The Production of Infrastructural Value and the Extension of the Electricity Grid: Demand-Side Response and Aggregators as Temporal Prospectors

Mette Kragh-Furbo
DEMAND Centre, Lancaster Environment Centre, Lancaster University, UK/m.kraghfurbo@lancaster.ac.uk

Gordon Walker
Lancaster Environment Centre, Lancaster University, UK

Mitchell Curtis
School of Built Environment, University of Reading, Reading, UK

Abstract

Infrastructures have recently been conceptualised as in process and dynamic rather than fixed and obdurate. We introduce the notion of infrastructural value to draw attention to the specific value that can be produced in something in relation to its participation in an infrastructure, its operation and management. We analyse demand-side response (DSR) as a case of infrastructural extension where value is produced in already-existing electricity consuming devices, generating a return for their response to the ends of grid management. We track the work of aggregators who enrol clients and their devices into providing combined synchronised responses contracted with the grid operator. This involves aggregators in activities of temporal prospecting, legitimation, optimisation and coordination. We argue that the notion of infrastructural value helps to articulate the relations between the fluidity and flexing of infrastructural boundaries and value making practices and consider other ways that this category of value might be explored.

Keywords: Infrastructure, value, electricity grid, aggregation

Introduction

While apparently obdurate and firmly in place, infrastructures have in recent re-conceptualisations been positioned as thoroughly in process and emergent, embodying dynamism rather than statis (Haarstad and Wanvik, 2017; Harvey et al., 2016; Shove and Trentmann, 2019). Electricity grid infrastructures are a case in point, with a variety of authors rejecting their conceptualisation as stable forms, including as 'large technical systems' (Hughes, 1983) made of component parts locked together, and instead opening up their dynamic qualities. As Graham (2009: 11) states "… any coherence that the electrical assemblage achieves as an infrastructure must never be assumed or taken as permanent and inviolable", while for Harvey et al. (2016: 7-8) electricity grids exist as a complication "of technologically mediated relations [that] pivot on their potential extendibility and the ways in which they *fold together* heterogeneous entities in networks". One of the implications of moving away from seeing infrastructures as 'fixed facilities' (Blok et al., 2016) in such ways, is that attention should turn to the processes through which flexibility, extension and reconfiguration are enacted and more 'fluid' forms of infrastructure emerge as a result.

In this paper we introduce the notion of infrastructural value as a way of opening up the relations between the production and distribution of value and the extension of infrastructural boundaries, and it follows, the reach of mechanisms of infrastructural management. Given that many, if not most infrastructural networks internationally are 'neoliberalized' (Narsiah and Ahmed, 2011; O'Neill, 2013), organised into variously competitive arrangements of private ownership and markets, along with state regulation to address 'overflows' of economic framings (Silvast, 2017), we should expect the ongoing dynamics of infrastructures to be closely linked to the production, configuration and distribution of economic value. There has however been little explicit analytical focus on the ways in which contemporary value-making processes have provided opportunities for boundary flexing and the extension of the disciplines of infrastructural management into new spaces.

We argue that working with the notion of infrastructural value - which we define as the assigned and realised value in something due to its participation in an infrastructure, its operation and management - helps to clarify and articulate relations between infrastructural extension and value making practices. Following approaches seeing value as social practice (Muniesa, 2012; Birch, 2017; Kornberger et al., 2015), as the "outcome of a process … and the result of a wide range of activities … that aim at making things valuable" (Helgesson and Muniesa, 2013: 6), we see infrastructural value as being actively produced, not a latent quality in material things, but an "achievement that entails bringing materialities, relations and discourses into alignment" (Bridge et al., 2020: 729). While infrastructural value might appear to be self-evident in an entity, this particular form of value is always produced in relation to its coherence with other infrastructural elements. A distinctly infrastructural value may be produced in an entity alongside other values it carries, may come and go over time, and be contested within processes of valuation. Both material things and those who own or manage them may be compliant with being valued for their participation in an infrastructure, or resist becoming 'infrastructured' in these terms.

We focus on the electricity grid as an example of marketised infrastructure, but also one that is very much in flux as a result of pressures for change as part of low carbon transition (Bridge et al., 2013; Kuzemko et al., 2016; Bolton et al., 2019). An important part of this transition are new mechanisms for keeping the grid 'in balance' through managing the level of demand to match the availability of low carbon supply. In so called 'demand side response' (DSR), some degree of time de-limited responsiveness in the scale of demand is sought after to the ends of grid coherence (Torriti, 2016; Torriti and Grunewald, 2014). Whilst what has also been termed achieving 'flexibility' in the timing of demand (Cardoso et al., 2020; Powells et al., 2014) can take various forms, in this paper we examine a particular DSR variant that is well established in the UK. This involves large scale industrial and commercial users of electricity becoming responsive to the needs of 'the grid' (nationally and sometimes regionally), in some cases through contracts made directly with the grid operator, National Grid, but more frequently now through the work of intermediary organisations known as 'aggregators' (Curtis et al., 2018; Langendahl et al., 2019), who accumulate the responsiveness of multiple clients into 'packages' that can return a profit by being responsive, at scale, to what the grid operator requires.

We take DSR as a case of infrastructural extension, working with the concept of infrastructural value to demonstrate how elements of wider contemporary value-making practices are important to innovations in how infrastructural extension is being achieved. Bowker et al.

(2019) observe a shift from large-scale material infrastructure investments in roads, rails and wires to investments in 'thinking infrastructures' such as categorisation, classifications and other forms of 'sorting out' (Bowker and Star, 1999) that structure attention, shape decision-making and guide cognition. We can also think of these types of investments as now integral to infrastructural extensions that produce or redistribute value in existing materialities. In the case of DSR it is through the contemporary value-making practice of aggregation that infrastructural value can be realised in widely-distributed, mundane and already-existing electricity consuming devices - such as water pumps, air conditioning systems and freezing and heating technologies. Whereas the consumption of electricity by such devices generates extant economic value for the electricity supplier and costs for the user, through the variant of DSR we consider they become re-categorised and re-valued for their participation in the management of the grid, bringing income to the user with aggregation crucial to enabling this redistribution of value to diffuse and grow in scale. Aggregators actively extend the grid through forms of 'sorting out' (Bowker and Star, 1999) that are distinctively temporal in character, and through which the infrastructural value of already existing electricity-consuming devices can become newly established.

Our empirical research, undertaken through interviews, observation and document analysis, focuses on aggregators and identifies a practice of aggregation composed of four interrelated value-making activities. First, *temporal prospecting* for DSR potential across a very wide field of electricity-using organisations and devices, enabled by the network space of the grid, but constrained by temporal needs; second *legitimising* the possibility of responsively turning down or up consumption and dealing with resistances this encounters; third *optimising* return and profitability through detailed temporal assessment and algorithmic prediction; and fourth *coordinating* the timing of response through the affordances provided by digital infrastructures. In discussing each of these activities we make connections to tools and techniques of producing market value across other domains, but also reveal a temporal distinctiveness than relates to their application to infrastructural ends and to electricity as a resource flow that has particular material qualities. As we shall make clear, making infrastructural value in this case involves "aggregating hitherto unsuspecting geographies" (Leyshon and Thrift, 2007: 109), but doing so in a way that foregrounds the temporal far more than the spatial.

