The impacts of domestic media and ICT:

A study of digital technology, energy consumption, data demand and everyday practice

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Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. This dissertation contains fewer than 65,000 words including appendices, bibliography, footnotes, tables and equations and has fewer than 150 figures.

The data used in the analysis and discussion chapters of this thesis has been collected as part of collaborative research conducted alongside colleagues from the School of Computing and Communications, Department of Sociology and The DEMAND Centre at Lancaster University.

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Contributing Publications

Bates, O., Lord, C., Knowles, B., Clear, A. K., Hazas, M., & Friday, A. "Exploring (un)sustainable growth of digital technologies in the home" *Proceedings of ICT for Sustainability 2015.*
This contribution forms the basis of Chapter 6, using data, analysis, and text from the paper.

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This contribution informs the analysis and findings that are presented in Chapter 5.

Bates, O., Hazas, M., Friday, A., Morley, J. & Clear, A. K., "Towards an holistic view of the energy and environmental impacts of domestic media and IT" *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems 2014.* This contribution forms the basis of Chapter 4, using data, analysis, and text from the paper.

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The home energy data collected during this study contributes to the analysis presented in Chapter 4.

Other Refereed Publications

Clear, A., Morley, J., Hazas, M., Friday, A. & **Bates, O.**, "Understanding adaptive thermal comfort: new directions for UbiComp" *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing. 2013*
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Abstract

The growth of domestic energy and emissions impacts correlates with growing digital technology (e.g. ICT, consumer electronics) domestication and usage. New and 'smarter' technology, cloud based services, and on-demand content are reshaping how, when and where digital technologies are drawn upon, with the trend being one of escalation for manufacturing (more devices purchased more often) and network reliance (more and more services are becoming 'cloud' oriented). This escalation raises concerns over the environmental impacts of domestic digital technology, due to its use more frequently, and across more social practices.

Motivated by this growth, there is now an even greater need to understand the underlying social situations and expectations that predicate certain ways and intensities of ICT in practice. The expectations of others, obsolescence (designed, or otherwise), changes of circumstances, life transitions, quality of experience, and expectations of technology all put pressure on users (or practitioners) contributing to the reshaping of social practices that involve digital technology.

Previous focus on eco-feedback and behaviour change, along with more current understandings of digital technology variation and escalation, are not terribly insightful or necessarily linked to demand. Due to this, the variations in social practices, and the links to the varying energy impacts of households, are often overlooked. To move towards an improved understanding of digital technology's role in social practices there is a need for both increased understanding of that role, and how these practices link to energy and emissions impacts. By improving this understanding it is possible to uncover the contexts in which energy demand occurs, and where it may be possible to lower energy demands. Through understanding the contexts of digital technology in social practices it is possible to gain deeper insights into the reasons for demand and impact variation.

To date there has been no application of a method that links qualitative (e.g. semi-structured interviews, photo elicitation) and quantitative data (e.g. per-device consumption data, per-application network traffic analysis) to provide a full understanding of how digital technologies are implicated in domestic social practices and energy demand. Based on mixed methods research, the three main contributions of this thesis collectively demonstrate

how researchers and designers can gain a more nuanced understanding of the energy and everyday life impacts that are linked to digital technologies. Such understandings can result in very different implications for design, and un-design of digital technology, compared to that of prior work.

First, through the combination of per-device energy monitoring across thirty-one participants, life-cycle analysis calculations, and semi-structured interviews, I bring to light a) the need for combining multiple methods, and b) broader scoped findings, contextualised by observations of practice, that go beyond more typical quantitative energy and emissions analysis. This contribution reveals the need for deeper understandings of the adoption and energy consumption of digital technologies.

Through the combination of qualitative (e.g. semi-structured interviews) and quantitative data (e.g. per-device consumption data, per-application network traffic analysis) my second contribution demonstrates how modern mobile ICT (tablets, smart phones) enables loosening of the temporal and spatial constraints associated with non-mobile ICT. This loosening leads to the increased frequency of performances of social practices that were previously more static (performed in-place), leading to increased demand on Internet and cloud services.

Third, to provide a deeper understanding of the roles of digital technology in social practices, I explore the meanings and competencies that surround digital technologies. Using interviews structured around photo elicitation, I explore the integration of digital technologies in ten participants' lives. This contribution reveals how the connections between digital technologies, convenience, meaning, and competency lead to growth in individual and sets of devices, practices, users, and across different spaces.

Thus, grounded in findings from three mixed-methods studies, this thesis interrogates how digital technology enables variation in social practices, which in turn leads to variation in energy impacts. To better understand the impacts of digital technology we should consider, more broadly, how these technologies feature throughout everyday life. Through better understanding the connections between everyday life, digital technology, and energy impacts we can better contextualise growth, and better design for more sustainable trajectories.

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Prologue

After five years of researching digital technologies, energy and emissions I am much more aware of the impacts of my own leisure and work life. I, like many, rely largely on digital technologies throughout my everyday life. In the last seven years my collections of digital technologies and media have grown. My smart phone allows me to be connected to the outside world at all times.

My laptop (provided by my workplace) enables me to access research materials, compose writing pieces, watch, listen, and keep up with the world, friends and family. The connected peripherals (e.g. monitor, speakers, external hard-drive) enable me to customise and make my experiences more satisfying (e.g. bigger displays for video playback, better audio playback via external speakers, using a mouse instead of a trackpad. As an avid gamer, I own several devices specifically for gaming. My PlayStation 4 is connected to my TV and a home cinema audio configuration so I can game with my friends who are hundreds or thousands of miles away. My five year old Mac Mini is part of the same configuration, allowing me to watch locally stored digital media. My five year old Xbox 360 sits in the shared living room, with a Gamecube and a PlayStation 3 owned by my housemates. Despite being connected to a shared TV, they mostly collect dust. For a long time, my tablet just sat at my desk, uncharged and unused, but every month or two, I use the tablet to read an ebook, or look at reference materials while tabletop gaming. It terms of my digital technology, this is just a snapshot of what I come into contact with in my daily life. I own a large number of other technologies and media (e.g. three other games consoles, two pairs of headphones, three pairs of earphones, a CD player, an audio amplifier, ten speakers, one sub-woofer, two monitors, one Wifi router, an Airport express, three network switches, one printer, just under two-hundred DVDs, seventy-three blu-ray, over eight-hundred CDs, eighty-three video games, four external hard disk drives, over three dozen gaming peripherals, two external sound cards, two keyboards, three mice, two USB hubs, six pen sticks, a broken iPad, metres and metres of cabling).

I may not be able to recall exact time-use or the detail of all my practices, but I am aware that: I mainly use my laptop for work, communication (e.g. email, instant messaging) and social networking; I use my smart phone throughout the day for communication (e.g. email, social networking using Facebook and Twitter) and arranging my time and keeping track of tasks (e.g. calendar, todo list). My games consoles are primarily used for gaming in the evenings and weekends alone or with friends. My PlayStation 4 is used for streaming video in the evenings using Netflix because it's easier to access Netflix than power up and navigate the ageing Mac Mini. I listen to audio at home through an audio receiver and speakers, headphones, or earphones via whichever device (e.g. laptop, smart phone) is to hand.

I spend more time using technology and more time connected to the Internet than I ever have. Even after removing Facebook from my smart phone I still impulsively access it while I'm using my laptop. I feel that without subsets of these digital technologies I would miss out on particular experiences and interaction. For example, without the PlayStation or Internet connectivity I might not regularly interact with friends who aren't local, without my laptop I would not be able to work and I would miss out on the social networks that life seems to revolve around. It seems necessary for me to own and use these technologies if I want to experience life. Without the regular performance of practices that these technologies support (e.g. communication, social networking, keeping up to date, gaming, watching) I might somehow lose touch with friends, shared experiences of new media like TV shows, and miss out on recent research and scholarly writing.

The growth of digital technology and the spread of its incorporation into practice contribute to growing impacts: for example high definition streaming over broadcast TV, communicating with images and videos instead of a phone call, playing online video games instead of sharing an experience with other people in my living room. This leads to escalating acquisition of digital technologies to support these practices (e.g. buying the latest games consoles to be able to game and communicate with certain friends, upgrading the software on my smart phone to support the latest communication and social networking apps). I feel that largely, I view these practices as not negotiable (e.g. I don't want to sacrifice my communication, watching, listening, or gaming), but in the past, when there have been financial constraints I have opted out of Netflix, Spotify, and gaming subscriptions (e.g. PlayStation Network, Xbox Live). During these periods, subscriptions were substituted these via other means (e.g. peer to peer downloads, local media, offline games) or substituted by other practices. The various compositions of these practices all contribute to impacts in different ways.

As a member of a community of researchers and designers, I feel we are at a critical point where we need to evaluate how digital technology has co-evolved with practices in order to gain better understandings of how this co-evolution is having environmental impacts.

When examining digital technology's contribution to environmental impacts and energy demand, we need to look at the wider systems of device manufacture, data communication and services, as well as the direct energy gadgets consume when they are plugged in. When considering how to design interventions, or studies of digital technology in situ it is important to consider how everyday life is implicated, and how this can affect the times and durations of demand for energy, and the digital technologies that are domesticated. Due to my own experience with digital stuff, I have decided to focus my research on the role of digital technology in everyday life, with an eye to better understand how these roles link to energy.

Chapter 1

Introduction

Consumer electronics (e.g. non-IT digital technology such as TVs, games consoles) currently contribute the most towards the UK domestic energy demand, having risen over 74% since 1990 [38, ch. 3] and is likely to continue growing with living room connected devices set to increase from 114 million to 267 million units shipped worldwide by 2017 [111, p. 5]. Home computing has more than doubled in impact since 2000 [38, ch. 3]. Multitasking whilst watching TV is done by 53% of UK adults [111, p. xi], encouraged by living room connected devices (e.g. device in the living room that are connected to the Internet) that are "blurring the line between passive and active entertainment" [111, p. 4]. Mobile digital technology ownership is expanding at an even more impressive rate between 2011 and mid-2013 (e.g. smartphones 35– 56%, tablets 8–42%, ebook readers 12–32%)[1], with 62% of adults using smart phones in 2013 compared to 54% in 2012 [91]. A report released in 2014 by Sandvine reveals figures for the daily demand for data from mobile technologies [114], highlighting a growth of 11% in average mobile data consumption.

Whist there are many academic and research communities that concern themselves with the sustainability implications of technology; in this thesis I am only interested in HCI and the community of researchers that intersects with it, Sustainable HCI.

The S-HCI community is made up of researchers that are concerned with sustainability and trying to reduce energy and emissions. The seminal work from this community includes publications that: encourage sustainability as a core element of design [15]; inform design by exploring the sustainable choices made by those living a 'green' lifestyle [145]; and, have mapped the the approaches, similarities, differences and emerging issues across S-HCI [40]. Since 2007 [83] the community has continued to be active, meeting regularly (e.g. [30, 67, 100, 124]) to discuss the latest developments and the direction of S-HCI [125]. Through the years, S-HCI research has focused on the reduction of energy and emissions

[1] http://www.pewresearch.org/data-trend/media-and-technology/device-ownership/

through intervention, behaviour change, and changing meanings of attachment. Given that broader HCI focuses on developing new technologies and new methods (and interactions) for increasing and improving use of technology, it is of growing importance to consider how digital technologies (e.g. media and ICT, domestic consumer electronics) are used in practice, and how the evolution of these practices leads to growth of use.

The primary motivation for this thesis is understanding the extent of the social and environmental impacts connected to the growth of digital technologies and services. The thesis examines specifically how technologies are used in practice, how technologies are configured in everyday life, and how these uses and configurations contribute to energy and emissions impacts.

In this thesis, the term ‘sustainability’ is used to imply a goal of limiting, stopping, or reversing the growth in energy and emissions arising from the infrastructures and technologies of everyday life. Specifically, this thesis refers to sustainability in terms of the relation between digital technology that is used in everyday life and both the negative and positive environmental impacts (e.g. first-, second, and third-order environmental impacts of ICT [64]). For example, the impact of manufacture, distribution, and disposal is linked to negative first-order environmental impacts of ICT [64]. Second-order effects encourage positive environmental effects through their influence on processes of production, transport and consumption. Third-order effects are the long-term “adaptations of behaviour and economic structures” [112, p. 349] which can lead to rebound effects [112].

1.1 Growth and escalation

The increasing ownership and usage of mobile digital technology is contributing towards a predicted growth in total European smartphone traffic from 0.5 exabyte (2014) to 4.6 exabyte (2020) per month (1.2 GB – 6.5 GB per month, per user) [45, p. 5]. This growth is mainly attributed to increasing demand associated with data-hungry activities such as video streaming and social networking [45, p. 169]. To support increasing demands, growth in provisioned infrastructures (e.g. telecommunications networks, wireless hotspots, 4G/5G end-points, charging points) and back-end services (e.g. data centres) is also incurred. In 2014, the UK coverage of premises for high-speed mobile networks is at 84% for 3G network coverage and 35% coverage for 4G, with growth of 4G infrastructures from the three main service providers varying between 2–14% over five months (June-October 2014) [93, p. 68]. The roll-out of 4G is predicted to reach 98% of the UK population by the end of 2017 [93, p. 8]. The number of publicly available WiFi hotspots in the UK grew from 33851 to 41798 between June 2013 and June 2014 [93, p. 104].

The cycle of rapid technological advancement encourages increasing energy and emissions impacts through shorter technology life cycles (e.g. regular digital technology upgrades). Increased opportunities to be connected lead to the utilisation of greater amounts of bandwidth (e.g. higher coverage of public WiFi and 4G connectivity), and increased electricity consumption of digital technologies due to more frequent and more devices being charged or used (e.g. growth in the number of living room connected devices [111]).

With the penetration of smart phones and tablets increasing, and wearable technologies becoming more mainstream, users are surrounded by opportunities to interact with technology throughout everyday life. This increased exposure can be seen to increase user reliance on technology in certain practices (e.g. communication, watching media, fitness and exercise, dating).

Considering growing mobile data consumption, widespread deployment of 4G and soon 5G, wireless telecommunications infrastructure is set to provide users with better connectivity and larger amount of bandwidth, further increasing opportunities for demand through higher-bandwidth transmissions (e.g. higher definition video [26], the adoption of ultra HD and 4K video content [93, p. 115–116], the deployment of HD voice [45]) and even more reliance on cloud or internet services.

In this thesis I quantify a number of the impacts of digital technologies. These include manufacturing and distribution (e.g. embodied carbon) (Chapter 4), charging and power use (e.g. electricity demand) (Chapter 4), and use of communications infrastructures and cloud services (e.g. Internet connectivity and data demand) (Chapter 5).

The increased reliance on digital technology is contributing to increasing energy and emissions impacts in three main areas: (1) *Embodied impacts*, which arise during the manufacturing and distribution of devices (e.g. production phase impacts [4]); (2) *Direct impacts*, which is the electricity that a device uses in the home (e.g. direct [8] or 'use phase' [4] energy); and, (3) *Indirect impacts* (such as the energy and emissions due to running communications networks and data centres) that are caused when a device inside the home relies on an external Internet or cloud based service (e.g. streaming a video using Netflix to a device in the home). These areas of impact are connected together by the practices that incorporate digital technologies. By applying Shove's *social practice approach* [121, p. 23] it is possible to explain how environmental impacts are linked (or not) to meaning (e.g. what the practice means to the practitioner), competence (e.g. the skills and know-how that are applied in a practice) and material (e.g. the technology itself). By applying a social practice approach I aim to provide accounts of how variations in the elements of practice (e.g. meaning, competence, material) contribute to variations in impacts (e.g embodied, direct, indirect).

1.2 Thesis outline

Chapter 2 provides an analysis of the related works, covering: the study of home energy and eco-feedback; understanding energy impact in everyday life; social practice and domestication approaches; the study of domestic digital technologies within HCI and their impacts; and, the impacts and practices of mobile digital technologies. I position my work in terms of its novel contributions along with the short comings and lessons that have been learned from previous work.

Considering more than just electricity or embodied emissions, Chapter 7.2 outlines an holistic paradigm that links the environmental impacts and evolution in social practices that occur through the appropriation, use, and growth of digital technologies. In Chapter 4 the holistic paradigm is applied, revealing the links between emissions, energy and social practices. The chapter concludes by highlighting the importance in understanding the underlying causes of variations in inventories of digital technologies (e.g. the use of individual devices, configurations of connected devices) and social practices (e.g. the pursuit of connoisseurship), and how these relate to energy demand and emissions.

To gain better insight on how the impacts of digital technology have grown, this thesis employs detailed accounts of digital technologies in the lives of three groups of participants. The thesis begins it's contribution in Chapter 4 by categorising the impacts arising from the use of digital technologies in the lives of thirty-two university students. Following this (Chapter 5), I study use of mobile digital technologies (e.g. smart phones and tablets) in everyday life, linking time-use to data demand. Finally (Chapter 6) through a personal inventory study, this thesis reveals where growth of use, practices, and expectations occurs in the lives of ten participants. The thesis concludes with a discussion of how digital technologies are growing existing and furthering new energy demanding practices, complemented by a discussion of potential new directions for HCI researchers concerned with the growths in social practices and everyday life that are coupled with the use of digital technologies.

Further exploring the link between practices and the indirect impacts arising from data demand, Chapter 5 analyses the use of mobile digital technology in eight participants lives. This chapter explores how social practices are co-evolving with digital technologies. This co-evolution is leading to increasing demands for data connectivity, encouraging blurring between practices due to softer temporal and spatial constraints [112] encouraged by mobile digital technologies', and can be seen (through the development of applications and their social networks) to digitally support existing practices. The chapter concludes with a discussion of the roles of mobile digital technology in everyday life, and how these roles can be seen to encourage data demand.

Chapter 6 outlines how the co-evolution of domestic digital technology and everyday life is leading to growth in impact areas other than just energy. This chapter expands on previous studies of growth by analysing where growth is arising in social contexts of ten participants (e.g. social practices). This discussion considers how growth surrounding digital technologies is usually discussed (e.g. growth in energy consumption). The focus of this chapter is on outlining areas that are sometimes overlooked when discussing growth or escalation associated with digital technologies. The chapter concludes by beginning a redressing of the growth of digital technologies to help better uncover the extent of the impacts of digital technologies on everyday practices (e.g. growth in practices, growth in ecologies of devices, growth of reliance).

I conclude the thesis in Chapter 7 with a summary of the contributions, finishing with a discussion of avenues of potential future work derived from the new understandings and contributions featured in this thesis.

1.3 Contribution Statement

In response to the escalating impacts and growth of domestic digital technologies, this thesis contributes an analysis of the energy, emissions and daily practices of digital technology in the home (Chapter 4) to help researchers account more fully for these impacts. This chapter leverages several mixed method approaches to provide new understandings of the impacts of digital technology in the domestic environment and in everyday life, linking embodied emissions, direct energy, indirect impacts and social practices.

The second contribution (Chapter 5) of this thesis is that it connects growing data demand with social practices that are performed using mobile digital technologies. This contribution goes beyond the previous focus on understanding data demand in the home [22, 72], or focusing on attitudes towards digital technologies [59, 68, 88], contributing an analysis of the role of mobile digital technologies in everyday life, the relationship between data demand and social practices, and new understandings of how these roles and relationships lead to varying amounts of energy and emissions impact.

Finally (Chapter 6), in an attempt to broaden the understanding of growth (e.g. growth in use, users, practices, spaces) that arises in everyday practices because of digital technologies, I provide a new discussion of the areas of growth in which these technologies are implicated.

Chapter 2

Related Work

Home computer ownership is at all time high in the UK (81%), with other digital technologies even higher (e.g. TV 97%, DVD Player 87 %) [38, ch. 3]. The energy consumption of digital technology (including home computing and consumer electronics), is the fastest growing domestic consumer, contributing the most towards domestic energy demand, having risen by around 850% (0.25 - 2.4 Mtoe[1]) since the 1970s [38, ch. 3]. Between 2000 and 2015 energy consumption from digital technologies grew by around 45% (1.6 – 2.4 Mtoe) [38, ch. 3]. In 2015, digital technologies contributed about 34% of total domestic energy consumption in the UK [38, ch. 3].

With European mobile devices downloading an average of 334MB of data per month (2014) [114], which has risen by over 800% since 2009 (35MB per month (2009) to 342MB per month (2012), and 4G/LTE at 1302MB per month (2012) [26]), the growth in demand for data and connectivity (described as *data demand* from here onwards) is a growing concern.

The energy consumption of network and data centres is estimated at 50% of that consumed by domestic digital technologies [31, 143]. Corcoran et al. anticipate the standardisation of 'thinner' clients, and more efficient consumer devices which rely more on the cloud for functionality [31]. They go onto predict that the proportion of energy consumption associated with the network and data centre side of demand will increase by 12% due to the required expansion of infrastructure [31].

Even with such high contributions towards total domestic energy, growing demands for data and signs of growth in Internet infrastructures, HCI research concerned with the energy, domestic daily life and social practices continues to primarily focus on services such as heating and cooling (e.g. [27, 119]), and food and surrounding practices (e.g. [17, 51]). By contrast, this thesis deals with the energy and environmental impacts introduced by digital

[1]Mtoe - Million tons of oil equivalent is used to represent 11,630,000,000 kWh.

technologies, themselves.

In the rest of this chapter I explore: the energy and emissions impacts of digital technologies; theory and concepts for studying everyday life; and, prior work in sustainable HCI. The chapter concludes with the motivation for a more holistic account of energy impacts and social practices, that when applied, can uncover the relationship between data demand and social practices, and encourage the exploration of growths associated with digital technology and everyday life.

2.1 Digital technology's impacts

There has been very little HCI research that attempts to quantify energy and emissions of technologies', though the importance of reducing of these impacts has been widely acknowledged. Blevis' seminal work in sustainable interaction design [15] attempts to dissuade the standard practices of disposal, encouraging renewal, reuse, re-purposing in design, and highlights the importance of considering the disposal of the old technology when developing replacements. In order to understand the extent that renewal, reuse, re-purposing, and disposal contribute to a technologies overall energy and emissions, it is necessary to quantify the associated impacts. This section explores methods for quantifying the demands associated with digital technologies.

2.1.1 Life-cycle analysis

Life-cycle assessments are performed to quantify the energy and emissions impacts that arise throughout the lifetime of a product or service. Life-cycle analysis (LCA) is a technique for evaluating the total environmental impact, including the material extraction process, manufacture, distribution , device usage (e.g. electricity consumption), and disposal or recycling. LCA uses material and energy data sources to calculate the carbon footprint of a technology or device. Due to the complex nature of materials extraction, processing, manufacturing and transport, it is widely acknowledged that there are inaccuracies in the overall emissions estimates, particularly for sophisticated products such as digital technologies.

Highlighting a lack of LCA on newer digital technologies, Teehan and Kandlikar [134] perform LCA on pre-2004 and post-2009 products. Their results show a 50–60% decrease in carbon equivalent, due to use of fewer materials. Through collecting their own mass data and cross-referencing this with the 'ecoinvent' database[2] Teehan et al. determine that

[2]http://www.ecoinvent.org/database/database.html

there is a linear relationship between mass and the embodied emissions released during the manufacturing phases of three pre-2004 and eleven post-2009 manufactured devices.

An in-depth survey of carbon accounting for ICT devices by Anders et al. in 2010 shows that typical errors in LCA literature are on the order of about 50%, even for similar products [3]. Thus, there may well be typically large inaccuracies in LCA. A survey of previous studies of LCA by Malmodin et al. [82] highlights that inaccuracies in LCA occur primarily due to a lack of transparency in the processes used for raw-material extraction, leading to large margins of error.

An extensive review of the LCA of ICT, digital media, and other digital technologies encourages future LCA of ICT to focus on the shortcomings of previous research [4]. This survey further highlights the need to account for missing data, the issues with transparency when dealing with secondary data, and the sources of data, since the parameters used in these calculations are "highly important" as "different assumption[s] may alter the result substantially" [4, p. 221]. The authors also reiterate the need for authors to clearly communicate assumed lifetimes of products.

2.1.2 Data demand

However, the energy and emissions associated with the manufacture, distribution, and use-phases of these technologies (e.g. LCA [4, 81]) only tells part of the story.

Modern smart phones, tablets and digital technologies (e.g. smart TVs, laptops, media centres) rely on network infrastructures and Internet (or cloud) based services for their core functionality. These services are accessed over different networks (e.g. wifi, 3G, 4G/LTE) and have varying energy impacts themselves (e.g. variation in size of data centres, bandwidth required or provided, and the way that content and services are distributed). It is important to consider how these devices are appropriated in everyday life, and how their usage leads to *indirect* demands and impacts. These demands are refereed to as *data demand* in this thesis, and are quantified in terms of data (e.g. MB of data) and where used for comparison as energy (e.g. kWh).

Outside of HCI, research focus is turning to quantifying data demand from Internet and cloud services, and associated environmental impacts (e.g. [31–33, 105, 115, 116, 118]). Similarly to LCA (Life Cycle Analysis) , those who attempt to quantify the impacts related to data demand sometimes find large margins of error (e.g. orders of magnitude difference in quantified data demand in kWh per GB [32]), especially when there is variation in use [118], and variation in the impacts associated with content distribution [117].

Even with varying estimations of energy and emissions (e.g. 7kWh/GB (2008) [143], 0.052kWh/GB (2012) [118]), there is little doubt that the growth in demand on these services is not likely to decline. Although the embodied and direct emissions of mobile devices are small, these devices should not be ignored. With data demand contributing 90% of the total use phase energy of tablets [66], data demand outweighs the impacts associated with the demands of charging (e.g. direct energy), especially when relying on mobile infrastructure as this is at least 1.75 times more energy intensive [118]. With up to 90% of the use phase energy consumption being due to data demand we cannot afford to ignore the indirect impacts just because a large proportion of their energy is "hidden" in the communication network and CDN/data centre.

2.2 Theory and concepts for studying everyday life

In this section I introduce relevant social science theory and approaches. Through using appropriate frameworks (e.g. social practice theory) it is possible to contextualise the link between demand (energy, data) and everyday life; how variations in practice may lead to variations in energy consumption. I then explore how a social practice approach opens up discussions around the dynamics of daily life.

2.2.1 Social Practices

Whilst there are many versions of social practice theory; in his article summarising their main components, Reckwitz defined a practice as "a routinized type of behaviour which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge" [108, p. 249].

It is perhaps more useful to employ a reductive model of practices. Shove et al. conceptualise Reckwitz's definition as entities that make up three elements in their reductive model: materials (technologies or other physical objects that facilitate a practice), meanings (symbolic significance of performing a particular practice) and competences (the skills and know-how associated with a practice, which are necessary for correct performance of that practice) [121, p. 23]. Taking the practice of cooking as an example, we can see how it can be divided into these three categories: the materials (the ingredients, kitchen equipment and cookbooks); competences (the ability to follow the cookbook's instructions, use the equipment and cook the intended meal) and meanings (the need and desire to eat homecooked meals).

Employing the use of such a theory moves the interest away from individuals and towards practices themselves; rendering these as the unit of analysis in research. By interrogating the meanings associated with a practice, or group of practices, it is possible to comment on how drivers, such as meaningful relationships between people, can affect expectations within a practice, thus enabling much more insightful exploration of the relationships between practice, digital technology and energy and emissions impacts. Given my interest in digital technology, the adoption of a social practice approach here avoids discussions of an individual's particular uses of a technology and opens up a dialogue around how that practice has come to be, what it accomplishes, and what it means and to whom.

Changes in practices

Naturally as technology, people, environment or infrastructure changes so do social practices. To effectively discuss the histories and futures of growth in social practices and associated energy and emissions surrounding digital technologies it is important to consider how, why, and when practices change. A social practice approach allows for the dynamic nature of social practices to be explored. Changes to one element can be seen to affect the others, and the practice itself, with links between the elements being made and broken leading to new practices emerging and old practices persisting or disappearing [121, ch. 2].

Through time, these elements can be seen to circulate and endure [121, ch. 3]. Using a social practice approach allows for deeper understandings of circulation and endurance in practices and their elements. For example if, to listen to music, one stops using a record player connected to a hi-fi and starts using an iPod and headphones, unforeseen impacts can be had on the practice. If the qualities of listening to vinyl records are important to the listener, the original device (the record player and hi-fi) may be brought back into practice (e.g. the old practice persisting). This may occur due to strong associated meanings (e.g. preferred experience of listening to vinyl) or older competencies persisting (e.g. digitising one's music collection is nothing like the older competencies of maintaining a record player or caring for vinyl).

Bundles and complexes of social practices exist, where practices have intertwined in such a way that when two or more practices occur in the same space, and can be seen as *"dense clusters and loose bundles that hang together in different ways across space and time"* [121, p. 152]. Bundles occur when practices overlap in time, location, or material [96], whereas complexes of practices are more tightly bound together, co-depending on each other, and are tightly linked, routinely, in both space or time (e.g. practices performed in sequences or at the same time) [121, p. 84–87]. For example, a bundle may occur when a practitioner checks their email whilst watching TV as the time and space of email checking overlaps with the watching. An example of a complex of practices could be listening whilst working or studying (e.g. listening to background music whilst essay writing). For the practitioner, these practices are are tightly coupled in the performance of working or studying, sharing space, time and a material.

By using social practice as a unit of analysis, the changes in social practice (e.g. the evolution or persistence of elements, the relationships between practices) can be explored to better understand the involvement of digital technologies in everyday life. We want to understand what implications digital technologies' incorporation in practice has for the future of energy demand and environmental impact. But, practices are constantly changing, and so is digital technology. By observing variations in practice across different participants, and discussing with them how things have changed over time, we stand to be better informed about how digital technology might develop to be lower demand and lower impact. Shove's simplified model shows us how changes in practice can be explained as a co-evolution of its materials, meanings and competencies.

2.2.2 Space, time and digital technologies

Røpke and Christensen highlight a number of areas in which digital technologies are enabling the softening of the temporal and spatial constraints surrounding social practices [112].

> *"In addition to the general applicability of ICT, mobile technologies and the internet offer a unique potential for softening the constraints of time and space. Many practices have become partially decoupled from their previous time–space location, and a more fractured timescape has emerged."* [112, p. 359]

The softening of these constraints can enable practices to continue in different times and spaces both inside and outside of the home (e.g. communication can now be done almost any time, anywhere with modern ICT). Digital technology can encourage practitioners to "activate dead time" by filling "unproductive time" with the activities supported by digital technology [112, p. 255]. This dead time can urge users to complete more tasks throughout the day, and may lead to feelings of "harriedness" that stem from the "anxiety regarding the temporal overload created by the proliferation of simultaneous demands" [129, p. 8]. Although the activation of "dead time" can be seen as positive by the practitioner, its filling has implications for energy and data demand due to services and infrastructures being required to be available throughout the day.

To understand how this spatial and temporal softening in practices links to energy demand and everyday life it is important to answer the following questions: how does this softening affect the everyday lives of practitioners (e.g. what are the effects of harriedness); how does this softening and activation of dead time affect peak demand; and, when does this softening encourage more bundling of practices?

2.3 Prior work in SHCI

SHCI research concerning the domestic environment and the impacts of digital technologies often looks at new ways that technology can be designed to reduce energy consumption and encourage more sustainable behaviours. Such research aims to do this by: a) reducing carbon and energy impacts, b) informing consumers and user so they can make reductions of their own accord (e.g. eco-feedback), and, c) design digital interventions that overtly or discreetly push the user towards a more sustainable (or less energy intensive) performance of practice. Research that attempts to complete the previously mentioned goals hinge on a common theme–that technological advancement will get us closer to sustainability. An example body of such research is that regarding eco-feedback in the home.

2.3.1 Eco-feedback in the home

Smart meters can be used to effectively collect live and accurate household energy demand data (e.g. electricity and gas) [37]. Feedback methods (e.g. monthly bills, in-home eco-feedback displays) provide consumers with varying levels of feedback on their consumption [36, 46]. A survey of energy feedback methods by Faruqui et al. highlights that 3–13% reductions are typical when using energy feedback approaches [46]. Even with feedback encouraging reductions, the reductions themselves can be difficult to sustain in the long term [60]. Given that it is difficult for researchers to accurately link changes (e.g. in behaviour, practice, usage patterns) undertaken by the consumers, to reductions in energy it is challenging to evaluate the true success of a feedback method [102].

Eco-feedback is resource centric area of research, focusing on the development of new technologies to increase awareness and understanding of resource consumption [34, 49]. This research is inscribed with motivations that can be linked to bodies of psychology and behaviour change research [48]. An outcome of eco-feedback and resource management research is that many consumers are *not* motivated by the environment, with consumers being more motivated by the financial benefits of saving energy [24], or community restrictions and goals [19, 99]. Woodruff et al. found that significant money and effort is required when attempting to live a more sustainable and self-sufficient life [145]. Chetty et al. confirm many of Woodruff's findings in the more general population [24], noting the potential "green divide" is being created "by making resource management available only to those who can afford the technologies to support being green" [24, p. 242].

Several authors are critical of the hyper-focus and narrow vision for effecting changes in domestic energy consumption using eco-feedback. Eco-feedback is "grounded in a basic assumption that home dwellers lack information" [102, p. 244]. The eco-feedback approach has been criticised by Strengers as being targeted at the “Resource Man” [132, ch. 3].

> “Resource Man is interested in his own energy data, understands it, and wants to use it to change the way he uses his resource. He is the ideal and individual consumer of energy, and his aim is total control and choice over his use of energy so that it is operating as efficiently as possible, in a way that suits his lifestyle.” [132, p. 36]

Strengers goes on to point out that, very few people are like the “Resource Man” because micro-managing resources with such attention to detail requires understanding of the unconscious and habitual nature of everyday life. These understandings are not captured by energy sensing and eco-feedback [132, ch. 5] leaving “non-negotiable” and “taken-for-granted” practices (e.g. cooking, bathing) [132, ch. 5] untargeted for reductions, with the primary focus remaining on areas of practice which can be classified as unnecessary or wasteful (e.g. better managing technology in standby, switching off technology that is unused). The savings to be had by such changes tend to be very small, and ignore the resource-intensiveness of practices that are broadly taken to be normal: showering, cooking, and watching TV.

Recommendations provided by eco-feedback are described as generalisable (e.g. managing standby of ICT [23]) for improving energy management, but are typically uninformed by the contexts of real life (e.g. reasons why devices are left in standby, use of technology can be different between users and not always seen as a target for switching off), limiting their effectiveness. Pierce et al. observe that everyday interactions with home appliances are performed “without conscious consideration of energy consumption but rather are unconscious, habitual, and irrational” [102, p. 1985], alongside a reluctance to micro-manage domestic ICT [102].

Typical eco-feedback, as Strengers points out [132, ch. 5] is unable to incorporate understandings of how practitioner’s own life (e.g. their social practices) contributes towards energy consumption. To better support reduction in domestic energy consumption, researchers and designers need to understand and incorporate contexts of everyday life: “what people do in their homes, how people use energy and water and why" [133, p. 2142].

2.3.2 Practice-oriented approaches in HCI

Using the reductive social practice model put forward by Shove et al. [121], the human and computer are de-centred from the analysis, with the practices, elements (e.g. material, meanings, competence) and links connecting elements becoming the focus. By considering the practice, instead of the user, it is possible to “engage with social and cultural dynamics” of everyday life [142]. HCI researchers dealing with everyday life have recognised the importance of this engagement, leading to a recent uptake in the use of social practice theory in studies of everyday life and sustainability [103].

To understand the role of sustainability in everyday life, Woodruff et al. [145] published a qualitative study of 35 households that had made "significant accommodations to their homes and behaviors in order to be more environmentally responsible". Their study reveals that the pursuit of sustainability can be difficult, circumstances constantly change which can be demanding mentally, financially and in terms of time. Their findings show that to have the most environmentally positive impact a sustainably responsible lifestyle has to be prioritised over the common American lifestyles that leverage modern conveniences [145, p. 320].

The impacts of digital technologies on both social practices and energy consumption are focused on less frequently within HCI. HCI research that focuses on the energy or environmental impacts of digital technology in everyday life has covered the following: the under utilisation of power management strategies of ICT [23]; the ownership of digital technology and its shared time usage [20]; and, the patterns of modern ICT usage across spaces in the home [72]. These papers all reveal interesting patterns of usage of digital technologies, but do not concern themselves with interrogating how IT is implicated in the growth of energy demand and emissions.

Previous work that has applied a 'practice-approach' to digital technologies include studies of how home network technologies, revealing practices that are specific to the home network (e.g. optimizing performance, recovering the network after a failure, prioritization of use) [35]. Researchers are also interested in thinking about how digital technology plays a role in daily practices in different future energy scenarios. These researchers have created design fictions where digital technologies are used in the accomplishment of: more sustainable practices (e.g. Wakkary et al. [141]); and, practices in a radically different future (e.g. Tomlinson et al. [136]). Perhaps closest in method and motivation to the work in this thesis is that of Pink et al. who discuss ethnographic and design practice examples when studying the energy associated with media consumption of domestic households [104]. Whilst the methods explored in these design fictions and design practices are useful when thinking about how to design for future practices and studies of everyday life, they steer away from the discussions of the relationships between practice and energy, specifically the importance in the link between everyday practices and growth in energy demand.

Whilst discussing the tensions and differences in approach in SHCI, DiSalvo et al. highlight that the "evaluation of long-term and systemic effects is a blind spot for HCI" [40, p. 1979]. One way to consider the effects of digital technologies (that HCI is often concerned with) is to consider the roles of these technologies in social practice. By understanding these roles and how they vary and change it is possible to better reflect on where the growth of energy impacts can be connected to digital technologies and everyday life.

Håkansson & Sengers' study of ICT in the lives of 'simple living families' is perhaps the most broadly scoped study of how ICT features in everyday life [57]. They uncover the roles (and restrictions) of ICT in the lives of families that "[choose to] 'live simply out of concern' for the environment and for their own quality of life" [57]. Their report captures detailed accounts of everyday life, highlighting how attitudes towards sustainability engrained in the lives of their participants has lead to concious reductions and restraint in ICT reliance. The findings of Håkansson & Sengers are particularly pertinent in that they emphasise the importance in considering how everyday life as a whole is messy, interconnected and hard to negotiate. This is especially true when considering personal qualities of life and sustainability, such as the concern with how much exactly is "enough".

