption, such as space heating, hot water use, cooking, or appliance operation, without requiring upfront capital investment DTU has the potential to alleviate forms of hidden demand suppression. Some households constrain energy use due to affordability concerns even when additional consumption would generate significant welfare gains and impose minimal system costs during surplus periods [39]. Incentivising demand at these times can enable higher comfort or essential energy use at low or zero marginal cost to the system, creating a positive social benefit alongside improved system balancing.

More broadly, the paper contributes to the economics of flexibility by recognising demand as an active margin of system adjustment, rather than a passive recipient of supply-side flexibility. The existence of DTU across multiple sectors demonstrates that, under certain structural conditions, paying for demand can be the least-cost and welfare-enhancing outcome. From a policy perspective, this implies a need to explicitly incorporate DTU into electricity market design, for example through targeted price signals, local congestion or curtailment-based incentives. Making this logic explicit is essential not only for understanding future electricity systems dominated by VRE, but also for designing markets and policies that align efficiency, decarbonisation, and social equity.

CRediT authorship contribution statement

Jacopo Torriti: Conceptualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research has been undertaken by the Energy Demand Research Centre (EDRC), supported by the Engineering and Physical Sciences Research Council and the Economic and Social Research Council [grant number EP/Y010078/1].

Data availability

No data was used for the research described in the article.

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