In so doing we make a distinctive contribution to existing literature on DSR which has largely focused on its technical and practical features (e.g. Li et al., 2016; Curtis et al., 2018), its role in relation to the broader transformation of electricity systems into smarter forms (Langendahl et al., 2019; Siano, 2014; Spence et al., 2015), its nascent extension into the domestic sector (Goulden et al. 2018; Powells and Fell, 2019; Calver and Simcock 2021) as well as market opportunities and barriers to DSR (Cardoso et al., 2020; Lockwood et al., 2020). In addition, our broader contribution is to bring the notion of infrastructural value into play in work on infrastructural dynamics, as well as to encourage more attention to value dimensions of infrastructure beyond its financialisation (e.g. Clark and Evans, 1998; Torrance, 2008; O'Neill, 2013; Knight and Sharma, 2015) and the reconfiguration of charging regimes (e.g. Brown and Pena, 2016; Loftus, 2006).

We begin by explaining more about DSR and its development in the UK, before then drawing on our empirical research to focus on the work and practices of aggregators in producing and distributing infrastructural value.

Balancing the grid and demand side response in the UK

Conventionally it may be thought that the electricity grid has an obvious end point, located where distribution ends and connected consumption begins, delineated by a property boundary and/or a device for metering flow from supply into use (Kragh-Furbo and Walker, 2018). Various conceptualisations, however, see users and the technologies through which resources are consumed as integral elements of infrastructures (Shove et al., 2015; Harvey et al., 2016) and in a number of recent developments as part of transitioning the grid into low carbon and smarter forms, any sense of a fixed boundary between an infrastructure managed in order to supply and consumers generating demand has become particularly blurred (Grandclément et al., 2019). This is not only through so called 'prosumption' in which consumers are also microgenerating producers of power (Olkkonen et al., 2017; Smale et al., 2019), but also by the extension of active moment-to-moment grid management into the dynamics of electricity consumption.

This need for moment-to-moment grid management comes from the distinct material qualities of electricity as a 'vibrant' energy form (Bennett, 2009), which means that it must (at scale) be consumed as fast as it is produced to avoid system breakdown. This imposes specific demands on the managed relation between electricity supply and demand within grid infrastructures and from the very beginning of grid formation has posed major practical challenges for system operators (Hughes, 1983). In the UK, throughout the period of a nationalised electricity industry from 1948-1989 (Hannah, 1979), sustaining balance and system reliability was achieved through mechanisms of central planning. Supply was orchestrated to meet variability in demand, with power stations turned up and down under instruction; and at times of really strong daily/seasonal peaks in demand, requests were sometimes passed to other nationalised industries such as steel works to temporarily limit their consumption in the (public) interest of system stability. During this period the electricity industry also took a number of initiatives to manage the timing of household demand, including calls for consumers to 'time-ration' their use of appliances, the promotion of off-peak electric heating in the 1950s and 60s (Carlsson-Hyslop, 2016), and from 1965 the availability of Economy 7 and other variable consumer tariffs (Hamidi et al., 2009) which through hardwired metering systems provided a differentiation between the cost of day time and overnight electricity use.

In 1989, and over subsequent years, the electricity system was transformed by moves to privatise and liberalise in an early example of infrastructural marketisation and state regulation (Mitchell, 2008). What had been an integrated system was taken apart, with separate units of generation, supply to consumers and grid operation, operating and interrelating through electricity market structures within the rules and oversight of the regulator Ofgem. The grid through this period rapidly folded in new actors (including new smaller generators and suppliers), new ideas, principles and rules that fitted with a different vision of what it would now be and how value would be distributed across its different elements. Competition and profit-seeking replaced an 'ethic of public service', but regulatory obligations meant that suppliers could not just 'merely spin meters' to increase profit (Guy and Marvin, 1995: 50).

For grid balancing specifically, privatisation meant that this role was now with National Grid, a private company. It had to sustain a functioning grid through the development of market-based mechanisms in which both core generation capacity and 'balancing services' - available to be drawn on when the grid was under particular pressure - were contracted and procured from multiple companies participating in the energy system. This implied a greater openness to how balancing might be achieved. As Guy et al (1999: 198) comment, the splintering of electricity industries, challenged the "extremely powerful supply-oriented logic of network development" with new approaches beginning to emerge. Amongst other things, this meant giving more attention to the possibility of intervening in the dynamics of demand as a cost-efficient and competitive alternative to seeking balancing services from supply-side operators turning up and down generation. In the early 2000s, a decade or so after the initial privatisation of the system, Ofgem (2002) sought to actively stimulate such thinking, setting up the 'Demand-Side Working Group' with the aim of reviewing the options available for demand-side participation in trading arrangements.

Other pressures also played into this shift to seeing demand as potentially malleable. So called 'peaking plants' deployed at times of high demand, provided electricity at a premium cost and were also typically high carbon emitters. As attention to carbon mitigation began to flow through energy policy, the case for seeking alternatives was strengthened further, and to some degree forced by the closure of large coal plants coming

Table 1. Summary of National Grid's 'Balancing Services' for frequency and reserve with their requirements and relative value (adapted from National Grid, 2016)

	SCHEME	MINIMUM SIZE	NOTICE PERIOD	DURATION	REGULARITY	VALUE
FREQUENCY RESPONSE SERVICES	Firm Frequency Response	10 MW	30 sec	Max 30 min Typically 5 min	10-30 times per year	££
	Dynamic Frequency Response	10 MW	2 sec	Max 30 min Typically 3-4 min	Daily	£££
	Enhanced Frequency Response	1-50MW	1 sec	Max 15 min Typically 3-4 min		£££
RESERVE SERVICES	Short Term Operating Reserve (STOR)	3MW	20 min	2-4 hours Typically <20 min	Able to deliver 3x per week	£
	Fast Reserve	50MW	2 min, reaching 50MW in 4 min	15 min		£
	Demand Turn Up	1 MW	10 min,	Min 30 min		£

to the end of their working life, or breaching new emission limits. By 2015, National Grid noted coal plant closure as "[t]he single and largest driver" of the need to "grow balancing services" (National Grid, 2015: 2). What was replacing carbon-heavy generation did not intrinsically help with grid stability, with wind and solar power adding much more complexity and intermittency into supply profiles. It was therefore argued that only by bringing DSR into play in more sophisticated ways, as part of a general 'smartening' of the grid (Clastres, 2011), could these newly dynamic elements of generation be integrated in the grid without it collapsing into chaos. As National Grid saw it, the grid was "continu[ing] to become ever more sophisticated and complex" with more intermittent generation meaning that "system needs are becoming less predictable and more volatile" (National Grid, 2017: 1). The procurement of DSR balancing services was initially focused on reducing demand, incentivising responsiveness by giving value to turning down electricity consumption when supply is under stress. Recently, however, the service of demand 'turn up' has also been procured to respond to situations when there is a surplus of low carbon supply, thereby giving value to users increasing electricity consumption at a particular point in time. Such flexibility, in its different forms, has been characterised by Angel (2021) as a 'socioecological fix' for the threat that the increased integration of renewable generation into the electricity system poses for prevailing capitalist logics of energy supply.