Like Håkansson & Sengers, I feel that it is important to understand the underlying roles of digital technology in everyday life. By combining understandings of these roles with quantitative energy impacts it may be possible to better account for the variations in energy demand brought on by the "messiness" of everyday life (cf. [11]).

2.3.3 Mobile digital technology

Relevant research in broader HCI focusing on energy and use of mobile technologies (i.e. smart phones and tablets) typically focuses on understanding the uses and consequences of mobile technologies. Some examples include: mobile information requirements [127]; patterns of mobile device use [16, 71, 85, 131]; the use of search in social settings [25]; how parents use mobile phones whilst caring for children [65]; Internet usage on smart phones [138]; why and where mobile phones are used in the home [86]; and, battery life and management (e.g. [5, 47]).

Typically, this research is motivated by understanding how to improve the user experience, locating efficiency gains in mobile technology usage and extending battery life through improved application design. This leads to a number of these papers suggesting "technofixes" [105]or frameworks for encouraging more sustainable behaviours and designs which are often limited in their scope of everyday life.

2.3.4 People, 'stuff' and the environment

The roles of physical and virtual "stuff" in everyday life have been uncovered through methods which have used personal inventories and domestic objects as a basis for exploration.

These studies have lead to a number of new and important lessons regarding digital technologies and the connection to energy impacts.

Perhaps the closest to quantifying some of the external impacts of digital technology in HCI is work by Huang et al. [68] who discuss the opportunities that there are for combating the "disposable paradigm" associated with the short lifetimes of mobile phones. Their paper follows on from Blevis' call [15] for more consideration of the disposal of technology, studying the short lifetimes of mobile phones. Huang et al.'s findings highlight that upgrades occur through the encouragement of contracts ending and special offers from providers being offered, and not the functionality and style of a mobile phone. Similarly, Hanks et al. focus on the attitudes towards the purchase, re-use and disposal of personal digital technology [59]. They explore why these attitudes may (or may not) relate to the environmental concerns of young people.

Odom et al. look more broadly at personal effects, studying the attachment, preservation, and reuse of possessions [88]. They further highlight the lack of attachment to digital technologies and discuss methods for designing for personal attachment. This work has continued with others studying how attachment influences longevity of the ownership of digital technology discovering that digital technologies that have fallen into a state of non-use are kept 'just in case' instead of being disposed of [52]. Influenced by stockpiling and short device lifetimes frameworks have been developed to encourage design that promotes the creative re-use of e-waste [73] and attachment to digital technologies [110]. This has culminated in a number of papers that try and tackle the obsolescence [69, 110, 113].

Unfortunately, some of this work is more aimed at enhancing experiences with archiving and keeping track of old data (e.g. [89]) (and the old devices that data was stored upon); and making interactions with older stuff more meaningful [73, 110] (even if that doesn't keep the person from acquiring new stuff). Whilst this research encourages design that can lead to less energy and environmental impacts, its focus is limited to particular possessions or artefacts that are used in everyday life.

2.4 Motivation

This thesis utilises practice-based understandings of everyday life, alongside quantified metrics for energy demand, environmental impact, time-use, and space-use.

Digital technologies, through their development, adoption and use throughout daily lives influence the way that users perform practices (e.g. digital technologies co-develop and affect everyday practices [112]). Mobile devices, that are rarely further than a few meters from their owner [39], can be seen to soften spatial and temporal constraints of social practices [112, p. 354-357], leading to increased performances of supported practices. This softening adds more complexity to the difficulties that are already presented in managing everyday life and personal qualities [57]. If one aim of the SHCI community is to encourage sustainability surround digital technologies then we must grasp a more holistic understanding of the connection between everyday life, social practices and energy – and how these things evolve together. To form this understanding the relationships between social practices and technologies need to be linked to the energy and emissions impacts that arise throughout their lifetime (e.g. embodied energy, direct energy, and data demand).

Chapter 3

Methodology

To provide an improved understanding of how digital technology and practice evolve, and the relation to energy demand and environmental impact, it is necessary to apply a mixed methods approach to capture: practices, energy demand (e.g. direct electricity consumption and that arising indirectly as a result of data demand), and greenhouse gas emissions produced by the manufacturing and transportation of digital technologies.

Outside of HCI, hybrid and mixed qualitative/quantitative methods have been discussed and used to better understand how measures of energy and environmental impact link to everyday life (e.g. residential heating [55, 128], the relationship between energy, social status and household income [56], laptop practices and energy use [130]). By supplementing quantitative data (e.g. energy, usage, network) with qualitative approaches it is possible to develop a more rich and nuanced understandings of how digital technologies are embedded into everyday life. These understandings enable a deeper exploration into how energy and data is relied upon in the undertaking of social practices, and can enable the quantification of social practices (e.g. capturing times of use of specific technologies and applications). For example, by combining per-device sensing (e.g. electricity, app usage, data demand) with qualitative data (e.g. semi-structured interviews) it is possible to link quantitative impacts (e.g. electricity/data demand) with everyday practices (e.g. cooking [28]). In better understanding these practices it is possible then to comment on how these technologies are connected to everyday life and energy. With this new awareness of the roles of energy in everyday life allows for the envisioning of alternatives that enable transitions towards lower energy demand and environmental impacts.

In this chapter I outline the methods used, the motivation for their use and the analysis that the application of these methods has allowed for.

By studying the social practices enacted by individuals it is possible to better grasp where variation occurs, and how variation in practices influences variations witnessed in energy demand. While studies that highlight trends in energy demand can be influential in finding norms (e.g. large scale studies studying peaks in demand) these studies often overlook the variation that can occur between individual participants (e.g. household occupants, individuals). As "social practices do not present uniform planes upon which agents participate in identical ways but are instead internally differentiated on many dimensions." [142, p.138], it is important to consider the variation present across similar practices. As Morley and Hazas highlight [84] understanding individuals, or in the case of their study "occupants", who have "a unique influence (of some kind) on variability in consumption", leads to a better understanding of variation in energy consumption.

3.1 Recruitment

More than half the participants who feature in this thesis are students. Studies of students have been criticised for not representing broader populations. However, as life transitions away from the support of parents and towards individual, students and young adults are in singular phase of their life where many areas of practice are changing. As a result of moving away to live in a new place, and meeting new people, they encounter new understandings (meanings), materials and competencies. In line with the growth in digital technology energy and data demand (highlighted in Chapter 2) the device usage characteristics of young adults aged 16-24 in the UK can be seen to correlate with growth. For example, young adults are more likely to exhibit characteristics of early adopters [92, p.49], contributing to growing device ownership. Further to this, the increased likelihood to layer digital technologies on top of other technologies [92, p.52] along with their relatively high usage of social media [92, p.45] is a further factor where young adults have been seen to contribute to this growth.

Table 3.1 provides an overview of the studies conducted, the participants and the data collected from these. The initial three sets of participants were recruited through engagement with participants who were taking part in a university campus energy competition attempting to encourage the students to use less electricity. When recruitment took place in 2011, the flats were part way through this competition. The flats presented in Bates et al. [7] were targeted for recruitment based on the diversity of their energy 'characteristics'. Each flat was then given a colour categorisation for the sake of identification. Blue was selected due to its large energy consumption profile, Yellow and Red for their low profile, and Green for its mid-range profile. As the methods had been designed in such a way that different sets of practices could be investigated: those involving thermal comfort and those involving digital technologies, additional student participants were chosen from the thermal comfort and adaptive thermal comfort studies (see Table 3.1). These participants were initially recruited given that their accommodation had a high average temperature, and due to the required infrastructure (e.g. per-room heating) to accommodate for this study.

Participants for the Android mobile digital technology study and photo study (see Table 3.1) were recruited using mailing lists, direct email, and flyers on campus noticeboards. Appendices C and D show the respective participant information sheets.

3.2 Quantitative data

Although I am critical of eco-feedback (see Section 2.3.1) as a sole means of addressing energy demand and environmental impact, I believe that the use of sensors, can be useful in developing new understandings of per-device (or per-appliance) use and energy consumption. By linking energy consumption to time and durations of use we can answer questions such as, when do particular devices consume energy, what are their patterns of use, and how do time-use and consumption vary in time and space?

The quantitative methods used allowed for the quantification of digital technology time and practice use, electricity consumption, and data demand. The two methods of data capture used were;

1. **Sensor deployments.** For the capture of per-socket energy data Plugwise plug sensors were used to capture live data relating to the electricity consumption. Fine-grain data was collected at 60 second intervals in the disaggregation of services study, and a 6 second intervals in the following studies (see Table 3.1). This collection of per-device energy data (e.g. watts consumed) allowed for the quantifying of electricity usage over the study period and eluded to periods of usage, and the varying power states of digital technologies. This is used in Chapter 4 to examine when devices are used in conjunction with one another; and to highlight the relation between direct energy demand to embodied emissions.

2. **Smart phone and tablet activity logging** (i.e. software that was deployed on smart phones and tablets to capture application usage, application foreground time data demand in and out, screen state, charge level and state, and attached accessories). Whilst a bespoke application was developed by an undergraduate to log those Apple products (see Table 3.1), the data for the Android mobile digital technology study was collected using a third-party application, DeviceAnalyser[1], developed by researchers

[1]http://deviceanalyzer.cl.cam.ac.uk/

at The University of Cambridge. The logs produced were then used in the data analysis, which results in Chapter 5, to examine times and durations of use of different application, their data demand, and when and how mobile devices were charged and updated.

3.3 Qualitative data

It has been said that it is important to connect quantitative data with theoretical approaches to more inclusively account for domestic resource use [21, p.954]. A social practice approach provides a framework for understanding how people's actions, habits, expectations, interactions and encounters with technologies and infrastructures are connected to energy demand, environmental impacts and data demand.

A basic interview schedule was constructed and semi-structured interviews were tailored to each individual participant, after the initial data analysis had occurred. The following qualitative methods were used to contextualise energy and technology with everyday life.

1. **Photo elicitation**. This method was used to explore the inventories of digital technologies and their place in everyday life. Participants were asked to photograph their digital devices to capture their inventories of digital technologies. This method draws on that of Gegenbauer et al. [53], who captured photographs of participants inventories, and Odom et al. [87] who perform an inventory study whilst studying "attitudes toward and relationships with interactive technology". A total of 107 photographs were captured across ten participants.

2. **Semi-structured interviews**. Initial structures (see Appendix A and B) were drafted out for the interviews and were customised for each participant dependant on a secondary data source (e.g. photo elicitation, graphed energy or smart phone usage data). Shove's reductive model of practice was [121, p.25] used to shape the questions in the interviews, focusing on all three elements: material (the technology owned and used), meaning (what the practice means to the person, and how this is affected by the material element), and competencies (skills and know-how necessary for not only the successful enactment of practice, but for the skilled use of technology also). Questions were targeted at understanding how the digital technologies fitted into the participants' everyday lives, and how that varied throughout the day, in space and time.

   In addition, graphed quantitative data (e.g. the participants energy or data use throughout the study period) and photos from the photo elicitation were used to prompt participants during this phase. These prompts enabled the participant to engage and recall practices and activities that were performed at particular times or in particular ways. On occasion these prompts allowed for participants to recall subtle practices and activities that they would have normally taken for granted and would therefore normally would have struggled to recall. These semi-structured interviews ranged in length from 42 to 105 minutes. The interviews were fully transcribed and then openly coded for general themes across participants from for each study.

This thesis continues in Chapter 4 with an exploration of qualitative and quantitative data collected in the Disaggregation of services, Thermal Comfort and Adaptive Thermal Comfort studies (Table 3.1). The following chapter uses data from these studies to provide new and more nuanced understandings of the relationship between energy demand and everyday life.

Study	Study duration	No. Parts.	My Roles	Data Collected	Ch.	Research output
Disaggregation of services study	December 2010 – June 2011	22	Primary role in recruitment, sensor deployment, analysis and visualisation of data. Co-researchers: Janine Morley, Adrian Clear.	Aggregate and per-socket electricity consumption, light, motion, interviews exploring practices	4	Bates et al. 2012 [7], Clear et al. 2013 [28]
Thermal Comfort study	February – June 2012	10	Primary roles in sensor deployment, maintenance, design of digital technology section of interviews. Co-researchers: Janine Morley and Adrian Clear	Quantitative energy, temperative, window and door data, interviews, thermal comfort digital and written diaries	4	Bates et al. 2014 [8], Clear et al. 2013 [29]
Adaptive Thermal comfort study	November 2012 – March 2013	4	Primary role in sensor deployment and design of interview questions surrounding digital technologies. Co-researcher: Adrian Clear	Adaptive thermal comfort data (e.g. thermostat, windows, doors, interactions), per-appliance energy data, interviews	4	Clear et al. 2014 [27], Bates et al. 2014 [8]
iOS Smart phone and tablet study	December 2013 - August 2014	13	Supervisory role in study design, software design, interviews, data analysis. Primary researcher: Rosalind Whittam (undergraduate).	Quantitative data representing iOS smart phone and tablet usage, interviews	5	Lord et al. 2014 [80]
Android mobile digital technology study	November 2014 – March 2015	8	Supervisory role in initial study design, interview schedule design, interviews. Primary researcher: Kelly Widdicks (undergraduate)	Quantitative data representing Android smart phone and tablet usage, interviews	5	Widdicks 2015 [144]
Photo elicitation study	June – September 2014	10	Primary role in study design, recruitment, interview schedule design, interviewing, data analysis. Co-researcher: Carolynne Lord	Photo of technology, interview data	6	Bates et al. 2015 [9]

Table 3.1 Overview of the empirical studies that contribute to this thesis and the author's involvement.

Chapter 4

Understanding energy and emissions of digital technology in the home

The contributions of this chapter are largely based on collaborative published work, Bates et al. [8]. This chapter is based upon data collected during studies designed and executed through a collaborative effort by Janine Morley, Adrian Clear, and myself that lead to several other publications [7, 8, 27–29]. Text presented in this chapter is based upon Bates et al. [8], in which I was the lead author, and therefore the primary contributor of the analysis, figures, tables, findings, and conclusions presented.

In this chapter I present findings from a mixed-methods study of domestic energy consumption in order to provide more complete and nuanced understandings of how digital technology is fit into everyday life to better understand energy and emissions impacts. This chapter exposes the link between the inventories, social practices, configurations of digital technology, and associated environmental impacts of thirty-three undergraduate students. Using these thirty-three I present specific nuanced findings that mixed methods studies enable (e.g. investigating the roles of constellations and connoisseurship, intentions and impacts of digital technologies, the roles of hub devices).

4.1 Methods and Data Gathered

This chapter focuses on the four areas of impact: embodied emissions; direct energy; indirect impact; and, social practices. I provide quantitative measures for both embodied emissions (in the form of kilograms of carbon dioxide equivalent, abbreviated kg CO_2e) and direct energy (in kilowatt-hours). Indirect impacts were not quantifiable using this data set and are therefore discussed in this chapter through the use of illustrative examples and specific examples of variations in practices that can lead to different indirect impacts. These examples are grounded in interview data. Calculating indirect impacts (e.g. infrastructure, cloud and CDN) from qualitative data is difficult as it relies on network traffic, path, data centre location (and power source), and infrastructure. Later in this chapter I illustrative examples are used to demonstrate how practices are shifting, and how these shifts can lead to changes in energy impacts.

Using mixed-methods this chapter draws on data collected across three studies (Table 4.1) of undergraduate students in the North West of the UK. Due to all three of the original studies being focused on multiple themes within sustainability (e.g. accounting for energy services in the home [7], thermal comfort [27, 29]), only a subset of the data collected in these studies is presented in relevant publications [7, pp. 112-5]. This chapter is based on the content of Bates et al. [8], with expansion on the topics (and variation) of embodied emissions, digital technologies in social practices, and configurations of digital technology.

All of the participants discussed in this chapter were students living in shared, on-campus accommodation. The flats in which the participants lived had between four and eight residents. All the flats had communal areas (e.g. central corridor, toilets, shower rooms, kitchen), with dorm rooms connected via the central corridor. Communal devices in shared areas (e.g. the kitchen) are not included in the analysis in this chapter. Typically the digital technologies that were present in communal areas included small TVs provided be the University, or docks, speakers or stereos owned by one of the participants. A summary of the studies can be seen in table 4.1

Study	Study Period	Participants	Interviewed Participants	Total Devices
1	March 2011 - April 2011	21	11	127
2	March 2012 - April 2012	4	4	21
3	November 2012	8	8	43
Total	-	33	23	191

Table 4.1 A summary of the three studies contributing to this chapter.

Inventories were taken on the initial visit to participant's rooms and flats. Fine-grain, per-device energy monitoring was done using Plugwise socket monitors, capturing consumption data for a total of 191 devices. Semi-structured interviews were tailored to the collected per-device consumption data. These interviews were used to improve the understanding of the uses and roles of media and ICT throughout the everyday life of the participants. These interviews were fully transcribed, and coded. In some cases interviews are supplemented with additional communique (e.g. emails, text messages) that were used as prompts to gain time-sensitive information pertaining to patterns observed in the energy data. All 33 participants are referred to using pseudonyms. Studies 2 and 3 studies ran for longer than 20 days but have been deliberately cropped to 20 days to allow for comparison with Study 1. The cropped segments were chosen to make them comparable, i.e. during term time and while the participants were resident in the flats.

4.1.1 Limitations and assumptions

The participants described in this chapter were all students, so their practices may not be seen as generalisable (e.g. essay writing, use of virtual learning environments, use of support forums). Also, students in higher education are in a transitional life stage in which new stresses, freedoms, responsibilities and complexities of life have to be dealt with. Whilst going through these transitions, students are likely to be engaged in new practices for the first time, evolve others to suit their current lifestyle (e.g. filling free time between classes), and plan for future lifestyles (e.g. life after university). This means that they are less likely to own a 'full' variety of digital technologies due to financial and spatial constraints, and that their practices may be less stable as a they living away from their parents for the first time.

With between 20–40% of the UK population ($\tilde{3}0\%$ in the US) having gone through higher education, and 3.6% of the UK population currently in higher education, students are a worthwhile demographic to study due to the development of habits and social practices that are continued into life beyond higher education.

When compared to other areas of practice (e.g. cooking, home heating and cooling, laundry), the habits and practices surrounding digital technologies are more likely to draw parallel with that of other parts of the population. For example, comparing the participants' ICT practices to other studies, e.g. Røpke et al. describe a similar set of ICT related practices in fourteen Danish homes [112] explaining the impact of ICT on social practices beyond energy and emissions, and Håkanson and Senger's study of simple living families, in which they study the role of ICT in their participant's daily lives given a slower uptake of ICT in their lives and the pressures from others [57].

Due to the lifetimes of the participants' devices being unknown, the embodied carbon illustrated in this chapter (e.g. Figures 4.2 or 4.3) represent emissions that would have arisen through the manufacture and distribution of a single device of the specified kind. The embodied carbon emissions discussed in this chapter make the assumption that the device is used by a single owner for the duration of its lifetime.

The inventory data collected in these studies does not include a full accounting of manufacturer or model data for any of the participants digital technologies. Due to lack of information on manufacturer and model it is not always possible to calculate the embodied emissions for specific participant's devices. In these cases it will be assumed that similar devices are within the same range of carbon emissions.

4.2 Inventories

191 devices and appliances were monitored for electricity consumption across the thirty-three participants' private study-bedrooms (Table 4.2). Fifty-one of these appliances were non-media or ICT related devices (e.g. kettles, coffee machines, electric tooth brushes, personal lighting, hair dryers, hair straighteners) and were not found to support digital technology practices or services in any way. While these appliances feature in Table 4.2 to fully depict the participants, my analysis targets the 140 digital technologies.

As shown in Table 4.2 the number of digital technologies owned by the participants ranged from very few (e.g. two devices owned by Zoe) to a much larger number (e.g. eighteen digital technologies owned by Matt). All participants owned a mobile or smart phone, other than Gary who owned two. Computers were owned by all thirty-three participants: twenty-nine just owning laptops; one with just a desktop; and three owning both a laptop and a desktop. Jill, in the midst of the study, replaced her notebook with a laptop. Connected devices were popular across sixteen of the participants, including additional displays (e.g. TVs or monitors) and peripheral devices (e.g. printers, powered speakers, external hard disk drives (HDD), powered USB hubs). The eight TVs that were owned by the participants were all also connected to at least one additional device (e.g. DVD player, games console, sound system, external HDD).

Where known, brackets (e.g. { Laptop, Speakers }) in Table 4.2 shows how the devices were virtually and physically connected. I call these groupings of devices *constellations* [8].

4.2.1 Constellations

Between 2000 and 2009, ICT consumption in the UK more than doubled from 3.1 TWh to 6.5 TWh [94]. This is in part due to the availability and ability to physically connect or network digital technologies in the home. Owen comments on the availability of technology and overlapping nature of domestic digital technologies:

> "The trend of convergence means more and more items–games consoles, tablet

Participant	Constellations	Non constellation media and IT devices	Other Devices	No. Devices	Total Constellations
Zoe	-	Laptop	-	2	-
Ellie	-	Laptop	Kettle	3	-
Thomas	-	Laptop	Alarm Clock	3	-
Aaron	-	Laptop	Alarm Clock	3	-
Wendy	-	Laptop	Hair Dryer	3	-
Jess	-	Laptop	Hair Straighteners	3	-
James	-	Laptop	Lamp	3	-
Jill	-	Notebook -> Laptop	Lamp	4	-
Donna	-	Laptop	Hair Straighteners, Lamp	4	-
Luke	-	Laptop	Lamp, Guitar Amp	4	-
Leah	{TV, Nintendo Wii}	Laptop	-	4	1
Miranda	-	Laptop	Hair Dryer, Hair Straighteners	4	-
Vincent	{Laptop, Laptop Fan}	Camera	-	4	1
Nathan	{Laptop,Speakers,Printer}	-	Toothbrush	5	1
Kevin	{TV, Xbox 360}	Laptop	Alarm Clock	5	1
Polly	-	Laptop	Lamp, Iron, Hair Dryer	5	-
Omar	{TV, Xbox 360}, {Laptop,Speakers}	-	-	5	2
Stan	{Desktop, Monitor}	TV	Hair Dryer	5	1
Darren	{Laptop,Speakers}	Camera	Lamp	5	1
Callum	{Laptop, Monitor, Tube Amp}	-	Coffee Machine, Hair Dryer	6	1
Emily	{Laptop, Printer}	-	Lamp, Kettle, Iron	6	1
Jack	{Laptop, Speakers}	-	Guitar Amp, Lamp, Fan	6	1
Natasha	-	Laptop, Record Player, Camera	Hair Dryer, Hair Straighteners	6	-
Rachel	{Laptop, Printer}	iPod Dock	Hair Dryer, Hair Straighteners, Lamp	7	2
Nadia	{Laptop, Printer}	iPod Dock	Hair Dryer, Alarm Clock, Hair Straighteners	7	1
Chloe	{TV, DVD Player}, {Laptop, Printer}	-	Fan, Alarm Clock	7	2
Kate	{TV, Xbox 360}, {Laptop, Printer}	Stereo, MP3 Player	-	7	2
Stephanie	{TV, Portable HDD}	Laptop	Lamp, Hair Dryer, Hair Straighteners, Toothbrush	8	1
Feng	{TV, Playstation 3}, {Laptop, Speakers}	iPod	Hair Straighteners, Lamp	8	2
Ian	{Laptop, Speakers}, {Laptop, Screen, Speakers}, {Xbox 360, Screen, Speakers}	iPod	Hair Straighteners, Alarm Clock	8	3
Henry	{Desktop, Monitor (2), Router, External HDD (2), Audio Receiver}, {Xbox, Monitor, Audio Receiver}	Laptop	-	10	2
Gary	{Audio Receiver, EQ, CD Player}, {Desktop, Monitor (2), Audio Receiver, Router, NAS}, {Xbox, Monitor, Audio Receiver}	Laptop	Guitar Amp (2)	13	3
Matt	{Laptop, Monitor, Stereo (2), Router, Airport Express}, {TV, IPTV, Stereo (2), Xbox 360, Mac Mini Server, Bluray player}, {Mac Mini Server, USB hub, HDD (2), Router, Airport Express}	-	Coffee Machine, Guitar Amp	18	3

Table 4.2 An overview of the inventories and constellations for the thirty-three participants. The table is sorted in ascending order of number of devices. Mobile and smart phones have been left out of the table to preserve space.

> computers, mobile phones, the above-mentioned printers, and even televisions– perform overlapping computing functions." [94]

This emphasises that people use multiple devices to perform one or more simultaneous tasks, requiring: a) technology to be left on so that a task can be seamlessly switched between devices, and b) simultaneous use leading to the "layering" of practices that rely on digital technologies (e.g. background TV or audio played through another device or constellation whilst a practitioner is performing a practice, such as communication, on another device).

A constellation is considered to exist and to be active when two or more connected devices are consuming electricity at the same time, often working in parallel to support the same practice. Participants were observed using multiple related devices to perform a task, requiring them all to be left on so that a task can be performed without interruption. Henry's constellation illustrates this:

> "*I suppose it's not really my computer I use as much but my stereo. I use that a lot, which is connected to my computer. So, the things that are hooked together are, I've got my hard drives, my router, my two monitors, my stereo and my desktop, that's all hooked together.* "

The contribution from a constellation relates to the nature of service provision. The higher complexity or number of constellations in a home, the more digital technology that is implicated in a service. A larger inventory of digital technology leads to more energy consumed by services and practices.

The complexity of a constellation entirely depends on its purpose. For example, Nathan's laptop and printer constellation, or Chloe's TV and DVD player constellation, could be considered as 'low complexity' because they allow for single-purpose extension of practices, such as printing documents, and watching DVDs. Other participants have more complex laptop-centric constellations that include speakers, additional displays and printers. These constellations are more complex as they can bring functionality to multiple different practices. For example, speakers being plugged into a laptop could be for a better audio experience within practices of watching and listening (e.g. listening to music, watching TV or a movie), or they could be for video or audio conferencing. Similarly, an additional display could be for improved work (or study) experience, watching video or playing games on a larger screen, or to enable the user to monitor several on-screen applications at once.

Constellations can shift over time, especially where devices are multi-purpose and aren't always required. Sometimes devices don't have enough inputs, motivating users to change between the input device (e.g. Ian owns a large display, but has limited inputs on the display meaning that he has to manually switch between Xbox or laptop), or one of the devices is portable and its usual physical position is not close enough to remain physically connected to the constellation (e.g. Ian uses his laptop on his desk and has to move it to the floor to connect to his constellation).

For those of our participants with their own routers and network switches (Henry, Gary, Matt), both wireless and wired local networks extend the potential for complexity of a constellation. The laptop with peripherals, and the TV connected to an Xbox become sub-constellations within the room once they are connected to the router. The router or network switch multiplies access to external connectivity (e.g. Internet connections), and also enables communications between two sub-constellations (e.g. the Xbox can stream video content from a laptop).

Constellations are central to understanding the variability across the impacts of digital technology. The vast majority of digital technology is now designed to be networked, leading to dynamic constellations. This dynamic is further extended when a constellation relies on services or applications that are Internet based. The availability of Internet and cloud services (e.g. streaming audio, reading the news, streaming video on demand) on digital technologies and constellations leads to more instantaneous demand, through more frequent reliance on services and infrastructures outside of the home (e.g. more frequent accessing of servers for media content, auto-downloads and backups, higher resolution content). The size (and growth) of a constellation also impacts the embodied emissions associated with an ecology (or inventory) of digital technologies.

4.2.2 Embodied Emissions

The embodied emissions of digital technologies have been discussed in section 2.3.4. In this section I investigate how embodied emissions contribute to the energy and emissions impacts of digital technologies. This section outlines the quantification of embodied emissions that are linked to other impacts later in this chapter.

Embodied emissions in this chapter describe the one off costs associated with the raw material extraction, processing, manufacturing and distribution[1] of a technology. Due to the complexity and opaqueness surrounding mineral extraction, processing, and manufacture it is difficult to definitively calculate the embodied emissions of a product. Those who discuss methods for LCA have long acknowledged that this leads to inaccuracies in the estimation of Greenhouse Gases (see Section 2.3.4). These inaccuracies are exacerbated when it comes

[1]LCA sometimes includes maintenance, repair, recycling, and disposal in an assessment. In this chapter I will just be concerned with raw material extraction, processing, manufacturing and distribution, and usage (direct energy) grounded energy consumption data collected during the studies.

to complex products (e.g. digital technologies).

Due to these inaccuracies, I take a conservative estimate from LCA literature to represent the embodied impacts associated with the raw material extraction, processing manufacturing and distribution of digital technology in the thirty-three participants inventories. Teehan and Kandlikar [134] calculate their own coefficient for the embodied emissions of digital technologies, they combine their own mass based impact data and the 'ecoinvent' database[2] that holds up-to-date, consistent and transparent Life Cycle Inventory (LCI) data. Using their calculated coefficient to compare pre-2004 and post-2009 products, Teehan and Kandlikar conclude that there is a linear relationship between mass and embodied emissions (e.g. 27 kg CO_2e per kg of product [134, p. 4002]).

	Embodied emissions (kg CO2e)	Mass (kg)	Source
Desktop	180	-	Tehan and Kandlikar
Laptop	200	-	
Monitor	190	-	
Smart Phone	45	-	Lord et al.
Mac Mini Server	180	-	Apple Tech Report
TV	405	15	Calculated using 27 kg CO2e per kg of mass. (Teehan and Kandlikar.)
Computer Peripheral	8.1	0.3	
Games Console	94.5	3.5	
Router/Switch	6.75	0.25	
DVD/Blu-ray Player	67.5	2.5	
CD/Record Player Separate	135	5	
Audio Receiver (Inc. Speakers)	405	15	
Computer Speakers/Dock	62.1	2.3	
Printer	81	3	
Camera	8.1	0.3	
MP3 Player	5.4	0.2	

Table 4.3 The calculated embodied emissions for digital technologies owned by the participants.

Table 4.3 shows estimated embodied carbon for the different devices found in the inventories of the participants. The embodied emissions calculated by Teehan and Kandlikar are presented in this table. For technology not calculated in their paper [134], the coefficient used by Teehan and Kandlikar in their analysis is used: 27 kg CO_2e per kg of product [134, p. 4002] to ensure the estimates are comparable. Additionally, I include LCA taken from whitepaper reports released by Apple[3] where applicable. To ensure that my embodied estimations are comparable to that of current HCI research, I use an average (e.g. 45 kg CO_2e) of the embodied emissions for smart phones reported by Lord et al. [80, p. 2731] which is based upon Apple's whitepaper reports.

[2]http://www.ecoinvent.org/database/ accessed Thursday 4th February, 2016
[3]http://www.apple.com/uk/environment/reports/ accessed Thursday 4th February, 2016

Table 4.3 shows that there are significant differences in impact between different classes of digital technologies: smart phones ($\tilde{4}5$ kg CO_2e); small consumer electronics (e.g. routers, digital cameras $\tilde{1}0$ kg CO_2e); desktop computers ($\tilde{1}90$ kg CO_2e); laptops ($\tilde{2}00$ kg CO_2e); and, displays, monitors and TVs (ranging from $\tilde{1}90$ to $\tilde{8}10$ kg CO_2e).

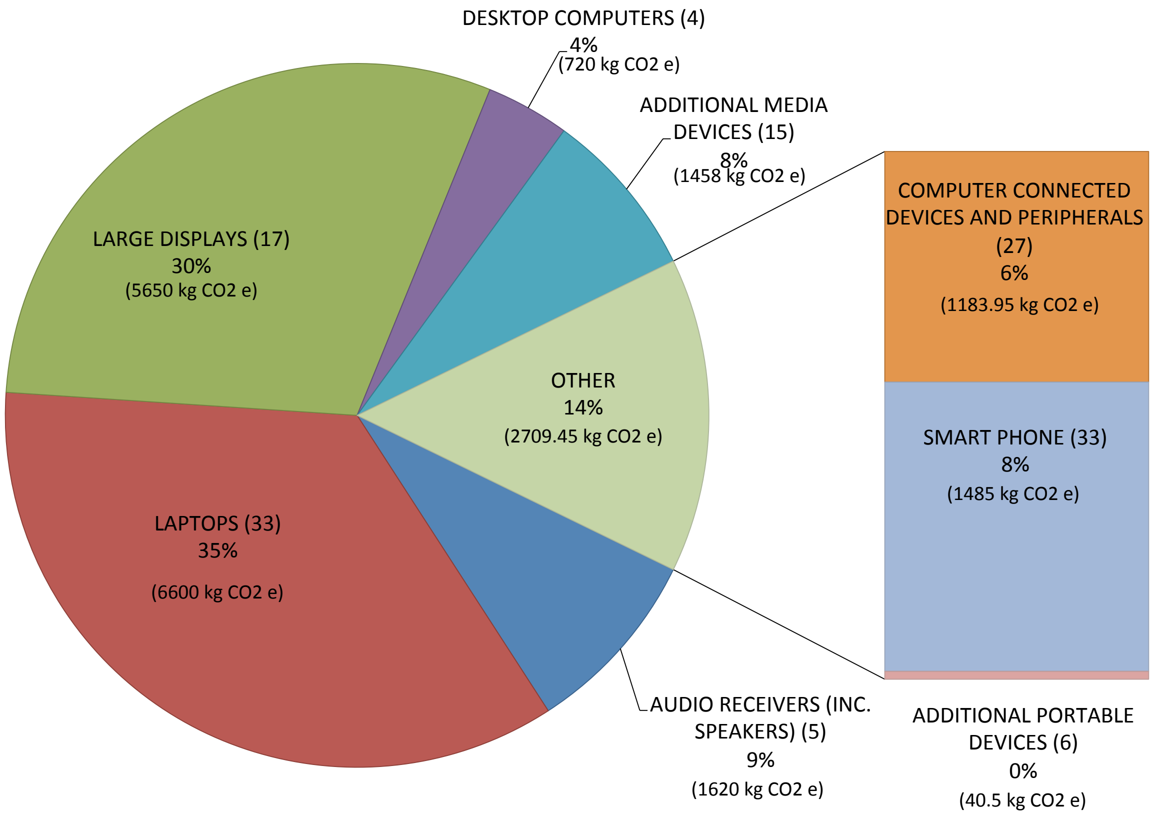


Fig. 4.1 Embodied carbon breakdown by category of device (140 devices across all participants). Additional Portable Devices includes small items that were uncommon across the inventories of the participants (e.g. digital cameras, mp3 players with impacts typically around 10kg CO_2e)

Figure 4.1 shows a a breakdown of the embodied emissions of the participant's inventories. The combined total of carbon emissions of the thirty-three participant's digital technology is 18757.45 kg CO_2e. This figure shows that the embodied emissions of laptops are the largest contributor of embodied carbon (35%), with an additional 23% of embodied emissions arising for the peripheral and connected devices that are often used in constellations with laptops, desktops, and TVs (e.g. Additional Media Devices, Computer connected devices and peripherals, Audio Receivers). Similarly, it shows that the majority of impacts associated with desktop computers (4%) and games consoles (4.6%, part of Additional Media Devices) can be attributed to the displays they are attached to, with large displays making up ~30% of total embodied emissions.

4.2.3 Linking embodied emissions to participant inventories

The ownership of more digital technologies (Table 4.2) correlates to larger embodied impacts (Figure 4.2). These larger inventories contain more digital technologies, and more complex constellations. Constellations are able to be expanded to include more and more peripheral and connected technologies, resulting in the highest embodied impacts (e.g. Gary, Harry, Matt in Figure 4.2).

The per-device distribution of embodied carbon (Figure 4.1) indicates that displays are the second largest contributor of embodied carbon, accounting for 30% of the total embodied emissions. When considering this in the context of participants inventories (Table 4.2), displays are the largest contributors towards embodied emissions, often larger than the rest of the constellation, for a number of participants (Figure 4.2).

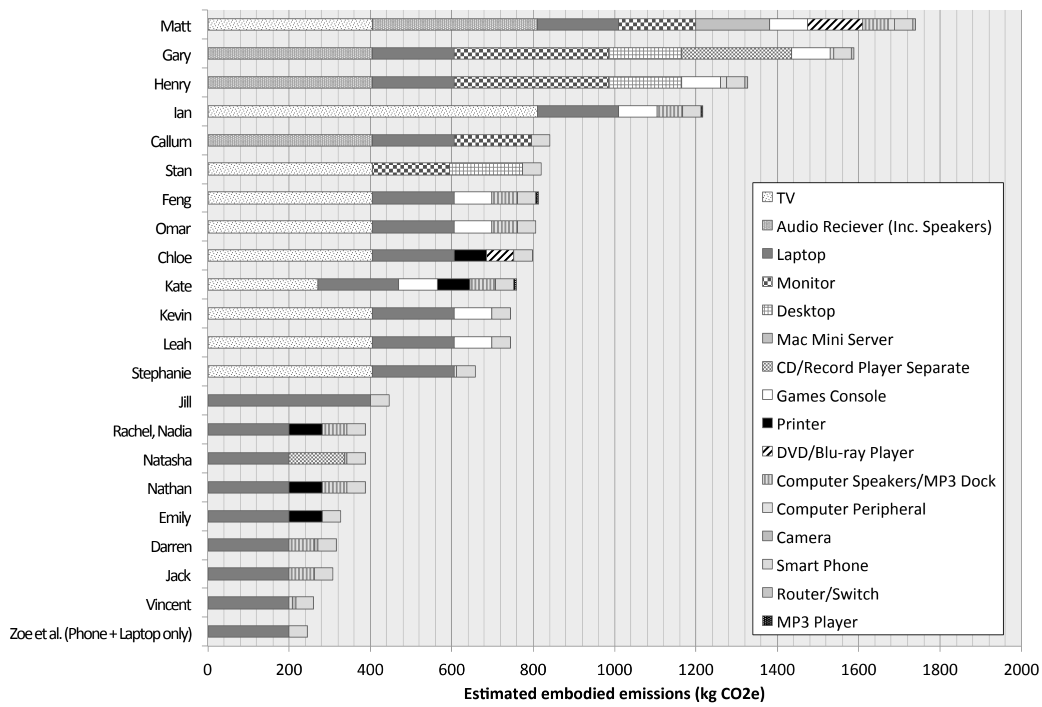


Fig. 4.2 The breakdown of embodied emissions across each of the thirty-three inventories.

