Streaming, Multi-Screens and YouTube: The New (Unsustainable) Ways of Watching in the Home

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ABSTRACT

Internet use and online services underpin everyday life, and the resultant energy demand is almost entirely hidden, yet significant and growing: it is anticipated to reach 21% of global electricity demand by 2030 and to eclipse half the greenhouse gas emissions of transportation by 2040. Driving this growth, real-time video streaming ('watching') is estimated at around 50% of all peak data traffic. Using a mixed-methods analysis of the use of 66 devices (e.g. smart TVs, tablets) across 20 participants in 9 households, we reveal the online activity of domestic *watching* and provide a detailed exploration of video-on-demand activities. We identify new ways in which watching is transitioning *in more rather than less* data demanding directions; and explore the role HCI may play in reducing this growing data demand. We further highlight implications for key HCI and societal stakeholders (policy makers, service providers, network engineers) to tackle this important issue.

KEYWORDS

watching, video streaming, sustainability, data demand, devices, households, everyday life, HCI, service design, policy

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1 INTRODUCTION

How and when do we watch films, TV programmes or video clips at home? We ask this at a time when digital devices and infrastructures (e.g. smartphones, data centres) are expected to contribute to 21% of global electricity use by 2030 [2]. ICT may exceed half the current relative contribution of greenhouse gas emissions for the transportation sector by 2040 [8]. Alongside this, Internet video takes a significant portion of our global online consumption (72% of consumer traffic in 2017) and has an expected Compound Annual Growth Rate (CAGR) of 34% for 2017–2022 [12, table 15]. Real-time entertainment (e.g. on-demand video) contributed to 41.46% of fixed, and 32.95% of mobile, peak traffic demand for Europe in 2015 [58]; these shares are even larger for North America, taking 67.35% of fixed and 35.39% of mobile peak traffic in 2016 [59]. As network operators plan their capacity based on peak traffic [57], growth in video streaming is a key driver in Internet infrastructure expansion and thus its climbing energy and carbon footprint.

There has been much discussion and dispute on the actual environmental impacts of the Internet [2, 3, 8, 41, 61, 62, 70]. Yet, technology efficiency gains are quickly overtaken by the rapid growth in Internet infrastructure [51] and service consumption [52], driving rebound effects [53] ('Jevons paradox' [28]). Growing ICT energy footprint will likely continue to rise in tandem with increasing streaming popularity and emerging technologies reliant on connectivity e.g. the Internet of Things (IoT) and Bitcoin [15].

We offer an in-depth analysis of month-long network traces and qualitative interviews from 20 participants to unpack the video-on-demand activities across 9 households. We identify the *why*, *how* and on *what devices* video streaming is facilitated and how the activity of watching is changing to incur more data demand (i.e. the *"demand for network connectivity and online services"* [39, pg. 2729]). Given, our community typically *designs for more* engagement which can lead to data demand (e.g. by second screen apps [18, 24]), we ask, what can be done to mitigate this energy impact and transition watching trajectories in sustainable directions [63]? We propose implications for the HCI community and society in challenging the growth of video streaming.

2 RELATED WORK

The practice of watching has been examined from a variety of view points, and for many years. Such work has explored the ways in which people watch TV [5, 60, 71]; analysed the adoption, use and changes in specific services (e.g. YouTube [11],

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BBC iPlayer [34], Netflix [32]); investigated live streaming (e.g. on Twitch [64], in China [40], and viewers' motivations for supporting streamers [73]); managing children's screen time [29]; discovered reasons for users multitasking their media [30, 31]; understood binge-watching [14]; the design of second screen apps [18, 24, 44]; and *"predictive preloading"* of video for work commutes [33]. Regrettably in terms of sustainability, this prior work has *not yet* considered the energy used indirectly from watching related activity, and may even add to the problem (e.g. with second screening).

