Electricity as (big) data: metering, spatiotemporal granularity and value

Introduction

Electricity is a distinctive phenomenon in terms of how readily its properties can be known. Whilst the consequences of electricity can be observed in various ways through the energetic work that it performs – in, for example, the intended movement of an electric fan, or the unintended consequences of electrocution - electricity itself is not directly perceivable in its presence, movement or amount. We may assume that electricity - '*the stream of vital materialities called electrons*' (Bennett, 2010: 28) - is contained within the wires and cables of an electrical network, but its quantity and flow do not directly display themselves. The making of its properties into data, and that data into knowledge and evidence with value (Leonelli, 2014), is therefore particularly important to the relations that are formed around electricity as a produced, managed and commodified socio-technical phenomenon.

In this paper we are interested in how electricity becomes evidence with value in the context of the current frenzy of data-related activity within energy systems and the wider emergence of big data and its socio-technical imaginary as '*a remarkable reassertion of empiricism*' (Bell, 2015: 24). Laying digital data infrastructures over electricity infrastructures has been seen as integral to the transformation of energy systems into low carbon forms, with the rhetoric of 'smartness' capturing many of the forms of change and innovation that have been imagined and advocated (Guy and Marvin, 1995; Clastres, 2011; Strengers, 2013; Bulkeley et al., 2016). Our aim is to establish both how, in becoming digital and a subject of big data (Kitchen and McArdle 2016), electricity is now able to be known differently; and what within its consumption and use is consequently becoming newly visible, accountable and able to be acted on. In so doing we seek to provide a distinctive account of electricity metering as a data-making activity, given that much of the existing literature engaging with metering in energy systems (e.g. Guy and Marvin, 1995; Jack and Smith, 2015; Luque-Ayala, 2016; Von Schnitzler, 2013) has had different concerns.

In consumption settings electricity flow reaches its end point in powered devices – computers, lights, air conditioners, motors, pumps, heaters and much else. Electricity meters as measuring technologies generate a quantified account of the flow of electrons arising from the functioning of these devices; and indirectly of how these devices are part of performances of energy-using practices (Hui et al., 2018; Shove and Walker, 2014). We conceive such meter*ing* as an activity (or process, see Whittle et al. 2015), a form of 'quantification work' (Espeland and Stevens, 2008) in which flow is measured and data is made and becomes mobile in particular spatial and temporal terms, enabling its entry into data infrastructures and schemes of translation and evaluation. Implications then follow for what is known and what is obscured, and how value is made and acted on (Leonelli, 2014). We interrogate metering activity and its transition into the making of 'bigger', more spatiotemporally granular data through focusing empirically on those actors actively involved in pushing forward, selling and materialising new metering technologies and related data infrastructures and services for larger businesses and public sector organisations. In these settings, 'advanced' digital metering of patterns of electricity flow is becoming established and routinely implemented, a trajectory that is significantly ahead of domestic applications (in the UK at least). Although household smart metering has received much attention, it is not yet firmly in place or operational at scale. We are interested then in how electricity as big data is being made commonplace, rather than its realisation as a product of research projects, trials or experiments (Hargreaves et al., 2010; Klopfert and Wallenborn, 2011; Powells et al., 2014; Naus and van der Horst, 2017), or its status in speculative claims about the future - which as Boellstorff and Maurer (2015) note have rather typified discussion of big data more generally.

We begin by spelling out further our conceptualisation of metering work in order to distil the key shifts made in the move from a metrological regime based primarily on meters as property-boundary fiscal devices, to a digital form in which radically new spatiotemporal orderings and dis-aggregations of electricity flow are being made possible. We then examine the claims of truth and visibility that are accompanying these shifts and their enrolment into management techniques that serve to more precisely apportion responsibility for electricity use, and evaluate particular patterns and instances of flow as normal/abnormal and good/bad, including in 'real-time'. We reflect on such value claims by opening up questions about the depth and significance of the performative consequences that follow. Having new tools for revealing and bearing down on energy use has demonstrable benefit, both internal to organisations and for societal goals of energy system transition. However, the scope of these outcomes is constrained by the economistic calculus that dominates value claims and the limitations of data-led framings of the behaviour change that is assumed to follow from producing visibility and apportioning responsibility to act. We conclude by considering the wider implications of approaching metering as a situated activity, and the need to further explore the patterns, geometries and politics of data-making that emerge in different settings and domains.