Opportunities for DSR to compete in providing balancing services were gradually introduced by National Grid from 2002 onwards, such that at the time of undertaking the research a suite of opportunities were being advertised[1]. Table 1 summarises the key specifications of each of the DSR services being procured, distinguishing between 'frequency response' and 'reserve services'. It is immediately apparent how important temporal conditions are, with frequency response (keeping the oscillating frequency of AC supply within an acceptable 'bandwith') particularly demanding in terms of the 'notice period' or speed of response (measured in seconds), compared to the slower 'reserve service' (measured in minutes) called on to cover more predictable peaks in system load. 'Duration' and 'regularity' are also specified and differentiated across the schemes and when combined with the minimum size of contracted response (in MW) produce a range of potential monetary values for participating organisations (as indicated in the final column of the Table). Those participating are paid both for being ready to be responsive (an 'availability' fee) as well as for actually responding (a 'utilisation' fee) within the contracted terms of their participation.

Through contracting for demand-side balancing services in these ways National Grid were purposefully extending the management of grid balance into spaces of electricity consumption, and by doing so constructing a market opportunity for those able to provide a service to the system within closely defined parameters. The minimum size threshold in column 2 of Table 1, set at MW levels, keeps the transaction costs for National Grid at an acceptable level, but also limits the contracting opportunity to those consuming electricity (and therefore able to switch off) on a substantial scale. Notionally this meant only bigger industrial operations could participate, however, these thresholds could also be reached by combining together small packages of responsiveness amongst a wider diversity of consumers, *if* they could be coordinated to respond together. Entrepreneurial demand response aggregators emerged to exploit this business opportunity, acting as profit-seeking intermediaries and new 'market agents' (Randles and Mander, 2011; Bessy and Chauvin, 2013). The first aggregators in the UK appeared in the late 2000s, and today there were 18 in operation (National Grid, 2021), largely stand-alone independents which have grown into substantial operations, but also established electricity suppliers who have also ventured into aggregation. In 2019, stand-alone aggregators provided 60% of contracted DSR capacity to National Grid, making clear their crucial role (The Energyst, 2019). Aggregators also bid into DSR contracts with distribution network operators (DNOs) that since 2018 have grown their flexibility services to help manage congestion on local electricity grids. However, National Grid, as the Electricity Systems Operator (ESO), remains the dominant actor in this market, as they procure more than 10GW of flexibility (projected to increase to 30GW in 2030 and 60GW in 2050) in comparison to the 1GW of flexibility procured by DNOs in 2020 (National Grid, 2020b; BEIS, 2021).

Methodology

The empirical data for this paper stems from a research project on the governance of energy demand that explored the ways in which the agency to govern energy demand has become distributed in new configurations across networks of actors, material technologies and infrastructures of different forms and devices of knowledge management, data processing and data representation. We focused on DSR as an increasingly vital space for the active governance of energy demand and zoomed in on aggregators as playing an important role in creating and realising these new configurations. While aggregating is clearly the headline task, the work involved in producing infrastructural value is multi-faceted. In order to understand this, we collected a variety of empirical data, including from two sets of semi-structured interviews, along with observation of industry events as well as collection and analysis of relevant documentation.

The first set of interviews were undertaken with representatives of four different stand-alone aggregators, operating in the UK; two of which were well-established and two smaller and more recently active in the market. The aim was to understand their role in developing demand response activity and the processes through which they engage with their clients (interviewees A1-A4). The interviews were carried out by MKF. Ethical approval for the study was granted by the Faculty of Social Science Research Ethics Committee at Lancaster University. A second set of interviews was undertaken with ten employees working for a single well-established aggregator, operating in the UK. They included employees working in sales as well as site operation. This set of interviews enabled a more detailed examination of the different aspects and stages of an aggregator's work (interviewees B1-B10). This second set of interviews was carried out by MC, as part of his PhD on demand response aggregators. We included this set of interview data in the analysis, as in combination, the two sets of data enabled both breadth and depth to be achieved within the analysis of aggregators' work processes. Ethical approval for this study was granted by the Research Ethics Committee at the University of Reading. See Table 2 for details on the interviewees.

Observations of five industry events and meetings were undertaken by MKF and GW, where DSR and aggregators were being discussed. This included the annual trade event for the UK energy management industry focused on metering, monitoring, technology and energy services, and a

Table 2. Interviewee characteristics

Interviewee ID	Role	Company ID
Interviewee A1	Co-founder and Executive Director	Company A
Interviewee A2	Commercial analyst	Company B
Interviewee A3	Operations manager	Company C
Interviewee A4	Chief technology officer	Company D
Interviewee B1	Sales – senior	Company D
Interviewee B2	Sales – junior	Company D
Interviewee B3	Sales – senior	Company D
Interviewee B4	Sales – junior	Company D
Interviewee B5	Sales – junior	Company D
Interviewee B6	Sales – junior	Company D
Interviewee B7	Sales – intermediate	Company D
Interviewee B8	Sales – intermediate	Company D
Interviewee B9	Sales – intermediate	Company D
Interviewee B10	Technical – senior	Company D

regional event organised by the same trade body, as well as a one-off industry event on sustainable building and building management. Fieldnotes were taken for each event. A variety of documents were also collected, focused on National Grid reports on DSR and flexibility, including from their Power Responsive campaign as well as minutes of their Demand Response Working Group meetings.

The data collected – integrating across interview data, fieldnotes and documents – were analysed both deductively, with a focus on aggregators and their work processes and role in identifying and developing demand response activity, and inductively enabling scope for unanticipated themes to emerge from the analysis.

Aggregators and the production of infrastructural value

Aggregation has arguably always been integral to (economic) value making, but has taken on new forms within the digital economy. Leyshon and Thrift (2007: 103) position aggregation as an important spatial tactic in the development of new asset streams, in which there is "the identification of a regionalization of value that would heretofore have been considered of little worth" with digital systems making "these new aggregations sufficiently visible to be operated on". The key activities of aggregation are thus 'searching out' new asset streams, on the back of new forms of expertise, and operationalising these through "computer software that enables [devices, individuals etc.] to be assessed, sorted and aggregated along dimensions of risk and reward" (Leyshon and Thrift, 2007: 108). Today, aggregation is part of the value work produced by many digital platforms, such as those focused on housing markets (Fields, 2019), crowdfunding (Langley, 2016) and the accumulation of consumer data (Thatcher et al., 2016).