Figure 4.2 shows the distribution of the embodied carbon estimates across the participants' inventories, grouped by device. This figure's breakdown of embodied carbon shows that the complexity and number of constellations owned by a participant tends to be linked with higher embodied impacts (e.g. Zoe's small inventory versus Matt's large complex inventory).

Displays always need to be in constellation with another device to be used, unless they were designed with integrated technologies (e.g. TVs with digital tuners, smart TVs with a USB/network interface for playback of digital content, TVs with integrated DVD players). The ownership of a peripheral device may lead to the purchase of a display, or vice versa. Lower carbon devices (e.g. DVD players, games consoles, desktop PCs) all require one or more displays to be used in practice.

For participants with less complex constellations (e.g. Leah's TV and Nintendo Wii, Chloe's TV and DVD Player, Stephanie's TV and Portable HDD) ownership of particular peripherals (e.g. games consoles, DVD players, external storage) can be observed to correlate with ownership of hub devices. Hub device are digital technologies that are central, which if were not included in the constellation would prevent the performance of the practices that a constellation supports. The ownership of 'hub' digital technologies (e.g. TVs, desktop computers) and peripherals (e.g. games consoles, displays, audio receivers and speakers) occurs across the majority of participants.

To gain a better understanding of why there are varying inventories and links between impacts it is important to consider why digital technologies are used and owned. In the next section I summarise the practices that the technologies presented in this section were implicated in. To better understand why a particular configuration of a constellation exists we need to know more about the practices that it is involved in. The configuration of inventories and constellations of digital technology is related to the participants social practices, in that the digital technologies owned are often selected to fit a particular purpose or bundle of social practices. In the next section I explore how the participant's social practices influence their inventories and constellations.

4.3 Social practices and digital domestic technologies

Digital technologies are heavily relied upon and intertwined throughout the everyday lives of the participants. The practices described by the participants can be categorised generally as work, education, communication, and media (information and entertainment) practices. In this section I will describe the practices that digital technologies are involved in, highlighting the variation in practices across participants and their entanglement in everyday life (e.g when and why practices occur).

4.3.1 ICT-supported practices

Laptops, smart phones, and desktop computers were the main ICT devices used, each used to support a variety of practices. Laptops were the primary ICT device owned and used by the participants. Laptops were used to support work, personal media and ICT practices. Desktops were used for a similar set of practices as laptops, occasionally being used by participants to perform long, uninterrupted computational tasks (e.g. Gary ran simulations on his desktop PC for consultation work) or as data servers (e.g. Matt served media content to other flatmates from his desktop). Laptops and desktops enabled simultaneous and intertwined performances of practices. The ability to seamlessly change focus leads to blurring of practices [112] (e.g. background music or video whilst working, communications via IM client, email or Facebook whilst reading or essay writing).

Throughout the study period, participants used their ICT for filling in free time and more structured practices. A variety of typical practices were observed to take place, including: communication (e.g. Skype, social networking), entertainment (e.g. browsing the Internet), work, and studying.

Social networking and communication practices become difficult to separate from other activities when carried out on ICT devices, largely because they are achieved through social media tools like Facebook and Twitter, and instant messengers that support asynchronous communications. In these cases, parties may respond in-between other tasks or even when they are next online.

Communication on ICT devices can also be done in pseudo–realtime, with the practitioners using instant messaging (e.g. Skype, Facebook chat) in the background on their computers, then responding as and when they can. Contrary to this, communication also took place synchronously. For example, Ellie, an international student maintained regular communication with her colleagues, friends, family and boyfriend back at home: *"I've a co-executive editor at my school and so we Skype every Wednesday "*, *"I Skype my family on the weekends and I Skype my boyfriend, at night usually"*. Communication, often through social networking (e.g. Facebook), was also seen to be utilised by some participants to coordinate events.

ICT was also used by the participants for tasks that filled leisure and free time, including reading blogs or news, browsing, and online shopping. The participants spent their working hours using their ICT (laptops, and desktops) for studying, alongside university and paid work. These working hours varied across the participants. The uses of ICT included word processing, accessing course materials and submitting coursework through the virtual learning environment, note taking during lectures, printing of course materials, and for revision. As mentioned in the previous section, Henry used his desktop computer for paid work, which involved running and maintaining a locally deployed *“test-bed”* used for running simulations and testing of software.

The main source of variation in ICT practices surrounds how intertwined or blurred the practices are. Some participants valued background audio so that they could listen whilst they worked or studied, whilst others found background listening distracting. Variation also stems from the kind of work or study that the participants were doing (e.g. use of the online VLE, Henry running a test-bed whilst doing other work, note taking).

4.3.2 Watching and listening

The watching and listening of video (e.g. watching TV, or movies) and audio (e.g. listening to music) content varied across the participants. For many, movies and TV shows were typically watched on personal laptops. The methods for watching video content varied; catch-up TV and video-on-demand services (e.g. BBC iPlayer, Netflix); downloaded from unlicensed sources (e.g. torrents, ProjectCatchUpTV); or from DVDs. Notably, four of the participants used TVs instead of laptops. Chloe watched using a DVD player connected to her TV, and Kate used her games console for streaming and DVD playback. Stephanie downloaded content to an external HDD and connected this to her smart TV for playback, whereas Matt used a desktop computer (Mac Mini) connected to a TV and speakers to watch downloaded video content. Flatmates Ian, Donna, and Henry all mentioned that ‘movie nights’ would occasionally be organised in the flat. These movie nights were often hosted by flatmates with larger displays (i.e. Ian or Matt). Sometimes impromptu watching of video in groups occurred. Henry reflected on socialising in the flat, recounting: *“people from the same flat, yeah we spend a lot of time in each other’s rooms, just talking and watching telly”*.

A large proportion of the participants reported that they listened to music. The participants used several different devices (e.g. laptops, audio receivers, speakers connected to laptops) to listen to music including dedicated devices (e.g mp3 players, Colin’s CD player) and smart phones. In some instances, participants listened to music with multiple devices, using external powered speakers in their rooms into which they could plug their laptops or MP3 players. For example Callum used a tube amp; Feng, Omar, and Nathan connected their laptops to external speakers, and; some participants used Hi-Fi separates that included CD players (Colin), record players (Natasha), equalisers (Colin), amplifiers and speakers (Henry, Colin, Matt).

Darren would bring his laptop and speakers to the kitchen so that his friends could take turns playing songs that they liked. Gary and Natasha had specific media devices for audio playback (CD Player, and record player respectively). Gary reported that audio was often listened to in the background, for instance, whilst studying or getting ready to go about their day.

Variation in watching and listening occurred across the participants, with practices of watching and listening relying on different devices (e.g. constellations, single devices), being performed in the background for some and foreground for others. There was also variation in space (e.g. listening in shared areas, shared watching in private bedrooms) and time (e.g. scheduling of watching).

4.3.3 Digital gaming

The practice of digital gaming featured in the lives of 12 participants. Nine of the participants owned dedicated games consoles for gaming, connected to either TVs or monitors. These consoles were connected to constellations that included large displays and speakers (e.g. Matt, Ian, Henry) and just TVs (e.g. Leah, Feng, Kevin, Omar, Kate) Jill and Henry both gamed using their computers, Jill using her laptop, and Henry using his desktop computer. Unlike watching and listening, gaming was primarily done in the participants leisure time, both alone (Collin, Feng, Gary) or with friends (Ian) and partners (Jill).

Nine of the participants owned games consoles. These were either connected to televisions or computer monitors. Henry and Jill did not own consoles, but gamed on their laptops. Collin gamed using both his console and his desktop PC. We saw variation in the extent of use across participants (between 0 and 5 hours per day), and University schedules also affected this. Jill notes how "*Usually in the evening I game before I go to bed,*" whereas Henry recalled how his gaming habits had changed as he became busier with coursework. As Jill notes, gaming is an activity that is often not overlapped with other tasks: *"While I'm gaming I can't do anything else . . . because it takes up the screen."* Group game nights—in a similar vein to group film nights—happened, although less often.

Similarly to watching, the two main points of variation in gaming are the digital technologies used in the practices (e.g. Ian's console and display, Henry's PC, Jill's laptop, Matt's complex constellation) and whether the practice was performed alone or with others. Non console gaming has the largest variation in terms of digital technology as it ranges from gaming on a laptop (e.g. Jill) to gaming on a large constellation (e.g. Henry, Collin).

4.3.4 When do media practices occur?

Similarly to the ICT practices discussed above, media practices were found to be interwoven with everyday life. Practices such as group TV or movie watching was found to be anchored to evening times (similarly to peak demand), and the watching of weekly TV shows would happen soon after their broadcast, through their online availability (e.g. through catch-up TV). For example Ellie had particular TV shows that she liked to watch weekly: *"America's Next Top Model and How I Met your Mother so those are like weekly"*. One participant, Donna, had a routine that involved watching BBC iPlayer whilst getting ready for a night out.

Leisure time (free time) would feature both time-filling ICT practices, as well as media practices that typically span larger periods of free time. Periods of leisure time mostly occurred when there was no work or study schedule. For Ian, leisure time involved watching TV or movies on his monitor. Ian's fondness for digital media often left him with a lot video content to watch, which he typically watched whilst "chilling", which meant watching content whilst *"lying in bed or sitting in bed"*.

When in his dorm room, Henry watches video content through catch-up TV services (e.g. BBC iPlayer, the universities IPTV service). Henry mentions that in the evenings, around the time people cook and eat their evening meal that *"everyone's normally in the kitchen about 5 or 6 and everyone watches Friends and there's Scrubs on at the same time so everybody watches that"*.

Media practices are interwoven with everyday life, with some watching and video gaming practices happening at spontaneous points during the day when users felt like being leisurely, and other watching and listening practices blurring into practices of work and socialising. Other practices of watching are much more prescriptive, in tune with the schedules of newly broadcast TV shows (e.g. Ellie), group watching at meal times because of the shared TV (e.g. Henry), and organised group watching.Due to the participants all being students, leisure and media practices often happened as and when the participant's felt like performing these kinds of practices.

The more prescribed or scheduled communication (e.g. Ellie Skyping with family and friends), gaming (e.g. Jill gaming with her boyfriend) and watching (e.g. group and meal watching) has different implications as it is linked with the free and leisure time of others. These practices often occur in periods where peak demand would occur (e.g. evening time).

4.3.5 Understanding practices: Linking practices to impacts

Understanding when and why social practices that include digital technologies (e.g. watching, listening, gaming, communication) occur is important to uncover how these practices are implicated in the blurring of social practices in everyday life. From the accounts reported in this section social practices can be seen to shape when, how and why digital technologies are used in the domestic environment.

Variation has been summarised for each of the above described practices. Variations occur in all elements of social practices' across the participants with media practices sometimes being seen as both individual and group practices. Practices such as communication, watching, and listening blur with work and studying for some participants, but not for others. Gaming has the ability to limit the simultaneous and interwoven interactions that are linked with the 'blurring' of practices as it can require full screen modes and captivates the user.

This section has also presented evidence of social practices that have recently become more reliant on digital technologies, for example, Donna watching or listening on with her laptop when getting ready for a night out. This is also an example of the bundling of practices.

By grasping a better understanding of how the material element is involved in a practice it is possible to better understand the relationship between variations in social practices and the variations in energy impacts (e.g. direct, embodied) arising from the participants' use of digital technologies. Examples include, individual practices (e.g. Jill gaming on her laptop) and bundles of practices (e.g. Donna listening whilst getting ready, several participants watching or listening to background media whilst working, communication blurring into all sorts of practices).

In the next section, I bring three areas of impact and daily life together (direct impacts, embodied emissions, social practices) and present my findings.

4.4 Digital technology configurations and social practices: Variations in impact

To give a broader view of impacts of digital technologies this section explores the the relationship between the embodied emissions and direct energy consumption. The section goes on to explore how variations in constellations and their configuration affects embodied, direct and indirect impacts. The section finishes by discussing the practices in which indirect impacts are implicated, and outlines where Internet-connectedness has influenced the direct and indirect impacts of the participants.

4.4.1 The relationships between embodied emissions and direct energy

Figure 4.3 shows a comparison of estimated embodied emissions footprint alongside the estimated direct carbon emissions over the course of a year. Direct energy consumption is estimated using electricity consumption data captured during the study assuming that the participant's consumption would remain the same for an entire year.

Single devices: Laptops, smart phones and small devices

The single devices (e.g. laptops, Matt's Mac Mini Server) owned by the participants contribute an additional 21% – 52% per year to the technologies embodied emissions (Figure 4.3). Assuming that single devices such as laptops have a lifetime of several years, these digital technologies can have comparable direct and embodied emissions, depending on their daily durations-of-use.

For small mobile devices, such as smart phones (and tablets), the direct emissions are vanishingly small. These devices typically have shorter life-cycles than laptops or other digital technologies, meaning that the embodied emissions associated with the manufacture and distribution of these devices is where the majority of their environmental impact lie.

The embodied emissions of small devices, such as wireless-routers, hubs and switches, is almost equal to the direct emissions. This is due to the these devices being powered twenty-four hours a day as they play an integral part of the communications infrastructure, providing the participants with connectivity for their digital technologies. These devices often have lifetimes that are longer than smart phones or laptops, and are replaced upon failure or when an upgrade is needed. Home routers on the other hand are issued by Internet Service Providers (ISP), and are therefore more likely to be replaced more frequently (e.g. when a user changes provider, when there is a fault, when the ISP is trouble shooting problems) than hubs or switches.

Large embodied emissions, even larger direct energy

Figure 4.3 illustrates two things; 1) devices and constellations with larger embodied emissions tend to have greater direct emissions, and 2) the largest quantities of direct emissions are due to large constellations.

It is important to note that even for the largest, power-hungry constellations on for the majority of the day (e.g. Henry in Figure 4.4), the yearly direct emissions still only reached half of the embodied emissions. Thus, while direct energy can be justifiable as a target for reduction through methods such as eco-feedback [133], the embodied emissions should never be underestimated.

By considering both the embodied emissions and direct energy consumption of digital technologies it is possible to expose a more full account of the impacts that these technologies have. To further expose why these technologies are acquired and used, leading to energy impact and emissions, it is important to interrogate the underlying social practices.

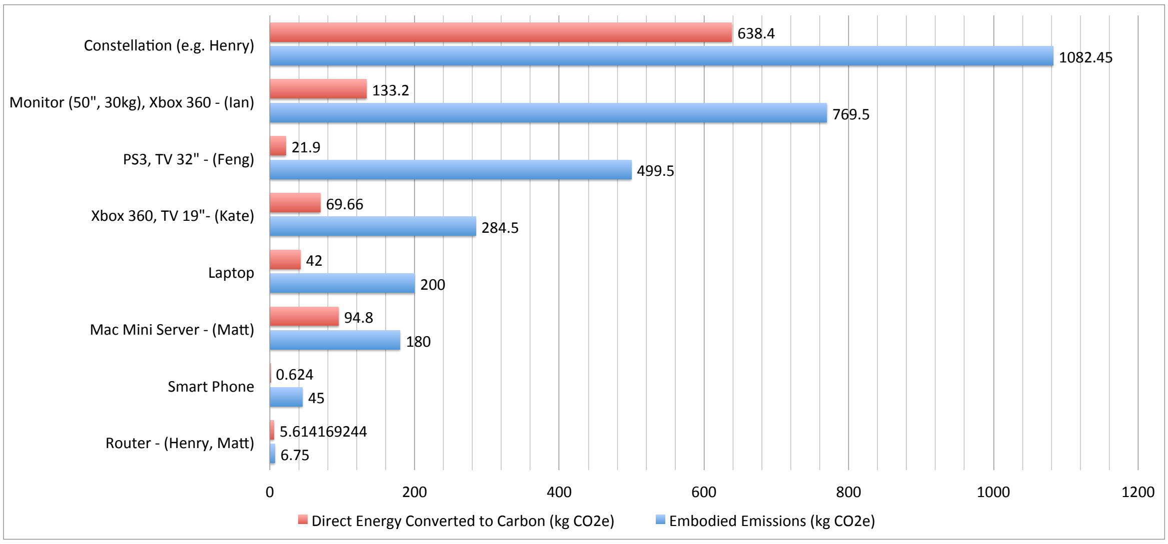


Fig. 4.3 Seven examples of the embodied emissions alongside direct emissions. Embodied emissions values are estimated using the values in Table 4.3. The yearly direct emissions estimate are based on the energy consumption observed in the study, and is calculated using the DEFRA 2010 conversion factor, adjusted to include Scope 3 emissions: 0.60 kg CO_2e/kWh.

4.4.2 The relationship between energy and practices

Social practices evolve when digital technologies are successfully domesticated into everyday life (see Chapter 6.3.1). Once a technology is successfully incorporated into practice that particular technology is implicated in that social practice, leading to energy consumption. A social practice co-evolves with a digital technology or constellation (e.g. through software or hardware updates that provide new functionality, through upgrades and expansions of constellations), affecting energy and emissions impact.

Similar practices, different impacts

As previously outlined (Chapter 4.3), the participants performed similar practices in their everyday life (e.g. communication, work and study, watching, listening, gaming). The most predominant source of variation within their practices lies in the material element (e.g. single devices, constellations), where a range of different devices are used for similar practices ranging from a smart phone to a large constellation. Smart phones contribute the least to yearly energy emissions, with constellations contributing the largest amount of energy and emissions (Figure 4.3).

A constellation becomes subsumed into more practices with the connection of additional digital technology. Constellations are able to expand through the connection of additional technologies which can in turn, lead to growing impacts in the supported practices. For example, the connection of a laptop to a display, now enables the use of an additional display in the performance of practices that are conducted using the laptop. Eighteen of the participants had peripherals (e.g. displays, speakers, printers, seen in Table 4.2) for use with their computers. I have found that connected devices roughly mimic the time-use patterns of the technologies that they are connected to (Figure 4.4). Small, basic constellations were the lowest contributors (Jack, Ellie, Rachel), for example: a laptop and a couple of peripherals (e.g. printer, speakers). Inventories containing a larger number of digital technologies (Matt, Henry) contributed between 3.8 and 41.1 times the amount of daily energy when compared to the small constellations (Figure 4.4). If the participants changed their social practices in such a way that they only required laptops, the total embodied emissions would have been reduced by roughly 50%.

For many of the participants (e.g. Nathan, Callum), constellations often comprised of a number of not particularly energy intensive devices, yet acting in concert they consume a significant amount simultaneously (e.g. Nathan's laptop, speakers and printer, or Callum's laptop, monitor and valve amp). Another interesting finding is that whilst a participant might put one device in a constellation to sleep (the laptop, monitor), the others (valve amp) might well carry on consuming energy. For Callum this was due to the automatic sleep function of his laptop and monitor that was not present on his valve amp. This was similar for Henry, whose monitors went into sleep mode more frequently than the rest of his constellation. Although Henry turns off the lights in his flat on a nightly basis, he still leaves his external hard-disk drive and router on all night. Matt's power management seemed to be almost non-existent; he left his Mac Mini Server, two external hard-disk drives, USB Hub, router, and Airport Express power up twenty-four hours a day.

The configuration of constellations

Constellations are often configured or set up around a central, hub or basis device, e.g. peripherals connected to a laptop or desktop, games console connected to a TV. Among the thirty-one constellations, I found that laptops were the hub device in fourteen of the constellations, desktops in three and TVs as the hub in nine instances. There are three occasions where monitors are used instead of TVs; this requires yet another device in the media constellation (e.g. amplifier or powered speakers) so that audio can be provided. It is hard to know when a well-peripheralised hub device is going to be called upon, making low power modes particularly difficult to automate (e.g. knowing when Henry's external HDDs, or Matt's Mac Mini Server is needed, figure 4.5). As a result, I observed hub devices in

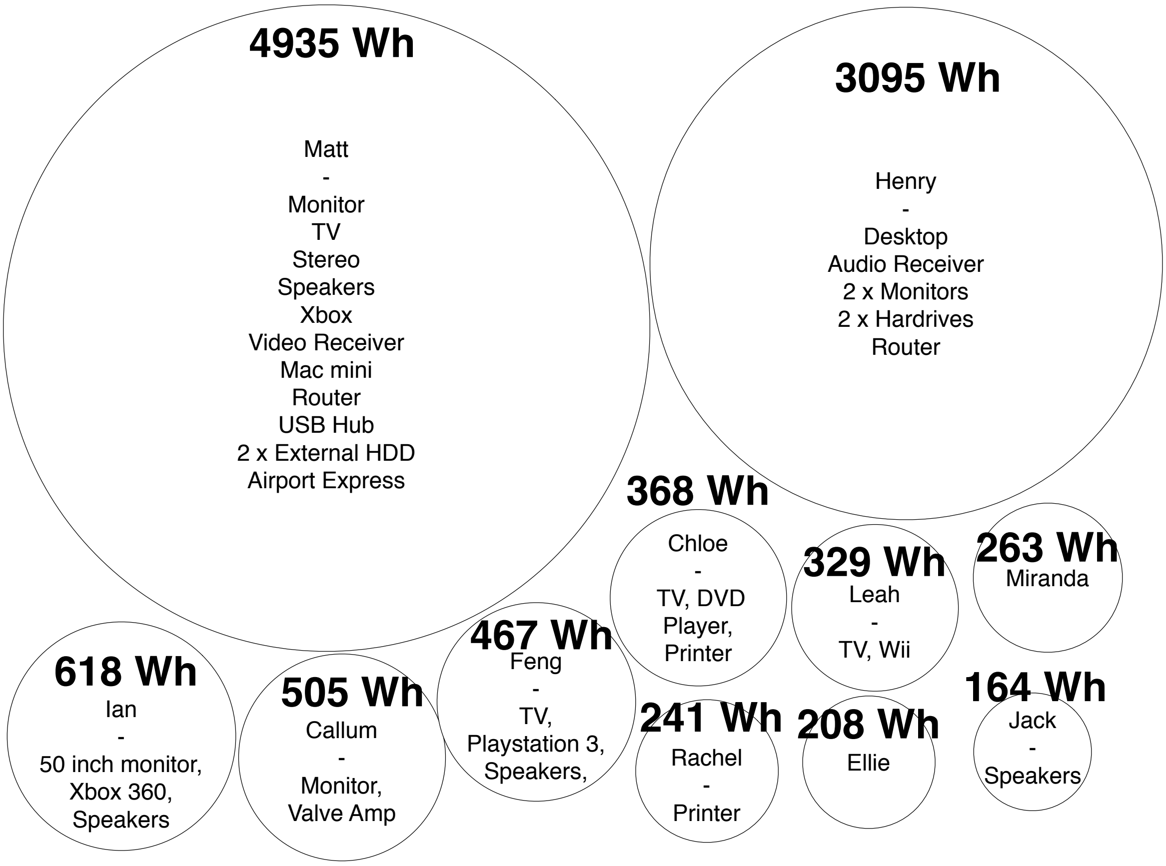


Fig. 4.4 The average daily consumption of eleven participants' devices, demonstrating the variation in inventory and direct energy consumption. Laptops and mobile phones are not listed, as all participants had one of each.

large constellations powered for all or most of the day (16 – 24 h.).

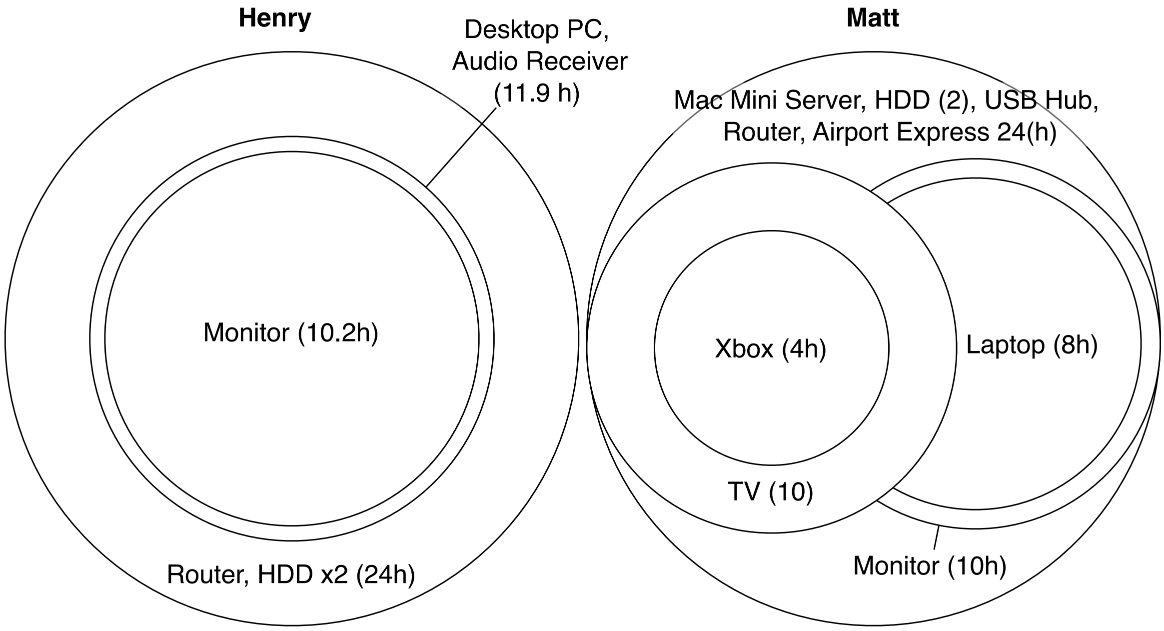


Fig. 4.5 The median daily use-time of Henry's and Matt's constellations. Henry's constellation had a router and two external HDDs as always-on, the monitor on average was in sleep (or off) for two hours of the desktop's consumption. Matt's always-on infrastructure included a router, Airport Express, Mac Mini Server, 2 external HDDs and a USB hub. There was cross-over of the laptop, and TV constellations, but the laptop and Xbox both relied upon access to the server.

4.4.3 Connoisseurs

The most complex constellations were observed to be owned *by connoisseurs*. I have previously defined media and IT connoisseurs as individuals who "spend more time gaming, working with IT, and watching TV and movies typically with linked complexes of specialised devices" [7]. I elaborate further on the concept here, and relate it to variations in impacts. Whereas constellations are sometimes configured to support additional practices of the individual, connoisseurs promote meaningful experiences in practice, by for example, adding speakers to a laptop so that the perceived quality of audio is higher.

Evidence of connoisseurship was observed across eight of our participants. Four participants (Matt, Callum, Gary, Henry) all had specialised devices for audio playback. Matt used a Hi-Fi plugged into additional powered speakers for audio. Callum had a valve amp to enhance experience of music and Gary had stereo separates including an amplifier, equaliser, and CD player. Henry also had an amplifier and stereo speakers that were connected to his PC and Xbox. Four other participants had constellations with large TVs specifically for a better visual experience when playing video games (Ian, Feng, Omar, and Kate). Ian had a 50" screen for playing video games with his Xbox, and watching movies.

Among the participants there were two (Henry and Matt) who have constellations that contribute about 42% of the overall digital technology direct energy across all participants. As well as this high direct energy impact, their constellations contribute 16.5% of the total embodied emissions. Their constellations contain always-on infrastructure, with one or two constellations layered on top of one another (Figure 4.5). These connoisseurs have expectations surround their digital technologies and constellations, culminating in a more customised selection of digital technologies (e.g. custom desktop computer, dual monitors, IPTV receiver, wireless router, and dedicated audio set ups). This shows that connoisseurship in one area of practice may inadvertently affect impacts of other practices (i.e. the attitude that Henry and Matt have towards quality of experience leads them to acquire specific devices, which then draw upon more energy to support a given practice (e.g. watching)). The connoisseurs not only own constellations of devices, they in fact own more constellations, and more specialised devices within those constellations.

Moreover, connoisseurs of digital technology strive for a high quality of service or experience, working to change or upgrade their constellations when circumstance and enthusiasm allow. Henry gives us an account of the upgrades that he performed on his constellation:

> "*Yeah, a lot. A lot different things. In my first year I had er (.) erm I bought my computer, a desktop computer and a single monitor and some cheap speakers, 15–20 quid speakers. And then, and then in my first year I bought a second monitor and some slightly better speakers and I upgraded some of my computer. Er then I bought an external hard drive. Then I my second year I bought a network switch, then some slightly better speakers, I've upgraded the speakers as I've gone, erm, and a better second monitor. . . . Then I my third year I brought back even better speakers [laughs]*".

Connoisseurs make opportunities for reduction in embodied and direct emissions more difficult due to their custom built constellations varying in purpose. For example, Gary's audio constellation was primarily used for listening to music, Henry's audio receiver and Callum's valve amp are used for any audio that comes through their respective PC or laptop whilst they are sat at their desks, where as Matt's audio receivers are used mostly in conjunction with his TV and Xbox for watching and gaming practices. Simply using laptops for practices that rely on these constellations would not be practical for Gary, Henry, Callum or Matt as a laptop may not be seen as a viable alternative that is able to provide the same level of quality as their existing, easily upgradable and reconfigurable constellations.

4.4.4 Indirect Impacts

Through analysis of interview data I are able to make observations concerning the practices that contribute to impacts outside of the home (e.g. reliance on Internet based video streaming services, accessing lecture notes through VLE, audible notifications on mobile devices that occurred during interviews).

Frequency of access and total data amount

Internet connectedness is a salient attribute of a majority of practices supported by media and IT devices. The streaming of media, social networking, mobile and laptop notifications, video gaming and education (VLE usage) illustrates that our participants relied heavily on the connectedness of their devices, even without explicitly mentioning being ‘connected’.

All twenty-three interviewed participants used the Internet to access course materials (e.g. assignments, lecture slides) for studying. twenty-two relied on streaming websites or other Internet-based services for TV watching. Callum “*downloaded off the Internet rather than live TV*”, whilst Ellie mentioned a shared access (with another participant) to a service that allowed her to download TV shows that she watched regularly. Aaron used the Internet to “research” new music, and to download music to fill his iPod.

It is possible to roughly estimate the indirect energy impacts of practices involving Internet-based services by drawing on impact estimates from current scholarly articles, such as those derived by Lord et al. [80] (e.g 0.2 kWh/GB). For example, Ellie’s streaming of two hours of TV per day might have added 50% to her typical daily direct energy impact; while Darren’s frequent social networking might have incurred an additional 10% to his direct energy impact.

Still, there are some practices that don’t require network access. Chloe for example exclusively relied on her TV and DVD player for media content. Other ‘non-networked practices’ include single player video games (purchased on optical disk), and word processing for an assignment.

Connectedness and the opportunities that ‘being connected’ provides, seems to increase direct energy consumption, because connectedness leads to more frequent, and longer durations of use of digital technologies. For example, Miranda’s laptop provided her with the opportunity to stream video-on-demand content whilst getting ready for a night out. Chloe likes to have her laptop running whilst watching video on her TV so she can see any new messages on Facebook. Jill likes to watch TV on her laptop whilst waking up and eating breakfast, and then has Facebook in the background while she works. These examples of opportunistic connections (video-on-demand whilst getting ready) and maintaining connection (Facebook chat in the background) show us that having a connection allows Internet enabled media and IT activities to become part of practices not strictly reliant on media and IT (e.g. getting ready to go out, eating breakfast).

4.4.5 Variation: in impacts, in ways of doing, in everything...

The variations in configurations, consumption, and impact are all caused by the infinite possible number of configurations of inventories (and constellations) of digital technologies and the social practices that they enable. Throughout this chapter I have mostly focused on the variations that arise in the configuration of digital technology in the home, linking these configuration choices, imposed or otherwise, to practice.

By identifying particular practices that encompass digital technologies, and then comparing these practices across participants, I have shown that it is possible to capture variations in life that lead to variations in consumption. This variation emanates in the configurations of digital technologies and constellations that are used in the accomplishment of social practices, leading to large variations in embodied and direct emissions across a set of similar social practices (e.g. work and study, watching, listening, communication, gaming).

Although I have not quantified indirect impacts across the participants, it is important to note that the applications and technologies used for consuming media are often reliant on an on-demand service. An increased reliance on video-on-demand (e.g. BBC iPlayer, Netflix, Youtube) and streamed audio (e.g. iTunes match, Spotify, Deezer) contributes to the escalating demands put on network and Internet infrastructures. Similarly, even though we are seeing efficiency gains across all digital technologies (e.g. less demanding TVs, games consoles), the electricity demand attributed to digital technology is still seen to be on the rise (Section 2.1). To better understand this increase, we have to think beyond the efficiency gains of digital technology, and instead focus on how digital technology is configured in the home in order to understand why the surrounding social practices are becoming more demanding.

In this chapter I have shown the importance in exploring the link between environmental impacts and social practices in which digital technologies are implicated. This chapter has revealed how configurations of digital technologies lead to varying impacts (e.g. constellations and their size), and how these configurations are used in performances of social practices. I have also shown that a mixed methods approach can be applied to gain enhanced understandings of the roles of connected digital technologies (e.g. constellations), and have added additional nuance to previous understandings (e.g. connoisseurs). In the next chapter I explore how mobile digital technologies are encouraging impacts in different ways from domestic digital technologies, focusing on their demand for data, and the impact on everyday life from devices that are always at arms length.

Chapter 5

Mobile digital technologies: Variation through time, space, and data demand.

This chapter is based upon data collected as part of an Undergraduate project by Kelly Widdicks [144]. I had a secondary role in the design of the interview schedule, recruitment, and the interviewing of participants. The transcription of the interview data was performed by Kelly Widdicks. All coded interviews, text, figures, and tables presented in the findings, analysis, and conclusions of this chapter are my own.

Up to this point I have focused primarily on the embodied and direct impacts with digital technologies, along with the role of digital technologies in social practices. To better grasp the indirect impacts of digital technologies we can consider how mobile digital technologies (e.g. smart phones, tablets) are used throughout daily life. By accounting for the use and indirect impacts of mobile devices we can better understand where and why these devices are being used, along with how these uses create a demand for data. To understand how social practices and mobile digital technologies are co-evolving, this chapter explores the role of mobile digital technology (e.g. smart phones, tablets) in everyday life, in order to uncover the relationship between data demand (e.g. the indirect impacts arising from Internet connectivity) and times of use. Through this exploration, this chapter contributes to a better understanding of the temporal variation of social practices and indirect impacts of mobile digital technology (e.g. impact of data demand, phone calls, SMS).

5.1 Impacts of mobile digital technologies

Increasingly, through expectations and social pressures, connectivity is seen as a necessity for life (e.g. maintaining relationships, being seen as productive [2]). Increased connectivity has impacts on global energy and emissions. To maintain connections to people in everyday life digital technologies rely on network connectivity and data. As mentioned in Section 2.1.2, network connectivity requires connection points (e.g. wifi hotspots, cell towers), backbone and local infrastructure, and data-centers. These all contribute to the energy and emissions impacts in the way of *data demand*.

Inspired by the large growth in demand on data centres and network and communication infrastructure (Section 2.1.2) connected to the use of digital technologies in everyday life, this chapter explores the use of mobile digital technologies (e.g. social practices), paying particular attention to usage time and increased reliance on data as a component of practice. The times of use and data reliance are of particular importance as they are likely to coincide with periods of peak domestic energy demand on the National Grid, that occurs "at breakfast time and from about five until ten in the evening" [95, p.7–8].

Mobile digital technologies provide their users with new opportunities to interact with digital technology, and as a side-effect to growing energy and data demand. Røpke and Christensen discuss how ICT is encouraging softening of the temporal and spatial constraints in social practices [112]. These constraints are softened due to the technologies' mobility and availability throughout everyday life. The softening of these constraints can be seen to contribute to impacts, especially in the second (e.g. changes in broader systems and processes), and third-order effects (e.g. medium to long term behaviours that rely more on ICT and its services) associated with increased performances of practices [112].

5.1.1 Previous Work in SHCI

As previously mentioned in Chapter 2, extending the lifetimes of mobile digital technologies has been discussed in HCI research (e.g. [59, 68]). With forecasts predicting escalation surrounding mobile digital technologies (Section 1.1) and data demand (Section 2.1.2) it is timely to uncover the connections between mobile digital technology use and growing impacts. With the increasing reliance on connectivity and data it is important to consider contributions in terms of overall and peak demand [105]. In accordance with this, I veer away from the embodied and direct impacts of digital technologies, focusing on data demand and its relevance in social practices.

Energy is used in the accomplishment of social practices (e.g. [112, 133]). My previous work introduces the reliance on Internet connectivity in the accomplishment of practices as “data demand” [80, p.2729]. Data demand is the quantifiable energy and emissions associated with “demand for network connectivity and online services” [80, p.2729]. In this chapter, I expand upon previous analysis of indirect impacts (e.g. data demand) and include impacts that are associated with phone calls and SMS messaging. By better understanding how the impacts of phone calls and SMS messaging compare to data demand it may be possible to encourage the design of less demanding communication.

Chetty et al. [22] study the effects of “home broadband” in 12 US households, focusing on users experiences with bandwidth caps. Their study is motivated by ISPs who provide a monthly ‘use it or lose it’ usage policy, charging users for any usage over their provisioned bandwidth. Their study reveals strategies for bandwidth management and optimisation, the implications of sharing a capped service, and suggest bandwidth conscious implications for design (e.g. directions for more bandwidth sensitive designs, moving away from ‘All you can eat’ plans). Although this study discusses bandwidth as a resource, data demand isn’t quantified. Regardless, this study highlights several important lessons that are applicable to mobile data demand: 1) people can be “mindful consumers” [22, p.3029], willing to attempt to manage data demand (bandwidth); 2) managing data demand is difficult due to uncertainty of what the source is i.e which application or device is demanding; and 3) there is room for “improved control over how “chatty” an application is, i.e., to configure how often it retrieves or sends data, or even calls its creator for updates” [22, p.3029].