Measurement, metering and the pre-digital: electricity as data

The generation of quantitative data about phenomena in the world is a ubiquitous and generally taken for granted activity. Numbers, Espeland and Stevens (2008: 431) argue, '*should be regarded as deeds*', whose making involves considerable work even when apparently straightforward. While electricity meters can be straightforwardly approached as devices that measure what flows through them – electricity moving from one 'side' of the meter to the other - we consider them here as key elements of meter*ing* as a socio-technical activity enacted in a particular situated manner. This activity, in simple terms, generates numbers measured by meters and mobilised as data objects from which value is derived; value, which in turn justifies and resources the metering work which generates the numbers. However, exactly what numbers are generated, as representations of which phenomena in space and time, and as part of realising what form of value, are all a matter of particular situated resolution. Starting from this perspective, we can then open up and analyse the transformation from pre-digital to digital metering activity that is the main concern of our analysis.

In the late 19th Century, when the foundations of the pre-digital regime of electricity metering were first being put in place, considerable work was involved in establishing how the measurement of electricity should be undertaken. Electricity at the time was only qualitatively known, including through theatrical displays and expert judgement of its intensities, form and effects (Gooday, 2004). Scientists though sought after its measurement and quantification. William Thomson's often quoted assertion of the epistemological supremacy of numbers was made specifically in the context of the struggle at the time to measure and better know electricity:

> '*I often say that when you can measure what you are speaking about and express it in numbers you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind*' (William Thomson 1883, quoted in Gooday 2004: 3)

Electricity initially proved resistant to being expressed in numbers, not least because there were fundamental disagreements about exactly what sort of phenomenon it was, but, in time, different qualities were isolated and calibrated and laboratory based measuring technologies became established. It soon also became clear that there were commercial applications of these technologies (Arapostathis, 2013). As electrical power became practically deployed, those seeking a return on investment in infrastructure and a way of financing the operating costs of electricity generation, looked to metering to establish the basis of an exchange value between supplier and customer. Accordingly the installation of 'direct-reading' electro-mechanical meters (Weranga et al., 2014), located in customers' premises and measuring flow across the meter in units of kilowatt hours (kW/h), became integral to the rolling out and extension of electricity infrastructure and use into the everyday practices of consumers. Electricity metering 'at a distance', as it diffused and stabilised into a form of metrological regime (Barry, 2005), had then a particular purpose in which three key sets of relations were established – in turn between equivalised powered devices, between flow either side of the meter and between measurement and meter reading.

First, as a scheme of quantification and data-making, metering necessarily involves commensuration, as defined by Espeland and Sauder (2007: 14), '*the transformation of qualitative relations into quantities that share a metric, a process that is fundamental to measurement*'. In electricity metering, commensuration is enacted through the shared metric of the kilowatt hour (Kw/h) which quantifies the functioning of electricity-using devices in terms of electricity flow. Such devices have hugely multiplied in their number and diversity over time as electricity demand has been co-produced with its supply (Harrison, 2013; Hughes, 1993 [1983]; Shove and Walker, 2014). Whilst electricity using devices can have qualitatively very different characteristics (e.g. a light bulb, air conditioner and computer) and the electricity flow they instigate can be deployed to very different ends (illumination, cooling, entertainment), commensuration through the metric of the Kw/h works to produce and enumerate their equivalence. The functioning of powered devices is homogenised through '*commensurating disparate entities*' (Espeland and Stevens, 1998: 318), quantifying the electricity they use rather than any other qualities of their working.

Second, whilst in principle the meter as measuring technology can be placed at any point in a wiring network, the early geography of metering 'at a distance' is configured singularly at property boundaries[1]. Its ordering role is to apportion electricity flow in terms of who is to be charged for it, a fiscal purpose. Meters then demarcated a physical boundary of responsibility and a relation between flow as consumption (behind the meter) and flow as supply (in front of the meter). Enabled by commensuration, this boundary demarcation also serves to aggregate the working of whatever set of disparate devices are drawing electricity flow across it. The specifics of the intensity of use, measured in Kw/h, of any one device behind the meter is invisibly aggregated with others, indistinguishable in the metered record.

