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Digitalisation, energy and data demand: The impact of Internet traffic on overall and peak electricity consumption

Over the last decade, concerns have been raised about increases in the electricity used by information technologies, other consumer electronic devices, data centres, and to a much lesser degree, Internet distribution networks. At the same time, 'smart' innovations are widely anticipated to help reduce energy demand across diverse sectors of society. Yet such potential savings, as well as the increasing use of other digital services, are predicated upon continued expansion of digital infrastructures. This paper focuses on the phenomenal growth in Internet traffic, as a trend with important implications for energy demand. It outlines an agenda to better understand how data demand is changing. Drawing on findings from our own research in combination with secondary data analysis, we examine the alignment of peak demand for electricity and data. Peaks in data appear to fall later in the evening, reflecting the use of online entertainment, but this is far from fixed. Overall, the paper argues that a better understanding of how everyday practices are shifting, in concert with the provision and design of online services, could provide a basis for the policies and initiatives needed to mitigate the most problematic projections of Internet energy use.

Keywords
Internet, infrastructures, peak electricity demand, digital technologies, social practices, time-use

1. Introduction

It is widely expected that Internet-connected digital technologies will play a key role in transitions to a more sustainable and more energy efficient future. Take for example the interest in smart meters, grids and cities. Yet growth in the number of connected devices, the number and type of services and the levels of data traffic, processing and storage mean that the energy used to power the Internet is growing substantially. At the same time, the services it provides are becoming increasingly embedded in everyday and organisational ways of life. The proportion of Internet users has steadily increased to more than 90% in many economically developed countries (Salahuddin and Alam, 2016). As digital infrastructures, and the services and products they support, expand ever further, even in countries where Internet access is already widespread, the energy implications of ongoing digitalisation[1] are broad, complex and uncertain (IEA, 2017).

Whilst industry estimates suggest that, by 2030, 'smarter' systems could save 10 times the carbon emissions they generate (GeSI, 2015) and whilst some commentators point to the potentially transformative effect of information and communication technologies (ICT) on the energy-intensity of the

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[1] The IEA (2017: 21) define digitalisation as “the growing application of ICT across the economy” “encompassing a range of digital technologies, concepts and trends such as artificial intelligence, the ‘Internet of Things’ (IoT) and the Fourth Industrial Revolution”.

many sectors of the economy (Kander et al., 2014; Perez, 2016; IEA, 2017), other authors argue that the overall directionality of ICT, as it is *actually used*, is unsustainable (Røpke et al., 2010; Røpke, 2012; Røpke and Christensen, 2012). Røpke (2012) argues that in addition to its own lifecycle impacts, increasing Internet connectivity in everyday life fosters new, or otherwise more energy-intensive, forms of demand that counterbalance energy savings. Similarly, research suggests that smart home technologies may be associated with increases in energy consumption, both directly and in *other* areas of consumption, such as lighting or heating (Hargreaves et al., 2017; Strengers and Nicholls, 2017). Meanwhile, research into how digitalisation affects travel patterns finds little evidence of anticipated, direct substitutions between travel and online accessibility, with more complex and debated effects emerging over time (Mokhtarian, 2009; Lyons, 2015).

Within homes, the arrival of Internet-connected and data processing technologies has been described as a "new round of household electrification" (Røpke et al., 2010). Together with older information technologies (TVs and audio systems)[2], such ICT now accounts for a significant share of household electricity consumption. Monitoring studies in UK households suggest that computing and consumer electronics together consume about 20 or 23% of non-heating related electricity use (Zimmermann et al., 2012; Coleman et al., 2012). More recent official statistics put this at 35% (BEIS, 2017), in line with earlier predictions from the Energy Saving Trust (2011). Not surprisingly, a range of energy-related research has explored how and why devices like TVs (Crosbie, 2008), mobile phones (Horta et al., 2016) and laptops (Spinney et al., 2012) are purchased and used, and how standby consumption in electronic and digital devices can be understood and addressed (Gram-Hanssen, 2009).

In other words, the energy research community has largely focused on the direct consumption of (consumer) products and a limited range of effects in other areas of consumption, including the potentials and pitfalls of smart energy technologies. However, this is only part of the story when it comes to energy demand associated with ICT. For instance, Bento (2016: 97) has called for attention to the energy required by mobile phone *infrastructures*, claiming it "is ten times higher than the direct consumption of the handsets" and thus could have a "sizeable impact on energy demand" particularly as phone take-up and infrastructures grow in developing countries. This topic is more familiar to other research communities.

For over a decade, researchers within industrial ecology, engineering and computing have debated and tried to estimate the net balance of additions and savings to carbon emissions and energy consumption as digital technologies, including infrastructures, become more widespread (for useful reviews see Hilty and Aebischer, 2014; Horner et al., 2016). The energy implications are often categorised into orders of effects, where first order effects are the energy used directly to produce and use ICT, secondary effects are the immediate consequences for other forms of environmental impacts (such as changes in travel) and tertiary effects are the ongoing changes as ICT is used over time, leading to other adjustments, changes and innovations (Fichter, 2002). The net balance depends on how these effects are calculated and what is included. Even for the most straightforward effect, direct consumption, there has been considerable

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[2] Coleman et al. (2012) use the term 'ICE' to refer to the broader set of information communication and entertainment devices that include older technologies such as televisions and radios, reflecting the convergence between audio-visual devices and computers.

variance in results, with different methods yielding very different estimates of how much energy the Internet uses, and what the consumption attributable to a MB of data traffic might be (Coroama and Hilty, 2014; Coroama et al., 2015; Schien et al., 2015; Aslan et al., 2017). Nevertheless, these studies all highlight growing levels of energy used by information and communication infrastructures, both in absolute terms and as a share of overall global electricity use (see next section).

This paper aims to put the energy consumed by the Internet firmly on the energy research agenda. Our goal is not to improve estimates of consumption, but to better understand the basis of the growth in traffic that underpins it. We argue that policies and interventions in this area should aim to do more than improve the energy efficiency of digital infrastructures: they can also focus on the growing demand for data. To this end, an understanding of how and why data demand is growing is important. In this paper, we discuss a range of approaches to investigate this topic. In particular, we suggest that households play an important role and that everyday life is a key site to investigate how infrastructural changes take place, alongside the design and governance of online services. Drawing on a selection of our own research, we begin to unpack a topic of core interest to the energy research community that has hitherto received little attention: its potential contribution to peak electricity demand. Could the energy used by digital infrastructures become more problematic for managing national peak loads?

The paper is organised as follows. Section 2 reviews evidence about the size of Internet-related energy demand. Section 3 explains why attention to everyday practices, as interconnected with policy and provision, can help to provide insight into these changes and outlines a number of approaches to this. In Section 4, we develop a discussion of the patterns of peaks and troughs in Internet traffic and to what extent they align with national peaks in electricity demand. We conclude, in Section 5, by considering the possibility for policies to regulate or otherwise shape volumes of data traffic, as part of a broader set of Internet energy policies.