Previous work by Kawsar and Brush studies the use of data demanding digital technologies in the domestic environment [72]. Their research explores the use of these technologies in 86 homes through the analysis of aggregate logs of networked devices and applications collected from the home router. Their quantitative data is supplemented with 18 interviews and 55 surveys. Their study reveals several novel findings about data demand in the home: there is higher activity in the afternoons and evenings for social networking and video watching [72, fig. 4]; tablets are used more frequently than smart phones [72, fig. 2]; and, screen size and usage context influences device preference for social networking [72, fig. 7]. Whilst these are important to consider when attempting to reduce the intensity of data demand this study doesn’t link its findings to any environmental impacts.

Previous work that studies everyday life and Internet connectivity has primarily explored the effects in terms of wellbeing (e.g. the effects of digital gaming [120], alone-togetherness [139], social expectations and negotiating relationships with friends and family [2]). Other than the study by Lord et al., who quantify daily data demand and explore how performance of practices came about using mobile digital technologies [80], practices have not been more broadly quantified (e.g. capturing the relationship between data demand and times of use across practices) or qualified (e.g. linking of practices to time, space and everyday life).

Unlike these former studies (e.g. Røpke and Christensen [112], Lord et al. [80], Chetty et al. [22], Kawsar & Brush [72]), this chapter is largely informed by both quantitative analysis of application and practice specific usage data, along with qualitative participant accounts that are used to compliment and reveal nuance in the presented findings.

Through exploring mobile technologies in everyday life, I reveal how mobile digital technologies are used to fill free time, have led to expansion in practices (e.g. communication practices have expanded across different mediums and applications), the support of "non traditional IT practices", migration and endurance of practices, and where new mobile specific practices have arisen. Using data from participants with Android phones, I expand upon my earlier analysis of participants with iOS devices [80, p.2729], specifically in the time use of mobile digital technologies, the softening of constraints in everyday practices, and quantifying the data demand of practices.

5.2 Study Design

To help better understand the connection between everyday life (e.g. temporal softening, blurring of practices) and escalating data demand (Chapter 2), I analyse the usage and data demand of mobile digital technologies by eight participants with Android devices.

This chapter continues with an overview of the methods and participants data, providing an overview of data demand and notable social practices from both the qualitative and quantitative data. The chapter then focuses on the most data demanding social practices: watching, communication, social networking and online dating, presenting an analysis of distribution of time use and indirect impacts (e.g. data demand, impact of phone calls and SMS) across the participants for these practices. The chapter ends with a discussion of the impacts of mobile digital technologies and how these impacts are connected to everyday life.

5.2.1 Methods and participants

The study was designed as a follow on study to the work of Lord et al. [80] as part of Kelly Widdicks' undergraduate project [144] with the collaboration of Carolynne Lord (Table 3.1), enabling the analysis that I undertake in this chapter. The study captures data that is both more granular and more detailed than the study by Lord et al..

To promote the study a poster and flyer were designed, providing study information and a point of contact. The poster and flyer were disseminated via local and university mailing lists and snowballing methods (e.g. information disseminated via participants to potential participants). Participants from previous studies were also approached via email. After two months of recruiting, eight participants agreed to participate.

The design of the interview schedule (see Appendix A) was initially based on that first used by Lord et al. [80] and was designed to uncover the integration of the device into everyday life, focusing on the social practices that device was associated with. The interviews were designed to encourage discussion surrounding the meanings and competence associated with the device as well as social practices in which the mobile devices were used. Similarly to the other studies (see Table 3.1) during the semi-structured interviews participants were presented with graphed data of their application and device use, battery levels, charging habits, and break-down of application usage in order to probe and foster deeper discussion of the devices' integration into everyday life.

5.2.2 Limitations and assumptions

This chapter relies on data collected using DeviceAnalyser[1 2], an application developed by researchers at The University of Cambridge. DeviceAnalyser provides time series data logging that captures usage of mobile digital technologies[3]. In this analysis the following data is used: network usage, application usage, application foreground state, phone calls, SMS, screen on, power and charging state. Due to the overlap of multiple application's foreground statuses and these only being updated every five minutes it is not possible to accurately determine which application is in the foreground and therefore in use. To more accurately determine when an application is in use I have calculated use time based on when an application has a foreground status and the screen is active (i.e. the screen is use).

The data collected that relates to the data demand of a core services and applications of the Android or Google operating system (e.g. Google Maps Services, Location Services, syncing services) is aggregated. Due to these services and applications being aggregated it is impossible to disaggregate individual services. For example, the data demand of the location service cannot be separated from that of the downloads and updates associated with the operating system. In this chapter when I discuss the data demand of the operating system it will also include data demand that arises due to any of the core services that are running. Aggregation is common across several groups of operating system services and applications. These groups can be categorised into Cloud (e.g. syncing of data to and from Google servers), OS (e.g. downloads associated with user interfaces or widgets of the oper-

[1]https://play.google.com/store/apps/details?id=uk.ac.cam.deviceanalyzer
[2]https://deviceanalyzer.cl.cam.ac.uk
[3]http://deviceanalyzer.cl.cam.ac.uk/keyValuePairs.htm

ating system), and app store (e.g. data demand associated with updating and downloading new applications). As it is unclear whether the OS or the user initiates the demand in these three cases I will not be analysing the use time of Cloud, or OS.

5.3 Participant overview

The participants are a mixture of undergraduate students (Harry, Mark, Victoria), postgraduate students (Holly, Xander[4]), and in full time employment (Tim, Bob, Amanda). Mark also works part time. The smart phone users (Harry, Mark, Victoria, Tim, Bob, Amanda) all keep their devices switched on throughout the day. The tablet users (Holly, Xander) have fewer days where their devices were active (Table 5.1). This was due to Xander's management of his devices' power to keep the battery charged whilst travelling abroad, and in Holly's case, allowing their device to run out of battery. All the participants maintain a regular work day, roughly between the hours of 9am–5pm either at their place of work or on campus. For postgraduate students Holly and Xander, the workspace varied dependent on their schedule and workload (e.g. for part of the study Xander was travelling for work). Evenings and weekends were typically filled with social networking, communication, hobbies and entertainment practices, with participants more likely to travel to different places at the weekends (e.g. visiting friends, Harry went bird watching, Amanda did her weekly shopping and chores).

Table 5.1 summarises the data demand, and predominant practices for the eight participants. In the table, practices that contributed the most towards data demand are mapped to a common practice as identified in the participant interviews (e.g. watching, social networking, communication). Matching applications to practices can be straight forward. Examples include: Harry's use of Rare Bird Alert for birdwatching, instant messaging applications across participants for communication, Bob's use of Strava for fitness or exercise, and Holly's use of ITV player for watching video.

When the underlying practice is ambiguous (i.e. the browser can be used in a number of practices) or is associated with an automated task by the device (e.g. background updates) the categorisation describes the broader task (e.g. browser, cloud, operating system). Through analysis of the qualitative data these ambiguities can be identified. For the example of the browser: Holly uses it for watching videos; Victoria uses the browser on her phone to access Facebook; and, Tim uses it for shopping. In this analysis, ambiguous applications are categorised by application type (e.g. browser, operating system, app store).

[4] Xander didn't use the tablet much six months prior to this study (see Section 6.7 for more detail).

Participant	Study Length (Active Days)	Daily Charging (Wh)	Total data demand / Avg. Daily (MB)	Practices with highest data demand	Notable practices in qualitative data
Holly	27 (14)	19	3788 / 271	Video-on-demand, Browser, Operating System, Games	Watching video, work
Harry	40 (40)	9	5320 / 133	Social networking, Dating, Operating System, Bird Watching	Bird watching (Hobbies), Online dating, Social networking
Mark	45 (45)	13	8096 / 180	Social networking, App Store, Communication, Dating	Social Networking, Sport, Online Dating
Victoria	16 (16)	5	408 / 25	Browsing, Social networking, Operating System, Travel	Social and professional networking
Tim	29 (29)	11	14016 / 483	Cloud Storage, News, Operating System, Social Networking	Keeping up to date, Fitness, Social Networking
Bob	16 (16)	4	1120 / 70	Social Networking, App Store, Cloud, Operating system	Social Networking, Keeping up to date, Repair and maintenance
Amanda	14 (14)	9	849 / 60	Operating System, Device Management, News, Browser	Occasional Browsing
Xander	15 (7)	12	3355 / 479	Video-on-demand, VPN, App Store, Browser	Watching video, gaming

Table 5.1 An overview of the participants data demand and social practices. Communication has been omitted from the table due to all participants mentioning this as a practice that was regularly supported by their device.

	Social Networking	Cloud	Watching	OS and App Store	Browsing	Dating	Communication	Other
Holly	0.39	1.08	2014.48	163.07	1560.80	0.00	18.49	29.78
Harry	4028.05	0.00	79.56	395.61	33.04	673.32	8.09	102.16
Mark	7034.70	0.00	6.40	478.23	77.17	126.26	203.08	128.10
Victoria	29.08	0.00	0.00	14.20	361.04	0.00	0.00	3.18
Tim	681.69	9981.04	1276.23	911.41	491.89	0.00	43.66	630.09
Bob	330.98	171.33	88.99	344.04	75.67	0.00	46.33	63.09
Amanda	0.00	12.92	0.12	737.60	24.79	0.00	1.47	72.32
Xander	0.00	3.89	1555.58	691.09	104.43	0.00	7.86	991.89
Totals	12104.89	10170.26	5021.36	3735.25	2728.83	799.58	328.98	2020.61

Table 5.2 A summary table of the data demand across the participants' practices. Values shown are in MB.

Table 5.1 also highlights areas of practice that the participants revealed their mobile device to play an important role in during the interview phase.

5.3.1 Demand summary

In this section, the largest demanding practices (Table 5.2) will be described on an application level. 194 unique installed applications were identified across the eight participants (Holly = 47, Harry = 31, Mark = 46, Victoria = 19, Tim = 74, Bob = 45, Amanda = 26, Xander = 43). Table 5.2 shows the variation in data demand across the participants' notable practices. The categorisation of broad practices and ambiguous applications is described below.

Social Networking. Social networking applications were present on the devices of all participants apart from Amanda and Xander. These applications are categorised based on their primary use being for browsing and contributing to social networks as well as communication (e.g. through instant and direct messaging). The applications that the participants used for social networking are Facebook, Twitter, Instagram, and LinkedIn. Large portions of data demand (Harry 76%, Mark 87%) are due to 'obsessive' (see Section 5.4) checking of social networks (see Section 5.5.3).

Cloud. Cloud isn't used to describe the 'Cloud' as a practice. Cloud is used to represent applications on the participant's devices that are used for automated and manual backing up and transference of data to a server outside of the users 'home' network. Observed applications include Dropbox and Google+, and contributed less than 1% for Holly, Harry, Mark, Victoria, Amanda and Xander. Google+ is an application designed for social networking. This was not the case for the participants, with data demand occurring from Google+ for two participants whose Google+ automatically backed up photos and video (Bob 15%, Tim 71%).

Watching. Holly, Tim, Bob and Xander used their devices to watch video, contributing 53%, 9%, 8%, and 46% of data demand respectively. Their practices of watching are supported by video-on-demand applications (e.g. Youtube, BBC iPlayer, ITV Player, 4oD, BBC Sport, BT Sport). Xander also watches media via a playback application that supports streaming from a URL or locally stored content (e.g. MX Player). Xander was the only participant who would preload video content onto his device so that he could watch it later. Xander preloads content so that he can watch videos without an Internet connection whilst flying and travelling abroad.

Operating System and App Updates. The Android OS itself operates a large number of processes and applications to provide its user with core functionality (e.g. interactions with the phone, updates, contact and calendar syncing, notifications). As mentioned in Section 5.2.2 it is not possible to disaggregate these processes and applications. For example the OS application that produced 163.1 MB of Holly's data demand is attributed to the downloads associated with the Operating System.

Similarly, demand created by app stores are in this category due to it being difficult to disaggregate whether data demand is due to the installation of a new application or update of an existing app. Xander, whose App Store demand is the largest apportions his app store demand to him downloading a number of applications and games before a trip he was taking, whilst the demand arising from Bob's updates were all automated and in the background. The demand associated with OS and app updates accounts for under 8% (ranging from Victoria's 3.5% to Harry's 7.5%) of the total data demand for Holly, Harry, Mark, Victoria, and Tim. For the other participants it was considerably higher: Bob 31%, Amanda 87%, and Xander 21%. These high proportions are due to these participants having lower demand across all other practices (see Table 5.2). It is especially high for Amanda due to her personal practices contributing very little data demand.

Browsing. All participants use their device for browsing the web. Some participants used different applications as their primary web browser, and this included the built in Android Browser and Google Chrome. The Google Quick Search application is also categorised as browsing as it is used to search the web, and forwards users to the browser. Other than browsing, the browser enabled participants to perform specific practices (e.g. watching video and social networking (Holly, 41%), email and social network (Victoria 88%)).

Dating. Harry and Mark use their smart phones for online dating through apps like OkCupid and Tinder. These applications are used throughout Harry and Mark's daily life and were used to generate 13% and 2% accordingly of their data demand. The dating practices of two participants account for around 2% of the total of all the participants' data demand.

Communication. All the participants used their device to communicate with others. This was done via phone calls, SMS messages, instant messaging applications (e.g. Whatsapp, Facebook Messenger), photo sharing (e.g. Snapchat), video calls (e.g. Skype) and email (e.g. browser, Gmail, Exchange). Data demand from communication varied across the participants, accounting for between 0% (Victoria) – 4% (Bob). Although the participants recount using Skype on their device, none of them appear to have during the study. This is a likely cause for such low demand.

Other. The categories that have not been covered above are those that have either the lowest data demand or were mentioned the least by the participants themselves, and are therefore being categorised as being less involved in everyday life. This includes a range of practices, including: hobbies (e.g. Rare Bird Alert, photography, a variety of games); banking and finance (e.g. Online Banking app, Paypal); listening (e.g. BBC iPlayer, BBC media player, Youtube, Google Music); keeping up to date (e.g. BBC News, Sky News, Sky Sports, Accuweather, Google Newsstand) gambling (e.g. Skybet); working (e.g. Android IDE); website management (e.g. Webget, Wordpress); travel and navigations (e.g. Google Maps), management of operating system (e.g. anti virus, battery management applications); fitness and exercise (e.g. Strava); photography (e.g. Android Camera); reading (e.g. Google Books); shopping (e.g. eBay Amazon); secure browsing (e.g. VPN); and, Referencing (e.g. Wikipedia).

This category accounts for less than 3% of data demand for three of the participants: 1% (Holly), 2% (Harry) and 2% (Mark). Tim routinely used his device for (see Section 5.4) keeping up to date (1%), listening (1%) and shopping (2%). For Amanda, her virus checker contributed 8% of her data demand. Bob used his phone for navigation (1.5% overall) and keeping up to date with current events (3%) (see Section 5.4). Xander's large data demand that has been categorised is due to his use of a VPN application on his device, for secure browsing and downloading video (see Section 5.5.2), which is used for 30% of his overall data demand.

To understand why there is variation in data demand across these categories we have to explore the role of mobile digital technologies in the everyday life. In doing this it is possible to quantify the time use and data demand associated with the above categories (and associated practices). The next section explores how the participants used their devices throughout the study, focusing on understanding patterns of use throughout the day and the underlying reasons for variations in use between the participants.

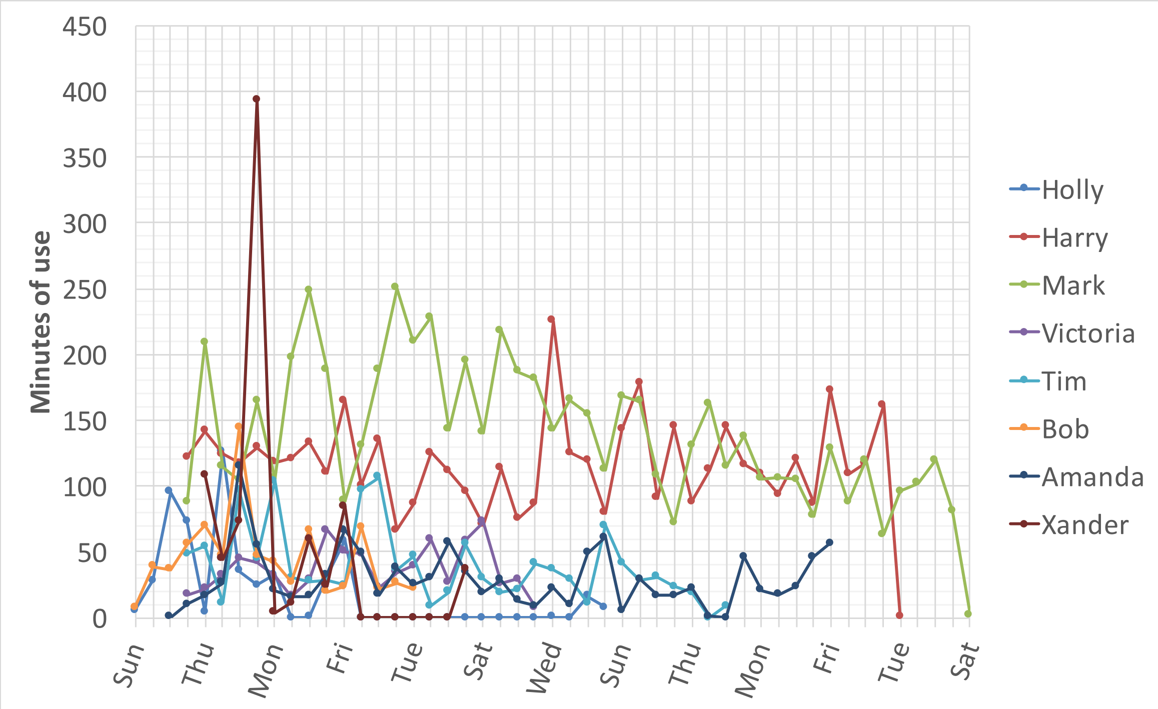


Fig. 5.1 A summary of the participants' use time across the study. This figure highlights the variation of use across the participants.

5.4 Exploring time and space

In this section I explore how the participants' mobile technologies feature in time and space during their everyday lives. This analysis is grounded in the data collected from the mobile device logging (see Section 5.2.1) and highlights the times of use of these devices and when the participants' typically perform their daily practices. This section begins by analysing the times of use of the participants' devices. It moves on to explore the relationship between time and space in everyday practices and finishes by summarising the circumstances in which variation in use can occur.

5.4.1 Device Usage

The mobile digital technologies owned by the participants are considered to be 'in use' when the device is unlocked and the screen is on. The daily use time of the participants varies from between 0.3 (Holly) – 383 (Xander) minutes (see Figure 5.1), with mean use time ranging between of 30 (Holly) – 138 (Mark) minutes per day, with the standard deviation from the aggregate being around 0.5 hours for each participant apart from Xander,

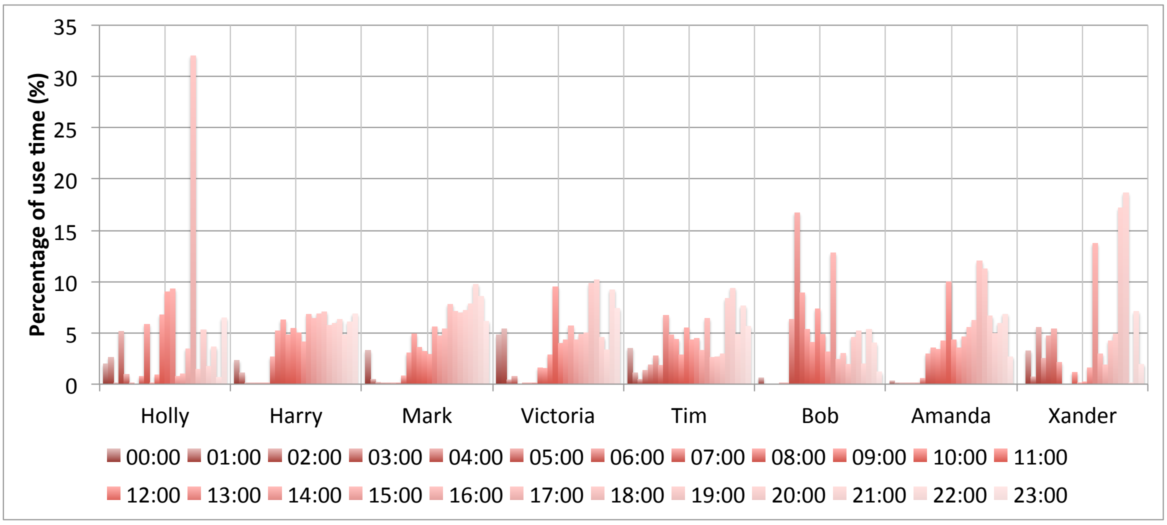


Fig. 5.2 A summary showing the per participant percentage distribution of usage through the hours of the day throughout the study. Times in the legend represent the start of the bin.

whose was 1.6 hours due to him using his tablet for 6.5 hours one day. The mean usage, assuming the participants sleep and do not use their device between 12am and 8am, shows that participants use their devices for between 3% (Holly) – 15.6% (Mark) of waking hours.

This relatively low deviation from the mean across the participants demonstrates how individual users of mobile digital technologies maintained similar usage throughout the study period. This indicates that each participant spent a similar amount of time with their device, on most days of the study period. The exception to this are Holly and Xander. Their usage of their tablets follows less of a pattern due to shorter, and less frequent periods of use of their device. For example, Xander's large one off peak amongst periods of significantly less use and ten days where Holly doesn't use her device due to it having ran out of battery (Figure 5.1).

Figure 5.2 shows distribution of time-use across the day for the smart phone users Harry, Mark, Victoria, Tim, Bob and Amanda. Victoria and Amanda seem to use their devices more around times of peak energy demand [95] (e.g. breakfast, lunchtimes and evening), Tim and Bob's usage in the morning, mid-afternoon and again in the evening mimic these peaks, whilst Harry has a relatively even distribution throughout the day. Mark's usage looks to increase through the day, peaking at around 22:00. The tablet users, Holly and Xander, can be seen to have less correlation with peaks in domestic energy consumption. Their distribution shows occasional peaks that are significantly larger than the rest of their use time.

The rest of this section analyses the participants' accounts to help uncover: (1) patterns of use throughout their daily lives; (2) the deviations from these patterns that can contribute to peaks and troughs in usage (Figure 5.1); and, (3) how these variations (peaks and troughs) relate to performances of individual or bundles of practices.

5.4.2 Everyday usage

Participants were asked, in detail, about how their device featured in their daily life. Their accounts vary but paint similar images of daily life. Typical daily routines start in the morning with the checking of time (Mark), alarms (Mark, Victoria, Xander), checking of current news and current events (Tim, Xander, Bob, Harry), working out at home before work (Tim), checking social networks (Bob, Xander, Mark, Harry), and online dating (Harry). Some participants use their devices for navigation (Bob), including travelling and commuting to work (Xander). In the car, participants' devices were used for radio or music (Xander, Harry, Bob), logging cycle routes (Bob - *"when it's sunny enough"*), charging (Tim), and navigation (Xander, Harry).

Usage during the working day varies across the participants. For some, their device was sometimes used to aid with their work (Mark, Holly, Xander) and communicate with colleagues (Bob). Although Mark doesn't really use his device for work itself – the screen isn't big enough – he does use a bibliography manager application for work, calendar, email, and document viewer.

For others mobile devices were used whilst at work or university, for checking the time (Amanda, Victoria), filling in free time (Xander, Bob), communication with friends (Harry, Mark, Victoria, Bob, Xander), and social networking (Mark, Tim, Bob, Holly). These examples show how the participants blur the lines between work and non-work practices [112].

Like the mornings, lunch hours tend to be filled with news, social networking, and communication being predominant practices. Evenings with mobile digital technologies comprise of communication (Amanda, Bob), social networking (Xander), watching TV or movies (Holly, Xander), shopping (Tim), and browsing (Xander).

At weekends the reasons for use are similar, with communication, navigation, hobbies social networking and keeping up-to-date on live sport events occurring more regularly. Some participants describe, more frequently keeping up to date with news and sporting events (Tim), organising outings and visits (Amanda), and hobbies (Amanda, Mark).

This overview of the participants daily life shows that all smart phone owners use their phones throughout the day. The variation across the participants is related to the practices that are performed throughout the day. For example, mornings start with catching up with news and social networks, during the day some participants use it more sporadically for social networking or communication whilst others use their devices for work, and in the evening devices for potentially more data intensive practices (e.g. watching TV or movies, browsing). In the following subsections, I focus on uncovering the reasons for variation in times of use that occur in the participants' daily lives.

5.4.3 Breaks from mobile technology

Deviation from the patterns of daily use of devices occurred across the participants. For some, this variation involved using their device less and getting away from technology was seen as a necessary part of their everyday life. Amanda actively avoids technology in her own time, *"I'm not a slave to technology, erm I use it at work 'cause I have to, I can download, I love the fact you can have information at your fingertips but I don't want to be on it at the end of the night"*. This is reflected in Figure 5.2 with her decline in device usage in the evening and by her leisure practices of dancing, walking and reading normally involving no digital technology, with her weekend use being for phoning and texting to coordinate and meet up with with friends. Bob likes to take breaks from digital technology during the week, as his work is related to computers. In an attempt to get away from digital technologies during his lunch break, he goes for walks, often not using his smart phone at all.

Although Victoria takes her phone everywhere she goes, and uses it throughout the day, she still likes time without her phone, *"at night time I try and just leave it, erm if I'm communicating with someone I'll probably be on Facebook and then I'll just try and have like rest from my phone cause I've had it with me all day"*. For Harry, his variation revolved around his weekend hobbies, leading him to not use his smart phone on Saturday mornings due to him being *"out bird ringing"* (attaching tags to wild birds).

5.4.4 Filling time

By contrast, when participant's devices were seen to fill "dead time" [112]. Holly recounts a period close to a deadline in which she was using her tablet to work on the bus:

> *"I was doing quite a lot of work even kind of travelling in and out, like now I'll be staring and see out the window but at the time I was kind of listening to interviews and writing notes and trying to read papers and everything on the bus, just trying to cram as much work as possible into a small amount of time"*

Harry checks social networks, communications and bird watching news in the morning, at lunch and in the evening. He views his patterns of checking as *"obsessive"* and has noticed that he checks his phone more more frequently through the day now he has twitter on his phone, stating that *"Twitter keeps you up to date with what's going on in the world all the time"*. His 'obsessive' checking is likely to contribute to his higher use time throughout the study (see Figure 5.1). Interestingly, Harry's Rare Bird Alert application encourages him to go to hot spots where bird sightings have been uploaded by other users, *"if there's something around locally or whatever and I'll go off"*.

Mark, who also has high daily usage, is a sporadic checker of his smart phone, checking it more frequently when there are news feeds announced that he is interested in (e.g. checking it every *"two to three minutes"* when there's football on at the weekends), and even more when there are notifications, *"whenever I get a notification I'll check my phone"*, or *"when I'm not doing anything I'll be checking my phone or just for the sake of it"*. Tim, like Mark, checks notifications *"when they flash up"* to see what they are, even though he isn't supposed to use his phone at work.

Obsessive checking, reactions to notifications, and pressures to work can be seen to fill "small pockets of time not focused on one specific activity and often perceived as 'unproductive time', like waiting for the bus or commuting" [112, p.355]. These small pockets of dead time, and along with increased multitasking supported by digital technologies are "enabled by the partial decoupling of many practices from previous time and space constraints through the use of ICT, contribute to a more densely packed everyday life" [112, p.356]. A more densely packed everyday life can be seen to increase the use of digital technology, which in turn leads to increased demand.

5.4.5 Space mediates possibilities for practices

The spaces which the participants inhabit create variation surrounding their devices. For example, Amanda, who works 9-5, has no cellular reception at work leading to her not checking her phone whilst at work. If and when Amanda wants to use her phone at work she has to go outside, otherwise *"if anybody needs me 9-5 they phone [her workplace]"*.

For the two tablet users, Holly and Xander, the spaces in which they would use their tablets was influenced by connectivity. Holly recently has had no Internet connection at her home, so her tablet's involvement in daily practice has been reduced. Her low time usage compared to the other participants can be seen in Figure 5.1 and Figure **??**. This has lead to Holly having to plan how she is going to use her tablet, pre-load content (e.g. reading for work, video) if she wants to use her tablet at home (e.g. for working, watching, listening).

Xander pre-loads his tablet with video content, games, maps and work when he knows that he will be without connection for longer periods of time, and will occasionally tether his tablet with his phone when there is no wifi. Xander also streams video content, across the Internet, from his home sever whilst travelling (e.g. on his recent trip abroad) or not at home. He tends to use his tablet in spaces where he doesn't want to get out his laptop or physically move to his laptop or desktop PC.

For Tim, the space that he's in affects his management of his connections. He actively manages mobile data when he's in spaces without wifi (e.g. when he's using his phone as a sat-nav), but otherwise leaves his wifi on all the time, unless the battery is running low. Victoria is unable to access mobile internet on her device, due to a suspected problem with her phone, and is therefore limited to using the Internet when on wifi.

The spaces which the participants inhabit influence variations in use. These variations have different implications in terms of impact and demand. Space can limit usage (e.g. Amanda's poor signal at work, Holly's lack of internet at home, Victoria's faulty phone) which can be seen to decrease opportunities to demand data. Whilst time spent in space where a device is available can lead to usage just because the device is there (e.g. Xander using his tablet when his laptop is out of reach).

5.4.6 Layering

Layering (previously mentioned in Section 4.2.1) is an important phenomenon when considering energy impacts in everyday life, as the impacts associated with the use of additional technologies are added on top of the on-going already engaged practices, contributing to increasing peaks in demand. Smart phones and tablets were used by Holly, Xander, Tim, Mark, Bob, and Amanda in practices that can be seen to overlap with other practices. Layering occurs when two (or more) social practices that are performed as part of a bundle or complex (see Section 2.2.1) are performed using different digital technologies. For example, layering occurs in the evening for Tim, who uses his phone *"quite a lot whilst watching tele and things, just browsing ebay or something"*. When Mark was asked whether he used his phone whilst watching TV he responded, saying *"yeah, [I'm] always flicking through it, it's a bad habit really"*.

Bob, who works at his computer, uses his phone alongside his work for emails and appointments, as the browser on his computer is often in the background. Holly, who uses her tablet as an additional screen for work, and also uses her device for video playback whilst cleaning her room. Whilst cleaning she likes to watch something *"that you can miss"*, viewing it as *"background TV"*.

	Social Networking	Cloud	Watching	OS and App Store	Browsing	Dating	Communication	Other
Holly	0.01	0.02	28.78	2.33	22.30	0.00	0.26	0.43
Harry	20.14	0.00	0.40	1.98	0.17	3.37	0.04	0.51
Mark	31.27	0.00	0.03	2.13	0.34	0.56	0.90	0.57
Victoria	0.04	0.00	0.00	0.02	0.43	0.00	0.00	0.00
Tim	4.70	68.83	8.80	6.29	3.39	0.00	0.30	4.35
Bob	4.14	2.14	1.11	4.30	0.95	0.00	0.58	0.79
Amanda	0.00	0.18	0.00	10.54	0.35	0.00	0.02	1.03
Xander	0.00	0.11	44.45	19.75	2.98	0.00	0.22	28.34
Total	60.28	71.29	83.57	47.32	30.92	3.93	2.33	36.02

Table 5.3 A summary of the participants' daily watt-hours per practice. This average estimation is based on the overall data demand of each practice seen in Table 5.2.

5.5 Practices and data demand

Data demand arises when a digital technology is used to perform a practice that is reliant on Internet connectivity for its accomplishment. The intensity of data demand varies dependant on: (1) the practices performed (e.g. watching requires streams of video whilst communication can be done using short text based messages); (2) the durations of these performances (e.g. the durations data demand); and, (3) the 'intensity' or quality of the data (e.g. the resolution of video or photos, the chosen medium used to communicate). This section explores the data demand associated with the largest demanding practices identified in Table 5.1, several of which (e.g. watching, social networking, communication) correlate with those seen to be the largest demanding practices by Lord et al., who propose that data demand peaks are becoming more prominent due to an increase in "social networking and real-time ("on demand") streaming of content" [80, p.2730]. This section finishes by exploring the significant data demand of online dating, and giving a brief overview of the data demand associated with updates and backups.

5.5.1 The impact of data demand

The data demand of the participants' devices is generated in three main scenarios: (1) through the users' interaction and use of an application that requires connectivity, (2) applications demanding data in the background, and (3) automatic and scheduled updates and backups. In this section I concern myself with the correlation between use of an application and data demand. Towards the end of the section I briefly discuss automatic updates and backups.

Data demand in Table 5.1 is measured in megabytes (MB)[5]. For these measurements of data demand to be informative, data demand can be used to calculate the energy associated with the energy impact from the use of infrastructure, and core Internet networks and data centres. In this chapter I use the estimation of 200 watt-hours (Wh) of energy consumed per gigabyte of data. This coefficient is a compound of three estimations of the energy required through the network infrastructure and data centre [115, 116, 118], and assumes a mixture of text and video traffic.

Data demand can be seen to add a significant amount when considering the overall energy impact of the participant's mobile digital technologies. To put this into perspective, the energy required to charge participant's device ranges 5–20 Wh per day.[6] Using the average daily data demand for the participants (Table 5.1) we can calculate that data demand adds between 5 Wh (Victoria) and 187 Wh (Tim) per day. Table 5.3 shows how much energy different possessive practices contribute to daily consumption through data demand.

To understand the relationship between data demand and everyday practices we have to consider how times of usage shape data demand. Figure 5.3 shows how the use time associate with the participants largest demanding practices (e.g. social networking, communication, watching, online dating) varies through time. Watching for Holly and Xander is less routine, with longer stints on Tuesdays (Holly) and Wednesday (Xander), and no use at all on other days. For Tim, watching happens for about 10 minutes or more per day. Those who date online (Harry and Mark), do so regularly throughout the week, with the occasional peaks and lulls. The lull in Mark's online dating is due to him stopping using OkCupid part way through the study. The use of social network applications shows that Harry and Mark are the largest users. Their participation in the study (40, 45 days) is for two weeks longer than the nearest user, Tim. Comparing Harry and Mark to Tim, we can see that Harry and Mark consistently use their social networking applications more. For communication the usage is a lot more consistent throughout the week for the participants. Mark however does have some peak days in usage. This figure also shows that Xander, Harry and Amanda use communication applications very little.

Due to there being no clear pattern in the distribution of use across weekdays and the weekend for watching, dating, social networking, or communication, this analysis will look at the distribution of data demand and use on a daily basis.

This section continues by presenting distribution of daily use time and data demand for watching, communication and social networking, and dating, linking this to the previously mentioned everyday circumstances (e.g. blurring, layering, softer temporal constraints, spa-

[5]Throughout this chapter I use the MB notation to represent 1,048,576 bytes or 1 Mebibyte (MiB).

[6]Based upon the amount of time spent charging per day and the capacity of the battery collected using DeviceAnalyzer

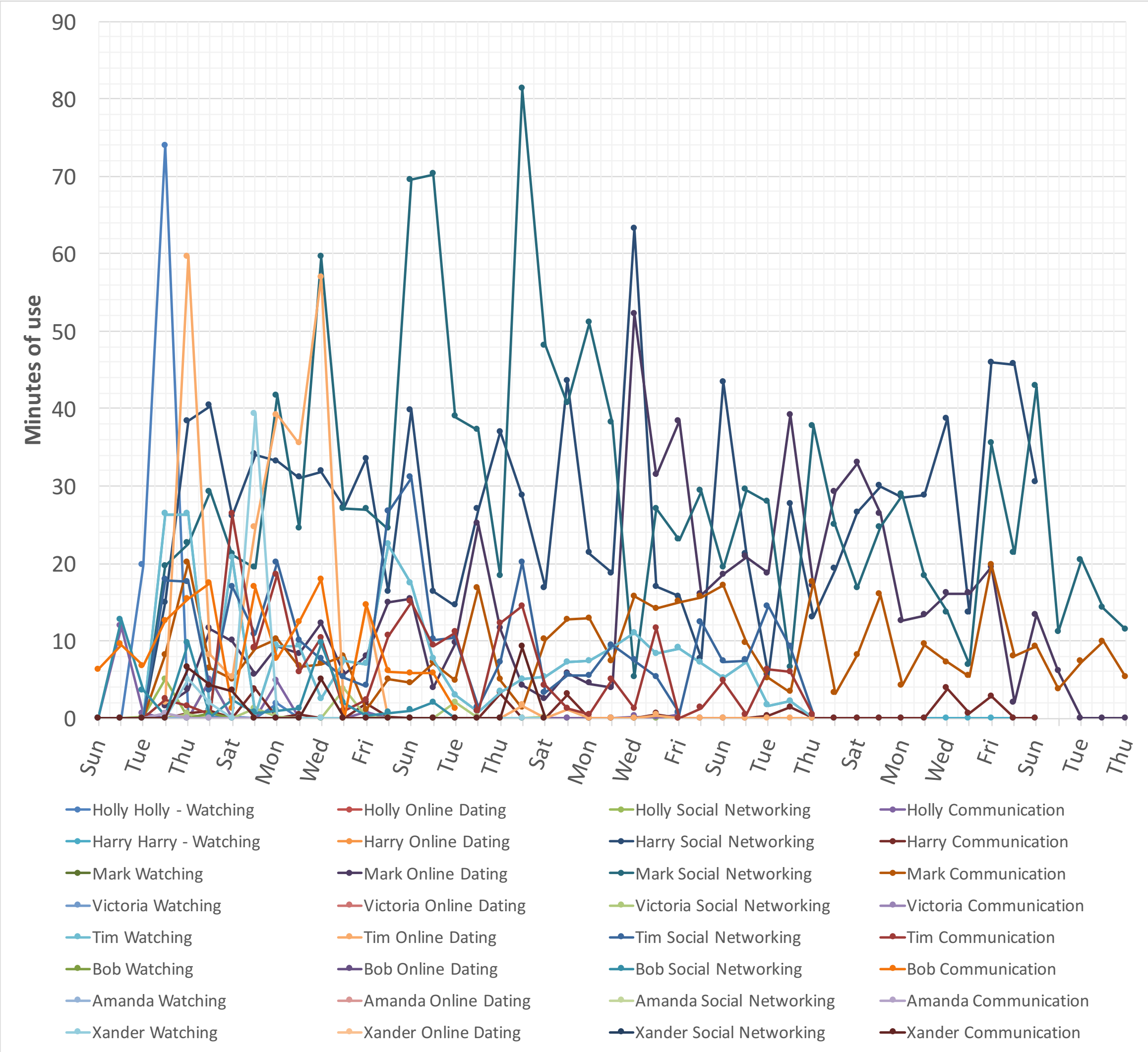


Fig. 5.3 The daily use time for the participants' largest demanding practices throughout the study.

tial constraints, and variations in everyday life) that occur throughout the participants' everyday lives. The following sections will reference specific examples (e.g. specific times of day) where use or data demand sessions could be inferred from the logged device data or participant accounts.