Third, whilst at the metered point measurement is continual, accumulating as a 'total consumed' over time, the making of a mobile data object is a distinct process, enacted in a particular way and with its own temporality. In the pre-digital regime the meter's measurement predominantly only

[11] Metering also takes place within the supply system to monitor flow from generation and distribution, but our focus is on consumption settings where the end uses of energy are located.

travelled beyond the device at points in time determined by the rhythms of producing customer bills, establishing a particular fiscally-determined relation between measurement and mobile data-making. This labour intensive start to a socio-material data journey (Bates et al., 2016), involved manual embodied transcription (by travelling supply company employees or potentially consumers themselves), transferring momentarily read numbers from meter dials to paper, and then to technologies of accounting and cost calculation. In, for example, a system of 'quarterly billing' just four data objects are therefore mobilised from the continually recording meter per year, readings being taken approximately every 3 months – approximately because the exact timing of manual readings was inevitably subject to locally encountered practicalities. This temporality therefore further serves to aggregate and obscure the detail of any one instance of energy use within the metered record.

To summarise, what we have then in the pre-digital period is a deeply sedimented but still particular form of metering work, enacted at boundary of consumption settings, producing an aggregated representation of the functioning of electricity using technologies. The meter produces in effect a trace of a slice of the ongoing everyday enactment of electricity-using practices (Shove and Walker, 2014), measured in Kwh, but in such aggregated spatial and temporal terms that nearly all the detail of that enactment - the work done by what devices, to which ends and as part of which practices - remains hidden. Electricity flow is rendered knowable but in scant terms, with few relations formed by the data sporadically made mobile. In many ways it therefore remains anonymous, lacking any more specific identity.

Digital metering: electricity as big data

Having established a way of thinking about metering as a situated activity, and distilled its pre-digital form, the rest of our discussion is focused on ongoing moves towards knowing electricity digitally. In jumping to the contemporary, details of the evolution and application of metering technology during the century-long pre-digital period and its relation to particular schemes of billing and paying (e.g. prepayment and basic day-time/night-time time of use charging) are necessarily overlooked. Our main concern is with electricity as big data and it is only with the arrival of digital devices, infrastructures and analytical capabilities that key big data qualities (Kitchin, 2014) begin to materialise.

In order to explore the production, use and implications of big electricity data we draw on three sources of evidence. First, an analysis of marketing materials (brochures and websites) from 23 providers of meters, metering services, energy data analytics and related software systems, representing most of such companies operating in the UK (as of late 2016). Second, interviews with 7 of these companies (with company directors in some cases, marketing representatives and/or technical specialists in others) that sell their products and services to a wide range of sectors including retail, transport, hospitality, education and manufacturing as well as an interview with an agency commissioning metering services for a large number of public sector organisations. Third, observations and informal discussions at a series of trade exhibitions, industry conferences, training sessions and workshops in the UK focused on energy data and its role in energy management, variously taking place during 2015-17 (8 such events in total). All of this empirical material was interrogated drawing on discursive social psychology approach to discourse analysis (Potter and Wetherell, 1987) with a focus on how energy management and energy data is accounted for, and in particular what assumptions are made about energy usage, and what realities energy data is imagined to produce. In combination this data[2] gave us substantial insights into the claims being made about the value of metering digitally, as well as (in the interviews and interactions at industry events), perspectives on some of the complexities involved in realising this value.

It was clear that there is a growing number of companies involved in the provision of metering and associated data management, analytical and software services. As one interviewee commented, '*there are a lot of players, so virtually every month, I see two or three new names*' (Interview 1). This commercial activity was almost entirely focused on selling technology and services to businesses and public sector organisations as *consumers of* electricity – a distinct reorientation therefore away from metering for the exchange value of suppliers. The value of measurement was to better know and intervene in electricity flow before it reached the fiscal meter of the supply company. The headlines of promotional material therefore coupled measurement with management, such as '*you can't manage what you don't measure*' (Company H); '*the greater the data, the better the control*' (Company A).

While such rhetorical phrases can be read as general appeals to management logics and their 'culture of quantification' (Porter, 1995), more specifically they connect to the practice of energy management and the work of energy and facility managers (Goulden and Spence, 2015). The specific claim is that their work can only properly be performed through having more data as its foundation. In the events and meetings we observed, this claim was ubiquitous and largely uncontested. An energy manager of a large city authority explained in a presentation at a trade event, that his job had for a long time been held back by his lack of knowledge about exactly how,

[2] In quoting extracts from this data we have anonymised all marketing material in the format Company A through to W, and interviews as Interview 1 through to 8.

where and when energy was being used across the complex portfolio of buildings he was responsible for. His enthusiasm for entering a new data-rich era was to have a new truth to underpin his work, to quote:

> "*I now have the truth… It's fantastic ... I want 100% data. I don't want to make excuses… I want a smart meter on a light bulb*".