2. How much electricity does the Internet consume?

Since methodologies and ways of drawing system boundaries vary, there is not a single, definitive figure of how much electricity the Internet consumes. Overall, it is estimated that powering digital devices (computers and smartphones) and the supporting infrastructures (communication networks and data centres) consumed about 5% of global electricity use in 2012; rising to over 9% if televisions, audio/visual equipment and broadcast infrastructures are included (Van Heddeghem et al., 2014). Other studies have produced broadly similar figures (Andrae and Edler, 2015; Malmodin et al., 2010).

In this section, we firstly review evidence that network and data centre energy consumption are significant within this and that they are growing; secondly, we consider the trends in data demand that underpin the expansion of these infrastructures and their energy use.

2.1 Network and data centre consumption is growing

Current estimates suggest that networks and data centres consume more than computers. According to Van Heddeghem et al. (2014) communication networks, including mobile, fixed broadband and telephone networks, consumed 1.7% of total global electricity use in 2012, and data centres 1.4%; together these infrastructural forms of consumption were roughly twice that of computers, at 1.6%. In fact, the balance between user devices and infrastructures has shifted markedly over the last few years as processing and storage functions are increasingly carried out 'in the cloud' and as smaller, low-power user devices like laptops and smartphones have become more widely used more than desktop PCs. As Corcoran and Andrae (2013: 1) note “there is a strong trend to push electricity consumption onto the network and data center infrastructure where energy costs are less transparent to consumers”. At the level of particular services, for instance, it is estimated that powering an LED TV for two hours to watch a film might take a similar amount of energy (120 Wh) as consumed in streaming it over the Internet (Schien et al., 2013). Plus, networks and data centres represent the largest share of energy consumption over the lifetime of tablets and smartphones: accounting for at least 90% of the total energy use including manufacture and charging (Hischier et al., 2015).

Most estimates of ICT-related energy consumption also predict steady growth. For instance, Van Heddeghem et al. (2014) estimate that the electricity consumed by digital devices and infrastructures is growing faster (at 7% per year) than global electricity demand itself (at 3% per year), with the rate of growth of networks highest of all (at 10.4%). Andrae and Edler (2015), also anticipating a compound rate of growth of 7% per year, calculate that the production and operation of ICT will rise to 21% of global electricity consumption by 2030: this is an absolute rise to 8,000 TWh, from a base of around 2,000 TWh in 2010. In a worst case scenario, this could reach as high as 50% of global electricity use by 2030, but only 8% in the best case. The IEA (2017), who estimate that networks consume slightly less (at 185 TWh in 2015) than data centres (at 194 TWh in 2014), foresee only moderate growth in the energy consumption of data centres of 3% by 2020. But they estimate greater uncertainty for networks, with scenarios varying between growth of 70% or a decline of 15% by 2021 depending on trends in energy efficiency.

To date, there have been significant improvements in the energy efficiency of data centres and networks: Aslan et al. (2017) suggest that, since 2000, the electricity intensity of data transmission in core and fixed-line access networks has decreased by half every 2 years. Shehabi et al. (2016) calculate that the growth in data centre energy consumption has slowed dramatically since 2010 compared to the previous decade, with an increase of 4% from 2010 to 2014. This is attributed to a range of efficiency improvements and a large shift towards hosting cloud-based services in ‘hyperscale’ data centres. As the IEA (2017: 18) note “energy use over the long run will continue to be a battle between data demand growth versus the continuation of efficiency improvements”.

Whilst the increases in efficiency are encouraging, particularly for data centres, they are yet to catch up with the growth in data traffic and, to date, “have been more than offset by increased consumption of services” and their changing nature, design and use (Preist and Shabajee, 2010: 583; Preist et al., 2016)[3]. Because of this, the absolute growth in energy used by digital infrastructures, especially networks, continues. The growth in data demand should therefore not be neglected by efforts to manage and

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[3] By our calculations, a rate of growth in traffic from 10 MB to 13 GB per capita per month between 2000 and 2017 (Cisco, 2017) equates to a compound annual growth rate (CAGR) of 52% over the same period as a 30% reduction in electricity intensity of networks (Aslan et al., 2017).

reduce global energy consumption. The rest of the paper turns to discusses this; after briefly considering *where* energy consumption by Internet infrastructures takes place.

Very few studies have considered ICT-related energy consumption at a national scale, so it is difficult to gauge what proportion is incurred in the country where services are used. To an extent, this will depend on the services in question: for instance, there are important differences in the distribution of energy demand across the infrastructure for streaming video-content compared to browsing websites (Coroama et al., 2015; Schien et al., 2015). But in modelling overall ICT-related electricity use in Sweden, Malmodin et al. (2014) assumed that only 25% of national data traffic travelled to and was processed in international data centres. If accurate, this suggests that the bulk of energy consumption in Internet infrastructures takes place in the country of use. In addition, Coroama et al. (2015) suggest access networks and network equipment in consumer premises (e.g. routers) consume more electricity than longer haul and transnational (metro and core) networks.

In Sweden's case, Malmodin et al. (2014) are optimistic that this electricity consumption will not grow substantially over time. This is particularly as less energy-consuming laptops come into greater use. Yet other changes are also taking place at the same time: a) higher performance, more energy intensive wireless routers are becoming more popular (Terry and Palmer, 2015); b) new forms of 'network standby' are being embedded into millions of connected devices, including smart meters and demand response enabled devices (IEA, 2014); c) coverage and take-up of more energy-intensive 4G/LTE networks is growing; and d) the nature of digital services and their consumption is becoming more data-intensive (Preist et al., 2016; Hazas et al., 2016). Overall, data traffic across fixed access and mobile networks continues to grow at a rapid rate.

2.2 Data traffic is growing

The growth in Internet traffic is often described as exponential. Traffic flows have indeed risen massively from 100 GB per second in 2002 to 26,600 GB per second in 2016 and the volume of traffic is expected to nearly triple within the next 5 years (Cisco, 2017). The demand for data, and the digital services that it supports, is growing partially because more people are going online. But the number of connected devices is growing more quickly than the number of users, with the global average expected to grow from 2.3 devices per head in 2016 to 3.5 in 2021 (Cisco, 2017).

Both fixed and mobile connection speeds are also growing, as are per subscriber volumes of data traffic. For instance, in 2011 UK households 'consumed' an average 17 GB of broadband data per month; by 2016, this had risen to 132 GB (Ofcom, 2012; 2016). The speed of home broadband connections also increased from an average download speed of 7.5 Mbit/s in 2011 to 37 Mbit/s in 2016 (Ofcom, 2012; 2016). Over the same period, there was an increase in the take-up of broadband subscriptions, from 68% to 78%, but this alone does not account for the increase in data traffic. Average traffic volumes for *existing* fixed line subscribers are also growing (Sandvine, 2014).