In the case of DSR, it is through a practice of aggregation and its interrelated value-making activities that infrastructural value can be realised for the purpose of grid balancing. Temporality is a key feature in realising this value, as any device's infrastructural value can only be actually realised if the device is switched *on* at the point in time that National Grid or a DNO needs demand to be cut; or, in the case of demand 'turn up', if demand can be 'shifted' and 'turned up' at a point in time when demand is low and renewable generation capacity is high[2]. Crucially, to be countable as enacted DSR, this 'response' must be evidenced as having taken place. Across all of the millions of electricity-powered devices in businesses and organisations distributed across the UK, there is evidently already much turning up and down, but it is only at those sites and moments at which precise, controlled and contracted responsiveness is made possible and then enacted and evidenced, that infrastructural value can be realised. For aggregators putting together packages of 'distributed responsiveness' that can be sold to National Grid or DNOs, the very particular conditions mean that there are significant challenges in identifying DSR potential, establishing and operationalising responsiveness and evidencing its performance. Over following sections, we show how aggregators establish the infrastructural value of already existing devices, putting working arrangements in place and establishing DSR aggregation as a profitable business opportunity. In turn, these are practices of prospecting, legitimising, optimising and coordinating.

Temporal Prospecting

In their discussion of the future of finance and capitalism, Leyshon and Thrift (2007: 98) use a prospecting metaphor (see also Mezzadra and Neilson, 2017) to convey how new asset streams are hunted down, and while the end goal is differently oriented, this term fits well with the initial task that aggregators undertake. Just like mineral deposits, electricity consuming devices with DSR potential are widely distributed across space, hidden within the material form of the operating sites of businesses and other large organisations and not immediately knowable. However, unlike mineral deposits their specific geographic location is largely irrelevant to their viability, given that all these devices are materially connected through the wires and cables of grid infrastructure, making the spatiality of DSR strongly networked at a regional and national scale. As explained earlier, electricity has a material instantaneity which means that wherever supply or demand is enacted within a networked electricity infrastructure, it is very immediately registered by the system in terms of overall balance. The physical, cartographic location of particular instances of supply or demand is, at this system scale, largely irrelevant to National Grid, although for DNOs regional or local area geographies of DSR potential can be important. Aggregators therefore have a large spatial geographical field across which they can hunt out opportunities. To do so, aggregators have to use bespoke classification systems to direct their attention to where potentially exploitable 'seams' of devices might lie (to continue the minerals analogy). In their accounts they draw on accumulated experience and know-how on which some basic assumptions about capacity and potential return can be built:

> For example, I know from experience that cold store warehouses often state how many pallets they can hold on their websites, so I check and if they have only 10,000 pallet storage then I don't bother as the potential is too low, if they have 100,000 then I contact them (B1).

As in this example, much of the initial categorisation of potential is done around scale in relation to the kilowatt (kW) capacity of each device, or the site's total capacity to provide response. Interviewees used various rules of thumb when asked about what the minimum kW capacity for participation, for example one indicating 'around 200kW' adding that "I think we can go lower but it's hard to know if it will be profitable or not so I tend to avoid assets with anything less" (B6), while another made clear the importance of how consumption is distributed "if they have 500 assets at 1kW each, then not worth it" (B2).

DSR infrastructural value is however not just about scale, as emphasised earlier, temporalities are crucial. The initial stage of prospecting based on theoretical kW capacity and identifying potential in place is therefore followed by a set of temporally structured assessments of site-specific operations. This includes the frequency of use of an electricity consuming device, how long at a time it is in use and how predictable and routine this is. As assessors learn more about temporal patterns, the potential resource available for demand response might change. An interviewee explains:

> Sometimes the client uses a faceplate value, like a 500 kW chiller, but its usage is very small, only 20 kW, which means it's not worth it (B3).

Developing some degree of knowledge of the temporal structure of a site's operation and electricity use as part of the prospecting stage is therefore important, informing whether to continue the assessment process, even though it is only when tested and optimised (see later) that this potential becomes fully material. Prospecting is therefore only a partial process, contingent on material and temporal specificities that can only be thinly evidenced by general classifications of site characteristics and rough approximations of patterns of electricity use.

Legitimising

Legitimation refers to the shared recognition of the value of an entity (Lamont, 2012), in this case the potential infrastructural value of a device in addition to its existing use value. When entities have more than one value status in this way, there is scope for conflict between them (Helgesson and Muniesa, 2013) and for one form of value to be seen as more legitimate, more worthwhile or significant than another. For aggregators negotiating this potentially difficult territory and legitimating what constitutes a novel and rather peculiar form of value is a significant challenge (Torriti, 2016). This means that when talking to potential new clients, the aggregator usually has to take time to carefully explain what demand response is and to deal with initial reactions to what is proposed. At the centre of these reactions can be a conflict between the temporal continuity implicitly assumed in operating the technologies that are part of an organisation's ongoing operations and the 'arrhythmic' disruption (Walker, 2021) to this continuity that appears inherent to demand response. As an interviewee explains, the initial assumption is typically that continuity is given and essential:

> No one in a business thinks anything can be turned off. It's all needed. There is no operations manager who will say to their boss that 30% of their equipment could be turned off (B6).

Another interviewee explains how it can take some time to work around these concerns:

> The people you really need to win over are the site managers, the people in charge of actually operation of the assets because they are the ones with the biggest concern around any kind of negative effect or damage that can be caused by switching an asset on or off. So we go on a very long journey with our clients (A2).

Legitimation of what is being proposed has then to address the apparent conflict involved in proposing that a device can temporally be 'rented out' to an aggregator (and in turn National Grid) for the purposes of grid management, and the loss of control that this implies. As an interviewee describes: it can be difficult "getting around the idea that someone else can start up or shut down their assets, outside of their control" (A4) and such concerns have to be managed carefully. Some devices are also more compliant to becoming infrastructurally valued, others more resistant. For example, air conditioning systems and freezer systems have an inertia in their outcomes (the air stays acceptably cool, the freezer contents stay frozen), which mean that the service they provide is not significantly degraded by being switched off for a short period (Curtis et al., 2018). Lighting systems in contrast have no inertia in their service (the light is instantly lost) and switching off can have problematic consequences. Other devices such as water pumps, may already do their work in a non-continuous way, such that the service they provide (water moved from one place to another) can be shifted in time. Aggregators therefore have to sort through the sets of electricity using devices in place and legitimate the value that some of them can realise in comparison to limited degree of disruptive impact, while also persuading clients of the potential temporal flexibilities in their organisation's operation.

Optimising

Optimisation in valuation processes refers to a pattern of rationalisation, typically through numerical calculations, oriented to particular ends, often to find the 'best' balance between what might be contradictory aims (Chiapello, 2018). For the aggregator, optimising is very much a financial decision based on what is profitable given the level of constraint or risk involved. To work out how to optimise financial return, aggregators draw on various kinds of data, including past patterns of electricity consumption from existing meters:

> There is quite a lot of research that the sales team is going into about the characteristics and processes around these different assets. So once they understand you know that a chiller can be turned off for a certain amount of time, once they understand what the customer is going to see, they can develop a picture around that (A4).