Others also used a language of truth to refer to what new data-making practices could realise, for example, a marketing brochure referred to achieving '*a single version of the truth*' (Company C), and a sales manager for a metering service provider commented:

> "*I believe that what's happening is that as you get more real time data, actually you do get the truth … you get a much truer picture. So I don't think the data was lying before, but I just think that it's a different picture*" (Interview 4)

The use of visual terms and metaphors was also recurrent, in terms of now being able to see with greater clarity, in new and better ways, to have 'transparency', a 'holistic view' or 'unmatched visibility' to quote various examples. One interviewee likened metering to a doctor being able to see inside a body:

> "*meters are like someone going to the doctor. So once the doctor starts to observe things, they find something with the patient and that's very much the same with our observations with a building*" (Interview 1)

Both truth and visibility are familiar tropes of big data. Big data sponsors profess '*that the more data there would be, the more truth we would have*' (Bell, 2015: 13). Ananny and Crawford (2016: 2) refer to '*the transparency ideal*' that has offered *'a way to see inside the truth of a system'* with *'[t]he implicit assumption […] that seeing a phenomenon creates opportunities and obligations to make it accountable and thus to change it*'. However, what it means to see any one phenomenon is contingent on its specificities and the mechanisms of its opacity or invisibility. As earlier argued, electricity has a particular material invisibility; its flow only enumerated *where* it is metered and *when* mobile data objects are created. This intrinsic spatial and temporal ordering and aggregation is specifically then what advanced, digital capabilities are being claimed to open up from their tight bounding in the pre-digital period.

In spatial terms opening-up is about the proliferation of sub-metering, which is measurement at points of the internal wiring network extending behind the fiscal meter. Flow is therefore not measured at the property boundary, but at multiple points within it. Sub-metering already existed to some extent in the pre-digital era, using conventional meters, particularly where organisations occupied sites across multiple buildings. Advanced digital meters - substantially cheaper to manufacture than their earlier versions, smaller physically, multi-functional and much easier to install (able to be 'snapped' over existing cables rather than 'wired in') – enable sub-metering to be proposed and established with much greater flexibility, and at a much greater density (Bedwell et al., 2014; Weranga et al., 2014). In examples we were given intensive sub-metering could add up to hundreds or sometimes thousands of sub-meters within larger organisations, with one company advertising its software analytics as being '*scalable to handle tens of thousands of meters*' (Company G).

In temporal terms opening up is predicated on a shift from manual readings to digital communication. Depending on device and system specification, data can be released from advanced meters at minute down to second and potentially sub-second intervals, this data then moving rapidly over wired or wireless infrastructure. Thousands of data points on electricity flow can then be generated per hour or day from each meter, a radical rescaling when compared to the quarterly, monthly or, at most, weekly manual readings of pre-digital metering. The vague temporal approximation of measurement by embodied meter readers is also replaced by an exact automated temporality in digital form making precisely time-stamped flow measures. As one marketing pitch put it, meters are thus worked harder, transformed from a largely 'idle asset' into a 'work horse' (Company D).

Seeing digital metering in these spatiotemporal terms gives a particular character to the truth and visibility claims that permeated our data. Truth, did in some cases relate to the more reliable and precise data made by digital meters as measuring technologies, but more substantially, and when linked to visibility, truth was in the realisation of disaggregation; the ability to know the drawing through of electrical current by powered devices, not in organisation or building-scale chunks accumulating over extended periods of time, but rather in a fine-grained granular form, more exact in its attribution of the source and patterning of flow in time and space. As expressed by an interviewee referring to the shape of a graph showing a detailed trace of electricity consumption data over time:

> "*I don't think energy management is all about accuracy, about precision. It is about understanding, and you get that understanding because you understand the profile, because*

> *you understand the shape, because you can see a spike where you hadn't seen a spike before*" (Interview 2)

If then in the pre-digital period the identity of electricity flow was largely obscured and homogenised through its aggregation, now as big data the possibility existed for it to be differentiated and assigned new specific characteristics and qualities.

Big electricity data and value

The capability to know electricity more intensely is clear, but what value is there in its realisation? Or to pose the question in a different way, if one metering and data services provider claims that '*best-in-class companies are moving from metering buildings to real time device monitoring*' (Company H), to what ends could such a radical shift and investment in the density of data-making, if taken literally, be justified? A range of claims about value were made across our empirical material, but we focus here on two interrelated categories in which volume and granularity are specifically enrolled.