Volumes of data traffic over mobile networks are also increasing, and at a more dramatic rate. Ericsson (2017) reported a 70% growth in the total mobile data between 2016 and 2017, and forecast a compound annual growth rate of 42% in global mobile data traffic through to 2022; that is an 8-fold increase compared to 2016. Cisco (2017) forecast a similar rate of 46% to 2021, which is much higher than the overall global average of 26%. Moreover, data traffic to smartphones, including that sent over Wi-Fi networks, is forecast to exceed the overall traffic from personal computers by 2021, accounting for 39% of overall Internet traffic, compared to PCs at 28%, TVs at 19% and tablets at 8% (Cisco, 2017). In 2016, this was 17% for smartphones, 56% for PCs, 16% for TVs and 7% for tablets.

Overall, according to Cisco (2017), ‘consumers’ (including households, university populations and Internet cafes) account for 81% of Internet traffic, and this is growing slightly faster than business traffic. By most accounts, this growth is attributed to two factors. Firstly, the availability of higher broadband and mobile speeds is thought to be “driving greater volumes of data downloads and uploads” (Ofcom, 2016: 6), resulting in “increased consumption and use of high-bandwidth content and applications” (Cisco, 2017: 19). Secondly, there is “evidence of an increase in the consumption of online video” (Ofcom, 2016: 29), which is broadly acknowledged to be “driving” much of the growth in overall traffic. Indeed, video-related traffic is already a highly significant and “all forms of IP video... will continue to be in the range of 80 to 90 percent of total IP traffic” (Cisco, 2017: 13). This is dominated by Internet video such as the streaming services delivered over the Internet, but also includes the corporate IP (Internet Protocol) networks that manage and distribute video content, videos on websites, live streaming of video, file sharing, gaming, and video surveillance.

Video is also associated with the faster-than-average growth in ‘busy hour’ traffic. This is the busiest 60 minute period during the day on a given network, during which traffic grew by 51% in 2016, and is forecast to continue to grow at a higher rate (35% CAGR) compared to average Internet traffic (26% CAGR) (Cisco, 2017). Whilst other forms of traffic are spread evenly throughout the day, Cisco (Cisco, 2017: 26) note that “video tends to have a ‘prime time’” and because of this the busy hour, which falls in sometime in the evening, is now much busier. Other reports also highlight the significant contribution of video to peak period traffic both for fixed access and mobile networks (Sandvine, 2015; 2016).

These trends in data growth represent grounds for ongoing caution, and concern, as to the overall trajectories of Internet-related electricity use. Firstly, mobile networks are more electricity intensive than fixed-line access networks (Malmodin et al., 2014) yet mobile data traffic is growing faster. Secondly, video traffic is associated with the growth in fixed and mobile network traffic, yet watching video across mobile networks is especially energy-intensive (Schien et al., 2013). Thirdly, data traffic in the ‘busy hour’ is growing at a much higher rate than average; leading to increased consumption at particular times of day as well as the expansion of networks (and associated overhead consumption) since “service providers plan network capacity according to peak rates rather than average rates” (Cisco, 2017: 26).

In sum, despite the ongoing debate as to the relative size of efficiency increases and overall energy consumption in networks, data centres and user devices, it appears that growth in data traffic continues to outweigh efficiency gains. We therefore take it as a working assumption that increased data flows over mobile and Internet networks represent an increase in energy consumption. We have also identified some important trends in data traffic growth. This allows some insight into what is changing, but more is needed, especially if we are to make a case for policies, initiatives and interventions that directly address data demand. In the next section, we argue that investigating the demand for digital services is a helpful step in this direction, and consider how this might proceed.

3. Approaches to investigate data demand

The demand for data, or *data demand*, can be conceptualised in a similar way to other inconspicuous and infrastructural forms of consumption, like electricity, gas and water. Like energy, data is not consumed in its own right, but rather for the services that it provides. An increasingly common approach to understanding and investigating the demand for such services is as an outcome of social practices (Shove and Walker, 2014; Gram-Hanssen, 2011; Røpke, 2009). Just like electricity, flows of Internet traffic become part of, and necessary to, the performance of a range social practices that make up everyday life as the services this provides become increasingly commonplace and integral to those practices (Lord et al., 2015; Widdicks et al., 2017). Data demand can thereby be defined as the levels of traffic required to deliver digital services.

Just as the carbon emissions of generating electricity can be attributed to households and particular end-uses, a similar principle can be applied to data. Whilst the energy consumed by the Internet may be internationally dispersed, flows of data traffic only exist to support specific services. In other words, infrastructural electricity use is not simply 'out there' as a technical characteristic of the design and engineering of Internet networks and data centres: it is intricately tied up with the services it provides and the activities this enables. Different amounts of energy are required by different services, but as a general principle, the more data that flows, the greater the energy consumed. We therefore take data demand as a proxy for energy demand.

Conceptualised in this way, there are several ways to investigate the processes that underpin growing data demand, and hence infrastructural energy demand. These include the design and provision of services, the nature of (increasingly) data-intensive practices and the more general and widespread integration of data-based services across society. In the following sections, we briefly outline each of these three approaches and a range of questions that might be generated and explored.

3.1 Service design and provision

As with research into energy demand, an obvious starting point is the data efficiency of digital services, and possibility of delivering the same services but with less data. Indeed, the efficiency of encoding and transmission of data is a key concern for content delivery networks such as those behind Netflix. In December 2015, Netflix reported improvements in its video-encoding efficiency that could reduce bit rates by up to 20%. This has been associated with a slight decline in Netflix's share of peak traffic, although no absolute values were available (Spangler, 2016; Sandvine, 2016). However, at the same time, the company is rolling out ultra-high definition (UHD) streaming services. By 2021, Cisco (2017) estimates that UHD could add approximately 10 Exabytes per month to global traffic flows. This shift from standard definition to high definition to UHD represents a massive increase in data intensity of this service, despite ongoing improvements in encoding efficiency.

Across many other digital and non-digital services[4], including electricity supply, the flows of data required to deliver them are also growing, and in ways that appear to have little to do with user-generated demand. For instance, studies of data traffic to and from mobile phones have revealed the considerable extent of 'background' data associated with updates and automatic synching with cloud services (Lord et al, 2015; Widdicks et al., 2017). These data flows are often designed into how software works. And as software updates are now routinely sent 'over the air' to an increasing range of devices, including computers and smartphones but also cars, thermostats and TVs, there are energy implications (Hazas et al., 2016; de Decker, 2017). Indeed, current estimates indicate that digital distribution leads to more carbon emissions, compared to distribution of software on optical discs, especially for large releases (Mayers et al., 2015).

These increases in the data intensity of digital services occur as "designers make the implicit assumption that the digital infrastructure is abundant, relatively cheap to the end-user and will expand to meet future demand" (Preist et al., 2016: 1326). This "cornucopian paradigm" (Preist et al., 2016: 1327) also extends to providers of non-digital services and governments, as digital forms of provision, management and control are sought to enhance productivity and revenues across diverse sectors. In other words, service demand, and the associated data demand, is not solely generated by those who use digital services, but also by providers. In moving towards policies that engage with this growing form of energy demand, it would be important to understand more about how these systems of provision and consumption operate. How do production and consumption practices inter-relate to shape the design of services? What role do governments and other institutions play in these processes of escalation? And are there ways to conceptualise and experiment with 'transitions' towards more sustainable product service systems (e.g. Hobson et al., 2017)?