5.5.2 Watching

Watching played a role in the lives of four participants (Holly, Tim, Bob, Xander). Video watching was seen to cross practices (e.g. Tim keeping up to date with sport and news, Holly watching TV or movies on-demand when she goes to bed, Xander watching content stored on his tablet, Bob watching videos on Youtube for DIY tutorials). Watching accounts for 53% of Holly's, 7% of Bob's, and 9% of Tim's, and 38% of Xander's overall data demand.

For Tim, BT Sport was used on Saturday afternoons to watch the football. Whilst this application was used for small amounts of time during those days (11%) it contributes to 91% of Tim's watching related data demand. The low time use and high demand is due to Tim's phone forwarding video to his TV whilst his phone goes into a state of not being used (e.g. the screen is off). Tim's use in the early morning is due to him listening to Youtube playlists whilst working out. When asked, he was unable to recount what he was using Youtube for during the other peaks, *"I dunno... I do use, I do use Youtube a lot"*.

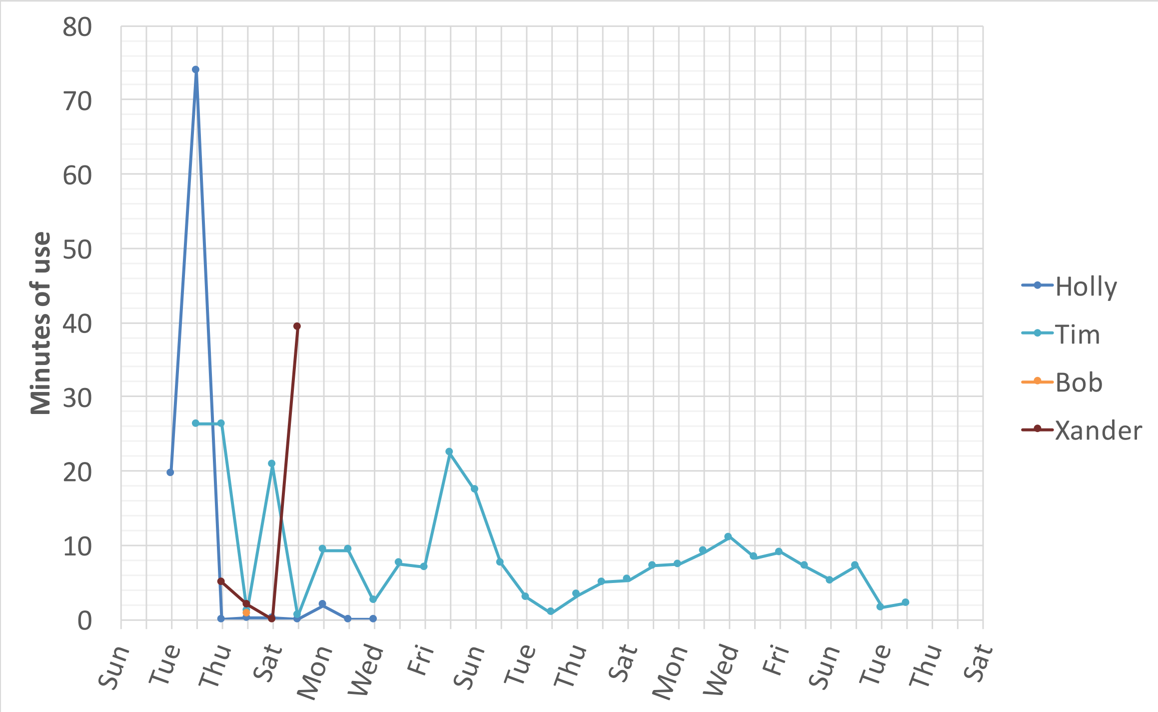
Holly's peaks in use (Figure 5.4a) and demand (Figure 5.4b) are from watching catch up TV via video-on-demand applications. There are due to distinctive peaks in use of around 20 minutes, which is approximately the length of an episodic TV sitcom. These peaks occur in the afternoon (15:00-17:00), evening (19:00) and at night when she watches TV to go to sleep (23:00-00:00).

Xander describes his evening routine involving watching:

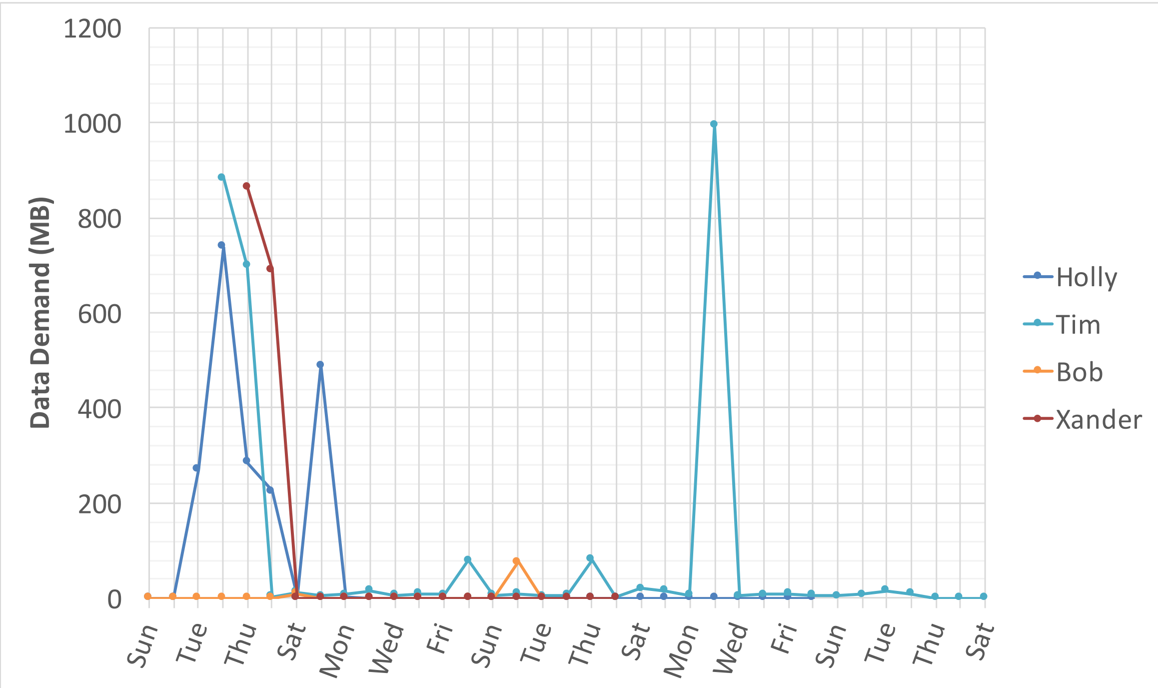
> *"There's like a stage where you're going to bed and you're like 'no I'm really going to bed now', the laptop is turned off... so I watch quite a lot of TV on [my tablet] "*

Xander's peaks in time use occur in the late evening, between 18:00 and 20:00, (Figure 5.4a) due to him watching video that has been preloaded onto his tablet. The peaks in data demand do not match with the peaks in use. The small amount of use that occurs on the same day as a peak in data demand are from the same application (Figure 5.4b), where Xander was downloading video to watch at another time.

Watching occurs other than in the routines that I have just described. Whilst discussing watching, Tim mentions that he sometimes watches videos that appear on his Facebook feed, *"if there's like videos on Facebook that people post I sometimes watch them as well"*.



(a)



(b)

Fig. 5.4 The distribution of use time and data demand associated with watching (a) Use times of watching, and (b) Data demand of watching.

Xander also streams from his web server directly to his device, *"I stream stuff through like a web server, I think it goes through [MX Player]"*. Xander's VPN application (categorised as 'Other' in Table 5.3) was sometimes used for downloading videos, contributing over 900MB to his total data demand. Another application that was used for watching is by Holly who sometimes used the browser to access catch-up TV websites. Holly's browser contributed 1560 MB of data demand. Whilst both of these applications were said to have been used to watch video there is no way to know precisely what share of this was for watching. With applications such as the browser supporting watching, and social networks allowing the sharing and linking to videos, it is likely that the data demand and time spent watching is higher than described in this section.

5.5.3 Social networking and communication

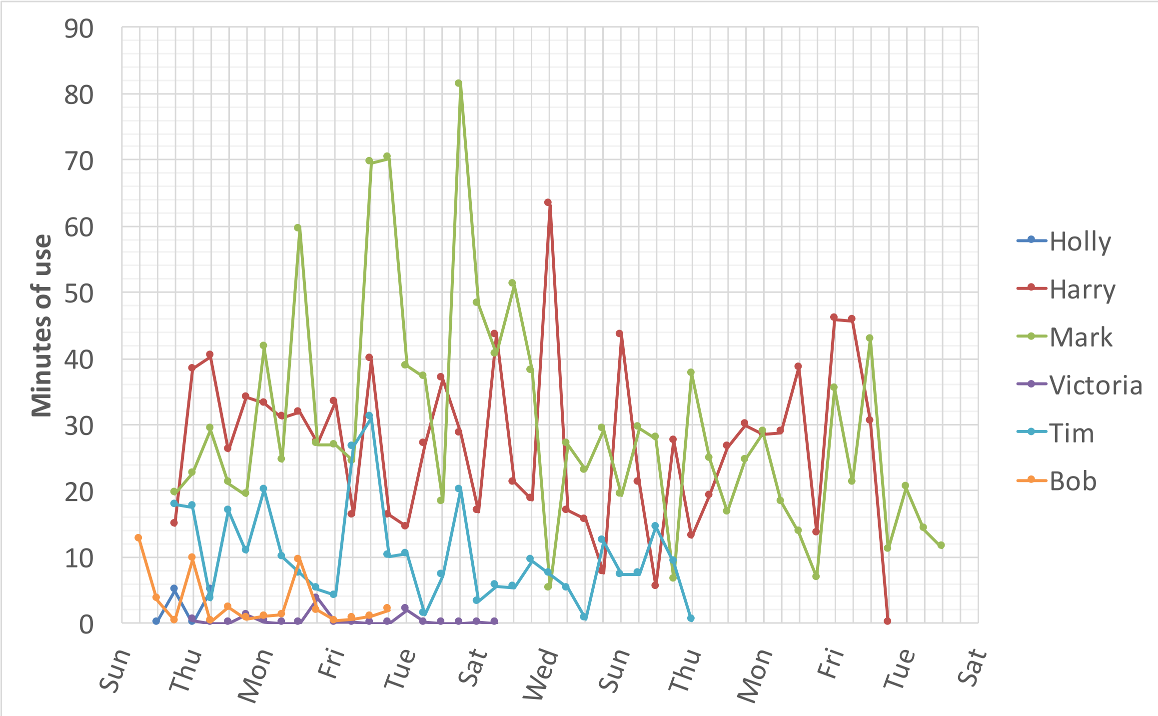
This subsection explores the differences in time-use and data demand of the participants' social networking and communication.

The highest data demand in social networking can be seen to be contributed by two participants, Harry and Mark (Figure 5.5b). Their high data demand can be seen to correlate with their higher use time of social networking applications throughout the day (Figure 5.5a), with a particularly large peak at around breakfast time (08:00-09:00) after no use throughout the night. Their higher use time is due to their 'obsessive' use of multiple applications for social networking (e.g. Twitter, Facebook, Snapchat) throughout the day.

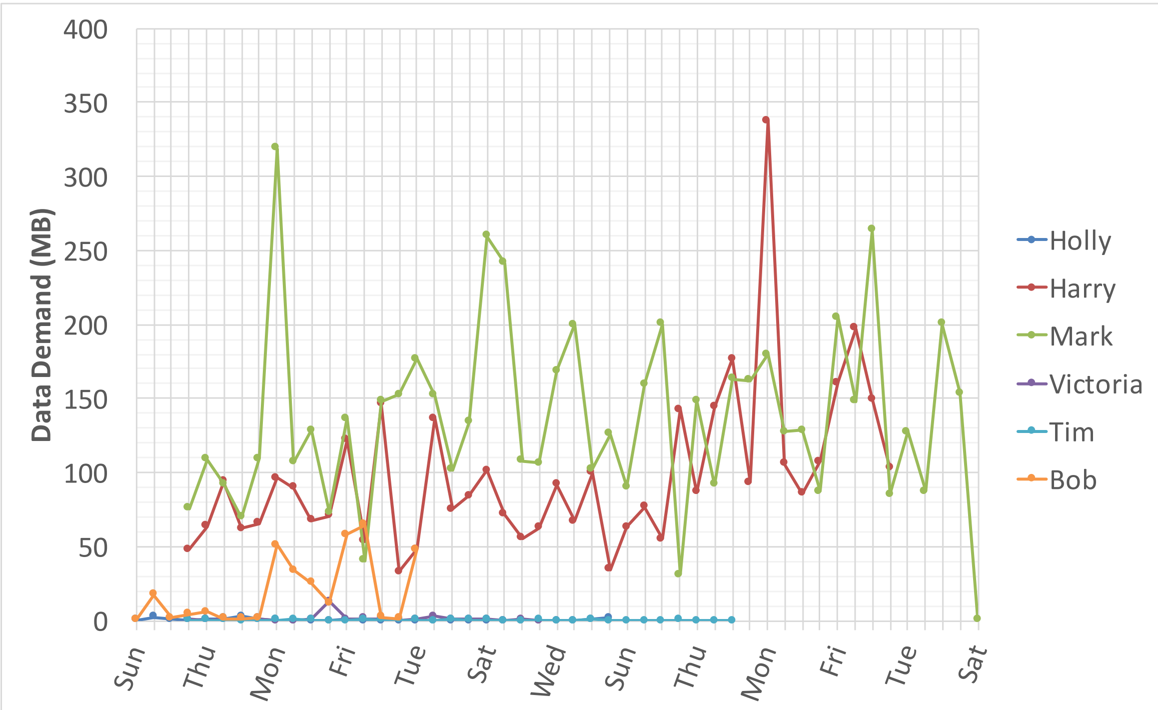
In comparison, Tim spends more time social networking than the other participants (Bob, Victoria), yet the peaks in his demand throughout the day (Figure 5.5b) are generally lower when compared to his usage peaks (Figure 5.5a). This is perhaps due to Tim's Facebook and Twitter feeds being less full of videos and images.

Generally, communication can be seen to have lower levels of data demand than social networking (Figure 5.6b). This is in part due to the lower use time of communication applications (Figure 5.6a), at around six times less than social networking. The lower data demand is also due to textual communications (e.g. email, instant messages) without attachments (e.g. work, images) being very small in terms of size (MB). For example, emails without attachments typically range from a few hundred bytes to a few hundred kilobytes dependant on length.

For communication, the largest data demand is contributed by Mark (Figure 5.6b). Whilst the times of use of his communication applications is comparable to others (Figure 5.6a) his largest peak in data demand was caused by him sending large attachments to work colleagues. Across all the other participants, email contributed the least towards data demand arising from communication.

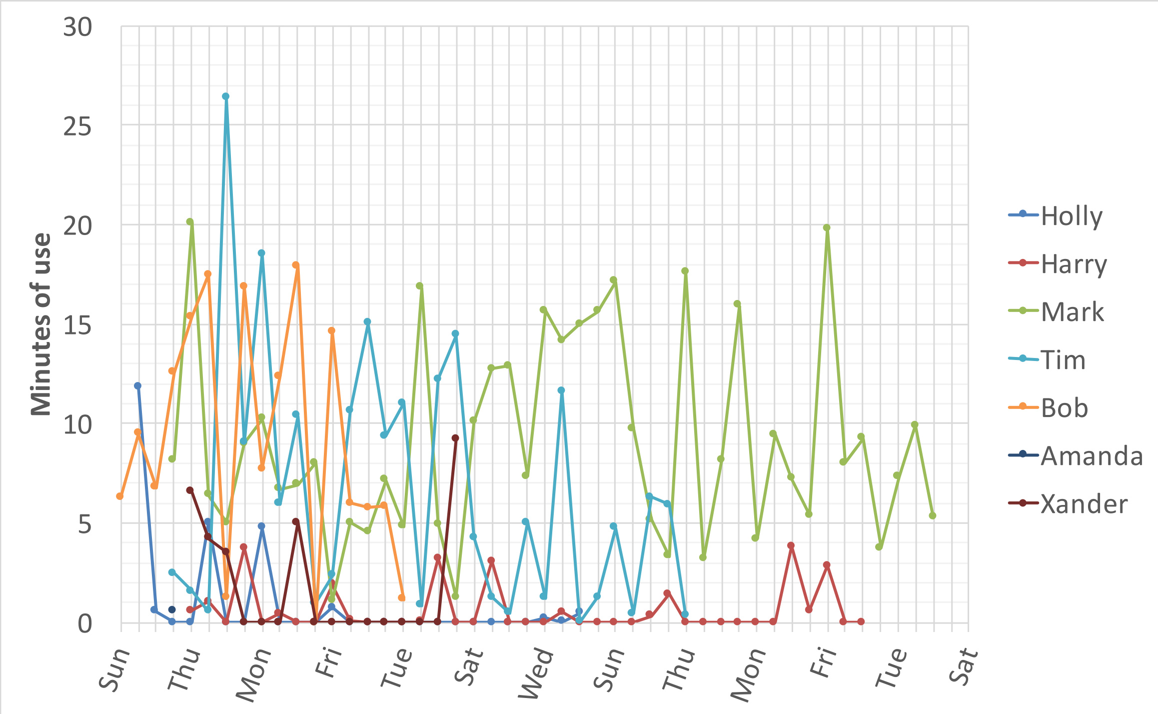


(a)

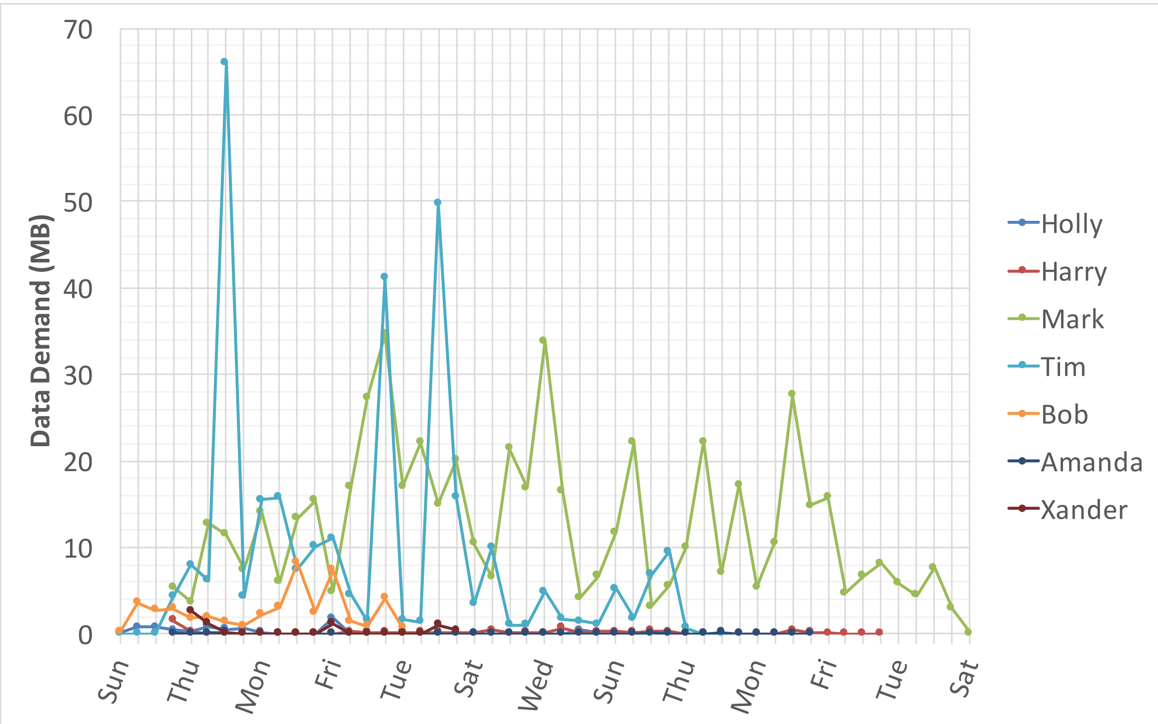


(b)

Fig. 5.5 The use times and data demand of social networking (a) shows the amount of time that relevant participants spent social networking, and (b) the breakdown of when data demand associated with social networking occurs throughout the study.



(a)



(b)

Fig. 5.6 The use times and data demand of communication (a) shows the times of use of communication applications, and (b) shows the data demand.

Part.	Phone Calls / Total seconds (median)	SMS Sent/Received (daily avg.)	Comms. data demand (daily avg.) (MB)	Social Networking data demand (daily avg.) (MB)	Data Demand (Wh)
Holly	-	-	19 (1)	0 (0.0)	4
Harry	33 / 2555 (35)	138/147 (3/4)	8 (0)	4028 (101)	807
Mark	32 / 2979 (27)	315/327 (7/7)	203 (4)	7035 (156)	1448
Victoria	82 / 12743 (58)	189/263 (11/16)	0 (0)	29 (2)	6
Tim	79 / 7827 (38)	26/39 (1/1)	44 (2)	682 (24)	145
Bob	22 / 1540 (49)	58/79 (3/5)	46 (3)	331 (21)	75
Amanda	209 / 30125 (69)	63/56 (4/3)	1 (0)	0 (0)	1
Xander	-	-	8 (1)	0 (0)	2

Table 5.4 A summary of indirect impacts associated with communication and social networking.

Holly, Harry, Amanda, and Xander have considerably lower data demand compared to Mark, Tim and Bob. Holly and Xander use their tablets occasionally (Figure 5.6a) for both email or Facebook chat. Amanda's low data demand is likely due to background data demand of Whatsapp (e.g. data demand arising whilst the application isn't being used) as it was only used on one occasion during the study, for less than a minute. Harry's use time is due to him sometimes using Facebook chat for communication. Tim's use of communication applications spike around breakfast and again in the evenings when he uses Facebook chat and Whatsapp chat to communicate with friends.

Peaks in time use of communication applications do not generally translate to peaks in data demand. Whilst Bob is a fairly consistent user of communication applications, sending large emails and Facebook chat messages are the reason for the peaks (Wed, Fri) in his data demand.

Of course, communication doesn't just contribute towards data demand; SMS messaging

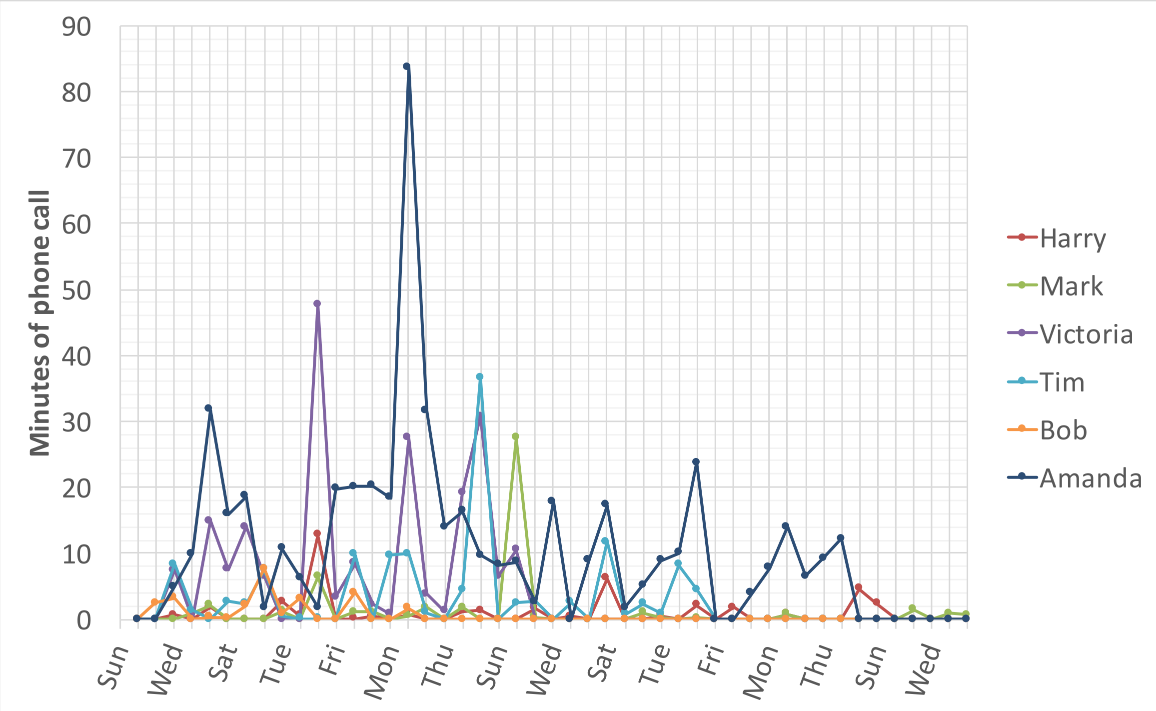


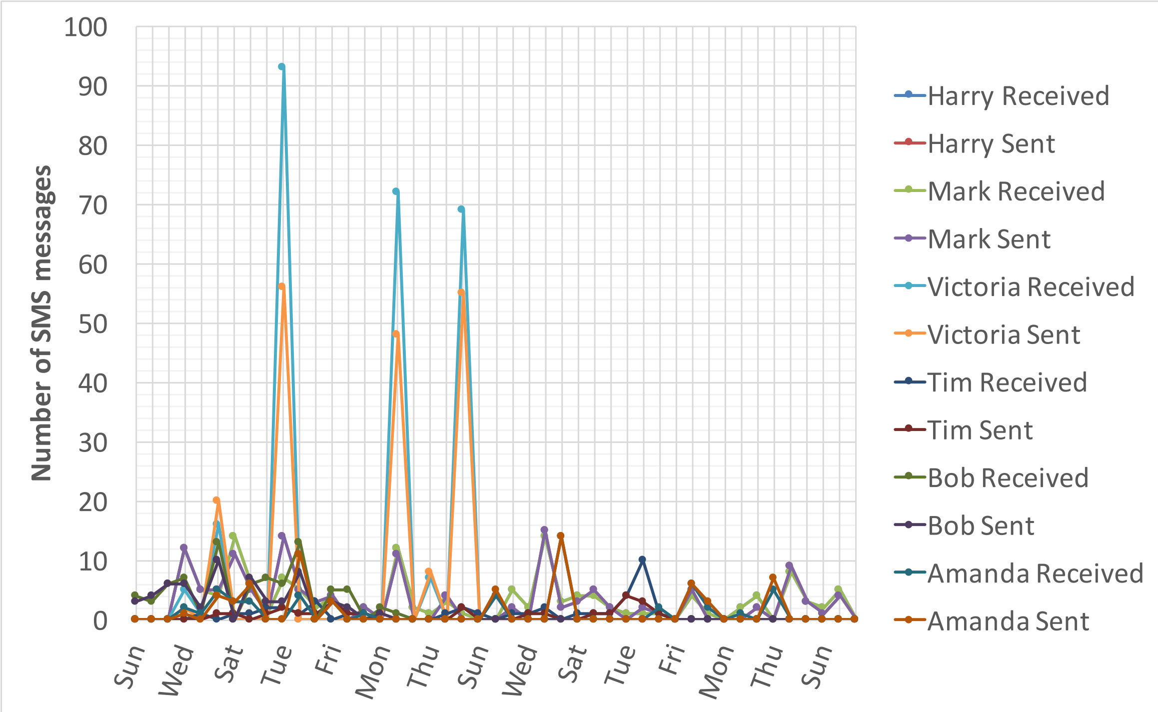
Fig. 5.7 A summary of the amount of calling time throughout the day.

and phone calls contribute towards indirect impacts. In this chapter, to illustrate the energy and emissions impact of SMS and phone calls I use the following coefficients estimated by Berners-Lee [14] and converted using the UK energy mix: 0.006 kg CO_2e (10 Wh) per minute of phone call; and, 0.000014 kg CO_2e (0.023 Wh) per text message. The phone calls, SMS messages and data demand relating to communications and social networking is summarised in Table 5.4.

Median daily phone calls add between 5 Wh (Mark) and 12 Wh (Amanda), whilst daily send and received SMS adds 0 Wh (Tim) and 1 Wh (Victoria) to overall daily impact for the participants.

To better understand how communication can vary in impact we can compare instances of different communication: a day of Victoria's intensive text (93 sent, 56 received) (Figure 5.8a), with an intensive phone call of Amanda (20 minutes) (Figure 5.7), and Tim's data demand arising from a 10 minute Skype call (2 MB). We can see that the energy and emissions of the phone call is the most intensive (200 Wh), followed by Bob's 10 minute Skype call (4 Wh), and then Victoria's day of intense messaging (3 Wh).

The variations that occur in times of communication and data demand (Table 5.4) are influenced by the various meanings and utilities of carrying out the practices in different



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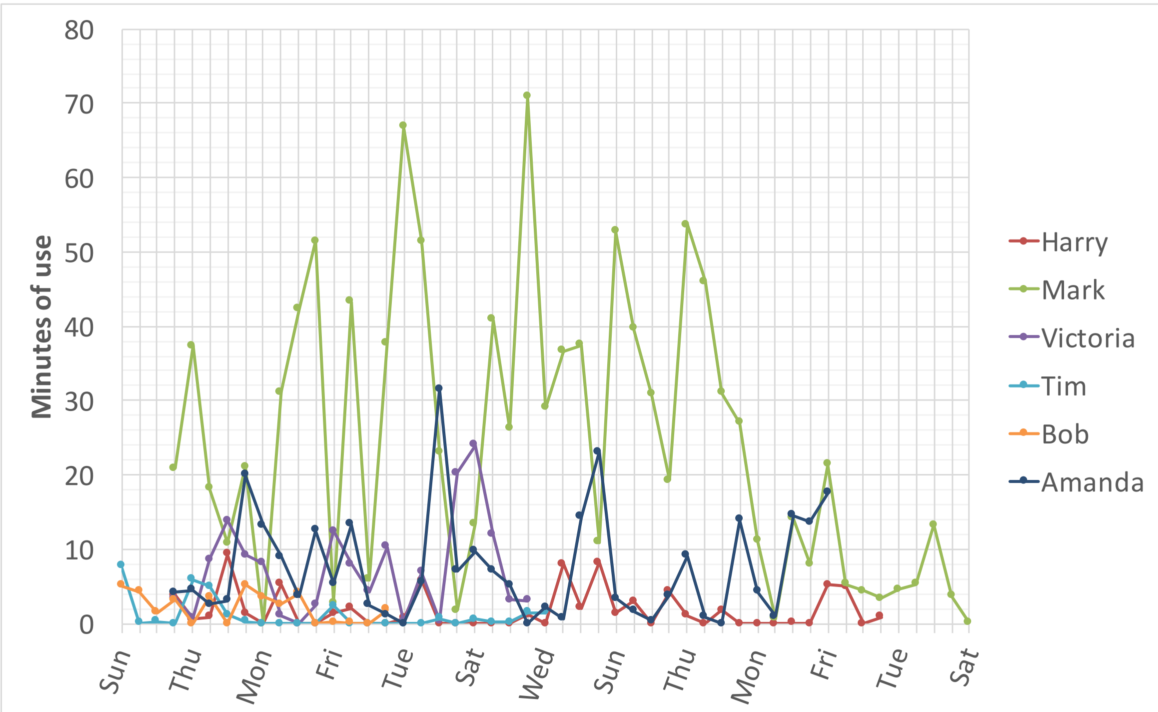


(b)

Fig. 5.8 The use times and amount of SMS messaging (a) when throughout the day SMS messages are sent and received, and (b) the breakdown of how much time the participants spent using the SMS application to read, write and send SMS messages.

ways.

Figure 5.8a shows a positive correlation between messages received and sent through the day. Notifications were seen to reinforce the urgency to reply, especially when communicating with friends or family. This urgency regularly lead to quick replies and short bursts of two-way communication, especially when participants had more free time (e.g. Victoria is more likely to reply quickly if she's free). Anxiety can also arise when participants feel the need to reply quickly to messages:

> *"Having previously left text messages for too long, they get to the stale period where you go like, 'oh I've left it too long now, what do I do?' <laughs> I feel that you should respond to texts as soon as you can. But then you don't want to end up in a situation where you're like text, text, text, text, text cause then you don't get out of the conversation, and I've got work, so there's like a happy balance isn't there"*. (Bob)

Another example of this is Victoria, who is bombarded by messages from her mum about *"random things"* which leads her to responded less frequently (see Figure 5.8a). Although she is hesitant to reply instantly to her Mum, she is more likely to send an SMS message than make a phone call as she finds it quicker to access the SMS application on the phone. However, she does make time for phone calls, finding more free time to 'chat' on Fridays and weekends.

Others, such as Harry, tend to reply to messages, *"pretty instantly"*. Mark, who is always quick to respond, increased his amount of daily texting in the midst of study due to him talking to someone new, *"if I'm talking to someone, if they're available at a particular time they're gunna text more often"*.

Xander prefers to use Facebook chat for communication because he can see whether the messages he has sent have been read or not. Victoria uses her browser for Facebook, when connected to Wifi, due to problems that she had faced with the cellular connection (e.g. 3G/4G) of her smart phone. She only really uses Facebook when she has additional content that wouldn't necessarily be sent over SMS (e.g. photos, links to websites).

Video chat is used by Bob to show his parents his son, due to them not living very close. Bob describes the experience of attempting to video call his Mum one particular Saturday, *"nobody uses Skype <laughs> so my mum doesn't really understand how to use it that well, so I'd have to ring her first to tell her how to turn it on <laughs>"*. Photos of relatives are also important to Amanda who uses Whatsapp to see pictures of her partner's grandchild.

Although there is some variation in the times and spaces that particular practices are performed with a mobile technology, patterns of use and data demand continue through everyday life. The data demand of social networking is large, due to obsessive checking of smart phones (Harry, Mark) and the higher data intensity of social networking from videos and images. Whilst data demand occurs throughout the day, peaks in data demand coincide when participants check their social networks first thing in the morning, and more frequently through the evening. It can also be seen that different methods for communication having different impact (e.g. phone calls are more energy intensive than SMS, video chat or email). Whilst these variations do exist, the meanings and utilities associated with particular practices also encourages variation (e.g. chosen application or method of communication). Some participants are less likely to reply to certain people (e.g. Victoria and her Mum), whilst others reply very quickly (e.g. Harry, Mark).

5.5.4 Online Dating

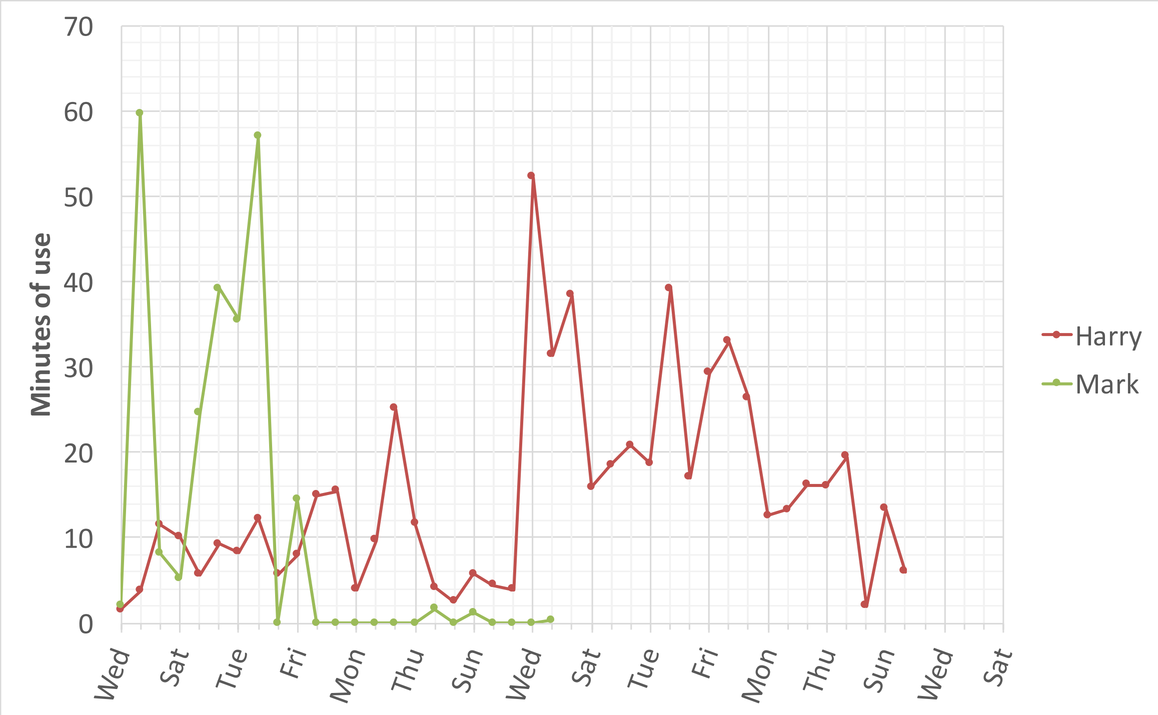
Online dating (e.g. Tinder, OkCupid) was seen to contribute towards data demand by two participants (Harry, Mark). Both participants used two applications for online dating (e.g. OkCupid, Tinder). Online dating contributes a significant portion of Harry's data demand, at 13% overall (17 MB/per day) and just under 2% of Mark's. Mark's low percentage is in part due to his daily usage of Tinder halting in the middle of the study, *"for personal reasons"*. This was not the case for Harry, who made it part of his "obsessive checking" routine, *"I generally have a bit of a pattern of like Facebook, and Twitter, and Rare Bird Alert, and sometimes Tinder"*.