Apportioning responsibility

The value of metering in the pre-digital period was to derive exchange value through delineating a boundary of responsibility between consumer and supplier either side of the fiscal meter. Sub-metering offers the possibility of further apportionment being carried out behind the fiscal meter, in some instances to the same billing-related ends. In the example of an airport, it was explained there was value in having '*very detailed signatures*' to more precisely pass on the cost of electricity being used by an aircraft, as a temporarily connected end-use device:

> *"when an aircraft lands, taxies right off the runway, before you get off, they basically plug it into the electricity supply, so they need to be able to bill to a very small resolution, just to the nearest half hour is not good enough, because the plane might only be there for fifty minutes"* (Interview 6)

Further examples of where it was seen as worth dividing up electricity flow through sub-metering, included sub-letting arrangements within organisations and buildings where electricity use had previously been 'included in the rent' at a flat rate (including shopping centres, hotels and large office buildings). Sub-metering was seen to give tenants more direct responsibility for their electricity use - also referred to as 'fair billing' on a number of occasions.

Rationales for apportioning responsibility in more granular terms were not though limited to billing. The flexibility to divide flow through sub-metering data into, for example, different floors of a building, different business functions and different cost or profit centres, was talked about both as a way of making electricity use known and visible in these categories (or 'drilling down' as an interviewee put it), but also allocating responsibility for that use to each of those units of activity, and the individuals working within them. Having apportioned responsibility (Bedwell et al., 2014) it was argued, the identity given to each portion of electricity flow would make it relevant and visible to those responsible for it, and incentives could then be introduced to promote or discipline attention, accountability, frugality or other positively valued engagements - data is '*an input to change behaviour*' (Company F) as described in one brochure and to '*empower positive change through greater intelligence*' (Company C) in another. Such initiatives to motivate energy-related behaviour change in workplaces have been increasingly experimented with over recent years (Staddon et al., 2016; Whittle et al., 2015), typically with forms of data-centred feedback and visualization as integral components. As well as there being evaluative questions as to the 'best' units that consumption data should be apportioned into, and then fed back to (e.g. individual v group level)(Bedwell et al., 2014), there are broader questions about the assumptions made in such initiatives about the causal relations between information and agency to which we will later return. We can for the moment though note how electricity is further abstracted through becoming fed-back and visualized data, translated into information that is seen to demand action rather than understanding. As one interviewee noted:

> "*you don't necessarily need to know what does a kilowatt mean, what does a kilowatt look like, you just understand what I call the key performance indicators*" (Interview 1)

Evaluating patterns

A second rationale, closely related to apportionment, centred on the value to be derived from making and comparing patterns in and from metered data. Patterns that could enable the evaluation of particular instances of electricity flow as normal or abnormal, better or worse, good or bad. There were recurrent exemplifications of this form of evaluation, with pattern analysis comparing energy use and costs between branches of multi-site enterprises (such as shops or restaurants); different floors of buildings; different levels of productivity or profiles of customer footprint; and across various temporal categories. Electricity flow data in these modes of analysis is both compared with itself over space and time, as well as being set in relation to other available quantified indicators of organisational performance. A recurrent representation used to demonstrate such 'analytic insights' took the form of the so-called 'top hat' diagram (see Figure 1), which visually aligns electricity flow over time with data about opening-closing, start-end, occupied-unoccupied times. Electricity use 'out of hours' is then evaluated as potential 'waste', as unproductive or unnecessary flow.

[Figure 1 about here]

Figure 1: Example of visualization of half-hourly measured electricity flow across days of a week in relation to times at which a workplace building is occupied

Such evaluation is taken further in software systems designed to produce automated 'alerts', 'alarms' or 'exception reports' when patterns in the measured flow data were judged to warrant intervention. Their production is an algorithmic calculative practice (Ananny and Crawford, 2016) following a temporal logic that expects what has been measured as normal before (averaged over a specific temporal granularity) to be what is subsequently measured in comparable periods of time. Problematic electricity data and the flow it represents is therefore that which doesn't properly fit into normal, expected temporal patterns. It is in the comparisons between data points, and the relations formed between them that value is made, value which is then tightly linked both to the logic of temporal comparison and the expectation that action can be productively taken to address apparent abnormalities and re-establish continuity. Algorithmic work here is, as Amoore and Pithuk (2005: 341) argue, both about '*making the extensity of big data … comprehensible*' but also directing attention to what is deemed to be important, following a tightly deterministic logic. The forms of abnormality in the data that could be spotted were described expansively by one company as '*negative readings, high readings, low readings, zeroes, spikes, missing data*' (Company M), with these constituting traces of both technical and human failings, for example, equipment breaking down or malfunctioning, electricity-using devices being switched on when they should normally be switched off (or vice versa) and employees opening windows or propping open doors.