3.2 Data-intensive practices

Another approach to investigating increases in data demand is to focus on forms of traffic that are either already significant or growing, and the practices related to them. As described in Section 2, video and mobile data are particularly interesting in this regard. Both account for significant share of Internet traffic and both are growing faster than average. In addition, the Internet of Things and Internet gaming are also expected to generate rapid growth in data demand, even if neither will account for a significant overall share of traffic, at least in the near-term. For instance, Cisco (2017) forecasts that, by 2021, machine-to-machine communications could account for 6% of global Internet traffic, which would still less than tablets at 8%.

As with energy consumption, the aims of better understanding the practices in which data demand is embedded are multiple, and include investigation of how such practices vary and change, how they have evolved over time, and what opportunities there might be to steer or shape them as they continue to unfold in the future. A first step, however, is to make a connection between data traffic and practices.

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[4] Data flows are growing across non-digital services as digital forms of monitoring, surveillance and control are integrated into them, such as with the supply of electricity when smart meters are installed.

In the case of video traffic, the connection appears to be clear. As outlined above, video traffic accounts for a large portion of overall data traffic and is behind growing 'busy hour' traffic levels. In Europe, 41% of peak period traffic in fixed access networks in 2015 was attributed to real-time entertainment services, growing from 30% in 2009 (Sandvine, 2011; 2015). The category also includes streamed audio services such as Spotify and video-sharing platforms such as YouTube, which by itself accounted for 21% of total peak period traffic (Sandvine, 2015). Thus, it is important to find out more about what forms of video, and other streamed content, are being used. What different practices, meanings and configurations are involved? And to what extent do these *multiple* changes in practice interact? We know, for instance, that on-demand and catch-up TV and film services only account for about 8% of UK adults' total TV viewing time, but this doubled between 2013 and 2016 (Ofcom, 2017: 92). A 'transition' in how people watch TV therefore appears to be underway, but how? And what are the energy implications if (or when) a much greater proportion of viewing takes place via the Internet?

Methodologically, in-depth interviews, observational studies and diaries offer the opportunity to explore how various forms of online entertainment are coming into use. Other insights might be gained through cross-cultural comparison. As shown in Figure 1, a much larger share of peak period traffic is associated with real-time entertainment in North America (at 67% in 2016) than in Europe (around 40% in 2015) but this has risen from 30% in 2009, which was then similar in Europe (Sandvine, 2011; 2016). This partly reflects a different infrastructural history of television in North America where cable TV is more widespread and the fact that streaming services like Netflix are more deeply established.

Analysis we conducted on digital development data collected for European countries (European Commission, 2015) suggests that higher household broadband speeds correlate more strongly with levels of subscription to video-on-demand services (as shown in Figure 2) than any other indicator of Internet use, such as the proportion of the population using the Internet, participation in social networking, accessing information about goods and services, voice calling, or online shopping. In other words, at a national level, faster broadband infrastructures seem to primarily facilitate Internet-based entertainment. Comparative country-specific research into the interacting histories of infrastructure, policy and entertainment practices that have differently co-evolved (despite convergence on some indicators) may highlight how policies and industries are already shaping these landscapes of service demand, and may yet do so in more sustainable directions.

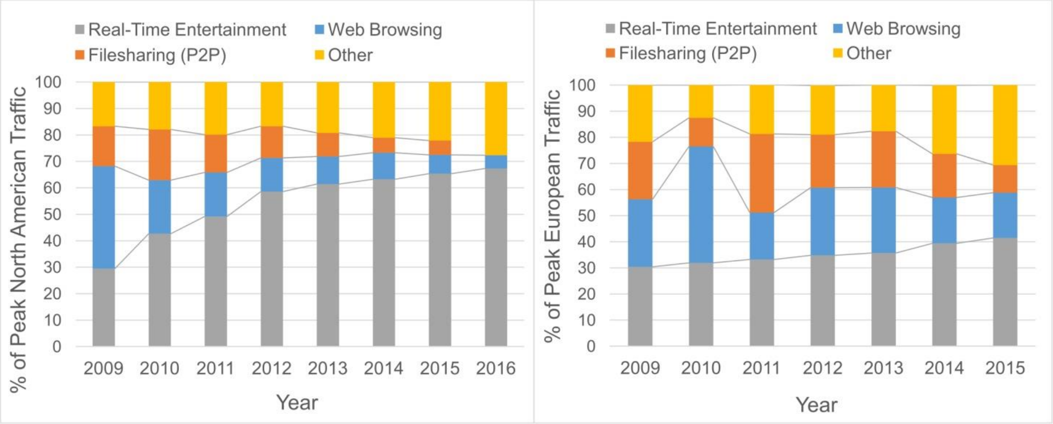

Figure 1. Composition of peak period fixed-line traffic in North America (left) and Europe (right) over time. Source: Sandvine (2011, 2014, 2015, 2016).

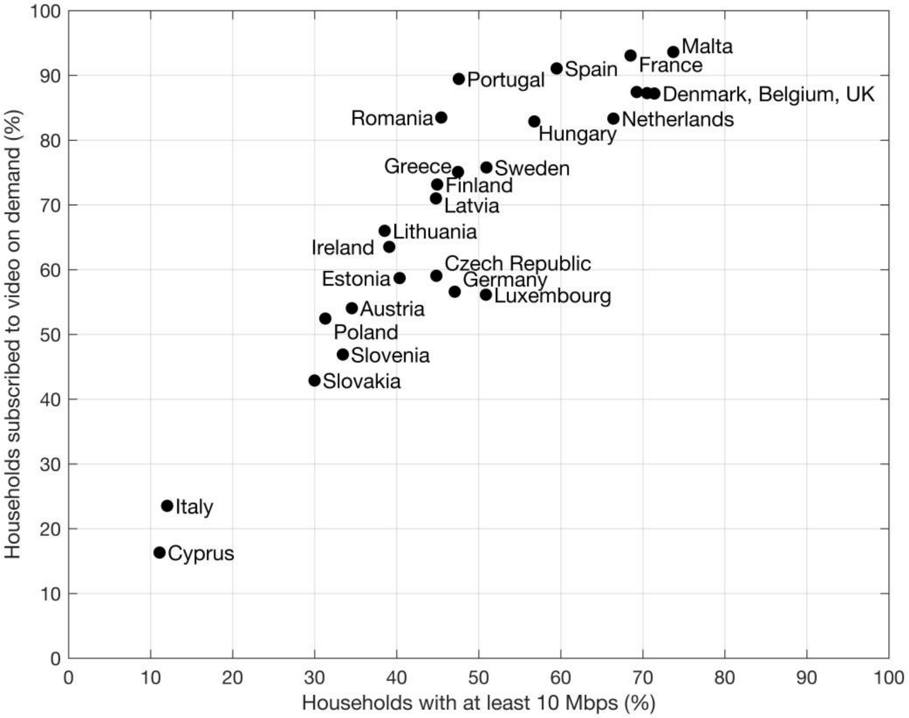

Figure 2. Correlation between household access to broadband speeds over 10 Mbps and subscription to video on-demand services in European countries. Based on original analysis of data from EC (2015).