Whilst the demand arising from online dating may only be from two of the participants, this practice is interesting to consider, as it is a practice that is relatively new (the last 5 years). Interestingly, both Harry and Mark spend time using these applications, regularly, throughout the day (Figure 5.9a). Online dating is perhaps most similar in use time and data demand to social networking. This is due to Mark and Henry including online dating in their routine checking of their phone throughout the day (e.g. peaks in the morning, and again in the evening).

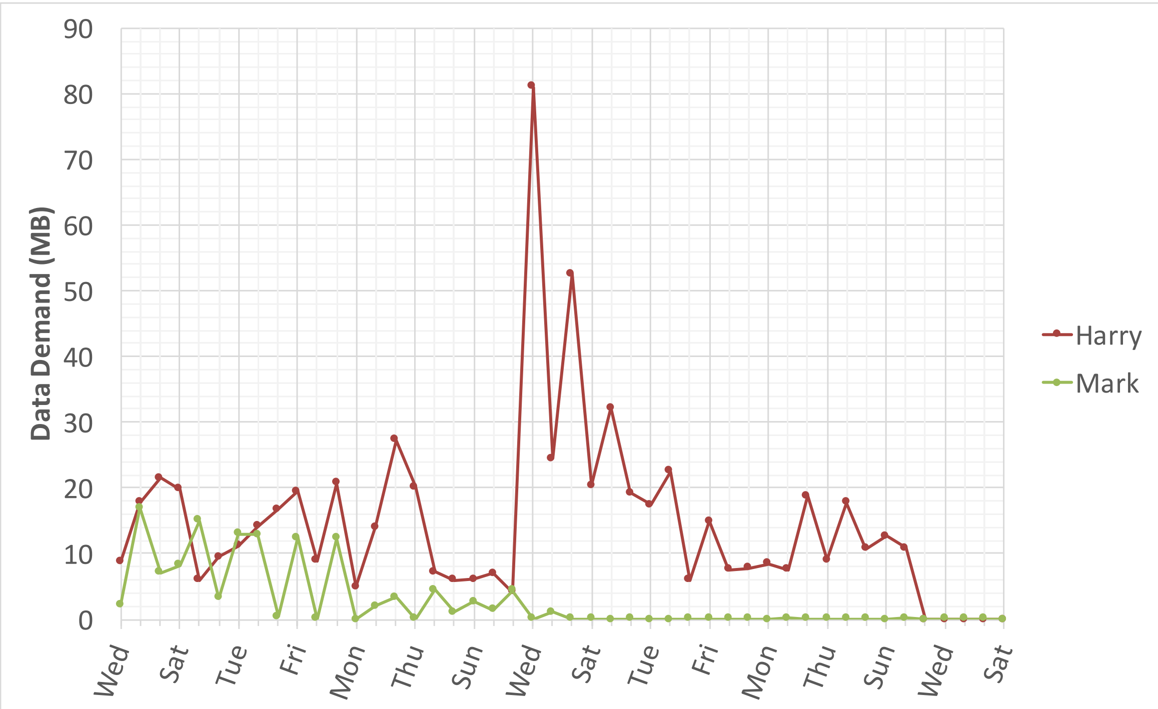
5.5.5 Updates and backups

Data demand from updates and backups account for 36% of the participants' overall demand. This demand arises in the following scenarios:

1. Updating current application or the OS.
2. Downloading new applications from the app store.
3. Syncing and backing up of data to a server or Cloud service (e.g. syncing of user information, syncing backups and shared documents to Dropbox).



(a)



(b)

Fig. 5.9 The use times and data demand of online dating. (a) shows the amount of time that relevant participants spent online dating, and (b) the breakdown of when data demand associated with online dating occurs throughout the participants' day.

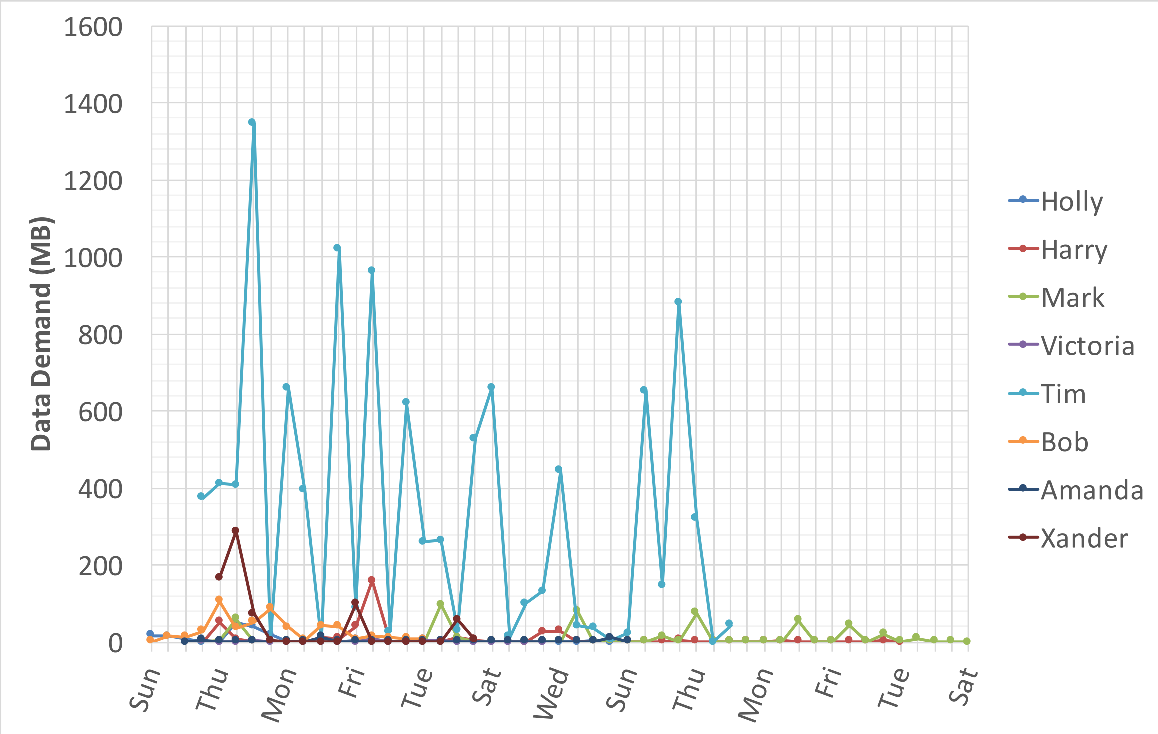


Fig. 5.10 The distribution of data demand for OS, App Stores, and Cloud.

These applications can perform updates and backups without the users knowledge. For some, these updates are seen negatively. For example, Bob gets frustrated when updates take a long time and prevent him from using his device. One particular participant's demand stands out from the other participants (Figure 5.10) accounting for over 10 GB (10,000 MB), 71% of his overall data demand. Tim's high demand is due to the Google+ automatically uploading videos and photos that he takes throughout the day. Xander having turned off automatic updates, chooses to manage these updates himself, performing updates as and when he wants. The spikes in Xander's data demand (Figure 5.10) are due to Xander updating and downloading new applications before his trip abroad. The other participants were unaffected by automated updates and backups. Alternatively, Mark manages his upgrades, choosing to update when there are updates available for several applications instead of updating them one at a time. Victoria actively avoids updates as she's worried that she'll lose all the text messages that are stored on her phone.

As can be seen in Figure 5.10, data demand arising due to updates and backups can lead to data demand throughout the day. For automated backups and updates these peaks occur at non-specific times of the day, governed by the application or OS (e.g. Harry, Mark, Tim, Bob, Amanda in Fig. 5.10).

5.6 Discussion

In focusing on the demand and time-use of applications arising from the performances of particular social practices, this chapter has uncovered the relationship between everyday life, use, and data demand. In this section I discuss what these findings mean in terms of impacts on energy (e.g. the impact of data demand) and everyday life (e.g. variation in the performances of practices), and highlight the variation that has been presented in my findings.

5.6.1 The impact of migrated practices

The majority of the data demand that occurs across the participants is due to practices that have migrated from other digital technologies (e.g. social networking, video-on-demand, online dating), whilst more ‘traditional’ uses of the device can be seen to have lower impacts in some cases (e.g. SMS, short phone calls). As new digital technologies get integrated into existing practices like watching, keeping in touch, gaming, and many hobbies, those digital technologies tend to increase energy demand, even if the time-use of the practices is not significantly increased.

Looking back to Table 5.1 the notable practices (e.g. the practices that the participants highlighted that they performed the most) are not always the most demanding in terms of data demand. For example, although participants spend a large proportion of time in communication applications the relative impact is small. Similar amounts of time are spent social networking, dating, and watching, and these practices are much more demanding in terms of data. A more extreme example of this is the demand associated with automated backups (e.g. automated backup of photos taken by Tim), in which 10000 MB of data demand occurs because of automatic backups.

The increased demand seems to be a combination of (a) the capabilities that current digital technologies now allow, and (b) the fact that these technologies in some cases simply use more data than is needed for practice (e.g. Facebook feeds containing video, video on demand defaulting to high definition, automated backups).

5.6.2 Mobile digital technology: impacts on everyday life

Røpke and Christensen suggest that mobile digital technologies support the softening of the temporal and spatial constraints of social practices [112]. Through my analysis I have found that mobile technologies can allow the amount of time spent on certain practices to increase (e.g. communication, dating, working). My analysis shows that practices (e.g. communication, working, watching) and broader activities (e.g. social networking, dating) that have been previously constrained by particular times (and devices) now happen throughout the day. Examples include Mark social networking and online dating during lunch breaks, Harry's "bird ringing" alerts throughout daily life encouraging him in his bird watching hobby, and Tim watching videos on Youtube throughout the day to fill time. Participants also reported using their devices whilst performing other activities (e.g. Holly watching whilst cleaning, Tim browsing and shopping on his phone whilst watching his TV).

Performances of practices are also being encouraged in places that wouldn't previously have happened. Examples include, catching up with current events and social networking whilst on lunch breaks (Tim, Xander, Bob, Harry), Holly working on the bus, both Xander and Holly watching videos whilst in bed, and gaming away from a desktop or laptop (Holly, Xander). Through increased performances throughout daily life, the participants' practices and activities are contributing to increasing data demand, and are thus becoming more impactful.

5.6.3 Peaks in practices

Peaks in usage and related data demand can be identified on a daily basis. For those who use their device throughout the day (Harry, Mark), these peaks occur first thing in the morning, again at lunch time, and then go on through the evening, matching with peaks in overall use time (e.g. Figure 5.2). This trend is generally the same across the participants, with no usage or demand through the night, a small spike in the morning, consistent use and demand from the morning through till the lunch time peak, and then increased use and demand in the evening before bed.

Morning peaks occur when the participants check social networks and current events (Harry, Mark, Tim, Xander). Lunchtime peaks occur for similar reasons, with more SMS communication (Harry, Mark, Bob, Amanda). Evening peaks are largest for social networking (Harry, Mark, Tim), online dating (Harry, Mark), watching (Holly, Xander), communication (Mark, Tim) and phone calls (Victoria, Amanda).

These peaks match with the peaks that are associated with domestic energy consumption. This is likely due to the affects of the working day on the availability of the participants, limiting the opportunities in which the participants can watch, social network, communicate, or online date.

With a future that seems to be converging on "in the cloud" functionality (and content) and reliance on high-bandwidth connectivity (e.g. wifi) it's important to consider how the demand for cloud services, infrastructures and data is going to shape the overall energy and emissions impacts of digital technologies. Data demand peaks are likely to become more pronounced as more functionality goes into the cloud. If this is the case, we should consider strategies for shifting these peaks in demand throughout the day to lessen their overlap with the peaks associated with domestic energy demand (e.g. around breakfast, and 5pm - 10pm).

Drawing inspiration from strategies suggested by Preist and Shabajee [105] and my previous work [80], 'wasteful' demand could be targeted to reduce digital waste. This could be an opportunity to re-evaluate caching on local devices, prioritising playback of cached media instead of new content (e.g. caching Tim's YouTube playlists and Holly's on-demand content), alongside time shifting the downloading of new content (e.g. Xander downloading video) to not coincide with peak energy or data demand. For a slightly higher impact solution designers could experiment with the temporal expectations of streamed media by purposefully creating latency on high quality and large streams to try and encourage low (or no) bandwidth alternatives (e.g. like Xander pre-loading).

For background updates and backups there is perhaps a need to be more strategic. Bob, who gets frustrated by updates that take a long time and affect his phone use might benefit from smaller and more strategic updates [80]. This kind of strategy could also be used to reduce the peaks during the daytime seen in Tim's Google+ photo uploading.

The growth of background, high-definition content being streamed poses serious implications for network and Internet service demand during peak hours. This is especially relevant when considering how the impacts of streaming media is likely to grow with the roll out of auto-playing video (e.g. YouTube's recent addition of autoplay) alongside 'ultra HD' content and growing screen sizes and resolutions of devices.

5.7 Summary

Complementing my prior work (e.g. Lord et al. [80]) this chapter has explored the role of data demand and on the impacts on everyday life that are encouraged by mobile digital technologies. This chapter has shown how performances of practices are increasing due to their migration from other digital technologies. In support of prior work (Røpke and Christensen [112]), my analysis has shown that mobile digital technologies are enabling practitioners to enact practices in new times and spaces throughout their daily lives. My analysis also shows where participants use their devices to fill "dead time" [112].

My analysis connects the usage of ten participants mobile digital technologies with their personal practices. The performances of these practices are contributing varying amounts of data demand that can increase the energy and emissions impact of practices. I have observed how peaks in use and data demand match with the peaks in UK energy consumption. My analysis uncovers variations from daily routines, including breaks from technology, layering and occasions when space mediates the possibilities for practices. From these observations I have been able to comment on why variation in times of use and data demand occurs across my participants. In an attempt to account more fully for the indirect impacts of mobile technologies, I have accounted for the impacts of data demand and the use of cellular infrastructure for phone calls and SMS communication.

Chapter 6

Exploring (un)sustainable growth of digital technologies in the home

This chapter is largely based upon the collaborative work published in Bates et al. (2015) [9]. The study was designed and performed as a collaborative effort with Carolynne Lord. Myself and Carolynne designed, recruited, and interviewed the participants together. Although this study was a collaborative effort, I am the primary contributor of the analysis and discussion presented in Bates et al.. Details that were left out of the original publication have been added throughout this chapter to emphasise the contributions and relevance of studying the relationship between everyday life and growth.

A significant portion of HCI and Ubicomp research aims to provide innovative research to support humans interacting with digital technology. Despite this, there seems to be less work focusing on understanding how digital technologies can lead to growth in use, dependence, and practices in everyday life. In this chapter I discuss how digital technologies have been, and continue to be, adopted in domestic practices—and how the growth of interactions with various ecologies of digital technologies can lead to growth in use and energy consumption. This chapter advances discussions within sustainable HCI and related communities on how to carry out research that positions sustainability as a core concern—socially, economically, and ecologically—emphasising that recognising limits to growth are important when trying to affect change in sustainable directions. This chapter echoes calls for more significant sustainability research from HCI [74, 97, 125], and sets out some avenues of design for moving in this direction.

6.1 Introduction

In this chapter, I concern myself with a number of interconnected domains that have a long history at the heart of HCI, Ubicomp and more recently ICT4S, research and design. As with the previous chapters, I refer to these as ‘digital technologies’; under this umbrella falls a whole array of interactive devices like smart phones, PCs and games consoles that support our daily entertainment, work, and communication practices, to mention a few. My particular focus relates to growth in the environmental impacts that the adoption and integration of digital technologies into everyday life have been part of.

Digital devices in the home are on the rise[1], with ownership of wearable technology alone set to double in the next year[2]. Significant rises in energy demand (Chapter 2), data demand (see Chapter 5) and GhG emissions follow from this, and some have reported on the potential negative effects of this proliferation of digital technology on domestic life (e.g. “together aloneness” [139]).

This growth in energy and data demand motivates the need to capture a) the diversification of digital technology throughout a variety of social practices in everyday life, b) why these technologies have been domesticated into practices, and c) where energy/data demand is intensifying through use in practice(s). Through expanding how we discuss growth it may be possible to gain a more nuanced understanding of impacts on the environment (e.g. energy and emissions) and everyday life (e.g. social practices, pressures and expectations) that are affected by digital technologies.

As Pargman et al. highlight, technology (in sustainable HCI) is designed to reduce impacts [97]. Typically this work ignores “a system’s inputs and outputs and its systemic effects”, contributing to unsustainability by “selectively draw[ing] a tight boundary around the implemented system in question” and selectively measuring their effects [97, p. 643]. Complementing this critique this work aims to provide better understandings outside the boundaries of traditional enquiries (e.g. just focusing on domestic electricity consumption) by studying how digital technology affects everyday life (e.g. temporally and spatially [112], second order and rebound effects [18]). These new understandings are necessary for those who are interested in how digital technology reliance translates to escalating demand and carbon emissions.

The design of domestic digital technologies influences how technologies are used or not used (becoming obsolete, abandoned or thrown away), affecting social norms and expecta-

[1]Accessed, September 2015 http://www.pewresearch.org/data-trend/media-and-technology/device-ownership/

[2]Accessed, September 2015 http://http://www.channelnomics.com/channelnomics-us/news/2372019/survey-wearable-tech-and-in-home-iot-devices-set-to-rise

tions of possession and use, which ties into end-use and production demand. In this chapter I analyse digital technology in everyday life to uncover: ownership and usage of devices in everyday life; the extent that digital technologies are incorporated in social practices (e.g. using Shove's social practice model described in Section 2.2.1); the encouraged use of digital technologies in practices by particular types of users (e.g. connoisseurs explored in Section 4.4.3); and, the physical spaces that the performances of practices have expanded into [112]. These factors contribute to the escalating energy and data demand and growing embodied emissions.

This chapter aims to contribute towards improved understandings of technological growth by: 1) identifying useful interpretations and valuations of "growth" as related to digital technologies in the home; 2) providing an understanding of how digital technologies have lead to growth with this specific set of participants; and 3) pointing to current factors that spur or limit growth in technological usage with an eye to identifying elements or strategies that steer technology in practice in favourable directions.

6.2 Related Work

'Sustainable HCI' often concerns itself with reducing the energy or environmental impacts associated with daily life. I propose a different tack: I instead critically reflect on the impacts of hardware, software and services that our participants use, and how this contributes to designing, implementing and implicitly promoting unsustainable practices and trends in everyday life.

Perhaps closest in both method and motivation are studies which have used personal inventories and domestic objects as a basis for exploring the role of physical and virtual 'stuff' in everyday practice. Such studies have included: insights into how home network technologies could support better user management [35]; understandings of the short lifetimes of mobile phones [68]; frameworks of personal attachment to inform the design of devices that are longer-lived and more likely to be cherished or passed on to others [52, 88]; reasons why electronic devices are kept even after they have fallen out of use [53]; how meaning is composed for digital data (messages, photo, video) compared to physical possessions [90]; how we might better support those who already devote significant effort and resources to reducing the impacts of their lives at home [145]; and how purchase, re-use and disposal of personal digital technology may relate to environmental concerns among young people [59].

Unlike the above works, I chose not to focus on any one element—such as specific devices like the mobile phone [68, 106], addressing obsolescence of end-user devices [109] or the specific reasons for acquiring new technology versus re-using old [59, 88].

Whilst digital technology in everyday practice has been looked at before, very little of this work has done so from a sustainability angle. This approach is similar to that of Håkansson & Sengers' "simple living households" [57] and Kawsar & Brush's [72] study with a different group, investigating the configuration of computer activities across devices, and the temporal and spatial arrangements of device use and computer activities in the home. Likewise, I take a broad view of our participants technology, looking at their whole 'ecologies' of devices (e.g. "implicit or explicit relationship among interactive artifacts in one's personal life" [70]), content and services, along with the varied daily practices in which these are implicated.

Håkansson & Sengers' exploration of the everyday lives of "simple living households" exposes the tensions in personal attitudes and meanings when considering the roles of ICT in a sustainable life. For example, ICT can be seen as a double-edged sword that is both a helpful tool in supporting sustainability whilst simultaneously providing very few limits in terms of what those who live simply consider to be "enough" [57]. As a result—and in contrast to Kawsar & Brush—I explore the integration of digital technology in everyday life to provide a stark illustration of how current configurations of digital technologies are as much about a) the day-to-day practicalities of employment and education, collaborating with others, and caring for loved ones, and b) about the happenstance of borrowed tech, hand-me-downs and contact with people having certain kinds of IT expertise, as they are about the space and time that these technologies are used in (e.g. the temporal and spatial arrangements of use [72], softening of spatial and temporal constraints of practices [112]).

6.3 Methods

A qualitative study of ten participants was conducted (seen in Table 6.1). The participants were recruited using flyers, newsletter advertisements and direct email between March and August, 2014. Each participant was assigned a pseudonym.

This study was designed as an extension of the Personal Inventories method [88], which was modified by Gegenbauer et al. [53], where home tours were replaced with a photo-elicitation. The study consisted of two-phases. Firstly, a photo elicitation of digital technologies exercise, where participants were loosely instructed to photograph anything that they considered to be "media or IT" and a part of their "daily life". The photographs captured by participants were hand-annotated by the researchers, and then used to construct an interview schedule customised around those technologies deemed important by the participant (see Appendix B). Secondly, a semi-structured follow-up interview was conducted

Name	**Living Arrangements**	**Important**	**Less Important**
Bettina	3 bedroom, single occupant	iPhone, {TV, PVR}	DVD Player, 3 x PVRs, iPod, CDs, DVDs
John	2 bedroom flat, lives with fiancée	{Smart TV, PS4}, iPhone	DVDs, {PS3}, Airplay speakers, 2 iPads, {PC, monitor, speakers}, Macbook, Laptop
Sarah	3 bedroom, lives with partner	iPhone, Kindle, Macbook	PC, server, {TV, media centre}, {speakers, amplifier, Logitech Wireless Music System}
Derek	2 bedroom flat, lives with partner	iMac, iPhone	iPad, work iPad, TV, Macbook, Speakers, DSLR
Xander	3 bedroom cottage, in the country, lives with Willow	Macbook, iPhone, router, cellular booster, DSLR, GoPro	Tablet, speakers, house iPod, {Desktop, Speakers, Screen, amplifier}, Kobo eReader
Willow	3 bedroom cottage, in the country, lives with Xander	Macbook, smart phone, external HDD, router, cellular booster	Kindle, DSLR
Jayne	3 bedroom house, lives with parents	iPhone, {TV, Sky+} Macbook	2 x TV, iPod, Printer, Mother's laptop, DAB Radio, Karaoke/DVD player
Malcolm	3 bedroom house, lives with wife, child and lodger	Smart Phone, Router, Laptop, 2x Tablet, {TV, BT vision box}	Wii, DVDs, Sky+ box, Software DVDs, iPod + dock, mp3 player, memory stick
Glenda	Co-housing occupant, lives half a year in France	iPad mini, Macbook, 2x iPhone, iMac, Time Machine, TV, 2 x DAB radios, high end HiFi, Landline, DSLR	–
Ron	2 bedroom bungalow, lives with 2 of his grandparents	iPhone, Macbook	Vinyl records, DVDs, Blu ray, TV, PS3, DVD/VCR, Sky+, camera, stereo separates (CD, Cassette, Record, Amplifier

Table 6.1 The inventories of the participants, divided by what they considered important and less important. Constellations of devices are grouped in braces.

that lasted between 60–100 minutes. From their inventories the participants were asked to identify a primary device if they had one, and to discuss which technologies they felt were important and less important in their everyday lives (see Table 6.1).

To understand how digital technologies were used through the participant's everyday life the interview questions and analysis were designed around the social practice model defined by Shove et al. [121, ch. 2], focusing on all three elements described in Section 2.2.1.

6.3.1 Domestication

Throughout this thesis I have used a social practice approach to explain the roles of meanings, materials (e.g. digital technologies) and competence in practices. Up until this point it has not been necessary to discuss the introduction and integration of a material into everyday life and subsequent practices. The domestication framework can be applied by researchers to better account for the phases during which a technology is said to be 'tamed' by its users into everyday life [13, 126]. The four phases are:

1. Appropriation; which refers to the process of possession although it is not limited to those who acquire the technology.
2. Objectification; concerned with the physical location given to the technology within the home, and the extent to which it is displayed and plays a role in an individual's sense of self.
3. Incorporation; focuses on those practices into which the material object has been integrated.
4. Conversion; when a technology reaches a taken-for-granted status.

Whilst phases one and three are more focused on a technology's practical uses, phases two and four are concerned with those meanings attached to that technology. Not all technologies pass through all four stages, and the sequence in which this happens is not confined to any particular order.

These concepts are effective in understanding changes in social practices as they help reveal why, and how certain technologies come to be domesticated, and as a consequence, why others are not. Investigation into the phases of appropriation of technology; which is mostly comprised of the "imaginative" work [13, p. 151] of trying to figure out particular uses of a technology deals specifically with understanding why (or why not) users incorporate technologies into particular practices.

It is important to note here, that the domestication of a technology does not end just because a technology has fallen out of use, and the arrival of new technologies can lead to re-domestication of older technologies within the home. The meanings associated with these older and no longer used technologies can affect the domestication of newer technologies long after they have been disposed of (e.g. endurance in elements of practices); as old ways of doing remain engrained (e.g. meanings attached to listening to physical media such as vinyl leading to preference of listening to vinyl over digital media), affecting the dynamics of a practitioners social practices.

By studying how digital technologies are domesticated and are situated ‘in-use’ in everyday life it is possible to gain new insight into the link between third-order effects and the growths that can be observed in social practices. The participants’ descriptions of the domestication and use of their digital technologies, captured in the interviews, revealed trends that are indicative of growth in terms of ownership (e.g. John, Malcolm and Xander like to keep up with new technology), use (e.g. Willow and Malcolm using laptops and work devices outside of working hours for work), reliance (e.g. Jayne, Ron and Glenda all rely on new technologies to allow them to communicate and keep up to date with the world), and the spaces that technology has become used in (e.g. all participants spoke about the different spaces in which their devices were used). Based upon these trends, myself and another researcher independently coded the interview data and then agreed that these four trends spanned a total of six overarching themes. These themes are: growth in single devices; growth in sets of devices; growth in individual practices; growth in bundles and complexes of practices (see Section 2.2.1); growth in single and sets of users; and, growth in the spatiality of practices. In the next section I explore what I mean by growth (Section 6.4) and how each of the six themes contributes to growth (Section 6.5).

6.4 Expanding the understanding of growth

The term ‘growth’ when used in a SHCI context is usually linked to the ‘directionality’ of the growth in ICT and digital technologies (e.g. growing emissions and impacts, growing ownership of digital technologies) but is there more to say? To better understand growth it is important to consider the implications of technologies on everyday life (e.g. adoption in practice, dependency upon it).

While this study only reflects a snapshot of a fairly restrictive set of participants’ digital technology—the participants could be considered middle class, citizens of industrialised nations, at different periods of their lives and careers—we can also clearly see recognisable variations of ownership (e.g. the participants own and have access to different ecologies of digital technologies), configuration (e.g. connoisseur-like participants arrange and configure their digital technologies differently from others) and importance attached to the kinds of technologies interwoven in their lives (e.g. Malcolm needs to be in contact with his wife throughout the day whilst away from home, with no home Internet connection Bettina sees her phone as her lifeline, John is much less attached to technologies provided by his work place). Digital technologies can lead to both positive or negative impacts of first-, second-, and third-order effects [112, p. 349]. For example, growth in reliance on digital technology has been observed to have negative first-order effects on the environmental impacts (e.g. growth in global energy and emissions impacts arising from manufacture and distribution of new technologies), but can lead to reduced second-order effects through the dematerialisation of various practices, (e.g. telecommuting [112]). The reductions in second-order effects may be counteracted by third-order effects in specific practices. For example, these technologies allow us to maintain digital friendships which can lead to an increase the frequency of digital (e.g. more communication, increasing data demand) and non-digital interactions (e.g. commuting more frequently to meet up). Growth in these interactions leads to increased total energy consumption for maintaining friendships [112]. Exposing how digital technologies feature in everyday life is important as it aids with the understanding of how digital technologies are contributing, either positively or negatively, to energy and emissions.

Reliance on digital technology has grown and become more engrained in everyday life. To better inform more ‘holistic’ understandings it is important to consider both: how demand is growing due to the co-evolution of digital technologies and social practices; and, how digital technology is encouraging growth other than in energy and emissions (e.g. how technologies are used to fill time that used to be viewed as “dead time” [112], the encouragement of the layering of practices (Section 5.4.6)). For example, streaming video-on-demand may be lower impact than buying physical media, but the video-on-demand service enables softer constraints for watching, leading to more opportunities for demand and growth (i.e. across devices, locations). The co-evolution of technology and social practice can manifest in different ways.

6.5 Exploring growth

In this section I explore the relationship between growth and the participants’ social practices. I discuss the following categories of growth: 1) single devices; 2) sets of devices; 3) individual practices; 4) groups of bundles or complexes of practices (Section 2.2.1); 5) single and sets of users; and, 6) the spatiality of practices. The term set is used to describe where growth has been affected across multiple (physically or virtually) connected entities.

6.5.1 Growth in single devices

The number of new mobile applications available is increasing monthly,[3] expanding the pool of potential uses of mobile devices. All of the participants owned smart phones, and seven out of the ten have access to at least one tablet computer. Smart phones were seen as important by all of the participants, who all interact with these devices throughout their daily lives.

Derek and Malcolm, who both have access to a laptop (Malcolm) or desktop (Derek) both described their tablets as central to their work and leisure practices. Derek, uses his tablet throughout the day to support work (e.g. email, notes in meetings, appointments) and in his free time for catching up on current events, finances and TV. Malcolm uses his tablet throughout the day for work, and in the evening for keeping up with current events, browsing and emailing. Ron's smart phone is used throughout the day for communication (e.g. SMS, email), social networking and keeping up to date with current events (e.g. Instagram, Twitter), and for listening throughout the day (e.g. podcasts whilst driving the work van and music in his own time).

Bettina's reliance on her smart phone (Figure 6.1) is a little different as it is her only device that is able to communicate with the outside word. This stems from not having a conventional land line or home broadband due to financial circumstances. She is dependent on her iPhone and sees it as *"her lifeline"* as it was her *"alarm clock, [. . .] only access to the internet, it's my diary, it's got my music—it's everything. So if I didn't have my phone I'd be in trouble"*.

Although neither Jayne or her Mum consider the tablet an important device, it is still regularly used on Sundays when family visit for Sunday lunch (see Figure 6.2), *"My Dad bought my Mum a Kindle Fire, which I don't think she's ever used ever if her life. But my nephew loves it because he plays games, so that normally comes out on a Sunday"*.

These examples show how relatively new digital technologies (e.g. smart phones and tablets) are growing through their incorporation in practices that used to be performed on other devices (i.e. browsing and email used to be associated with desktop computers) and performance in other spaces (e.g. Jayne's nephew is now able to game at Jayne's house).

[3] Birth, life and death of an app. A look at the Apple App Store in July 2014. Accessed September 2015 (https://www.adjust.com/assets/downloads/AppleAppStore_Report2014.pdf)

Fig. 6.1 Bettina’s smart phone.

Fig. 6.2 Jayne' s nephew gaming whilst eating Sunday lunch (Jayne).

6.5.2 Growth in sets of devices (e.g. ecologies and ecosystems)

Whilst in this thesis, digital technologies have been accounted for as inventories of participants devices (Section 4.2), or as part of constellations (Section 4.2.1), this chapter explores the roles and relationships of digital technologies in ecologies and ecosystems. Broader ecologies are interconnected due to their involvement in the personal lives and practices of the participants (e.g. [70]), and can stretch beyond just the devices owned by an individual (e.g. devices owned by others). Ecosystems represent a subset of devices that are connected due to shared operating systems (e.g. Mac OS and iOS) and have collaborative applications that enable the synchronous sharing of applications, multimedia, communication and data (e.g. iCloud, iTunes, iMessage).

Ecologies of related digital technologies grow through the addition of new components in that ecology. For the new technology to be integrated in everyday life they pass through two phases, adoption and integration [107]. The ownership of one technology from a single manufacturer can sometimes lead to future purchases from the same manufacturer, leading to growing reliance on a particular ecosystem (e.g. Ron and Glenda relying more on Apple products).

John's purchasing of a smart TV led to his old TV being moved to the bedroom. Re-adoption of technology, and re-definition of the meanings of technologies [107] (e.g. John's old TV now having a different meaning in his ecology) play a role in the growth of digital technologies, as technologies that have already been adopted and integrated into practice can more easily remain in an ecology. Although this TV remained in John's ecology, the bedroom TV is not used, *"we'll just drag a laptop in and put the laptop on if we ever need to watch something, while one of is ill or anything like that really, or I'm really tired. Sometimes if I'm really tired I'll lie in bed and watch on the ipad or the laptop"*.

Malcolm, owns two tablets, an older iPad, and a newer Android tablet. As his iPad is on its *"last legs"*, he gave it to his son. He jokes that if it broke, "we'll have to buy him a new one because he's used to the iOS interface". In his eyes the iPad has reached the end of its lifetime, and has been replaced to accommodate his personal practices. Although the tablet has reached its end of life it still remains in his ecology. Its meaning has been re-defined and the iPad now is important during meal times, as the distraction of the tablet keeps his son calm, making it easier to feed him.

Ron regularly upgrades to new technology. He currently relies on Apple products: a new MacBook Pro and iPhone 5S. The importance of the features of this ecosystem to Ron are clear. Ron values synchronous content, communications (Twitter, email and instant messaging) and cloud applications (e.g. iCloud, iTunes Match) as they are seen by him to be important for his workflow and everyday life. Ron tries out a range of cloud based services and applications as he wants to improve his practices as best he can, enabling him to perform them when and wherever he requires.

6.5.3 Growth in individual practices

Growth in practice occurs when the practice develops a competence or meaning that relies more on digital technology. For example, Jayne's latest smart phone enabled her to follow tennis whilst she was away from the her home TV. Jayne is passionate about tennis, so this has lead to her using the official Wimbledon application and updates via Google on her phone to access fixtures and scores throughout the day.

Communication is increasingly facilitated through a growing number of applications, leading to growth in frequency of use. Malcolm uses 'Line'—an alternative application to texting that uses wifi data connectivity instead of SMS—due to poor cellular network coverage at his home. Instead of going without due to poor reception at home, Malcolm (and his wife) expanded their communication practices to include a new application, allowing them to maintain a constant stream of communication. Willow also uses Line to maintain more regular contact with a friend currently working in Japan. Jayne uses iMessage on her iPhone to maintain group conversations between 4 close friends. Facebook was used by several participants to communicate with friends (Xander, Sarah, Willow, Malcolm). Facebook allowed for participants to switch between devices (e.g. smart phone to laptop), and enabled communication to incorporate the sharing of links to video and photos between the group. Communication with friends and family is a high priority for all of the participants and as a consequence, the expectations surrounding these practices have grown (e.g. Jayne's group messaging, Willow's international conversations); further contributing to the growth in their practices and their impacts.

6.5.4 Growth in sets of practices

Through multi-functional digital technologies (e.g. laptops, smart phones, tablets), and growing ecologies, the practices that can overlap (e.g. bundles and complexes of practices), or be performed at the same time, become larger and more complex (e.g. listening to music whilst cooking, emailing or working whilst watching TV). For example, Malcolm who uses his tablet in the evenings for catching up, emailing, does this whilst watching TV in the living room with his wife.

Growth in sets of practices is facilitated by digital technologies finding their way into more practices. For example, whilst Glenda's Apple ecosystem isn't growing (i.e. she's not buying more Apple devices), she has found a way to make her Apple ecosystem work

Fig. 6.3 Pancake - Xander and Willow's NAS.

for her. Glenda owns primarily Apple branded digital technologies and recently completed some *"wonderful Apple lessons"* that taught her how to use her Apple products. Motivated by her training, she is now more comfortable in using her Apple ecology leading her to use digital technologies in larger sets of practices now that she is living abroad. A few examples include, watching catch-up-TV on her iPad, researching things that she wants to buy online, reading news through the kindle app on her iPhone and iPad, and showing friends photos she's taken on her MacBook or iPad. She likes to carry her iPad around with her as it contains all of her information (e.g. calendar, reminders, notes, research papers).

Background tasks such as automated backing up, and streaming media (either locally or from the Internet) are often done in the background of other practices whilst the devices are active and connected to the home network. Xander and Willow rely on their media server named "Pancake" (see Figure 6.3) for accessing their joint media library and for regular, automated backing up. Pancake is an old laptop that has a broken screen. It is used as network attached storage (NAS), with 2 x 2TB external drives, one for back ups and media content, the other for redundancy of the media and back ups. Ron, like Xander and Willow, automatically backs up his data. Using both iCloud (for his phone) and a backup service BackBlaze[4] to host all (e.g. all of his digital media, backups of his phone and tablet) of his data and media in the cloud.