In making value in these terms, some degree of spatiotemporal precision is crucial, real-time data indicating something is 'wrong' and enabling, if not demanding, a real time response; and that 'wrong-ness' being more immediately traceable because of the smaller and less aggregated parcels of flow that are being monitored. Rather than devices and their use within practice performances therefore able to be invisibly unstable or erratic in their electricity-using consequences, automated surveillance enables their disciplining. This was talked about as establishing control over electricity as an unreliably consumed commodity, for example:

> *"[our system] issues alarms via email and social media (e.g. twitter) when it detects anomalies in expected consumption, putting **you** in control.* (Company N)

As this extract demonstrates, the surveillance that underpins this apparent enabling of control is able to be enacted over a widely distributed geography, with alerts transmitted across social media and data feeds leading to variously located visualization screens and dashboards – such as in energy managers offices locally and at 'head office' within multi-site organisations, in consultancies or subcontractors offices or increasingly on mobile devices enabling surveillance on the move. Gunther et al. (2017) argue that such 'portability' is a key feature of big data applications in organizations, enabling data to travel between contexts and across organisational levels and hierarchies. A key contrast from the pre-digital metering regime then is how electricity data journeys can be far more extended and flexibly configured, with implications for what forms of comparison, evaluation, responsiveness, 'emergent insights' (ibid; 201) and applications of data analytics might be realised and translated into governance frameworks aligned at different scales.

This is particularly clear in how the value of temporal granularity was extended, in some of our interviews and more recent industry events, to users maximising the economic potential of their interactions with the electricity grid. Larger electricity consumers are now charged variable prices for their consumption at different times of day, particularly at times of peak load on the grid (Torriti, 2016; Walker, 2014). National Grid also runs various 'demand response' schemes designed to incentivise bigger electricity users to cut back on their electricity use when 'the grid' needs them to (Curtis et al., 2018). Specific flows of electricity therefore have come to acquire different monetary cost and value. To capitalise on such developments metering and pattern analytics have become integral to sorting out cheaper from more costly flows, establishing the scope for avoiding electricity use during costly periods, and/or for reducing consumption when contracted to by National Grid. Closely targeted metering (of specific consuming devices and of their switching on and off) subsequently then evidences to National Grid the responsiveness actually enacted, establishing that electricity was *not* consumed when it normally would have been. Through data portability new relations are thus being formed across scales with measures of on-site electricity flow and non-flow mobilized far beyond their enactment, and entering into the information circuits that are central to the governance of national-scale energy markets (Ozden-Shilling, 2015).

Performativity and granularity: promises and cautions

Having described and distilled key features of measuring electricity flow digitally and the emergence of capabilities to enact metering with far more spatiotemporal granularity, analytical sophistication and data portability, what significance might be reasonably ascribed to these developments, particularly in terms of the goals of energy system transformation?

In principle there is much to be positive about the making of big electricity data, reflecting broader claims about a range of 'natural alignments' between big data and business and organisational sustainability objectives (Etzion and Aragon-Correa, 2016: 147). As made clear in the introduction, energy use matters beyond just the internal balance sheets of individual businesses and organisations, with the governance of energy use enrolled into wider societal goals of carbon mitigation and energy system transition. Data-driven targets, audits and evaluations are designed to promote performances of various sorts, they are "*part and parcel of the performative nature of social relations*" (Busch, 2017: 670) shaping what is to be responded to and in what terms. If therefore, through the formation of digital data infrastructures, energy use is able to matter more to day-to-day management, priority setting and decision-making – including because data about electricity is now closer to the expected standard of reliability and granularity of other organisational datasets about costs, productivity, return on investment and so on – then wider societal value can be realised. The data-dependent articulation between internal energy management and the 'demand responsiveness' now being sought after for the good of the electricity system as a whole is a case in point. We might even be positive about how the escalating energy-use burden of digital technologies and infrastructures themselves (Ropke and Christensen, 2012) can be balanced, at least to some small degree, by the benefits of knowing electricity through big data. Not only might data centres act as sources of useful data-driven heat production (Velkova, 2016), but at least some of the vast data they contain might help enable energy use elsewhere to be better understood and managed. Following this line of argument the International Energy Agency has recently argued that digitalisation has 'transformational potential' for the better efficiency of energy systems, holding down energy demand even as the growth in digital technologies pushes it upwards (IEA 2017; 11).