Such a 'picture' of potential and optimisation is again very much temporally framed, taking into account not only usage patterns but also the 'control variables' for each asset (variables which are already wired into the pattern of its operation) meaning that for a bitumen tank a shift in measured internal temperature, or a water pump a change in measured water pressure, would override its switching off for demand response purposes:

> For a water pump it might be pressure, various monitoring of pressures on either side, if there is a difference, it would suddenly turn on because that's its job, and then determines our range of flexibility that we can operate within (A2).

Availability of a device may also be affected by other factors such as weather conditions, for which the aggregator will have to assess the scale of constraint on possible revenues. This involves developing detailed insights into exactly how devices operate in order to work out what return can be achieved and how to optimise revenue:

> So water pumps make up a large part of our portfolio, so whether it rains or not will determine whether or not they actually turn on, so the first application of machine algorithm really was around historical data to provide forecasts, a week ahead or a month ahead (A2).

As the interviewee explains, tools and techniques like algorithmic machine learning – processing historical data to make future-oriented assessments - have become increasingly important to their optimisation processes, given that these are necessarily attuned to the temporal structures of the balancing services market. Aggregators have to bid for contracts and regularly update the National Grid on availability of capacity and are therefore constantly having to make assessments of the electricity use that they anticipate can be responsively avoided in the future across their portfolio of clients. Becoming more sophisticated in these temporally structured assessments, taking better account of the contingencies they can foresee in the performance of the assets and income they have created, and learning from past discontinuities between anticipations and enactments is therefore central to their business model. In such respects, they therefore share much in common with other financially oriented actors also using algorithmic technologies to attempt to better know the future from the performance of the past (Pasquale, 2015; Leszczynski, 2016).

Coordinating

As noted earlier the spatial possibilities of infrastructural value are enabled by the connectivity and instantaneity of the grid, but alongside this, digital infrastructure is also required in order for information to be exchanged and acted on and for aggregation to be achieved. First, aggregation only works if there is a synchronisation of multiple clients cutting their consumption at the same time, so that a 'package' of coordinated responsiveness is mobilised. This means that aggregators need to distribute a signal to their participating clients when National Grid indicates a response is needed because of a system balancing need. Typically, aggregators install control units on a client's site, which receive an instruction signal from the aggregator and use these to either automatically switch off or on specific devices, or to request local operators to manually do so. How, when and which control units are activated is worked out between aggregators and clients and written into contracts, for example, specifying how often an instruction will be issued and periods of the day that switch-off can and cannot be deployed. Such specific conditions also depend on the National Grid scheme being serviced and the specific parameters this mandates (as detailed in Table 1). For example, for 'frequency response' services, controls operate automatically so that switch off can happen very fast in response to a drop of frequency on the grid supply. Which units to activate when an instruction is issued is worked out through randomisation, as an interviewee explains:

> So each asset is effectively controlled locally so we are not saying this one and this one. The way it works is that it is randomised, so if the frequency goes all the way down to 49.7, all of them will switch off, but if it goes down to 49.5, they will all flip a coin and half of them will get heads and turn off and half of them will get tails, so when you aggregate enough, those statistical variations sort of cancel out and you do get a perfectly linear line, and everything is done on site (A2).

In the case of 'reserve' services, the speed of response required is slower and instructions can be relayed through local operators. Regardless, the installed control units enact the terms and conditions for the response of electricity-powered devices, coordinating switching off across the aggregator's multiple clients and making demand response operational.

The second form of coordination necessary centres on the provision of disaggregated evidence of the specific responsiveness that has been enacted. Advanced digital metering technology enables measurement of electricity flow at specific points on-site, granulated into temporal units such as consumption measured per half hour, minute or second (Kragh-Furbo and Walker, 2018; Bedwell et al., 2014). Whilst in some cases data can be drawn from existing metering systems to evidence drops or increases in consumption, the specific temporal conditions of responsiveness generally mean that additional metering infrastructure is installed. For example, to participate in 'frequency response', it is necessary to install temporally intense and exact metering, as an interviewee explains:

> You need to respond within seconds and then therefore to provide that service and prove that we have delivered that service, we need to install our own second by second meter on every asset. [...]. So if you'd need to do frequency response, you specifically need 0.1 hertz metering so that's 10 times a second (A2).

Such temporally precise information on changes in electricity consumption provides the basis of the calculation of income to the client from the aggregator - along with a baseline fee for being 'on call' and potentially available to be responsive. And when pooled together with information from other clients, also provides the basis for establishing proof of speed and scale of responsiveness under the terms of contract established between the aggregator and National Grid. In these ways, technologically mediated and enabled information flows are intrinsic to demand response operating and becoming parcelled together and to the income that is derived from the infrastructural value established in a device.

Discussion

We have explained how in DSR the extension of the electricity grid and the balancing discipline of grid management is entering into organisations that do not in any way have that as their central role, and into devices that are not normally operated to the ends of infrastructural coherence. We have used the notion of infrastructural value to engage with the way in which this shifting of the boundary of the grid is being realised, with electricity-consuming devices newly valued, newly generating an income flow, because of what they can contribute to grid balancing. We have emphasised that producing and diffusing this form of infrastructural value is very much an achievement whose realisation is dependent on a set of specific interrelated practices enacted by value-seeking aggregators. National Grid established DSR as part of the electricity system, but only by aggregators prospecting, legitimising, optimising and coordinating infrastructural value, has the enactment of many thousands of synchronised moments of devices responding to signals been able to grow in scale, becoming a significant part of how grid balance is sustained, with substantial further growth intended. Currently, industrial and commercial DSR amounts to 1GW of contracted 'turn down' capacity, with National Grid expecting this under various scenarios to double within 2-3 years and grow potentially to 13GW by 2050 (National Grid, 2020a). Where this capacity happens and where therefore the managed grid extends to, is significantly contingent on the infrastructural value-producing work of aggregators and their ability to hunt out and realise new market opportunities.

Through our discussion we have pointed to how the four set of activities involved in producing this specific form of infrastructural value are also associated with other arenas and end-goals of contemporary market making and functioning. Prospecting for value, legitimising its status, optimising returns and coordinating information flows have become established aspects of value-making practices, but they take on a distinctive character in being applied to DSR and the ends of establishing infrastructural value. As we have emphasised, what is most distinctive is how temporality is configured both in contracted DSR schemes and across the different activities performed by aggregators. Infrastructural value can here only be realised in precise and calculated moments of demand response that are contingent on and limited by real-time grid balancing needs and usage patterns; and at the same time, these moments of response must be prospected for and legitimised, optimised and their coordination enabled in advance. There is some ongoing infrastructural value in fees paid for being available to be responsive, but this is only realisable in the mid to long term, if it is matched at some point by actually utilised time-coordinated response (although the relationship between availability and utilisation varies in the contractual arrangements for different DSR schemes).