3.3 Data demand across everyday life

Instead of singling out particular practices, like those associated with video traffic, another approach to investigating the connection between growing energy demand in digital infrastructures and everyday practices is to focus on the increasing variety of practices and thereby spaces and times in which digital services are used. Mobile devices have come to support and modify the practices undertaken while waiting for the bus, waking up in the morning, going to sleep at night (Røpke et al., 2010; Røpke and Christensen, 2012) and whilst watching TV and spending time with family at home (Spinney et al., 2012). In such ways, digital services come to be positioned more centrally within a range of practices, and move in status from luxury to a necessity, much like electricity itself.

Walker et al. (2016: 130) describe how a home broadband connection came to be included in assessments of minimum income standards; that is, as of the "basic necessities that everyone should be able to afford". Initially, in 2008, a broadband Internet connection was thought to be a basic need only for households with secondary school children to enable homework. This was extended in 2010 to all non-pensioner households, since the Internet was used "so widely in life – from applying for jobs to getting discounts – that people without it are disadvantaged" (2016: 134) and then to all, including pensioners, in 2014, reflecting reduced access to the Internet in public spaces, such as libraries. These narratives of 'necessity' point to particular services, for which lack of access poses a disadvantage. These may not be the most data intensive services but they do help define the social importance and significance of broadband connectivity.

Importantly, 'essential' digital services are in flux, and there is more to understand about the processes by which services are 'domesticated' on an ongoing basis (Hand and Shove, 2007). As with other approaches, a range of questions could be explored: how do expectations and experiences of 'need' emerge and circulate?; how do providers and consumers interact to co-define these expectations?; and what role do governments and other institutions play to reinforce, shape or challenge these dynamics?

4. Peak demands: the timing of electricity and data demand

In this section, we examine in more detail a potentially significant point of connection between practices, data demand and energy demand. Just like national electricity grids, traffic flows in local Internet networks vary across the day. As already highlighted, traffic during peak times (or busy hours) is growing faster than average, in large part due to growing video-related traffic during these times. Because peak periods fall in the evening, the question of their timing and constitution is relevant to efforts to manage and reduce peak electricity demand. To gain more insight into this potential alignment we draw on our own research in combination with secondary data analysis.

4.1 Overall network peaks and prime time

The Internet is, of course, a globalised network of networks and it makes little sense to talk of an overall peak in traffic across the whole Internet. However, there are a number Internet exchange points around the world which switch traffic between regional and international networks. Some information about the volumes of traffic flowing through many of these exchanges is made publicly available[5]. This shows that at most large Internet exchange points there are significant daily fluctuations in traffic volumes which peak

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[5] Detailed archives are not available, so it is difficult to compare patterns of traffic over the course of a year or to investigate changes in peak timing and durations.

in the evening between about 8pm and 10pm local time[6]. The peaks are at least double the lowest traffic volumes, which typically occur between 3am and 5am. Interestingly, these peaks also seem to vary by day of the week. For London and Frankfurt, over several weeks in summer 2017, there was seemingly least traffic overall and lower peaks on Saturdays (though still in the evening); Fridays and Sundays also tended to have lower peaks than for the remaining days of the week. In the larger exchanges at Amsterdam and Frankfurt, levels of traffic are also higher in the winter (although set against a pattern of steady growth from year to year).

So what shapes these patterns in Internet traffic? Do they simply reflect, as it appears, the timing of practices that access audio-visual content? We can investigate this link by looking at time-use data. Whilst national time-use surveys do not (yet) tend to make a distinction between online forms of viewing and live terrestrial broadcasting they do show that watching television is predominantly an evening activity which peaks between the hours of 8pm and 10pm in the UK (Torriti, 2017). Based on the 2005 Office for National Statistics National Time Use Survey, Torriti (2017) calculates that over 45% of the UK population report watching TV[7] at around 9pm on weekdays.

To this, we can add data from our own research. A specialised time-use diary study was completed by 16 participants in the UK as part of a larger research project including interviews (with all diarists, plus others) and in-home energy monitoring (with a subset of the diarists). Participants were recruited by a variety of means including postal leaflets and items in email newsletters and were offered a voucher (£30) for completing the diary and taking part in two interviews, one before and one after the diary task. All participants had access to fast broadband at home, and lived in rural and sub-urban areas. Of the 16 diarists, 11 were female, 4 were retired, 4 had children under the age of 18 living at home, and 3 lived by themselves. Ages ranged between 35 and 79. In the diary, participants logged when they were using a computer or mobile device, using an Internet connection or watching TV (by any mode) over the course of one week falling sometime between July and October 2016 (different weeks for each participant). For two days of the week (for those who work, this involved one working and one non-working day), participants recorded all their activities in their own words on a schedule sheet. Activity categories were then assigned for each half hour interval by the analyst. For the other five days of the week, diarists recorded in a table when they were 'online', watching TV, and at home.

A similar pattern of evening watching was evident in these diaries as reported in national time-use surveys (Torriti, 2017): levels of participation in watching TV were highest in the interval of 9:00 - 9:30pm. Figure 3 overlays the participation rates in online activities and TV watching for an average day in the diary study against the traffic profile for the London Internet exchange (LINX) for a single day in summer. This shows that, at least for this group of participants, watching TV appears to match patterns in Internet exchange traffic flows better than other 'online' activities: that is, the 'prime time' for TV viewing correlates well with peaks in Internet exchange traffic. For comparison with a larger exchange, Figure 3

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[6] Please refer to traffic profiles on the websites:
https://ams-ix.net/technical/statistics
https://de-cix.net/en/locations/germany/frankfurt/statistics
https://www.linx.net/tech-info-help/traffic-stats

[7] The time-use category also includes listening to the radio and playing games but following Torriti (2017) we equate this mostly to television.

also includes the same day's traffic profile from Amsterdam (AMS-IX). Although we cannot comment on the relationship to time-use in this region, the timing of peak Internet traffic at least appears to be similar elsewhere in Europe.