However, we need to be very much aware of the naive promises that can accompany the arrival of digital technologies and big data imaginaries, in particular the creation of an illusion of 'near omniscience' for those seeking new means of management and control (Busch, 2017). The forming of new relations around energy data, and their entry into agentive schemes of evaluation and action, is only a *potential* outcome of digital metering as an activity, rather than an intrinsic achievement of the 'cleverness' of new devices or the radical acceleration of data accumulation. Transparency is never absolute with decisions still made as to exactly where and how frequently the hidden materiality of electricity flow is to be made visible. In our empirical material, the general value of speed (Beer, 2017) was uncontentious, but the specific measure given to so-called 'real-time' variously shifted from data-making every second, to every minute, 6 minutes and 15 minutes. Furthermore, as Annay and Crawford (2016) argue, visibility can be 'disconnected from power', giving only the illusion that action follows directly from knowledge. A more cautious assessment of the emergence of electricity as big data in the settings and networks of commercial actors we have been concerned with, highlights a number of limitations or wider concerns.

First, across all the claims, arguments and rhetoric we encountered, financial framings dominated. Economic calculus framed the value of visibility, the particular forms of granularity that were sought after, and the actions this enabled; to reduce energy costs and contribute to the 'bottom line', directly or indirectly. Whilst this is unsurprising, there is a difference between enumerating electricity flow in terms of cost units and other metrics such as carbon units. Translating flow into carbon units forms differently configured relations between sources of low and high carbon electricity generation and their end use (Lovell and MacKenzie, 2011), such that driving down costs does not necessarily reduce carbon in proportionate terms. A focus on carbon could also prioritise different configurations of spatiotemporal granularity and different algorithm-enabled comparisons and evaluations in the ongoing management of electricity consumption. There is therefore some slipperiness in the assumption that the internal organisational value derived from knowing electricity as big data, will automatically translate into wider societal value.

Second, even where the value of granular and real time data is cast in terms that mobilise senses of responsibility for climate change and care for the common good – rather than just saving money for the business – this is typically through logics that too easily find causal relations between information provision, awareness and action. Or in more Foucauldian terms that too readily see technologically enabled information feedback as a 'mode of capture' (Braun 2014) disciplining conduct in line with governance objectives. A recent systematic review of workplace energy saving behaviour change initiatives (Staddon et al., 2016) makes clear the lack of reliable evidence of their impacts, including the use of real time feedback and visualization technologies. Others have emphasised how employee engagement through digital tools can in practice be subject to the situated realities of such things as building designs, staff and financial cuts, institutional cultures of risk aversion and disagreement as to who is and should be responsible for energy management (Bull et al., 2015; Palm and Darby, 2014; Whittle et al., 2015). Such observations connect to broader critiques of individualistic, information led behavioural approaches to achieving sustainability and related goals (Shove, 2010; Strengers and Maller, 2015), with alternative frameworks emphasising the structuring effects of routines, material arrangements and conventions which mean that resource and energy use is deeply embedded in institutional and social dynamics, rather than readily subject to the agency of individual staff, or those seeking to manage them (Shove and Spurling, 2013; Hargreaves, 2011; McMeekin and Southerton, 2012). Critiques also focus on assumptions about the rationalities of such 'users' (Shove and Royston, 2014; Hargreaves et al., 2010) with Strengers (2013: 3) arguing that the 'smart ontology' that underpins visions of energy system transformation is refracted through imagined masculine ideals of an 'efficient, technologically-enabled and rational consumer'. Whilst this figure may arguably be easier to materialise in business and organisational settings than in domestic ones, we cannot assume that alternative identities do not permeate into being an energy user at work. For these reasons we should at least have some scepticism that big electricity data can be performative in the way that it is expected (or promised) to be.

A deeper critique would also point to the incrementalism built into the arrival of big data into the work of energy managers. Spotting waste, searching for inefficiencies and misbehaving technologies (and people) and feeding back on performance, however ever cleverly automated, real time and comprehensive, is to stay within the established bounds of energy management logics. Working with modes of automated algorithmic comparison that take what is normal and usual in the past as what should be normal and usual in the future is also antithetical to any more dynamic or disruptive sense of normativity and change. Marres (2015) sees the framing of domestic smart meters as limited, expanding the cast of implicated entities to some degree, but still blind to bigger questions about the relationship between technology and social change. Certainly we see no evidence in our data of any intent to open up such questions, suggesting a conservatism that underpins not only the normativity of specific modes of algorithmic analysis (Ziewitz 2016), but the agenda of data-led energy governance more generally