This form of temporality, when digitally enabled, has connections to the temporalities of high frequency trading (Zook and Grote, 2016; MacKenzie et al., 2012), more than to longer term trajectories of return. What matters in DSR are precise enactments of the present; a willingness to respond and an enacted response at exactly the right time in relation to the structure of clock-time and its divisibility into precise units. What is primarily valued are the rate of response (speed) and duration of response. This valuation of the 'here and now' contrasts quite strikingly with the longer term returns normally associated with infrastructural investment and with entities that have a more intrinsic, stable or enduring infrastructural value. DSR may therefore be temporally distinct and unusual but demonstrates that producing infrastructural value can enter into novel temporal territory and may do so increasingly in the future.

In this respect there are links to the temporalities and valuation practices of the sharing economy. In Bardi and Eckhardt's (2012) terms, in the sharing economy consumption of shared materialities is 'access-based' with the consumer 'acquiring consumption time with the item', often paying a premium price for so doing, and in patterns mediated and enabled through digital technologies. Indeed, one of the tactics used by aggregators to explain their work is to draw analogies with well-known instances of the sharing economy, in particular Airbnb. Such analogies stand up to some degree, in that as with various examples of monetised forms of sharing, DSR involves achieving "higher utilisation of the economy's idling capacity" (Schifferes, 2013), with that 'idling' made temporally responsive to the needs of the electricity system. However, distinctly unlike Airbnb, there have not been multiple potential rent-paying actors looking to pay for accessing the temporary use of devices. This makes it a decidedly asymmetric example of the enrolment of a sharing logic into economic relations, if indeed it makes sense to think of it in these terms.

Having only few rent-paying actors – National Grid as the main actor, and the six DNOs providing some smaller, but growing market opportunities - also emphasises how infrastructural value in this case is a potentially volatile achievement. If National Grid decide to change the terms of their contracting, to withdraw specific DSR schemes, specify new minimum capacities or temporal criteria, then the calculative frame within which aggregators are working is readily de-stabilised. As we emphasised in conceptual terms infrastructural value is an achievement rather than a fixed quality and its enactment in a device may therefore be lost, but also gained anew as DNOs increasingly deploy DSR in order to manage pressures on regional and local infrastructural capacity. This could to some degree diversify the opportunities for aggregators to build a portfolio of contracts and protect against volatility, but particular electricity-powered devices can still become 'de-valued' by other means. For example, through a change in their ownership, through changes in the patterns of their use, or if they become more critical to an organisation's functioning and therefore less available for turning up or down at the behest of a grid manager. Hence the need to conceptualise infrastructural value – and the detailed topography of the extended grid - as an ongoing and contingent process, temporarily held in place by sets of contractual, material, spatial and temporal relations, rather than a permanent condition.

Conclusion

> And do things have several values? Yes, what things are worth can be manifold and change - and these values can be conflicting or not, overlapping or not, combine with each other, contradict each other. All, or almost all, depends on the situation of valuation, its purpose, and its means. (Helgesson and Muniesa, 2013: 7)

We have shown that the concept of infrastructural value is analytically useful in focusing on the specific value that can be produced in something in relation to its role in the ongoing operation and management of an infrastructure. We have positioned infrastructural value as an accomplishment achieved through practices of assessing value and holding sets of relations in place, and that, in marketised infrastructural systems, the fluidity and flexing of infrastructural boundaries can be directly subject to how infrastructural value is made and distributed.

Star and Ruhleder's (1996: 112) question "when – not what – is an infrastructure" is therefore particularly apposite, with grid extension enacted not as a fixed material addition as conventionally understood (new wires, cables, generating and transmission technologies etc..), but as a structured and systematic process of producing temporally transient infrastructural value in already existing materialities. To become 'infrastructured' (Blok et al., 2016) in this case is to be newly valued, forming an extension of the managed grid that in enabling intervention into the dynamics of demand, is becoming increasingly important to how low carbon transition in electricity systems is expected to play out.

Having introduced and exemplified the notion of infrastructural value in this way, what other analytical work might it do? In DSR specifically there are new directions in which infrastructural value is now being extended, including into domestic settings and smaller businesses with different scale, temporal and legitimation characteristics (Powells and Fell, 2019; Torriti, 2016; The Energyst, 2019), and enrolling new types of devices such as battery systems and electric vehicle charging networks. DSR is a particularly involved instance of infrastructural dynamics, but distinguishing infrastructural value from other forms, working through the details of its production and the conflicts and resistances entailed might be similarly productive in other cases. These could include other instances where the move towards 'smarter' infrastructures across a broad field involves the incentivisation of time-delimited responsiveness to digitally enabled information flows. How infrastructural value is produced within the diffusion of particular innovations could also merit analytical attention, with, for example, the existing materiality of building roofs becoming newly valued in relation to the development of solar technologies, and bike sharing systems distributing infrastructural value between bikes, docking stations and digital platforms in ways that are quite distinct to traditional ownership and use. Accounting for shifts in infrastructural value over time as extant infrastructures become de-valued, followed by their revaluing and repurposing - as with rail corridors turned into linear parks (Loughran, 2014), or public land and military facilities becoming commercial assets (Whiteside, 2019) – also gives attention to longer term dynamics in infrastructural valuation processes.

Working with infrastructural value could also readily move into more normative territory, asking questions about how this category of value *should* be assessed and distributed and the ends to which it is deployed. This has not been our focus, and the DSR variant we have discussed has not been overtly controversial. Even so there are questions to be asked about who is profiting and to what extent from the distribution of value in this way, whether perverse incentives are built into decisions about how and when to consume electricity for those participating in DSR and, more fundamentally, whether seeking flexibility and responsiveness within the electricity system is how a low carbon transformation should be achieved. Case studies of DSR in practice may well be able to answer some of those questions as well as further research on the political economy of DSR and the flexibility markets. For Angel (2021), flexibility as currently being pursed is simply a way of sustaining capitalist imperatives of accumulation, doing nothing to challenge its underlying socio-ecological contradictions. Seeing infrastructural value in more normative terms could therefore open up to possibilities of alternatively configured provisioning systems, including those which in Angel's (2021: 13) terms are open to "more liberatory spatiotemporal rhythms of socio-ecological life" and in which value is understood beyond its monetary form as part of market-based rationales.

Acknowledgements

We are grateful to our interviewees and for the insightful and helpful comments of reviewers. The article was supported by the Engineering and Physical Sciences Research Council [grant number EP/K011723/1] as part of the RCUK Energy Programme, and by the EDF as part of the R&D ECLEER Programme.

References

Angel J (2021) The Flexibility Fix: Low-Carbon Energy Transition in the United Kingdom and the Spatiotemporality of Capital. *Annals of the American Association of Geographers*. Epub ahead of print 22 September 2021. DOI: 10.1080/24694452.2021.1941745

Bardhi F and Eckhardt GM. (2012) Access-Based Consumption: The Case of Car Sharing. *Journal of Consumer Research* 39(4): 881-898.