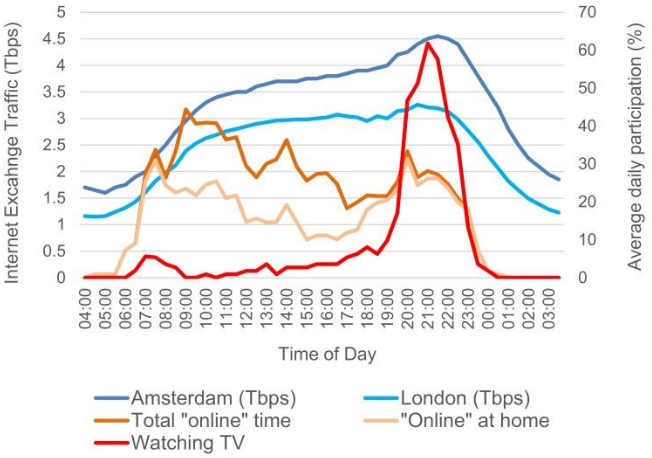

Figure 3. Time-use diary data and traffic volumes at two Internet exchange points. This graph compares activities recorded by 16 people in England (from one week sometime in summer or autumn 2016) with traffic volumes at Amsterdam (AMS-IX, 2017) and London (LINX, 2017) exchange points on a single day in summer (26/7/17).

From the interviews, we know that the other 'online' activities reported in the diaries prominently included checking emails, news, weather and social media, banking and searching for information on products, travel arrangements and personal interests (such as family history or gardening). Peak times for accessing these services were in the morning: when volumes of traffic at exchange points are much lower compared to the evening. This concurs with evidence that general web-browsing and other online services including social media applications are associated with lower levels of data demand than video-related applications.

However, the diary study suggests that online activities, other than TV watching, may also contribute to the evening Internet peak, and particularly the earlier hour (between 7:30 and 8:30pm). This is a time, after the evening meal, when some of the diarists would continue work for the evening *instead* of watching TV, others would do something online *before* watching TV (perhaps completing a purchase they researched earlier), some would go online on a tablet or phone *whilst* watching TV (perhaps to keep up with discussions in a forum, or communicate with friends) and others would do something online (such as update a blog) *whilst other family members* watched TV in the same room. In any case, it is clear that the evening is not *just* a time for watching TV, but that other 'online' activities frequently take place alongside or in close sequence.

A significant portion of the 'TV watching' recorded in the diaries was Internet-based. Most commonly, this involved catch-up services like BBC iPlayer or streaming services like Netflix. Two of the diarists only ever watched TV this way and most had access to Internet-based media services of some kind, which they used during the week. However, it was more common to watch programmes that had been recorded from terrestrial and satellite broadcasts, as well as live content from these channels. Indeed, other surveys suggest that live TV is still is still, by far, the most frequent way to watch television in the UK, and accounts for 80% of viewing time compared to 8% for online viewing (Ofcom, 2017; see also BARB, 2017). Yet the popularity of Internet-based viewing is growing. For instance, the number of BBC iPlayer requests grew by 23% between April 2016 and 2017 (Bell, 2017). Subscriptions to streaming services are also growing: by the end of 2016, almost a quarter of UK households subscribed to Netflix, up from 14% at the start of 2014 (BARB, 2016).

If current growth trends in online viewing continue, the peak in 'national' Internet traffic, as indicated at traffic flows at London Internet exchange, looks set to grow. At present, peak data demand occurs later than peak electricity demand (Figure 4). Although it is unclear by how much, this additional data traffic must add to national electricity consumption through distribution and access networks and nationally based servers. The current offset between data and electricity peaks is therefore welcome. If the growth in data traffic remains concentrated later in the evening, the additional energy use this requires may not add much to the national peak in electricity demand.

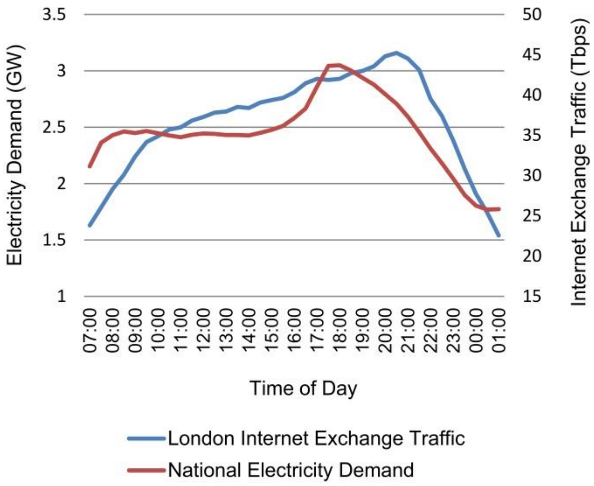

Figure 4. Peak data and electricity demand in the UK. Compares national electricity demand for England and Wales (source: National Grid (2017)) and Internet traffic at the London Internet exchange (source: LINX (2017)) for a single Wednesday in winter (1/11/2017).

However, as levels of data demand grow overall, the associated infrastructural energy consumption will add to peak electricity demand. Whilst peak electricity demand is only problematic in the UK during winter months, national time-use studies suggest participation in TV watching is also higher than average in the winter and starts earlier. For instance, in 2005 40% of respondents reported watching TV by 7:30pm in February, a level which is not reached until 8:30pm in June (Torriti, 2017). Furthermore, an increased take-up of online viewing among groups who watch TV earlier in the evening will also add to peak electricity demand. Ostensibly, this could include older retired groups and younger children; but further investigation is required. Also, there was some evidence in the diary study that the new-found mobility of watching on-demand TV on a tablet (for instance, in the kitchen whilst preparing dinner) might also be contributing to demand in the early evening.

Given the rapid rate of change in household data traffic and access speeds, and an overall decline in hours of TV watching which is primarily due to younger groups watching less (Ofcom, 2017), it would be wise to assume that current patterns of TV watching are far from fixed. On the one hand, on-demand watching and time-shifting through digital video recorders (DVRs) appear to allow greater flexibility in the timing of television viewing. Indeed, there is evidence that online viewing tends to take place later in the evening compared to viewing on a TV set (BARB, 2017; Bell, 2017; plus see next section). Also, the distinctively British phenomenon of the 'TV pick-up', when kettles are turned on at the same time after popular soap operas, has also been much reduced in recent years; a fact attributed to time-shifted viewing (Jamieson, 2016). But despite minute by minute de-synchronisation, the general timing of TV watching might not have changed much. Indeed, evidence from the diary study suggests online viewing *on a TV set* occurs at similar times as live or recorded watching (between 8pm and 10pm). We can hypothesize that the interrelation between TV viewing and other practices of working, commuting, eating and sleeping holds the timing of this kind of viewing in place, regardless of whether it is on-demand or not.

Nevertheless, further analysis of time-use surveys in the UK suggests that the timing of TV viewing *has* changed between 1970 and 2005. As shown in Figure 5, the timing on both weekdays and weekends shifted over this period: on weekdays, which are more problematic for peak electricity demand, TV viewing between 5:30pm and 7:30pm fell but marginally increased earlier in the afternoon between 3pm and 5:30pm. This paints a mixed picture for peak electricity demand and indicates trends which warrant further exploration with the most recent time-use survey.