Conclusion: metering as a situated activity

The making of data about electricity has evidently moved on considerably from its origins, but the drive for quantification expressed by William Thompson in 1883, and the finding of truth-value in that quantification, still endures. The frenzy of measurement activity he was caught up in at the time is mirrored now by another, focused not on the basics of knowing electricity as a phenomenon, but on quantifying its flow in time and space to other ends. We have argued that all metering as an activity involves both commensuration between electricity-using devices and spatial and temporal orderings and aggregations, and have demonstrated the radical opening up of this spatiotemporal work that digitisation is enabling. Making electricity knowable as big data, we have argued, is to give its flow more specific and differentiated identity, more relate-able then to its consumption in the specific devices and practices that pull it through the meter, and to schemes and routines of normative evaluation. For the actors whose accounts we analysed new 'truths' are able to be created, truths that are seen to matter because of the value they bring to the enablement and legitimisation of forms of managing and acting. Electricity flow materialises then as an apparently far more countable and accountable phenomenon, although, as we have cautioned, the performativity that follows for the realisation of energy and carbon management objectives should not be too readily presumed.

The forming of new sets of relations between digital energy data and the integral technologies and performers of energy-using practices is articulated in analogous terms by Marres (2012: 295), who, in reflecting on a smart metering initiative in a domestic context argues that "*as digital devices allow for the monitoring and analysis of energy-in-use, they make it possible to render energy demand as a dynamic practice, in which an array of heterogeneous … entities are implicated*". Teenagers and toasters are her examples of social and technical entities that '*are situated on the same plane*' (ibid: 294) within the temporal peaks and troughs of visualised data. For workplace and organisational consumption settings we can add a vast array of other heterogeneous entities that are potentially being made more precisely relatable to energy flow through big electricity data – including functioning and malfunctioning technologies, staff in categories and collectives, patterns of weather and climate, opening and closing hours, specific activities, work practices and customer behaviours and time-varying electricity prices, distributed within and beyond the spatial configuration of any one organisational energy management regime.

Exactly what and who is actually included in such a cast of implicated entities and to what end depends on how metering work and its valorisation are practically enacted. As a situated sociotechnical activity it is an empirical question as to how metering is performed, how the measurement it enacts is patterned in space and time and how data-objects with value travel into governance schemes. Metering we have stressed does not take one pre-given shape, either in pre-digital or digital regimes - with variability even more apparent if we look beyond electricity to the metering of other utilities such as gas, water, heat and communications (Cowan, 2010; Guy and Marvin, 1995), and beyond the UK to other infrastructural and institutional geographies. There are undoubtedly far more metering geometries now available, but which out of the range of possibilities are being assembled, where and why remains to be established. Our investigation has focused on the perspectives of those actively promoting new technologies and services, but in the face of their selling and intermediary work, decisions remain to be taken by prospective clients both to meter and *not* to meter, to do so more or less intensively, convinced or otherwise by the value that can be achieved by moving from small to big (or at least bigger) electricity data.

Such decisions are not restricted to the larger business and public sector organisational settings we have been interested in. Much debate has also revolved around the introduction of new systems of electricity metering in domestic settings, in a variety of socio-political and geographical contexts (for example Von Schnitzler 2013; Horne et al. 2015; Luque-Ayala 2016). These cases have opened up not only debates about the cost and value of investing in new devices and infrastructures with particular data-making and handling capabilities, but also wider questions about the fairness and ethics of instigating new metering and related charging regimes, the translation of derived data into areas of governance far beyond the energy sector - such as census-making (Newing et al., 2016) - and related implications for data security and surveillance.

Clearly then one of the distinctions to be better understood is how metering work does and does not enrol forms of relation that enter it into more overtly controversial and political territory. In this respect it was striking that across all of our UK-based empirical material and related public commentary there was little evidence of the concerns about privacy, intrusion and data ownership that have characterised the roll out of government-mandated domestic smart meter installation programmes (Naus et al., 2014; Horne et al., 2015; McKenna et al., 2012). This absence could reflect both clearer data ownership lines and the expectation that business and public sector organisations will already in all sorts of ways monitor the performance and behaviours of their employees. In an era of Digital Taylorism and the 'quantified self at work' (Moore and Robinson, 2016), the possibility that employers may take advantage of the surveillance capacities of fine grained, real-time electricity data, may not, unsurprisingly, be a significant concern. Workplaces and homes would appear then to be quite different as sites of energy-related 'data politics' (Ruppert et al., 2017), with differently configured sets of relations established around apparently comparable innovations in metering technology and big data making.

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