Bedwell B, Leygue C, Goulden M, et al. (2014) Apportioning energy consumption in the workplace: a review of issues in using metering data to motivate staff to save energy. *Technology Analysis & Strategic Management* 26(10): 1196-1211

BEIS (2021) Appendix II: Smart Systems and Flexibility Plan Monitoring Framework. Monitoring Flexibility for a net zero electricity system. July 2021. Available at: https://www.gov.uk/government/publications/transitioning-to-a-net-zero-energy-system-smart-systems-and-flexibility-plan-2021 (accessed Nov. 29, 2021).

Bennett J (2009) *Vibrant Matter. A Political Ecology of Things*. Durham: Duke University Press

Bessy C and Chauvin P (2013) The Power of Market Intermediaries: From Information to Valuation Processes. *Valuation Studies* 1(1): 83-117.

Birch K (2017) Rethinking Value in the Bio-economy: Finance, Assetization, and the Management of Value. *Science, Technology & Human Values* 42(3): 460-490.

Blok A, Nakazora M and Winthereik B R (2016) Infrastructuring Environments. *Science as Culture* 25(1): 1-22.

Bolton R, Lagendijk V and Silvast A (2019) Grand visions and pragmatic integration: Exploring the evolution of Europe's electricity regime. *Environmental Innovation and Societal Transitions* 32: 55-68.

Bowker GC and Star LS (1999) *Sorting things out: Classifications and its Consequences*. Cambridge, Massachusetts: The MIT Press

Bowker GB, Elyachar J, Kornberger M, Mennicken A, Miller P, Randa NJ and Pollock N (2019) Introduction to thinking infrastructures. In: Kornberger M, Bowker GC, Elyachar J et al. (eds) *Thinking Infrastructures*. Bingley: Emerald Publishing Limited, pp. 1-13.

Bridge G, Bouzarovski S, Bradshaw M et al. (2013) Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy* 53: 331-340.

Bridge G, Bulkeley H, Langley P and Van Veelen B (2020) Pluralizing and problematizing carbon finance. *Progress in Human Geography* 44(4): 724-742.

Brown CA and Pena JL (2016) Water Meters and Monthly Bills Meet Rural Brazilian Communities: Sociological Perspectives on Technical Objects for Water Management. *World Development* 84: 149-161.

Calver P and Simcock N (2021) Demand response and energy justice: A critical overview of ethical risks and opportunities within digital, decentralised, and decarbonised futures. *Energy Policy* 151: 112198

Cardoso CA, Torriti J and Lorincz M (2020) Making demand side response happen: A review of barriers in commercial and public organisations. *Energy Research & Social Science* 64: 101443.

Carlsson-Hyslop A (2016) Past Management of Energy Demand: Promotion and Adoption of Electric Heating in Britain 1945-1964. *Environment and History* 22(1): 75-102.

Chiapello E (2018) Optimisation in the context of financialisation. In: King V, Gerisch B and Rosa H (eds) *Lost in Perfection: Impacts of Optimisation on Culture and Psyche*. London: Routledge, pp. 13-23.

Clark GL and Evans J (1998) The Private Provision of Urban Infrastructure: Financial Intermediation through Long-term Contracts. *Urban Studies* 35(2): 301-319.

Clastres C (2011) Smart grids: Another step towards competition, energy security and climate change objectives. *Energy Policy* 39: 5399–5408.

Curtis M, Torriti J and Smith ST (2018) Demand Side Flexibility and Responsiveness: Moving Demand in Time Through Technology. In: Hui A, Day R and Walker G (eds) *Demanding Energy: Space, Time and Change*. Cham, Switzerland: Palgrave Macmillan, pp. 283-312.

Fields D (2019) Automated Landlord: Digital technologies and post-crisis financial accumulation. *Environment and Planning A: Economy and Space*. Epub ahead of print. DOI: 10.1177/0308518X19846514

Goulden M, Spence A, Wardman J and Leygue C (2018) Differentiating 'the user' in DSR: Developing demand side response in advanced economies. *Energy Policy* 122: 176-185.

Graham S (2009) When infrastructures fail. In: Graham S (ed) *Disrupted Cities: When Infrastructures Fail*. London: Routledge, pp. 1-26.

Grandclément C, Pierre M, Shove E and Nadaï A (2019) Contentious Interfaces: Exploring the Junction between Collective Provision and Individual Consumption. In: Shove E and Trentmann F (eds) *Infrastructures in Practice; The Dynamics of Demand in Networked Societies.* Abingdon: Routledge, pp. 143-154.

Guy S and Marvin S (1995) Reconfiguring urban networks: demand-side management in the United Kingdom. *Journal of Urban Technology* 2(3): 45-58.

Guy S, Graham S and Marvin S (1999) Splintering Networks: The social, spatial and environmental implications of privatization and liberalization of utilities in Britain. In: Coutard O (ed) *The Governance of Large Technical Systems*. London: Routledge, pp. 149-170.

Haarstad H and Wanvik TI (2017) Carbonscapes and beyond: Conceptualizing the instability of oil landscapes. *Progress in Human Geography* 41(4): 432-450.

Hamidi V, Li F and Robinson F (2009) Demand response in the UK's domestic sector. *Electric Power Systems Research* 79(12): 1722-1726,

Hannah L (1979) *Electricity Before Nationalisation. A Study of the Development of the Electricity Supply Industry in Britain to 1948*. London: The Macmillan Press Ltd.

Harvey P, Jensen CB and Morita A (2016) Introduction: Infrastructural Complications. In: Harvey P, Jensen CB and Morita A (eds) *Infrastructures and Social Complexity. A companion*. Oxon: Routledge, pp. 1-22.

Helgesson C and Muniesa F (2013) For What It's Worth: An Introduction to Valuation Studies. *Valuation Studies* 1(1): 1-10.

Hughes T (1993 [1983]) *Networks of Power: Electrification in Western Society, 1880-1930*. Baltimore: The Johns Hopkins University Press.

Knight ERW and Sharma R (2015) Infrastructure as a traded product: A relational approach to finance in practice. *Journal of Economic Geography* 16(4): 897-916.

Kornberger M, Justesen L, Madsen AK and Mouritsen J (2015) *Making Things Valuable*. Oxford, UK: Oxford University Press.

Kragh-Furbo M and Walker G (2018) Electricity as (Big) Data: Metering, spatiotemporal granularity and value. *Big Data & Society*. Epub ahead of print 9 February 2018. DOI: 10.1177/2053951718757254

Kuzemko C, Lockwood M, Mitchell C and Hoggett R (2016) Governing for sustainable energy system change: Politics, contexts and contingency. *Energy Research & Social Science* 12: 96-105.

Lamont M (2012) Toward a Comparative Sociology of Valuation and Evaluation. *The Annual Review of Sociology* 38 (21): 1-21.