For Xander, gaming on his desktop PC (see Figure 6.4) was done mostly when virtually hanging out with his brother, *"It's more a social thing, so my brother, we used to hang out quite a lot as kids. We've both gone to uni and sort of separated a bit. The only time we get to socialise is with Skype or Skype whilst playing a video game. So we do quite a lot of that to keep in touch."*. For Xander, this complex of practices has evolved from a previous version of socialising with his brother. Whilst this complex might not be new (i.e. gaming

[4]https://www.backblaze.com/

Fig. 6.4 Xander's desktop used for gaming and socialising with his brother.

and socialising), the practices themselves can be seen to have grown as they now require an Internet connection and two computers.

Sometimes digital technologies play a part in practices that don't always contain digital technology (e.g. Jayne, Xander, John, Willow stream media whilst they cook). For Malcolm, the iPad paid a crucial part in maintaining his son's attention whilst trying to get him to eat, *"He doesn't like to sit still, and so to get some food into him what we do is get the tablet on the dining room table and we'll let him use Youtube[...]If I had nothing else, I'd need my sons tablet, otherwise he'd starve."* These are all examples of how bundles (e.g. watching or listening whilst cooking) and complexes (e.g. the reliance of Malcolm on the iPad to get his son to eat) are occurring in everyday life.

6.5.5 Single users and sets of users

Higher levels of growth can be attributed to individuals (connoisseurs) who "strive for a high quality of service or experience" (Section 4.4.3). Due to higher competence with the technology, connoisseurs tend toward integration of more digital technology and larger constellations, with more and more frequent upgrades [8].

Sarah's housemate, like several of our participants (John, Xander, Ron, and to a lesser extent Malcolm) is a connoisseur who has custom built the constellations and networks in the home used by Sarah. John and Xander both own and maintain custom constellations of digital technologies to heighten their experience. Ron has a specialist collection of vinyl records, and has optimised his work flow between his iPhone and Macbook, communica-

Fig. 6.5 An example constellation in Sarah's house. Connected to it is an Xbox 360, amplifier, and micro-PC.

tion and leisure experiences through the use of a variety of customised Internet and cloud applications. Malcolm's fondness of gadgets and technologies lead him to incorporate technology throughout his life, *"I like gadgets and I've always tried to become as tech'd up as possible"*.

The effects of connoisseurship by one person has knock-on effects for others who share technology and space. For example, Xander configures most of the digital technologies in the house that he and Willow live in. Xander has even set up a backup, specifically for Willow, *"I back it up because Willow sometimes erases the whole media collection, and she's just like Òh yeah, it's gone, I don't know what has happened'. Oh my god. So now we have a backup, which is for Willow's laptop, read-only, and so I can restore it if goes again."* These configurations (e.g. sharing larger libraries of media through Pancake, automated backing up) lead to his partner Willow's practices having higher impact). Sarah could be seen to share her housemates' technologies. Whilst Sarah had many photos to discuss in her interview, the only devices that were solely hers were her iPhone and Kindle. The other devices (see Table 6.1) were shared and therefore required a negotiation of sorts (e.g. choosing one of several methods for watching, the constellation itself) given that *"everything in the house is custom built"* by her housemate (see Figure 6.5). It also meant that Sarah had to learn how to use these configurations of technologies to perform some of her personal practices (e.g. listen to music, watch the TV).

There were definite benefits to living with connoisseurs, however, and Sarah described how she uses her housemate's MacBook on a daily basis when home, as her own had broken. Her own remained in the same state given that, ... *"No it's fine because there are several laptops in the house, [...] everyone else is ok with me using one of their spares, or their main laptop. That's fine"...*

6.5.6 The spatiality of practices

The spaces in which practices can be performed are growing, both within the home and outside of the home. Spread in the spaces of use occurs for three reasons: 1) mobile technologies (e.g. laptops, smart phones, tablets, e-readers) are not restricted in space like other digital technology (e.g. laptops, TVs), 2) the spread of infrastructures of network connectivity allowing access to Internet and cloud services (e.g. on-demand video, email, browsing) in more locations, and 3) technologies provided by an employer or bought for study often find use beyond their intended purpose, and end up being integrated into more domestic practices.

When talking about their digital technologies, Derek, John, Xander all identified technologies in their possession which had been bought for them by their employer. This meant that duplicate technologies were often owned (e.g. Derek had two iPads, John's work iPad was used as well as his finacée's). Despite this, the uses of these work devices were frequently seen to blur the boundaries of practices, leading to work bleeding into practices of leisure and domesticity.

Some, such as Malcolm, valued the access that their mobile devices gave them to work resources, *"I receive my personal and my work emails because at work we have Google Apps for work that's hooked up. So I just sync in... Occasionally it's important... If I'm out and about during the day then it is handy"*. For Malcolm this sometimes lead to blurring between work and non-work practices, *"...but I then check work emails at night and at weekends and reply to them as well. I'm thinking that maybe I shouldn't do that so much."* For Derek, being allowed to work away from the workplace appeared to influence his perceptions of appropriate activities at work, *"If I look at some personal emails at work that's fine because I do work emails at home."*

Technology provided by employers can be seen to expand practices through practitioners finding ways to integrate new technologies into other practices. For Derek and John, the digital technologies provided to them by work was used for watching. Derek uses his iPad for watching on-demand video on his tablet, whilst John has integrated his iPad into his and his partners watching practices. They use the tablet to 'cast' video content from Netflix to

Fig. 6.6 John's TV. Connected to it is his PlayStation 3, PlayStation 4, and Google Chromecast.

his Chromecast which allows him to watch the streamed video on his TV (see Figure 6.6).

Having carried out much of her preparation for her day job on her laptop, Willow was now finding it difficult to make the distinction between work and home life. Certain consequences of this on participants' experiences were clear. Willow, for example, found that she frequently worked on her laptop when she'd previously intended to carry out more leisurely activities.

> *"I haven't found the work-life balance yet so it's kind of being more working. I think it could be a reason for switching to the tablet, not that I have, but there's so much work stuff on [the laptop] that even if you are sitting there, and you are browsing the Internet, or doing something else, I'll have the Powerpoint window up there[. . .]"*—Willow

Despite the way in which technologies have been cited for increasing flexibility and improving productivity in and out of the workplace, the effects can be seen to carry on beyond the working day; increasing both negative (e.g. squeezing of time, leading to 'harriedness' [129]) and positive influences (e.g. flexibility) over the way that people perceive the divide between their work and home lives.

6.6 Difficulties and challenges in addressing growth

Growth linked to digital technologies has featured in the everyday lives of our participants. In this section I reflect on the difficulties that are faced by everyday practitioners. These difficulties are important for researchers to consider when trying to address the previously outlined growth.

6.6.1 Felt importance

From the interviews, it was clear that certain practices were more important to the participant as they deliberated (with themselves) over which digital technology was more important than another, and why. Often, communication with family and friends was the practice held the most highly, spanning multiple devices, and leading to their important device(s) being linked tightly to practices of communication.

Glenda's iPad, Macbook and iPhone were especially important to her whilst she was in France, as they were her only means of communication to family, friends and for work. Her communication was enabled across multiple technologies in her ecology (e.g. iPhone, iPad, MacBook), and spanned space due to her having to find Wifi spots outside of home. Malcolm's choices of important technologies revolved around maintaining contact with his family, and ensuring his wife was comfortable whilst off work ill. Malcolm felt that the TV and connected peripherals (its constellation) are important for his wife's well being whilst she was pregnant and stuck at home, *"If she didn't have [the TV and connected peripherals] she'd be very sad, and she used it to relax when she was well, but now she needs it even more, just to take her mind away from the constant pain she's in"*. Having been re-appropriated, the iPad was seen to be absolutely essential as it was linked tightly with keeping his son occupied enough at meal times to ensure that he ate.

For all the participants, the breakage of an 'important' technology (see Table 6.1), would result in immediate replacement of the technology (usually within a couple of days), even if they had another device which was technologically capable of performing the same function. For example John values his leisure time highly, which mostly revolves around the usage of his smart TV and connected devices (e.g. constellation). His desire for new and up-to-date technology (to further his enjoyment of TV and video games) meant that he would replace any important device (his smart TV, PS4, iPhone) if and when it broke. On the other hand, his laptop is provided by work, and is subsequently seen as less important as he still has a desktop and access to his wife's old laptop if needed.

With this in mind, how can researchers consider what is negotiable in terms of technology?

6.6.2 Dependence

Dependence on Internet connectivity was displayed across all the participants. From the photos and interviews, the majority of participants' device ecologies relied upon Internet connectivity. The participants indicated a high dependence on digital technologies (Table 6.1) that were used for communication (e.g. smart phones, laptops, tablets) and home network infrastructure (e.g. routers, Willow and Xander's device used to boost cellular reception in the house). These devices are key to the participants' dependence on Internet connectivity. For Xander and Willow, dependence on connectivity was a focal point in the interviews. They had recently moved into the country and were faced with unforeseen communication problems, *"[we had] issues where the broadband, I think water got on it, and it was just cutting out every three minutes and we were going crazy. You were just cut off."*—Xander.

Through the interviews, eight of the participants revealed that particular digital technologies allowed them to work whilst at home or on-the-go (e.g. John, Glenda, Xander, Willow, Malcolm). Ron's reliance on Internet connectivity went beyond this. For Ron, Internet connectivity is required to use his Apple ecosystem (e.g. MacBook, iPhone), paid for services (e.g. iTunes Match, iCloud, BackBlaze), and the functionality he found essential for his work and personal organisation (e.g. email, Adobe Creative Suite for creating promotional materials).

Internet connectivity also enables a variety of communication practices, such as long distance of communication (e.g. Willow), and getting around poor infrastructure (e.g. Malcolm). Jayne purchased an iPhone to allow her to communicate with a selected group of her friends via iMessages group messaging. If she was without Internet connectivity on her phone she would not be able to perform this practice.

6.6.3 Competence

The complexity of the digital technology configurations varied between participants, due to the their knowledge and passion for their domestic digital configurations (e.g. home networks, connected devices). Competence and connoisseurship was seen to increase the complexity of constellations in participants lives. The use of more complex configurations (e.g. larger connected ecologies and constellations, more frequent interactions of digital technologies in practice) through connoisseurship (e.g. Xander, John), or having access to digital technology configured by a connoisseur (e.g. Sarah, Willow), can be linked to more energy intensive performances of practices (Section 4.4). Connoisseurship, can be also be seen to link to more reliance on cloud based services (Ron) and larger investments in data storage (Xander).

With this in mind it is interesting to consider how competence plays a part of growth in device use and social practices. Through this study I have showed that dependence on technology (Ron), convenience and financial comfort (John), and prioritisation of family needs over greener digital technology (e.g. Malcolm was put off buying a Fairphone[5] due to the additional costs compared to buying a phone off of eBay) are all factors that can prevent connoisseurs from considering more sustainable trajectories (e.g. slower growth) for digital technologies.

6.7 Reflecting on growth

Although I am able to categorise areas of growth, and potential challenges, we found that the participants were faced with circumstances that they felt were out of their control. This makes it more difficult to redress growth in domestic digital technologies head on. In this section I highlight circumstances that affect digital technology use in the participant's daily lives.

Hand me downs and gifts. Derek discussed the way in which he had received his TV on account of family members updating their own, and having passed on their old model to him.

... *"It was like, there's a spare TV in the family–Derek's moving into a house–here you go, have a TV. To be honest if we hadn't been given that, it's unlikely that I would have bought one. 'Cause I already had an iPad"*...

Given Derek's preference for catch-up TV over scheduled broadcasting, he explained its continued presence by saying *"it seems like you have to have a TV in the house don't you?"*. Removal of the TV, however, would have directly impacted his partner who watched live programs.

Similarly, Xander was left with an unused tablet that he was unable to appropriate[6]. In having received the tablet as a gift, the 'imaginative work' [76] during appropriation was not conducted and Xander found that the device was unable to fit into his ideas of what a tablet should and can be used for, leading him to later acquire a new Kobo e-reader with a better battery life; just for reading. Although, Xander was unable to find a place for the tablet, Willow went on to use it regularly.

It has been suggested that lower impact devices could be a viable alternative for per-

[5] http://www.fairphone.com/

[6] Interestingly, 6 months later Xander participated in the Android Study and had found a place for his tablet (see Chapter 5)

forming similar practices with higher impact devices (Section 4.4). This study shows that when an additional device joins an ecology, it doesn't necessarily get appropriated into the practices of the intended user (e.g. Derek's gifted TV, Xander's tablet), and can simultaneously encourage more use in the daily life of others (e.g. Willow using the tablet, even though she bought it as a gift for Xander, Derek's partner using the TV).

Negotiating periods of no connectivity. Although Xander and Willow struggled watching their favourite TV shows whilst they were experiencing intermittent Internet connectivity in their house, they negotiated this by maintaining a hoard of content that would normally be streamed or downloaded (e.g. video-on-demand, peer-to-peer downloads) and performed pre-loading and uploading (e.g. videos to share with friends or family) when they had more persistent connections at work or in public Wifi areas. Pre-loading of content has been suggested by several researchers for reducing demand at peak times [80, 105]. Xander and Willow's account shows that while the pre-loading of content is inconvenient and requires some additional effort, it still allows them to enjoy watching TV.

Glenda spends part of her year in a small rural village in France, with a poor Internet connection. This means that communication (e.g. emails) and work (e.g. downloading academic papers) has to be pre-planned. If it's urgent, Glenda walks down to the village and sits on a wall where she's been able to find a connection she can connect to, and sends her drafted emails. Without a stable Internet connection, Glenda spends a lot of time reading books, walking and socialising, considering her life *"healthier"* in France when she's using technology less.

Whilst a number of participants are reliant on Internet connectivity for video streaming (John, Derek, Malcolm), gaming (John, Xander) communication (Jayne, Malcolm, Xander, Willow, Sarah), and cloud services (Ron) throughout their everyday life, Willow, Xander and Glenda show examples where it is possible to still use digital technology even when connectivity is neither stable or guaranteed. They also show that if required practices can be adapted in accordance with the surrounding environment (e.g. Xander and Willow pre-loading content, Glenda going to find Wifi in the village, Glenda using technology less).

One connected device is enough. Bettina, who lived alone, demonstrated the way in which her particular financial circumstance affected the uses of digital technology. Her laptop has fallen completely out of use since she stopped having an Internet connection at home. Bettina negotiates not having an Internet connection at home effectively, and was able to carry out the tasks that she required connectivity for either at work or with her iPhone. When asked whether she'd consider installing a connection were money not an issue, she replied:

... *"Absolutely. But because I'd have to buy the phone line and then you know, the* *monthly payments for that, and then the monthly payments for the Internet. It's just way over my budget. So, something has got to give... and I'd rather eat [laughs]"...*

This points to some digital technologies having the potential to be seen as more negotiable, with a smaller ecology of devices being a viable alternative as circumstances change.

Clearly, there are opportunities to dissuade or slow growth. Although barriers such as perceived importance can encourage stronger relationships with digital technology, leading to dependence, these strong relationships can be shaken up in the occurrence of circumstances that affect wider practices (e.g. Xander and Willow's Internet connectivity disruption, Bettina's financial constraints). The participants' willingness to change their practices around inconvenience shows that it may be possible to stem growth of digital technology and everyday life.

6.8 Towards limits to growth: Directions for sustainable ICT

Taking into account what we have learned from our participants, this section lays out some initial directions for designing digital technologies in ways that are more congruent with sustainability and more cognisant of the ripple effects of such designs. In line our with recent calls for more radical research questions I present a set of design ideas and directions that are fitting when considering how to limit how digital technologies are growing into our lives (cf. [75]) that might lead to higher impact wins for sustainability. This section ends with questions this study has raised and new challenge areas it highlights

6.8.1 Growth from sharing, gifts and hand downs.

The argument for sharing technology has been made before in sustainable HCI [15]. In contrast to Blevis [15] and Brush et al. [20], I believe that the sharing of technologies that are seen as less-important can be *worse* with respect to sustainability impacts (e.g. connoisseurs like Xander and John sharing their constellations with their partners leading to higher impact practices, Derek's parents gifting him and his partner a TV leading to non-incorporation for Derek and a larger ecology). It is important to consider how sharing can decrease impacts and demand, but we must also be careful to consider how shared devices can serve as gateways to growth in use, practices, and lifestyles (e.g. through the use of complex constellations). There appear to be certain points at which sharing can influence larger demand. Consider that a shared resource (e.g. sharing an Internet connection) may reduce impact, whereas sharing access to a complex constellation of digital technologies can increase demand (e.g. Sarah, or Willow using their respective house-mate's constellations). Communities concerned with ICT and sustainability should consider evaluating the demand of sharing digital resources, especially when these resources can lead to higher (i.e. negative) impact and growth in practices.

6.8.2 Designing for non-reliance

It was surprising to observe with the participants how quickly technologies that did not even exist until recently have become indispensable (e.g. heavy reliance on cloud services, streamed media and mobile devices). Their indispensability does not necessarily comport with reality—for example, life would be liveable without a tablet, no matter how much one may have grown accustomed to it; yet there is a certain degree to which technology has integrated itself into normal practice that means that its breakdown would 'be catastrophic'.

To encourage non-reliance on digital services, and slower growth in device use, compromises on UX (e.g. more caching), or new functionality to enable higher resilience in the occurrence of a failure (e.g. increased offline functionality for less cloud reliance, collapse proofing in the event of infrastructural or societal collapse [137]). Inspiration might be drawn from simple-living families [57, 58], whose more offline style of living would likely be minimally disturbed in the event of certain failures (e.g. cloud service failures, problems with streaming).

In addition, and as a corollary to the above—as a means of potentially enabling greater focus on such pursuits—it is worth considering how to reduce people's reliance on non-necessary digital technologies (e.g. technology considered less important). Getting to grips with how to affect these attachments and design for casual usage is not a simple challenge by any means, as it requires anticipation of practices that might arise through use. Nonetheless, the fact that the participants deemed ICT such as smart phones, laptops, e-readers, tablets and TVs (and peripherals) as important, non-negotiable fixtures in their lives is problematic.

Current technologies encourage soft temporal and spatial constraints leading us to be 'switched on' or 'plugged in' more [112], which both extends practices outside of the home and increases energy demand [80]. This can be seen to have both positive and negative implications. For example, to take some of the pressure off, Malcolm's phone allows him to handle his work correspondence whilst baby-sitting or picking his child up from pre-school. It's important to consider how the technologies shape everyday-life in such ways that can lead to 'multiple temporalities', leading to more fragmentation and rushed practices [78]. I wish to reiterate calls to consider design of technology to enable as well as encourage people to maintain a more casual attachment to their technologies. For example, we should consider how to re-design existing technologies to enable people to disconnect and use highly demanding technologies less (e.g. encouraging people to stream less, and even to switch off devices altogether and venture outside). There already exist interventions that remind users to take breaks, for example, but an interesting question to explore is whether and how features inherent in the design of ICT and associated software might support reduced adhesion to screens. How might we anticipate or evaluate whether our research encourages a reliance on technology that we don't (or shouldn't) even need?

6.9 Are there limits to the growth facilitated by digital technologies?

Amongst the participants I have observed that an abundance of digital technology has enabled and in some cases necessitated more technologically complex and media-rich lifestyles (e.g. growing sets of interconnected devices being used in practice), resulting in continually increasing demand for digital technology (e.g. Ron, Malcolm, John). This is clearly a win in terms of economic (e.g. more technology is being sold) and cultural (e.g. these devices are encouraging technological advancement) growth. These 'wins' point towards the tensions between (environmental and social) sustainability and a need to continually produce new technologies (e.g. Silberman et al. [125]). Silberman et al. suggest that a sustainability agenda requires a shift away from repurposing old technologies to meet new needs. In line with this suggestion, and perhaps veering away from the tensions outlined beforehand, I encourage those who are concerned with the impacts of digital technologies on the environment and everyday life to consider how we can lessen our reliance on the technologies that we rely on throughout our daily lives.

6.9.1 A low-carbon future for non-negotiable technology

It is worth considering the broader, global implications of digital technologies becoming 'non-negotiable' (e.g. technology we are highly dependent on). In particular, the non-negotiable technology owned by today's industrialised practitioners will soon become non-negotiable world-wide. This growth in non-negotiable digital technology has astonishing implications for energy impacts and data demand. Given that my participants highlighted a number of devices that they consider important in their daily lives, how do we go about setting a goal for a low-carbon future in which everyone globally owns the technologies that they *really* cannot live without?

If we, as concerned researchers, are serious about tackling 'wicked' sustainability problems (e.g. climate change, infinite growth) we should begin to consider how we can support the non-negotiable technology for the entire population of the planet, and how we can support these non-negotiable technologies with low or even zero-carbon footprint? Could everyone live like Bettina, with growth happening much less frequently? Could everyone become more independent from Internet connectivity like Glenda, using more centralised Internet hotspots?

6.10 Summary

From the participant accounts I have captured variation in daily practices that involve digital technology. Although this set of participants may not necessarily be representative of less technologically dependant populations, I am confident that they sufficiently represent how digital technology is impacting everyday life and leading to growing usage and interactions, and increasing (energy, data) impacts and demand.

Digital technology has both positive and negative impacts on everyday life (e.g. allowing Xander to ‘hang out’ with his brother, enabling Glenda to do her work whilst in France) with varying environmental impacts (e.g. instant messaging on a smart phone vs. large desktop PCs and cloud services for socialising whilst gaming). These practices achieve similar goals but have vastly different energy impacts and associated meanings.

I suggest that if research disciplines (ICT4S, HCI, Ubicomp) are to successfully progress towards a more sustainable future they must begin to consider limits to growth and more regularly attempt more radical, more impactful changes (e.g. designing for non-reliance, a zero carbon future for non-negotiable technologies), instead of putting the majority of its efforts into low(er) impact persuasion (e.g. attending to the impacts of background tasks).

Chapter 7

Conclusions

This chapter recaps and summarises the main contributions of this thesis. I revisit the research aims of the thesis, summarising how the conclusions of Chapter 4, Chapter 5 and Chapter 6 contribute new understandings that achieve the aims of the thesis. Section 7.3 builds upon the outlined conclusions, reflecting on possible pursuits that myself and the sustainable HCI (SHCI) should work towards when attempting to tackle the impacts of digital technologies on the environment and everyday life.

7.1 Summary of aims

The overall aims of this thesis were to 1) understand digital technologies' reshaping of social practices, growth in social practices and everyday life (more time, more space, more digital technology), and escalations of associated impacts through a mixed methods approach; 2) provide improved understandings of how modern mobile digital technologies, through the softening of the temporal and spatial constraints of practices, lead to increased frequency of performances and increased data demand, 3) applying the paradigm to better understand where growth is occurring in individual and sets of devices, practices, users, and space.

This thesis contributes to these research aims with the following findings:

1. Chapter 4 provides new understandings of the reshaping of social practices, growth in social practices and everyday life (more time, more space, more digital technology), and escalations of impacts associated with digital technologies through the application of a mixed methods approach that uncovers the variations in energy impacts and social practices related to digital technologies:

    - I have shown that combining multiple methods and multiple sources of data (e.g. qualitative and quantitative) is beneficial when attempting to provide more holistic understandings of the environmental impacts and everyday life that are connected to digital technologies (e.g. linking practices to digital technologies).

- I have provided new understandings of the contexts of digital technology in social practices (e.g. the configurations of digital technologies for use in daily practices, connoisseurship). I have shown how this variation in an individual's social practices (e.g. layering and bundling of practices) and everyday life links to quantifiable variation in the energy intensity of practices.
- I have shown that the variations in energy impacts exist due to variations in social practices (e.g. strong meanings associated with media and ICT practices by connoisseurs), in which varying configurations (e.g. single devices, constellations) and personal requirements (e.g. quality of experience) affect the elements of the practice, leading to variations in the energy and emissions impacts.

2. I have contributed new accounts of how indirect impacts (e.g. data demand) relate to everyday life and social practices (Chapter 5):

- Through the contextualisation of social practices and digital technology I have explored the reshaping of how, when and where mobile digital technologies are drawn upon (e.g. obsessively through the day) and how this reshaping has varying impacts on everyday life and data demand (e.g. obsessive checking of social networks encourages large amounts of data demand.
- I have quantified the indirect impacts (e.g. data demand, phone calls, SMS). The findings show that data demand vastly outweighs the impact of charging mobile digital technologies. The data demand alone adds between 100% and 1000% to the daily consumption of mobile digital technologies.
- Cloud backups and automated downloads contribute a large amount of towards this data demand (over 30% across my participants) all of which is contributing to the escalating network reliance.
- I have demonstrated how modern mobile digital technologies enable loosening of the temporal and spatial constraints (e.g. notifications, filling free time) previously associated with practices that were performed using less mobile digital technologies (e.g. online dating, Harry's 'bird ringing', watching). This loosening leads to the increased frequency of performances of social practices that were considered to be more static (performed in-place), leading to increased demand on Internet and cloud services.

3. By considering where growth occurs outside of quantifiable energy impacts (Chapter 6), I have shown that:

    - Ecologies of digital technologies are growing, which links to trends of escalation for manufacture (more devices being purchased more often). This also links to the energy intensity of social practices that are supported by constellations of digital technologies. This is particularly intensive when connoisseurship plays more of a role in practice.
    - Social practices that rely upon digital technologies are shaped by the meanings, materials and competence of the individual (e.g. Malcolm's practices are very different from Ron's or Glenda's). Circumstances and situations arise in the daily life of individuals which lead to reliance on some digital technologies which the practitioner sees as non-negotiable.
    - I have revealed how the connections between digital technologies, meaning, and competency (e.g. the elements of social practices) influences growth in individual and sets of devices (e.g. ecologies and constellations), practices (e.g. bundles and complexes), users (e.g. connoisseurship encouraging performances of practices that include more digital technologies), and across spaces (e.g. blurring between practices) (Section 6.5).
    - I have demonstrated how circumstances (e.g. gifting, hand-me-downs, financial constraints) of the users (practitioners) surrounding digital technologies often shape the variations and growths that can be observed in social practices.

7.2 Introducing an holistic approach

Whilst the conclusions presented in the previous section link directly to my initial research questions and aims, this section presents overarching themes and findings. Leveraging findings from this thesis I outline a more holistic approach for gaining deeper understandings of the relationships between domestic energy and emissions, social practices and the energy and emissions impacts occurring outside of the home.

7.2.1 Why an holistic approach?

The holistic approach stems from the need for a better understanding of how the domestication and use of technology leads to varying impacts on the environment, and the ways in which a domesticated technology affects social practices, and their practitioners. Throughout this thesis I have demonstrated how exploring the anecdotal accounts of practitioners as well as energy impacts is important. Combing qualitative and quantitative methods in this context is of particular importance as it enables a greater understanding of how social practices relate to the significant variations in environmental impact, even in the enactment of similar practices.

Within HCI, previous work has focused on the individual components of this approach, but little attempt has been made to show the relationships between the impacts of digital technologies, and other domestic appliances. The current methods for understanding the energy impacts that arise from the usage of domestic media and ICT focus primarily on two areas: (1) quantitative data: device energy monitoring and profiling, and (2) qualitative understandings of social practices in the home.

Device energy monitoring and profiling draws on the Quantitative energy consumption data collected in a home shows how much energy a device, group of devices, or household consumes over a period of time (e.g. [34, 44, 49]). The limitations of this are that research using these methods only captures quantitative consumption data and will not be able to uncover the context behind the use of a particular appliance or technology (i.e. the underlying social practices) that lead to a demand for energy.

The findings of Chetty et al. [24] point to a lack of householder awareness of the fine-grained data of energy use and the cost of domestic appliance and digital technology use, suggesting opportunities for design to fill this "information gap" by offering contextual information at the point of use (or by creating better interfaces) and for powering off or tracking the status of lights and appliances around the home.

Through qualitative data collection and analysis (e.g. interviews structured around quantitative data or photo elicitation data), greater understandings of the role of technology in social practices is revealed. Through the application of Shove's social practice model [121] it is possible to discuss, in detail, the ways in which digital technology (i.e. the material element) plays different roles across a practitioner's social practices (e.g. [101]).

7.2.2 The Four Core Elements

By using a mixed methodological approach (Chapter 3) I have demonstrated how the combined exploration of social practices, embodied carbon, direct energy and indirect impacts uncovers nuanced accounts of use and practice. These accounts have allowed me to better associate energy and emissions impacts with everyday life. By linking the variations and dynamics of everyday life to energy and data demand I have provided a more holistic understanding of energy and emissions impacts of digital technology. Thus, to understand the

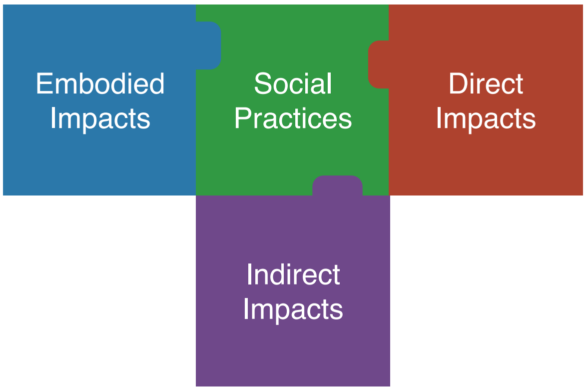


Fig. 7.1 An holistic approach.

energy and emissions associated with domestic digital technology a more holistic approach least include the four elements that have been explored in this thesis: Chapter 4 links direct impacts and embodied emissions to the social practices performed by students; Chapter 5 explores how similar social practices can have vastly different indirect impacts; and, Chapter 6 explores how digital technologies are growing in everyday life in order to understand what this means in terms of designing for limits and sustainability.

To summarise, the four core components are as follows:

1. *Embodied emissions* which arise from the manufacture and distribution of hardware.
2. *Direct energy consumption* that arise from the electricity usage of digital technologies in the home.
3. *Social practices* that involve digital technologies in their performance. The social practices element is at the centre of the holistic approach (Fig. 7.1) as energy and data are resources that are required in the performance of practices that involve digital technologies.
4. *Indirect impacts and demand* that arise due to the demand placed on mobile and Internet infrastructures and services (e.g. cloud services, cellular and core network infrastructure, Internet services and applications).

7.2.3 Embodied emissions

Perhaps the most overlooked impacts of digital technologies in HCI are those impacts other than direct (use-phase) energy that are incurred through the manufacturing, distribution and disposal processes, such as those investigated in life-cycle analysis (see Section 2.1.1). In the case of digital technologies, the embodied emissions released during the manufacturing and distribution phases of a product can be large in terms of the overall emissions associated with its life (Chapter 4).

The shortcomings and assumptions made regarding life-cycle are not always presented, or may be based on dated information (e.g. [8, 68]); and the coefficients used are not usually generalisable (e.g. 27 kg CO_2e per kg of manufactured product). For example, the coefficient used in Chapter 4 of this thesis used estimations of Teehan et al. [134] in which there is likely to be a large margin of error. This margin of error is a consequence of Teehan et al. assuming a linear relationship between mass and carbon footprint in manufacturing. This estimation is likely to be hugely conservative due to the complexity of the high-definition touchscreens and batteries with high energy density of smartphones and tablets which have a large embodied impact. In short, the "raw material acquisition stage [is] the most dominant stage for environmental impacts" [4, p.213].

Despite the inaccuracies, using estimations grounded in LCA research and life cycle assessments of technology, I have shown that it can be informative to (1) estimate the embodied emissions of digital technologies to allow for comparison to other impacts (e.g. direct impacts, indirect impacts) (Section 4.2.3); and, (2) use these estimates to compare technologies to one another, particularly when one technology may be used in the enactment of similar practices (Section 4.4).

7.2.4 Direct energy consumption

Direct energy represents the electricity that is consumed by an appliance or technology. In this thesis, direct energy has been discussed in terms of kilowatt hours. Direct energy consumption arises when a digital technology is plugged into a power point and is drawing electricity. Within ubicomp and HCI research direct energy has often been used to provide energy feedback, and when discussing reductions in electricity consumption. But direct energy reveals little about the specific activity due to many devices being multi-functional. A device actively consuming electricity does not signify active use, nor does simultaneous consumption of two or more devices mean that they are being used in parallel or with one another. Moreover, even if a device drawing electricity is being actively used by a practitioner, it is often not straightforward to say what it is being used for.

I have shown that in order to verify whether a device is being used (a) by itself, (b) in-conjunction with other technology (e.g. Constellations), (c) to simultaneously support more than one practice, or (d) not being used at all, more observation and understanding of a practitioner and the technology's role in practice is necessary (e.g. Chapter 4).

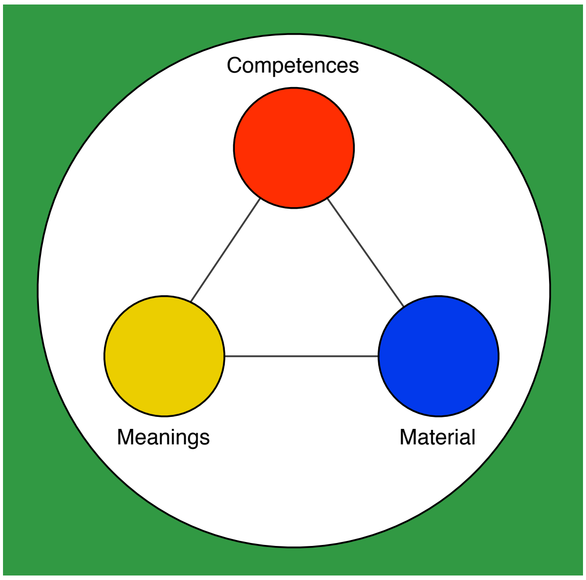


Fig. 7.2 The three elements of social practice based upon Shove et al. [121, p.25]

7.2.5 Social practices

As discussed in Section 2.3.2, social practice approaches have been previously employed within HCI. Despite this, within sustainable HCI a social practice approach is usually discussed in terms of understanding the composition of practices, transforming practices [103], and designing new interventions in practice. In this thesis I have adopted the social practice approach presented by Shove et al. [121] to explore how social practices (see figure 7.2) evolve in everyday life due to changes within and influences that link all three elements of practice (material, meaning, competency).

These three elements of social practice are intrinsically linked, with changes in an element leading to changes in the other attached elements (e.g. a change in material can also lead to a change in both meaning and competency). When discussing technology it is important to understand a practitioner's meaning and competency of both the practice they enact and the supporting materials. Meanings (e.g. reasons for attachment, negative and positive experiences), competences (e.g. skills, know-how, expertise) associated with a social practice can be seen to affect the practitioners' usage of a digital technology in everyday life (Chapter 6). The usage of a technology in practice directly relates to the direct energy consumption (Chapter 4) as well as indirect impacts (Chapter 5).

7.2.6 Indirect impacts

Within ubicomp and HCI, the main focus in Internet and home network usage research is often focused on an Internet connection that is shared within the home [22, 35, 72]. This body of work contributes to understandings of which devices rely on Internet connectivity and the work provides accounts of the activities and social practices that are connected to the data demand generated by the use of digital technologies.

In this thesis I have described network traffic (e.g. use of the Internet or a cloud service) as an indirect demand. Indirect demand is the demand on an Internet service or resource (via telecommunications infrastructures) that can arise through the use of digital technologies. In Chapter 5 I have analysed data demand and the energy impacts associate with phone calls and SMS messaging to demonstrate how a growing bank of applications and devices link to the indirect impacts of practices. These practices rely on connectivity both in and out of the home and are contributing to escalating demands on Internet services due to (new and evolving) performances of social practices that rely on networked digital technologies (e.g. video-on-demand for watching, cloud storage for backing up data and sharing of digital media).

I continue this section by reviewing the overarching themes from my findings, and finish by suggesting how the application of the holistic approach would be beneficial in broader HCI research.

7.2.7 Applying a more holistic approach: over-arching themes and conclusions

Whilst the holistic approach has been presented as a conclusion to this thesis, I feel that the methods used throughout my studies can be viewed as a starting point for such an approach. The main advantage of applying such an approach is that it provides a more full account of the energy and environmental impacts of digital technologies and allows for the contextualisation of these technologies to be more usefully understood. This exploration reveals the subtleties and nuances of digital technology in daily life and exposes why variation occurs. Lessons learned from these understandings can be influential in the design of more sustainable futures (Section 6.8 and 6.9).

Digital technologies have been domesticated and incorporate throughout the daily lives of the participants (Chapters 4, 5 and 6). It might be fairly obvious that ICT and digital technologies are used for communications, and that these practices are important to individual and groups of practitioners. A more holistic study of digital technologies in everyday life reveals the following:

1. Digital technologies are often used in constellations either because more than one connected device is required (e.g. console gaming) or for a better experience (e.g. Matt, Henry and Ian's constellations customised for watching, listening and gaming). Larger constellations tend to lead to larger environmental impacts and are prone to further expansion.

2. Portable and mobile digital technologies (e.g. smartphones, tablets, laptops) encourage the softening of temporal and spatial constraints on practices often leading to more use time of devices (e.g. Chapters 5 and 6), increasing indirect impacts, especially data demand.

3. Significant indirect impacts arise form the media rich and data intense performances of practice that digital technology enables. Indirect impacts (e.g. data demand, phone calls, SMS) can be seen to add up to 1198 Wh per day just from the participant's smartphones[1].

4. Obsession and habitual, frequent checking (Chapter 5) is particularly evident in particular practices on always-available mobile digital technologies (e.g. social networking, communication, dating). This is linked to larger indirect impacts.

5. People have expectations over the digital technology that they own, and the digital technology that others own. Chapter 6 details examples of third parties' expectations and subsequent influence over digital technology ownership (e.g. Jayne being influenced by her friends to get a particular smartphone, Derek having a TV forced on him).

6. A willingness to adapt to circumstance can be seen across several of the participants (e.g. Xander and Willow who preload digital media, Glenda having to schedule her emails and uploads, Amanda and her friends and family adapting to her having no signal at work). Perhaps less obvious is that students (e.g. Henry balancing gaming and work, Holly working on the bus) adapt their digital practices when they have different work loads, potentially influencing the amount of time they spend streaming video and online gaming.