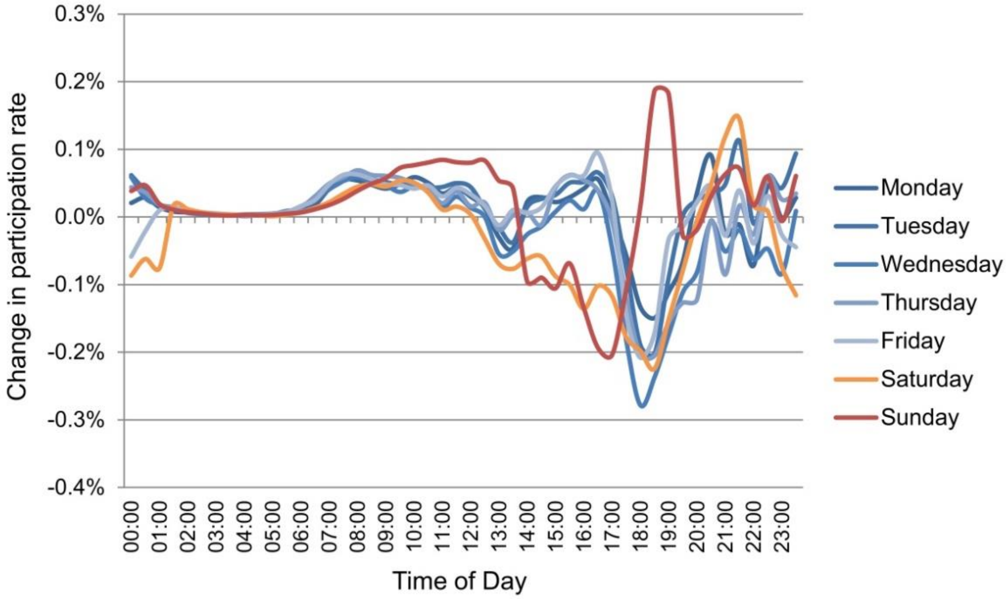

Figure 5: Percentage point change in `TV, media & games' reported in each half hour of each day in UK between 1974 and 2005. Based on weighted data from the Multinational Time Use Study (Gershuny et al., 2012), reproduced from Anderson (2015) with permission.

4.2 Mobile network peaks

The timing of peak data demand specifically on mobile phone networks could also have consequences for national peaks in electricity consumption. Firstly, as noted in Section 2, the rate of growth in mobile data traffic is higher and it is more energy-intensive (especially when streaming video) than for fixed access networks. Secondly, as the diary study suggests, mobile phones and tablets may be involved in different patterns of watching on-demand video-content compared to that accessed through TV sets. So when does traffic in mobile networks peak? And what kind of practices does this reflect?

Evidence of traffic patterns specifically in mobile networks is not as readily accessible as overall traffic at Internet exchange points (to which mobile networks also contribute). To get more insight into *the timing* of energy demand across mobile networks and the extent to which this coincides with national peaks in electricity demand, we turn to data collected from mobile devices themselves. A pre-existing dataset has been generated by an activity logging app called the Device Analyzer. It is an Android application, available on the Google Play store that can be installed by volunteers on smartphones and tablets and captures data about the device, including volumes of data used by particular applications. It was designed by researchers at Cambridge University who curate and share the resulting dataset with other researchers, where volunteers have given their permission[8].

We conducted secondary analysis on a subset of this data where: (1) logs consisted of at least 14 days with the latest data collected on or after 1st January 2014, (2) had a network-based location in the UK or Ireland for at least half of the contribution days, and (3) used apps or demanded data during their logging period. This resulted in 398 devices[9]. Methods are reported in full elsewhere (Widdicks et al., 2017) and explanation given of the different application categories. Here, we revisit and extend this analysis, using the same methods, to explore further patterns of data demand over the day and by day of the week. Unfortunately, we cannot differentiate from this data whether the data flows were accessed via mobile or Wi-Fi over wired access networks. This would be an important avenue for further investigation.

Nevertheless, a clear time profile of data associated with mobile devices is apparent, and as with Internet exchange points, it also peaks in the evening (Figure 6), but in this case the ‘busy hour’ comes later: mobile device traffic peaks between 10pm and 11pm. There is also something of a smaller peak in traffic at the start of the day. These patterns vary somewhat by day of week, which is likely to reflect the different sets of practices that take place. Of particular interest is the level of traffic that falls between 5pm and 7pm, coinciding with the national UK peak in electricity demand: this is greatest on Fridays and lowest on Mondays, Saturdays and Sundays. At present, it is unclear what these patterns reflect: is the traffic on Friday is associated with social activities, earlier departure times from work or something else? It is also unclear whether this traffic occurs when commuting (over mobile networks) or when at home or a workplace (over Wi-Fi). These are important questions to explore in further research.

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[8] More information and instructions on how to access the Device Analyzer dataset are provided at https://deviceanalyzer.cl.cam.ac.uk/.

[9] Due to anonymity restrictions associated with this dataset, we do not know the age, gender or device make-up of this sample; all those who participated indicate they were over 18 years old.

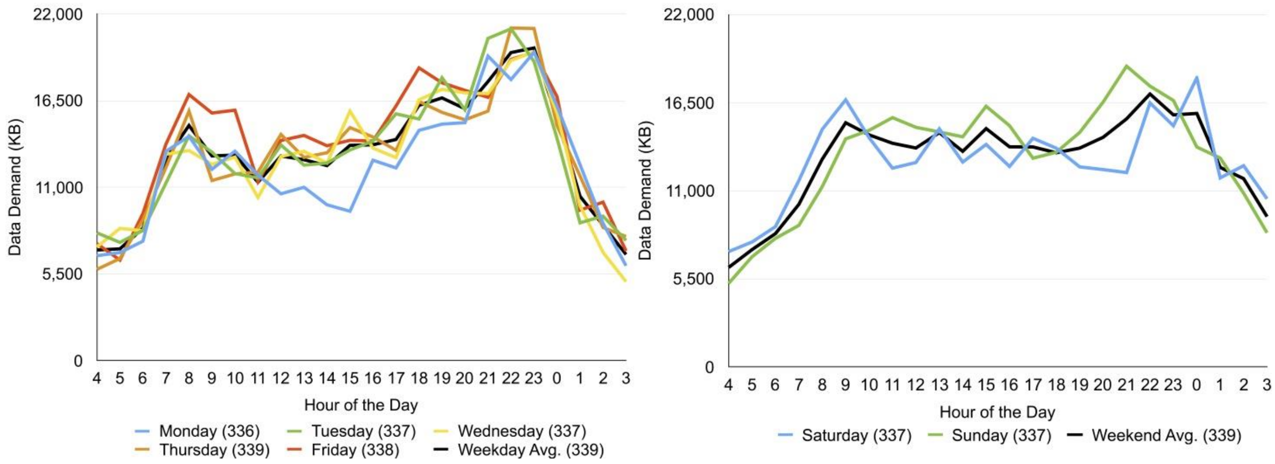

Figure 6. Average data traffic (upload and download) of smartphones and tablets by day of week. Each hour represents the average data traffic in KB per hour per device that occurred over the following hour. The figures in brackets show the number of devices included in the sample for each day.