Langendahl P-A, Roby H, Potter S and Cook M (2019) Smoothing peaks and troughs: Intermediary practices to promote demand side response in smart grids. *Energy Research & Social Science* 58: 101277.

Langley P (2016) Crowdfunding in the United Kingdom: A Cultural Economy. *Economic Geography* 92(3): 301-321.

Leszczynski A (2016) Speculative Futures: Cities, Data and Governance Beyond Smart Urbanism. *Environment and Planning A: Economy and Space* 48(9): 1691-1708.

Leyshon A and Thrift N (2007) The Capitalization of Almost Everything: The Future of Finance and Capitalism. *Theory, Culture & Society* 24 (7-8): 97-115.

Li B, Shen J, Wang X and Jiang C (2016) From controllable loads to generalized demand-side resources: A review of developments of demand-side resources. *Renewable and Sustainable Energy Reviews* 53 (January): 936-944.

Lockwood M, Mitchell C, and Hoggett R (2020) Incumbent lobbying as a barrier to forward-looking regulation: The case of demand-side response in the GB capacity market for electricity. *Energy Policy* 140: 111426.

Loftus A (2006) Reification and the dictatorship of the water meter. *Antipode* 38 (5): 1023-1045.

Loughran K (2014) Parks for Profit: The High Line, Growth Machines, and the Uneven Development of Urban Public Spaces. *City & Community* 13(1): 49-68.

MacKenzie D, Beunza D, Millo Y and Pardo-Guerra JP (2012) Drilling through the Allegheny Mountains. *Journal of Cultural Economy* 5(3): 279-296.

Mezzadra S and Neilson B (2017) On the Multiple Frontiers of Extraction: Excavating contemporary capitalism. *Cultural Studies* 31(2-3): 185-204.

Mitchell C (2008) *The Political Economy of Sustainable Energy*. London: Palgrave Macmillan.

Muniesa F (2012) A Flank Movement in the Understanding of Valuation. *The Sociological Review* 59 (s2): 24-38.

Narsiah S and Ahmed W (2011) The Neoliberalization of the Water and Energy Sectors in South Africa and India. *Journal of Asian and African Studies* 47(6): 679-694.

National Grid (2015) *Future Balancing Services*. 1 October 2015.

National Grid (2016) *Power Responsive. A short guide to how your business can profit from Demand Side Response*. August 2016.

National Grid (2017) *System Needs and Product Strategy. UK Electricity Transmission*. June 2017.

National Grid (2020a) *Future Energy Scenarios. GB gas and electricity transmission*. July 2020.

National Grid (2020b) *Power Response. Annual Report 2020. A roundup of developments in demand side flexibility markets in GB*. 2020.

National Grid (2021) *Commercial Aggregation Service Providers.*

Ofgem (2002) *The review of the first year of NETA - a review document vol. 1*. 24 July 2002

O'Neill PM (2013) The financialisation of infrastructure: the role of categorisation and property relations. *Cambridge Journal of Regions, Economy and Society* 6(3): 441-454.

Olkkonen L, Korjonen-Kuusipuro K and Grönberg I (2017) Redefining a stakeholder relation: Finnish energy "prosumers" as co-producers. *Environmental Innovation and Societal Transitions* 24: 57-66.

Pasquale F (2015) *The Black Box Society: The secret algorithms that control money and information*. Cambridge, MA: Harvard University Press

Powells G, Bulkeley H, Bell S and Judson E (2014) Peak electricity demand and the flexibility of everyday life. *Geoforum* 55: 43-52.

Powells G and Fell M (2019) Flexibility Capital and Flexibility Justice in Smart Energy Systems. *Energy Research & Social Science* 54: 56-59.

Randles S and Mander S (2011) Mobility, Markets and 'Hidden' Intermediation: Aviation and Frequent Flying. In: Guy S, Marvin S, Medd W and Moss T (eds) *Shaping Urban Infrastructures: Intermediaries and the Governance of Socio-Technical Networks*. London: Earthscan, pp. 75-91.

Schifferes J (2013) Profiting from Sharing (Part 2). In: *RSA Blog entries*, 6 August. Available at: https://www.thersa.org/blog/2013/08/profiting-from-sharing-part-2 (accessed 09.12.2022)

Shove E, Watson M and Spurling N (2015) Conceptualising connections:energy demand, infrastructures and social practices. *European Journal of Social Theory* 18(3): 274-287.

Shove E and Trentmann F (2019) *Infrastructures in Practice: The Dynamics of Demand in Networked Societies*. Abingdon: Routledge

Siano P (2014) Demand response and smart grids – a survey. *Renewable and Sustainable Energy Reviews* 30 (February 14): 461-478.

Silvast A (2017) Energy, economics and performativity: Reviewing theoretical advances in social studies of markets and energy. *Energy Research and Social Science* 34: 4-12.

Smale R, Spaargaren G and van Vliet B (2019) Householders co-managing energy systems: space for collaboration? *Building Research & Information* 47(5): 585-597.

Spence A, Demski C, Butler C, Parkhill K and Pidgeon N (2015) Public perceptions of demand-side management and a smarter energy future. *Nature Climate Change* 5 (2015): 550-554.

Star SL and Ruhleder K (1996) Steps towards an Ecology of Infrastructure: Design and Access for Large Information Spaces. *Information Systems Research* 7(1): 111-134.

Thatcher J, O'Sullivan D and Mahmoudi D (2016) Data colonialism through accumulation by dispossession: New metaphors for daily data. *Environment and Planning D: Society and Space* 34(6): 990-1006.

The Energyst (2019) *Demand Side Response: Shifting Value*. *2019 report*. London: Energyst Media

Torrance MI (2008) Forging Glocal Governance? Urban Infrastructures as Networked Financial Products. *International Journal of Urban and Regional Research* 32(1): 1-21.

Torriti J (2016) *Peak Energy Demand and Demand Side Response*. London: Routledge.

Torriti J and Grunewald P (2014) Demand side response: patterns in Europe and future policy perspectives under capacity mechanisms. *Economics of Energy & Environment Policy* 3(1): 87-105.

Walker G (2021) *Energy and Rhythm: Rhythmanalysis for a Low Carbon Future*. London, UK: Rowman & Littlefield Publishing Group, Inc.

Whiteside H (2019) The state's estate: Devaluing and revaluing 'surplus' public land in Canada. *Environment and Planning A: Economy and Space* 51(2):505-526.

Zook M and Grote MH (2016) The microgeographies of global finance: High-frequency trading and the construction of information inequality. *Environment and Planning A: Economy and Space* 49(1): 121-140.

Notes

1 In October 2020, a new frequency response product 'Dynamic Containment' was introduced to replace the dynamic and enhanced frequency response services. The min. size is 500 MW with a notice period of under 1 second with output sustained for 15 minutes. The service is procured day-ahead and paid an availability fee (National Grid, 2020b).

2 National Grid (2017: 3) notes that its 'Demand Turn Up' service encourages energy users to 'increase demand (through shifting, not wasting unnecessarily)'.