Mobile data traffic is growing at an alarming rate, increasing 55% from 2016–2017 [21]; this growth is facilitated by the roll-out and adoption of new infrastructure (e.g. 4G [49]) and the opportunities for mobile data use they create (e.g. 5G and smart cities [27]). Thus, it's no surprise that researchers in this domain have focused on the data demanding nature of smartphones and tablets [39, 43, 72]. However, the bulk of global Internet traffic is still accessed through fixed networks (e.g. in-home Wi-Fi), demanding 67 Exabytes (EB) per month (57 EB more than mobile) in 2017 with an estimated 225 EB by 2022 (a 27% CAGR 2017–2022) [12, table 15]. What's more, there are many other types of Internet-connected (and non-mobile) devices that have yet to be studied in sustainability terms, including smart TVs and games consoles.

To understand data demand from media and IT in the home holistically, Bates et al. [6] suggest quantitative analysis of network data. Network data has been previously logged in the home, and video watching has been found to be one of the top Internet activities [35]. Yet the associated data demand has not been discussed. As data demand *"is designed into practices through its embedding in technologies and apps that we use to support them"* [72, pg. 5361], we should explore everyday life to discover what is causing such demand and how we as designers and engineers, can counteract it.

Streaming has been identified as a key category of traffic to target in HCI [72], as it augments peak electricity demand [43]. Access to faster infrastructure has also been positively correlated to increases in video-on-demand subscriptions [43]. Yet the energy associated with the Internet infrastructure is not simply correlated with *active* streaming; this relationship is more complex. Internet usage norms follow a 'Cornucopian paradigm' [51]—i.e. growth in streaming leads to further growth in Internet infrastructure, and as a result, the total associated energy consumption also increases.

Some designs have already been proposed to improve users' watching experiences that could possibly advance the activity in more sustainable directions. These have included: removing video 'auto-play' to help address binge-watching behaviour [14]; providing short summaries of TV series to prevent users re-watching entire episode collections prior to new season releases [71]; and pre-downloading video on fixed-access networks for mobile consumption [33]. Other work has focused on reducing the network load and energy consumption of Internet watching, e.g. by predicting watched content and recording it via broadcast TV for an 'offline' on-demand service [45]. Within sustainable HCI (SHCI), Preist et al. [51] have provided a rubric for addressing digital infrastructure impacts (building on Blevis [9]). They touch on designing for reduced data associated with watching, e.g. by downloading episodes of a series a user is watching at off-peak times or by creating 'video on/off' mechanisms for partially used streams [51]. More research is needed *within HCI* to discover what changes or interventions are feasible *for users*, or required *in society* to reduce watching data demand.

Most recently, Rigby et al. [55, 56] have investigated on-demand viewing across devices for 20 participants to uncover contextual and situational factors of video streaming, including which and why different devices are chosen for streaming, where it takes place, and who with. Whilst they highlight important findings (e.g. three quarters of watching sessions were carried out alone; YouTube is the most popular service), their 14-day diary studies do not uncover data demand, nor distinguish it across services and devices [56].

In this paper, we scrutinise the activity and data demand of *watching* in the home. We go beyond prior work by using a mixed methods analysis of qualitative interviews based on analysis of month-long traces of network activity. This allows us to uncover the new ways in which watching data demand is composed across different devices (including newer devices such as TV dongles), services (including video watching on Facebook), and types of users (and families). Our richly detailed dataset provides the HCI community with insight into video-on-demand activities. From this, we are in a unique position to highlight how HCI researchers and practitioners can adapt video streaming toward more sustainable Internet consumption, and discuss the broader implications for the HCI community *and* society (e.g. policy makers) regarding Internet growth.

3 METHOD AND PARTICIPANTS

We gathered quantitative and qualitative data on Internet and device use in the home using a mixed-methods study, based on established SHCI methods [6, 39, 72]. Twenty participants (nine households) took part (summarised in table 1[1]) between June 2017–January 2018, and were recruited through email flyer advertisement and snow-balling methods. To protect the anonymity of the participants, pseudonyms are used in this paper.

[1]Tim and Connie (H3) have two children (daughter aged 5, son aged 3), data demand was logged on their parent's devices and is discussed in this paper, but they were too young to be interviewed.