In addition to overall traffic profiles, we also investigated the share of traffic on the smartphones and tablets associated with video content. As shown in Figure 7, this analysis suggests that watching-related apps, a category that includes video on-demand services like iPlayer and Netflix and video-sharing platforms like YouTube, are the primary contributor to the peak in overall traffic seen in Figure 6. Interestingly, it also shows that the ‘prime time’ for TV viewing, described in Section 4.1 (8-10pm), actually represents *a dip* in video traffic on mobile devices, with most video traffic occurring *later* in the evening. To the extent that this traffic is associated with viewing films or programmes, rather than short videos on YouTube, it suggests that mobile devices are used to prolong hours of ‘TV watching’, perhaps after the main TV set has been turned off. This is supported by the diary study, in which instances of TV watching later in the evening tended to occur on mobile devices, and especially tablets. One participant remarked how it “opens up a whole new world to watching television in bed” if she’s having trouble sleeping, whilst another reported that watching on a tablet in bed by himself, after having watched something with his family the living room, helps him to fall asleep.

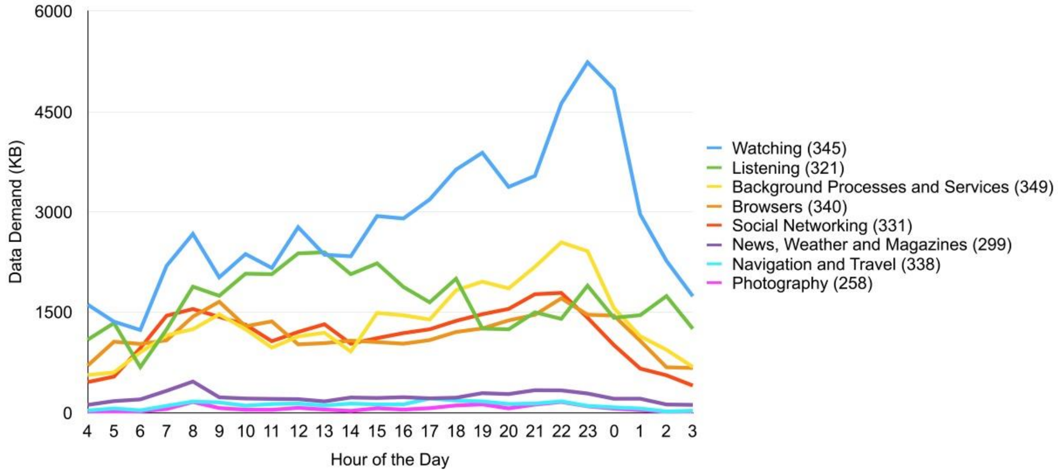

Figure 7. The hourly data demand, averaged across days, for a selection of application categories. Each hour represents the average data traffic (upload and download) that occurred over the following hour. The figures in brackets show the number of devices included in the sample for each category.

Whilst viewing video content over Wi-Fi networks later in the evening, or middle of the night, does not indicate a problematic trend for peak electricity demand management, the earlier evening increases in video traffic between 4pm and 8pm (Fig. 7) may be more problematic; especially if this represents use of video-on-demand services over energy-intensive mobile networks. Ofcom (2017) report that more than a third of people in the UK now watch TV outside the home, with 16% doing so whilst commuting or travelling. Whilst this might involve previously downloaded content, our analysis of video traffic on mobile devices shows that there *is* an increase in data flows during common evening (and morning) commuting hours. As the take-up of 4G/LTE increases, on the go, on-demand viewing becomes more of a possibility. If this form of watching does grow, this will almost certainly add to electricity load at peak times.

5. Discussion

In this paper, we have argued that the electricity consumed by information and communication infrastructures is of increasing importance as a share of global electricity use, and as a potential contributor to peak electricity demand at a national scale. To date, this topic has not received much attention within energy research literature, nor within discussions of energy policy: beyond the efficiency of network devices and data centres. Through highlighting the prominent trends associated with the growing flows of data across these infrastructures our aim has been to outline a number of research questions and approaches to investigating data demand. By focusing on the practices in which data demand is embedded, both in the use and provision of digital services, the social scientific energy research community is well placed to respond to these challenges. In doing, and in following some of the directions set out here, we hope that a research base can be developed to both inform and inspire policy initiatives in this area.

This is an agenda in which managing the growing energy demand associated with online activities has to be more than a question of efficiency, renewable energy and natural cooling technologies in data centres. Whilst data centres are important, this does not address the electricity consumed by distribution networks. Moreover, containing the overall growth in energy demand associated with digital infrastructures is more than a question of efficiency: it also requires limiting the growth in traffic, to at least keep in step with efficiency improvements, a balance which has not so far been the case.

Whilst many stress the importance of improving the energy efficiency of ICT, including standby functions, routers, mobile and fixed access networks and data centres (Terry and Palmer, 2015; Bento, 2016; Corcoran and Andrae, 2013; IEA, 2014; 2017), the very idea to limit data demand, in any form, goes against the dominant paradigm in which digital services and government policies, alike, are designed. Current government policies in many countries aim not only to extend Internet access to households and citizens who do not already have it, but also to make existing connections faster and faster. In the UK, the aim is for 95% of the population to have access to “superfast” speeds over 24 Mbps by 2020 and the government has committed to introduce a universal service obligation of at least 10 Mbps: “the speed that will meet the typical needs of a family for them to be able to stream films, carry out video conferencing and browse the web at the same time” (DCMS, 2017). In other words, the ability to stream TV programmes and films is being written into minimal requirements that all households in the UK will have a right to expect and request. This is at a time when terrestrial broadcasting still provides TV coverage to virtually all UK homes, and when many already use DVRs to bring on-demand like flexibility to their viewing (Ofcom, 2017). By encouraging extra data traffic, such policies have implications for global energy demand and carbon emissions. But they make little, if any, consideration of this. In other words, they could be seen as ‘invisible energy policies’ (Cox et al., 2016).

The challenge of addressing the growth in data demand requires detailed attention to the trends that underpin it. Whilst statistics clearly indicate that video traffic is growing rapidly, by investigating when and how people use online viewing services, we have shown how the timing of electricity use associated with data traffic could become relevant at a national level. We have also demonstrated that everyday practices (reflected in time-use data and mobile device use) are an important site at which to understand these changes. This is not to suggest that the practices in which digital services are accessed are the most appropriate site of intervention. It is also important to consider how the provision of video-related services is being re-organised and what role policy, institutions and commercial organisations are playing within these developments. Activities like checking social media have become more data-intensive as videos, including adverts, are increasingly embedded in feeds. Moves towards UHD streamed media also add to the normally invisible energy demand of watching TV and films via the Internet.

In sum, and in the context of climate change targets, there must be better options for dealing with Internet-related energy demand *as it develops*, rather than allowing it to become a ‘problem’ that will be harder to tackle once data-intensive services are more thoroughly embedded in normal, everyday life and thereby ‘locked in’.

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