7. Participants expressed the perceived importance and necessity of specific digital technologies were expressed by participants (Chapters 5 and 6). All of the participants that feature in this thesis see digital technology and ICT as a necessity for at least one

[1]Using the most intensive participants' daily data demand 1500 MB at 300 Wh (Tim), 84 minutes of phone call at 840 Wh (Amanda), and 148 SMS messages 58 Wh (Victoria).

practice in their life, with smartphones (e.g. Bettina's dependence), Malcom's son's tablet, and devices for work (e.g. Willow's laptop for work, the student participants all require a laptop or PC for work) being of particular importance. Even Glenda, who didn't express much dependence on digital technology would have found it particularly difficult to maintain her writing and communication (her interview was over Skype), and life in a remote village without digital technologies.

Connoisseurs

Connoisseurs feature in both Chapter 4 and Chapter 6. These participants' devices often had the largest overall environmental impact and were observed to have impact on the practices of the people they lived with. Given that connoisseurs' devices were observed to have considerably large energy and environmental impact than my other participants (e.g. Chapter 4). I believe that connoisseurs are interesting targets for intervention studies around digital technology and environmental impact.

Connoisseurship in various forms appears in a breadth of existing literature. Some examples of where connoisseurship and connoisseur-like practices have been studied are: the exploration of the roles of loved objects and activities in social relationships and consumer well-being [1]; the enactment of green fashion consumers in Scandinavia who are a combination of "the knowledgeable green connoisseur – a consumer that knows quality when he/she sees it – and the green hedonist in search of the good life" [50]; a study of the motivations, practices, and experiences of those who put substantial time, effort and care into living a more green and sustainable life [145]; the purchasing choices that are made in order to strive for uniqueness in product domains that are "symbolic of identity (e.g., music or hairstyles, rather than back- packs or stereos)" [12]; the "connoisseur consumer" [135, ch. 1] who in consumer culture tend to be upmarket consumers who "seek new 'position possibilities' by using particular knowledge, skills and possibilities" [135, p. 19]; and, novel approaches for using practices (as opposed to demographics) in categorisation of consumption in other areas of resource use (e.g. water) [6].

My research goes beyond the aforementioned works and demonstrates that connoisseurship occurs in and around digital technologies. Furthermore, I have demonstrated how connoisseurship leads to increased quantifiable embodied and direct impacts (Chapter 4). Finally, I have shown that their passion for particular experiences in practice can be see to contributing significantly to exponential growth of broader impacts surrounding digital technologies (Chapter 6).

Time and space

The affect of the blurring of space and time in and across practices has been a theme that comes up throughout this thesis. My findings complement existing literature on the blurring of time and space in everyday life. Examples include: digital technologies' effect on activities in place and space [41, 62], smartphones in everyday discourse [61]; work and busyness [77, 98]; technology and busyness in everyday life [78, 122] and, more broadly technology and globalization [63, 140]. My analysis differs from these existing works by commenting on how practices blurring through space and time link to energy and environmental impacts. These impacts that are not often considered in discussions of the use of technology in time and space (e.g. indirect impacts arising from data demand, reliance on cloud services). My analysis also contributes a detailed study of practices, providing nuanced accounts of a broader range of daily practices.

The softening of temporal and spatial constraints on practices, paired with the availability of technology and connectivity are encouraging more frequent and more intense sessions of energy and data demand throughout everyday life (e.g. large automated backups, streaming of on-demand video, data rich social networking and communications). Moving forward, HCI researchers should consider how energy and data play roles in their research. For example, how do the apps we design use these resources, how does the technology we design and implement encourage (or not) more energy and data demand in new times and spaces?

7.2.8 Applying the holistic approach beyond this thesis: Lessons for HCI

From my findings and discussion I recommend that HCI practitioners concerned with digital technology and sustainability should apply mixed methods approaches to understand the variety of contexts (and practices) in which technologies that we design are implicated. Furthermore, an approach of this kind reveals how variations in these contexts have (not insignificant) implications on energy and the environment, and that researchers should more often consider how the increasing use of digital technologies and the cloud correlates with escalating indirect impacts.

Whilst this thesis does not concern itself with quantifying the energy and emissions associated with the development of software, it could be extended to understand how the resources spent on software and hardware design and development contribute in terms of overall energy and emissions (e.g. direct, embodied, indirect) and how this development connects to a technology's uptake in practice.

Given that the indirect impacts (e.g. data demand) associated with the use of digital technology is rarely considered, performing a holistic analysis of different groups and demographics could reveal new insight. For example, how would simple living families [57], those actively making sustainable choices [145], or those in developing countries compare in this thesis. This would be useful to open up further dialogue in the HCI community about the implications and roles of digital technologies in sustainable practices and futures.

Smart homes and smart cities research should consider lessons that a holistic analysis could provide. A smart home (or city) can be viewed as a constellation in itself, with multiple devices (e.g. sensors, actuators, data hubs) connected together to collect data and automate environments. The energy and environmental impacts of these systems should be seriously considered, given that 1) their components will layer on top of existing digital technologies in and out of the home, and 2) there is an indirect impact associated with the processing and storage of the data collected in these systems. Considering the shortcomings of eco-feedback and the environmental cost of the instrumentation of (smart) homes and cities at scale, it is worth evaluating whether the potential perceived reductions in energy consumption associated with domestic practices outweigh the environmental costs of installing and running these systems.

Another application of the holistic approach is on the maker and fabrication space. If HCI is concerned with environmental impacts and promoting best practices, we should consider an holistic evaluation of the DIY maker space [79]. This space is particularly interesting given that: 1) the social practices surrounding this technology are fairly new and less established; 2) fabrication has less known affects on the environment in terms of energy, emissions and waste; and, 3) new practices encouraged in this space could lead to future practices becoming reliant on this technology, much as how smartphones have become central to daily life for many people. More broadly, design and research in HCI should consider how a specific technology or intervention is implicated in a complex design space where dependence on digital technology, layering and bundling of practices is occurring and blurring across time and space.

7.3 Future Work

In this section I will discuss the different directions for future research and design that have been developed throughout this thesis. This section should be seen as both directions of follow-on work, but also, more broadly, reflection on some of the dominant directions of current sustainability research concerning digital technologies and everyday life.

7.3.1 Focusing on everyday life

To better grasp the impact of digital technologies it might be necessary to study how rhythms of practices (e.g. the flow of social practices in daily life [54]) are affected by the possession and usage of digital technology. As my research only captures a snapshot of the participants' lives, better accounts of the evolution of routines are required; these may uncover new understandings (e.g. when layering occurs) of how these technologies are fostering barriers to sustainability. These understandings may also uncover how more sustainable routines come into (and remain in) existence (e.g. will Bettina's reliance on her phone persist when her circumstances change?). To go beyond the boundaries of my thesis, more longitudinal ethnographic studies should be used to understand how previous iterations of practices have informed the current rhythms and routines of the practitioner. Future work should also explore how elements of these practices persist and influence future iterations of practice.

Gaming is one area of practice where the variation in complexity and energy impact is huge. Examples of this variation include: gaming with handheld device (e.g. Nintendo DS, apps on smart phones) which can be seen to have a low energy impact; offline multiplayer gaming in which the impact of the use of one constellation is shared between the practitioners; and, an individual practitioner playing an online game with a lobby of sixty other people, whilst streaming his gaming to a live online audience (e.g. using TwitchTV[2]). It is important not to ignore the evolution in complexity in new practices, behaviours, and ecologies, and how these may encourage unsustainability through reinforcement with repeat performances and rapidly evolving technology.

Related to this is a need for new understanding of how digital technologies have historically influenced the softening of temporal and spatial constraints of social practices. I personally do not have the data to talk about how my participants' social practices have evolved through time and am therefore unable to make comparisons to previous iterations of practices. To fill this gap, longitudinal research should be conducted, following participants over not months but years to study the evolution of times, frequencies, and spaces that practices are to be performed in.

7.3.2 Better Understanding Connoisseurship

A resulting challenge of an open and fast paced technological world is that particular groups of people will always consider quality of experience their primary concern. These connoisseurs (chasers of quality in practices) are often drawn to technology that can enhance their experiences throughout daily practices (e.g. buying surround sound for watching TV or

[2]http://www.twitch.tv

movies).

Connoisseurship links to the competence, meanings and materials in social practice. As shown in this thesis, connoisseurs strive for higher quality of experience in practices, which often impacts the frequency of upgrades, and the ecologies (e.g. constellations) they own. As I have only studied the connoisseur in terms of domestic digital technologies I am unsure of the full reach of connoisseurship in everyday life. To better understand connoisseurs it might be interesting to study how connoisseurship affects practices other than those that rely on digital technologies in order to provide a more definitive understanding of connoisseurship. For example, is the process of buying a car, or organising a trip, optimised for the same reasons, and in similar ways, as their digital technology? With a more definitive understanding we may be better equipped to answer questions such as, does connoisseurship always lead to more impactful trajectories? Are there limits to what a connoisseur will try to improve the quality of experience of? How does a connoisseur affect others in their life outside of their home (e.g. family members, friends, co-workers)?

7.3.3 Study of both sides of sharing, flexibility

Peer reviewers have been critical of my attempts to discuss the negative impacts of sharing; or the flexibility that technology provides (e.g. working on the move) on everyday life.

It's important to consider how the the social structures in which we live and work requires us to be flexible to meet the expectations of others (e.g. employers, friends, family). Does everyone see the merits in being able to work more flexibly because of ICT (e.g. Malcolm using phone whilst looking after his kids [65])? As I've discussed (Chapter 4 and 6), a life filled with more complex ecologies of technology has larger energy and emissions impacts. How do these larger, more complex ecologies affect our well-being? I would like to encourage more empirical work that looks at how technology and the pace of everyday life (e.g. harriedness) effects the well-being, along with the priorities and decisions made by practitioners.

7.3.4 Understanding data demand in the domestic environment

With an unconscious reliance on cloud and the Internet, local storage and physical media is being phased out (e.g. laptops no longer ship with DVD drives). With a higher reliance on cloud and Internet storage and services, domestic digital technology is contributing more and more to data demand.

The study of the indirect impacts of mobile digital technologies (Chapter 5) uncovers several areas of impact that are linked to data connectivity (and demand) in less mobile or fixed domestic digital technologies: (1) mobile digital technologies share similar functionality with digital technologies and are likely to have similar patterns of demand (e.g. social networking can be done across devices); (2) certain practices aren't well optimised on mobile digital technologies (e.g. touch screen makes writing large amounts of text difficult, smaller screens aren't optimal for watching long videos) and are therefore more likely to be performed using other technology (e.g. watching longer videos is more likely to happen on TVs and laptops); (3) mobile technology layered on top of the use of other technology (e.g., checking emails or social networking whilst watching TV), increasing the blurring across practices; and, (4) there is data demand that arises from streaming in the background performances of other practices (e.g. Malcolm and his son, Xander whilst cooking, Jayne whilst cooking, Holly whilst cleaning).

7.3.5 Becoming systems thinkers [43]

The sustainability dilemma has implications far beyond the energy consumption of digital technology, and the homes we live in. As I have attempted to demonstrate (Chapter 6), the unsustainable growth and impacts of domestic digital technologies are part of a wider set of social norms and institutions (e.g. expectations of friends, family, and work) and various other forces (e.g. the economic imperative for more 'stuff' to be sold). I would argue that attending to the things that we might reasonably assume to be 'our responsibility' as people with the know-how to realise these (albeit) small wins is *necessary but insufficient* [9]. Clearly, we must improve in terms of recognising and designing with an awareness of the systems-level impacts of our research and development. And yet, for many of us in this field, systems thinking is foreign and difficult [43]. Perhaps this is because digital technologies have obvious potential to reduce energy and emissions impacts in some areas of practice (e.g. video conferencing vs. travel), whilst the impacts associated with medium and long term behaviours or practices are unknown [112]. For example, we know that digital media is reducing impacts associated with the manufacture and distribution of physical media, but how much are these impacts being offset by the energy and emissions associated with the additional data demand brought on by binge and background watching, just because we have access to video-on-demand services.

7.3.6 Reconsidering the place of implications in S-HCI

The collaborative work that I have been part of has been critical of implications for design that are encouraged in HCI. Part of the formula for the acceptance of a paper in the leading conferences in HCI is the inclusion of a set of design ideas (implications for design), that outline avenues for future work [42]. These not only take up space in a publication, but also limit the length of discussions that we are able to have due to authors having to tailor their findings and discussion to clearly link to the implications for design.

How often do researchers carry implications forward in order to create designs in their future work? Rather than suggesting another set of narrowly-scoped 'new' ways to reduce energy demand or impacts, we should be using our writings to discuss broader impacts or theories (e.g. un-design and slow design in digital technologies [80], limits to growth (e.g. [97]). We could also include the extent of the research's impacts on the environment or everyday life [125] in an attempt to be both critical and more responsible when we design [10].

With the influence of HCI over policies and future technologies how can sustainable HCI influence slower growth or limits to growth of energy and data? What lessons can be learned from other fields and put into practice (e.g. politics, practice and sustainable transition management [123])? It is an appropriate time to put new strategies into practice and ask broader HCI what its attitudes towards sustainability are, and what policies it plans on implementing that speak to sustainability.

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Appendix A

Android Study Interview Schedule

Android Device Study Interview Schedule

Briefly introduce the interviewer(s) and describe the schedule of the interview:

- Find out a little about the participant.
- Talk about the participant's device and its use.
- Mention details about the study – what it's about, all data will be anonymised/pseudonyms will be used, interview will be recorded

The Participant:

- Can you briefly describe yourself?
- Who you are?
- What you do?
- How you like to spend your free time?

The Home:

- Living arrangements (house, flat, shared accommodation)
- Who do you live with?
- How much time you spend there?

The Device:

- When did you get your device? Where did you get it from?
- What were your reasons? Had you wanted one for a while before buying it?
- Do you know anyone else with a device? Is it an Android device? Did they influence your choice in getting one?
- Why Android over other brands such as Apple/Blackberry?
- Do you have any other Android products? What is it about Android that you prefer over other companies? (design, function)
- How do you see your device? Music player, media device […]
- Have you customized your device in anyway? -> wall paper, case, screen brightness etc.
- Do you have any accessories for your device? Are these official Android accessories?
- If you lost your device would you have to replace it immediately?
- Have you thought of upgrading, or would you consider upgrading your device soon?

<if tablet>

- Why a tablet over a phone? E.g. screen size

<if phone>

- Why a phone over a tablet? E.g. easy size to carry around

Other Technologies:

- Is this your main device?
- Can you describe to me the other technologies that you use? E.g. I'd say I use my computer, phone and tablet a lot.

<if multiple devices>

- What device would you use for what task?
- Have you integrated your devices in any way? E.g. merged contacts
- Has your use of other technologies changed since having the Android device? How?
- Do you ever use any of these at the same time as your device? E.g. like watching the TV and fact checking/playing games on your device?
- If you had 1 hour free at home where you had to fill up time which of these, if any would you go for? -> 30 mins, 10 mins

Understanding General Use:

- Is it a shared device, or are you the only one that uses it? Do you ever use it at the same time as others -i.e. sharing photos, watching videos?
- Would you say that it's a work device, or a home device? If home, do you use your device to share data, play music, or control any other devices/the house (e.g. the heating?)
- Can you describe how you've used your device on a weekday in the past two weeks? Is this a fairly typical day?
- Can you do the same but for weekend use? Is this fairly typical?
- Have you ever taken your device on holiday; was your use then different?
- Has the way you use your device changed in the time you've had it?
- Do you feel like you use your device to its full capabilities?
- Where do you generally use your device? -> At home: which room (on show or hidden), On-the-go: in what context.
- Do you use your device to share or communicate with others? Cloud, dropbox, Skype etc

App Use:

- What apps do you think you use the most?
- Do you regularly visit Google Play to renew your apps?
- When are you likely to use each app?
- Do you ever find it difficult to carry out a task without using an app? If so, what? For example, I always use the Trip Advisor app before I go away/go to a restaurant, or IMDB before watching a film.
- **Show graph of app use (explain graph, ask questions)**

Charging:

- Can you describe how and when you'd normally charge your device? -> Where do you normally charge?
- If you were out and about and you ran out of battery, would you find that stressful in any way?
- Can you remember a time in the past two weeks when you've ran completely out of battery? How did you deal with this?
- **Show graph of charging times (explain graph, ask questions)**
- Do you think the times you charge your device depend on the times you use your device?
- **Show graph of power/brightness times (explain graph, ask questions, compare to charging graph)**

Mobile Internet/Messaging:

<If Wi-Fi only>

- Do you use it on-the-go?
- How does this affect using it outside of the home?
- Does this affect the way that you use your device when on-the-go? e.g. preloading/downloading websites etc
- **Show graph of Wi-Fi data sent times (explain graph, ask questions)**
- **Show graph of Wi-Fi data received times (explain graph, ask questions)**

<If mobile data>

- What kind of contract do you have for your data plan on your device?
- Do you ever run out of mobile data before the end of the month
- **Show graph of mobile data sent times (explain graph, ask questions)**
- **Show graph of mobile data received times (explain graph, ask questions)**
- Do you ever disable Wi-Fi/mobile services? If so, why? E.g. conserve battery levels/contract restraints.
- **Show graph of times connected to Wi-Fi/Mobile (explain graph, ask questions)**

<if messaging>

- Do you feel that you use text messaging over other messaging services, such as Facebook Messenger?
- If one more than another, why? E.g. contract restraints/better service
- When are you likely to message someone?
- **Show graph of number of SMS sent/received (explain graph, ask questions, compare to data sent/received)**
- **Show graph of SMS times (explain graph, ask questions, compare to times connected to Wi-Fi/Mobile)**

Constraints:

- Do you feel that you use your device to its full capacity?
- Is there anything that you'd like to be able to do with your device that you can't? -> What are the reasons: Android constraints, there's no app for that, don't know how to do it?
- Do you find the form/ design of the device constraining in anyway? Or alternatively, does it allow you to do things that you couldn't do with your other technologies?
- If you could change something about your device what would it be?

Summary:

- Anything you want to know/questions?
- Thank the participant

Appendix B

Photo Elicitation Interview Schedule

KEEP A TRACK OF THE PRACTICES THAT ARE MENTIONED BY THE PARTICIPANT DURING THE INTERVIEW

- **Contextual**
  - Tell us about your household
  - Number of people in house, who uses what, time spent in the house

- **Typical Day**
  - What does a typical day look like in terms of media and IT devices? Do you check your phone, do you watch movies on your iPad, is television important? Do you have set top boxes, VCRs, etc.?
  - Typical weekend with media and IT in your home?

- **Photos**
  - Walk us through the photos
  - Could you group these into 'important' and 'not important'?
  - Why are these the most important?
  - Why are the others not important?
  - Have any of your devices fallen out of use? What do you do with them then?

    <If out of use now>
    - Why do you still keep them?
    - What do you do with old, broken or out of use devices and media?
  - Do you remember doing anything differently before you had any of these devices?
    - And before that…?
    - Why did you replace the device?
    - How long did you have it?
    - What was it before that?
    - How long do you expect this one to last?
  - Do you share any of these devices?
    - How does this work?
    - How is the sharing negotiated?
    - Is sharing difficult?

- **Main Device**
  - Could pick your 'main device, or the media and IT picture' that is the most important to your everyday life?
  - Why is this your primary device?
  - Can you walk us through 24 hours with your -- ?

    <If overlapping functionality>
  - Why do you own --, if you have --?
  - If you lost your "primary device", or it broke, what would you miss the most?
  - Are there any other devices within your home that you'd have to replace straight away if they broke, or you lost them?

- Can you describe how and when you charge this (primary) device? (nightly, sporadic, regular pattern)

- Has there been a time within the last two weeks where you have ran completely out of battery?

<If yes> Do you find this stressful?

<if iPhone was the main device, follow up with brand and Smartphone questions>

- **Brand**

- Why the brand X?

- **SmartPhone**

- What kind of apps do you use on your Smartphone?
- Managing Internet connectivity (WiFi/mobile data connections)
- What kind of phone contract do you have?

Do you ever run out of mobile data?

<If yes> Is this common? What do you do when this happens? Do you find it stressful?

<If no Smartphone>

- Why do you not have a Smartphone?
- Is there anything that would make you consider getting one?

- **Internet Use**

- What do you typically use the Internet for on a weekday? What device?

Weekend?

<If no Internet at home>

- Do you preload/download things for when you're at home?
- Have you ever had the Internet at home?
- Reasons for not having the Internet at home?
- Would you ever consider getting the Internet at home?

- **Online Content**

- Syncing content between devices?

<If yes> Do they all have the same/similar content?

- Do you use a service to sync content between devices or back up content?
- Subscription Services

- **Constellations**

- Are any of your devices connected together? e.g. do you have external speakers, amplifiers, DtoA converters, or headphones?
- Do you dock your devices (e.g. to your hifi)? stream to bluetooth docks etc.
- Any inter device networks in the home

- **Connoisseurship**

- Custom built computer? - Why?

<If they live with non connoisseurs>

    -

    <If not a connoisseur, but lives with one>

- Do you feel that you use the devices and technology in your home to the full extent?

- **Layering**

- Devices you use together: console, tablet, phone, laptop?
- Background noise?

- **New/Future Purchases**

- Have you acquired anything recently (last few months)?
    - Has that changed the way you use SOMETHING?
- Can you think of any examples where you've bought a new device and that has overshadowed another device, or changed the way you use other devices?
- Since taking these photos have you bought any new media or IT devices/things?

<If yes> How has this changed how you do things?

<If no> When do you consider buying new media and IT products? Where do you get advice for buying new products? - advice from friends/family/colleagues, technology magazines/websites,

- Are you planning on any future purchases?

- **Television**

-Live TV

<If yes> Scheduled programming?

-Recording live tv

<If yes> When do you watch the recorded shows? Is there a particular time (ritual)? Do you wait to watch particular shows with certain people?

-Streaming/downloading media

-Physical media

<If tweets> Do you respond to encouragement on the television to hashtag things?

- **Laptop**

- Reasons for having two laptops?
- Are they used differently?

<If yes> How and for what do you use laptop 1; laptop 2?

- Do you ever need to transfer stuff between the two? How?

- **Media collections** (CD & DVD collections)

- Do you, and how do you listen to or watch these?

<If yes> When do you typically watch or listen to these?
- Has and how this changed since getting iPod, iPhone?
- Are these uploaded on any devices? (Digitisation of collections)
- Because she doesn't have the Internet at home does she use it more outside of the home? Work? Free wi-fi?

- **Books and ebooks,** other print media/digital versions (magazines, newspapers, online blogs)

- **Social media**

- Do you use social media?
- Is it important to you?
  <If yes> Why?
- Which platforms do you use?
  <If yes> Why?
- When do you use social media?
- Do you have push notifications enabled to your phone, other devices?
  <If yes> For which apps?
  If you had a notification for each of those applications when you looked at your phone in what order would you look at them?
- When do you respond to notifications? (as they arrive, in 'dead time', randomly?)

- **Intimate communication**?

Alternative methods? e.g. communication with friends and family via games, and apps
-Other than as a form of communication how do integrated games fit into your day? Are there any specific examples? Are these any different from the multiplayer games?

- **Tablet**?

<If yes>
- What kind of tablet?
- How long have you had a tablet?
- What kinds of things do you use your tablet for? (work, entertainment, media, on-the-go use)
- How often do you use your tablet? (Daily, weekly, barely ever, never)
- Is there anything you'd like to be able to do on your tablet that you feel you can't?
- Is there anything that you prefer doing on your tablet, over your other media and IT devices?
- Is there anything that you'd avoid doing on a tablet i.e. move over to the desktop to do X ?

<If not>
- Room for a tablet or ereader? Why?
- What is it about the tablet that you don't like?

- **Scheduling** of certain activities?

- **Killing Time**
  Do you ever have time to kill at home? -> What do you do in this time?

<If yes>
If you were at home and had 10 mins to kill, what would you do?
  - If you were at home and had 1hr to kill what would you do?

- **Ask about any practices noted at top**
  - How did you use to do X before you had device Y to do this?
  - How would you do X if you no longer had device Y?

OPTIONAL:

- **Sustainable Living**
  - Do you feel that you have an interest in sustainable living?
  - In what way? How do you attempt to live sustainably?
  - Are you interested in sustainability when it comes to media and IT in the home?
    - If yes, in what ways?

- **Further Studies**
  Would you be interested in participating in a follow up study (smart phone logger or home network)?

Appendix C

Participant sheet for the Android Study

LANCASTER UNIVERSITY

Participant Information Sheet

We are conducting a study into Android device usage and habits. We would like to invite you to participate. This sheet provides information about the study and what participation will involve. We hope it answers any questions that you may have, but if you do have any further queries please feel free to contact: k.widdicks@lancaster.ac.uk

Project Title: The Impact of Android Devices on Energy Consumption and Data Connectivity Demand

Aims of the research:

The aim of this project is to research Android device use in day-to-day life, and we are interested in finding out patterns of usage and daily routines with regards to it. In order to do this, we will be exploring the frequency and nature of interactions with such devices to gain an understanding of how different people use them.

Study procedure and the participant's role:

This research will collect data on how you are using your device over the duration of the study, and will involve installing an application onto your Android device, that will run in the background. The data that will be recorded is as follows:

Device:

- When you turn your phone on and off
- The times when the screen is turned on and off or your device is unlocked
- The version of the operating system and the type of device
- The time and date
- The volume of the different audio streams (ringer, media volume, etc.)
- The times at which the phone is charging
- The battery level and voltage
- The brightness level of the screen and whether brightness is dynamically adjusted
- Periodic sensor readings, such as brightness, acceleration, air pressure (depending on availability)
- When the alarm clock is triggered
- When you place the device in a dock or attach a headset

Applications:

- Which parts of device analyzer you use as well as internal logging and crash reporting
- A list of markets where at least one application was installed from
- A list of installed applications and which market they were installed from
- Updates and removals of applications
- When you clear the data of an application
- The running processes and their memory and CPU usage as well as their importance
- The 10 most recently started tasks
- How much data each application transferred

Location:
- Location based on the network cell you are connected to **(ability to opt-out)**

Phone/SMS/Contacts:
- Whether your phone is ringing normally, is silent or on vibrate
- The times when phone calls are made and text messages are sent and received as well as the number of characters per text message
- Values for the phone numbers involved (anonymised), as well as whether the number is local or international, and if it comes from a contact
- The number of contacts, and how many email and phone numbers are stored for each contact

Photos/Media/Files:
- The amount of free internal and external storage
- When the external storage card is inserted or removed
- The times when you take pictures and how many pictures you have

Connection Information:
- When you enable and disable airplane mode
- Which mode of network connectivity is available
- Whether the phone is roaming or not
- Cellular signal strength
- The amount of data transferred over 3G and Wi-Fi
- When you enable and disable Bluetooth and Wi-Fi
- Data about Wi-Fi networks (anonymised) that are in range
- Data about Bluetooth devices (anonymised) in the vicinity if another application initiates a Bluetooth scan (device analyzer will not initiate a scan by itself)
- When you enable tethering or the mobile hotspot

Identifiers:
- The identifier (anonymised) of the inserted SIM card
- Anonymised GSM (Global System for Mobile Communications) cell IDs (**ability to opt-out)**

In addition to allowing the Device Analyzer application to be installed on your device, you will be asked to participate in a follow up interview (of up to 1 hour, see below).

Before the study, you should download the free Device Analyzer application, created by the University of Cambridge, from Google Play. You should log on with the user code given to you by the researcher, and then allow the application to start logging your device data in the background. The privacy section of the app allows you to choose whether to enable or disable logging GSM (Global System for Mobile Communications) cell IDs, your location based on the network cell you are connected to, or your installed and running applications. For this study, please enable the logging of installed and running applications.

The study will last for a period of two weeks to one month. Over this period, in order for data to be collected, the app must not be paused at any point and must run in the background. For logs to be stored, you should make sure that there is at least 10Mb of space free on the device daily, and you must allow the log data to be uploaded onto the University of Cambridge's server periodically.

Participation in this study is entirely voluntary. You may withdraw at any point, stopping any future logging, and you need not give a reason. Any data collected up until that point will not be used in the study, and can be requested to be deleted from the University of Cambridge's server as well. Your continued participation in the study should be as informed as any initial consent, so please feel free to ask for clarification, or further information via the email address at the start of this document. Before the study commences you will be asked to sign a consent form to confirm that you have received and read this information sheet, and that you are willing to take part in the research. You will be given the opportunity to give yourself a pseudonym on the consent form –or alternatively, one can be provided for you, which will be used if you are referred to in a research paper, or any work resulting from this study by the research team listed at the end of this document.

You will also be invited to take part in an interview. This could last up to an hour. It will be conveniently located at a place of your choice and will be informal. During the interview phase you have the right to withdraw at any time, without giving a reason. And if you so wish, we will not use any of the preceding discussion in our research. The interviews will focus on the way in which you have incorporated the device into your everyday life, exploring your daily habits and how (or how not) your Android device supports these.

Confidentiality and anonymity:
Any information collected from your Android device will be treated with the utmost confidentiality. This means that only the research team will have access to any raw information that can be specifically associated with you, and any information that is shared beyond this team will be made anonymous. This means that details such as your name or any identifiers will be removed. This will apply to any publications, presentations, or any discussion with other colleagues in the University and by other researchers that have access to the online Device Analyzer dataset.

How will the data be used and protected:
We will treat data that you provide or that is collected on the use of your device in accordance with the Data Protection Act 1998. This means that any personal information stored in physical format (paper, readily playable recordings) will be stored in a locked filing cabinet in a locked office on Lancaster University premises. Any personal information stored electronically will be stored on a secure, password-protected server. Any personal information that is transported electronically on a mobile device (a laptop or memory stick) will be encrypted and/or password-protected. Any data logged will be stored electronically on the University of Cambridge's server; however this will be made anonymous.

The information collected will be used to inform the development of further research and may be included in publications and presentations. Data may be kept for further research in the future; however this again, will be anonymised.

Risks of participation:
As no detailed information about the explicit use of applications on your device will be logged, the risks related to this study are minimal. Data on personal contacts or communications will be handled in an appropriate manner, for example phone numbers stored will be anonymised, but no contact names

of those contacted by phone or SMS will be saved. While it will be possible to see that they have been used, the explicit use of social networking or IM applications will not be logged. Although the study involves recording the amount of data sent and received by Wi-Fi or mobile data, the nature of this data is not logged. Therefore it will be impossible to identify any websites visited, searches made or the nature of app use such as what sound, music or videos are watched with a given application.

None of the data is likely to be attributable to you once made anonymous. However, there is a slight risk that people that know you well could identify you from quotations, or from the online Device Analyzer dataset, although all efforts will be made to ensure that any identifiers are removed.

There is also the risk that running the logging app over the study period could have an adverse effect on battery life or running speed while the app is running in the background. The app has been tested prior to the study and this impact has found to be negligible although it is possible that you may notice a difference. We do ask, however, that participants keep 10Mb of storage space free daily on the device for the duration of the study, to ensure that the app is able to store the log files, and allow the data to be uploaded to the University of Cambridge's server so it can be removed from the phone. This could interfere with your usual device usage if you normally use up all available space.

Furthermore, if you allow other researchers to access the data online, then it is added to the online dataset after you have had 3 months to review it. Therefore, if you continue to use the application after this study and do not request for your data to be removed from the dataset, other researchers may access and use your work anonymously.

Benefits:
There may be no personal benefit to you from participating in this project and there is no financial incentive to do so. However, you can view the data collected in a visual form by the Device Analyzer using the application itself (https://deviceanalyzer.cl.cam.ac.uk).

Your participation will allow us to research the use of Android devices "in the wild" in order to gain an understanding of how and when people tend to use these devices, and how they fit with everyday life. This could be helpful for furthering the technology and tailoring it to the needs of different kinds of users.

About the researchers:
The research team are based in the School of Computing and Communications (SCC), and Sociology, at Lancaster University.

Research Team:

Kelly Widdicks (SCC)
Carolynne Lord (PhD student, Sociology)
Rosalind Whittam (SCC)
Oliver Bates (PhD student, SCC)
Dr Janine Morley (SCC and Sociology)
Dr Adrian Clear (Research Associate, SCC)
Dr Mike Hazas (SCC)
Dr Adrian Friday (SCC)

Concerns:

If you are not satisfied with the manner in which this study is being conducted or if you have any concerns regarding your participation, you may contact (anonymously if you so choose):

Dr Paul Rayson
Lecturer
School of Computing and Communications
Infolab, Lancaster University, Lancaster, LA1 4WA
01524 510357
p.rayson@lancs.ac.uk

Appendix D

Participant sheet for the Photo Elicitation Study

Participant Information Sheet

We would like to invite you to participate in a study on the use and role of media and IT for activities and habits within the home. This sheet provides information about the study and what participation would involve.

We hope it answers any questions that you may have but any further queries can be directed to:

Oliver Bates
School of Computing and Communications
Infolab 21, Lancaster University, Lancaster, LA1 4WA
01524 510373
o.bates@lancaster.ac.uk

Project Title: Understanding the life-times of media and IT in the home.

Aims of the research:
This study seeks to gain an understanding of the various types of roles that media and IT can play within the home. We are interested in particular, in the range of devices that are owned and used in daily life and how different combinations impact on daily activities. The aim of this study is to understand the ways in which different homes depend on, and use different devices and configurations of media and IT in their daily lives. We are interested in anybody, no matter how big or small they consider the role of media and IT to be in their daily lives.

Study procedure and the participant's role:
This research will collect a limited range of information on the use of your home and the appliances in it via the photos the participant takes and through interviews.

The study will require **2 hours** of your time, 1 hour for you to take photos of media and IT in your home, and 1 hour for the interview. We will agree convenient times with you to transfer the photos and to organise the interview.

Participation in this study is entirely voluntary. You may withdraw at any point during the study, and up to 2 weeks after the interview. You need not give a reason. If you request, any data collected up until that point will be destroyed. Your continued participation in the study should be as informed as any initial consent, so you should feel free to ask for clarification or new information throughout. Before the study commences you will be asked to sign a consent form to confirm that you have received and read this information sheet and that you are willing to take part in the research. You will have the opportunity to choose a different name (pseudonym), which we will use if/when quoting you in any publications or presentations.

Those taking part in the study will also be invited to take part in an interview. This may last up to an hour. It will be conveniently located at a place of your choice and will be informal. During the interview process you will have the right to withdraw at any time. You do not have to give a reason for doing this, and if you wish, we will not use any of the preceding discussion in the research.

Confidentiality and anonymity:
Any information collected from you or about the use of your home will be treated with confidentiality. This means that only the research team will have access to any raw information that can be specifically associated with you. Any information that is shared beyond this team will be made anonymous. This means that details of your name and your home will be removed. This will apply to any publications or presentations or any discussion with other colleagues in the university.

Dictaphones containing interview audio will be stored securely, and will be erased within one week, once the interview audio has been transferred to a secure server on campus at the University. The photos and interview transcripts will be stored in anonymous form. Interview data is made anonymous at the point of transcription. Anything present in the photo inventories that may reveal the identity of a participant or other occupant of the household will be digitally altered to maintain anonymity before presentation in external documents, academic papers, or presentation of any kind.

How will the data be used and protected:

We will treat data that you provide or that is collected on the use of your home in accordance with the Data Protection Act 1998. This means that any personal information stored in physical format (paper, readily playable recordings) will be stored in a locked filing cabinet in a locked office on Lancaster University premises. Any personal information stored electronically will be stored on a secure, password-protected server managed by the University. In accordance with University policy, we will encrypt any mobile devices (e.g. laptop or memory stick) which contain personal or identifiable data.

The information collected will be used to inform the development of further research and may be included in publications, presentations and two PhD theses. Only anonymised information will be retained indefinitely for on-going research purposes.

During the interview, there will be ample opportunity to discuss the photos you provided to us, in detail. However, you may at any time request a copy of the data we have collected, and we will provide this to you in full, in an intelligible form.

Risks of participation:
The risks of participating in this study are minimal. However, despite concealing your name and where you live, there is a risk that you may be identifiable from the information provided in your interview by those who know you personally and your house may be identifiable by those, such as your immediate neighbours and friends, who see the study taking place. In this case, the impact on you is likely to be negligible since the study does not aim to explore any particularly sensitive topics. Any elements in photos considered to be identifiable (including that which may identify people you live with, through photos of their media and IT) will be removed or obfuscated (e.g. digitally blurred).

Those who agree to the study taking place in their home must be aware that the interviews may involve discussion of activities or devices in the home that relate to your co-residents. If any other names should be raised in conversation they will be treated with the same caution as those who are participating directly: changed to a pseudonym and stored in the same way.

We realise that you may have concerns over your privacy. We are interested only in how media and IT plays a part in your home. Our research protocol will preclude any observation of real-time data collection. We will however take appropriate security measures to ensure that others do not inadvertently access the data. If such inadvertent disclosure should occur, this would only include information about the ownership and use of particular appliances. To reduce the risk posed by inadvertent access, we will ensure, as far as possible, that the collected data is not explicitly linked to your home.

Benefits:

There may be no personal benefit to you from participating in this project. We offer to compensate your time with a £10 Amazon voucher. For those who are interested will endeavour to make the data collected from you in summarised form, on request.

The research that your participation makes possible will help to inform the academic research community and policy makers about the relevance, potential gains of, and suitable techniques for, studying domestic activities and their requirements in detail.

About the researchers:

The research team are based in the School of Computing and Communications (SCC) and the Department of Sociology at Lancaster University.
It is funded by a Lancaster University Faculty of Science and Technology CASE studentship with Microsoft Research, and a DEMAND Centre studentship.

Research Team: Oliver Bates (PhD student, SCC)
Carolynne Lord (PhD student, Sociology)
Dr Mike Hazas (SCC)
Dr Adrian Friday (SCC)

Concerns:

If you are not satisfied with the manner in which this study has been conducted, or if you have any concerns regarding your participation you can contact (anonymously if you so choose):

Professor Jon Whittle
Head of School
School of Computing and Communications
Infolab 21, Lancaster University, Lancaster, LA1 4WA
01524 510307
j.n.whittle@lancaster.ac.uk
http://www.scc.lancs.ac.uk/people/