H#	Participant Pseudonym (Age Range, Gender, Occupation)	Personal Devices (Avg. Daily MB, No. of Days)	Shared Devices (Avg. Daily MB, No. of Days)
H1	Ben (20s, M, Freelance Artist)	Android Phone (911, 50), PC (476, 7), Amazon Echo (21, 48), Kindle (11, 47)	Freeview Box (60, 57), *Sonos Speakers, Smart Meter*
	Gemma (50s, F, Retired)	iPhone (63, 57), iPad (177, 56)	
	Martin (50s, M, Retired)	iPhone (300, 57), iPad (195, 57)	
H2	Laura (50s, F, Business Partner)	Android Phone (31, 31), Amazon Fire Tablet (101, 33), Work Laptop (87, 16), Personal Laptop (29, 2)	
H3	Tim (30s, M, Tax Consultant)	Android Phone (1305, 34), Amazon Fire Tablet (35, 3), Laptop (521, 7)	Smart TV (387, 34), YouView Box 1 (15, 36), YouView Box 2 (44, 36), Android Box (40, 1), Google Chromecast (2899, 4), Windows Phone (19, 17)
	Connie (30s, F, Nurse)	Android Phone (273, 33)	
H4	Alan (50s, M, Banker)	Android Phone (3, 25), Windows Laptop (146, 9)	iPad (342, 29)
	Denise (50s, F, Services Representative)	iPhone (77, 29)	
H5	Ella (30s, F, Lecturer)	Android Phone (99, 27), Laptop (2716, 27)	*Google Chromecast, Now TV Box*
	Kevin (30s, M, Researcher)	iMac (216, 7), Android Phone (36, 1), *Laptop*	
H6	Fred (40s, M, Accountancy Firm Employee)	Android Phone (2435, 28), *Work Laptop*	Amazon Fire Stick (453, 20), Laptop (25, 16), Desktop PC (508, 9), Smart TV (47, 28)
	Julie (40s, F, Medical Secretary)	Android Phone (266, 28)	
	Heather (10s, F, Secondary School Student)	Android Phone (1696, 27), Android Tablet 1 (977, 20), Android Tablet 2 (655, 18)	
H7	Ian (40s, M, Accountant)	Work iPhone (157, 12), Personal iPhone (110, 10), iPad (66, 11), Laptop (171, 4)	Sky Box 1 (704, 20), Sky Box 2 (1101, 32), Hudl Tablet (100, 16), Xbox 360 (170, 10), Printer (0.3, 7)
	Olivia (40s, F, Community Coach)	Personal Android Phone (36, 24), iPad (65, 9), Laptop (285, 8), *Work Android Phone*	
	Nick (10s, M, Secondary School Student)	Android Phone (318, 21)	
	Peter (10s, M, Primary School Student)	Android Phone (0.2, 10)	
H8	Rachel (30s, F, Accounts Assistant)	iPhone (568, 27), Amazon Fire Stick (2634, 27), Laptop (373, 13)	
	Sally (0s, F, Primary School Student)	iPod Touch (145, 26), Amazon Fire Stick (46, 27), *iPad*	
H9	Xavier (20s, M, PhD Student)	iPhone (586, 23), iPad (2699, 25), Kindle (1, 23), MacBook Pro Laptop (99, 22), Sonos (14, 25), TV (9, 19), PlayStation (5072, 21)	

Table 1: A summary of the participants and their device use. The number of log days varies per device due to devices not demanding data on every study day or logging issues for Ben's PC and H7's printer. Devices in italics were not logged in the study (e.g. Olivia was unsure if work would permit her work phone being logged, H5's shared devices were missed in setup).

To log Internet use, we replaced the home-router in each household[2] and deployed a mini-PC to log and store Internet flows for one month duration (mean 35 days, max. 58, min. 26)[3]. We logged the source and destination IP addresses and bytes transferred, and used logged DNS and DHCP requests to map each flow to human readable domains and participants' devices.

For the qualitative data, we conducted two individual, semi-structured interviews with each participant: one before the logging phase to discuss their use of devices and the Internet (mean duration 40 mins, max. 88, min. 16); and one after the logging phase to discuss visualisations of their quantitative log data (mean duration 30 mins, max. 70, min. 12)[4]. Each participant attended both of their interviews except Kevin (H5), who only undertook the first. Interviews were fully transcribed, open coded for themes, and then codes were cross-compared for further analysis.

To understand data demand in the lives of our participants, the top 357 high level domain suffixes (responsible for 90% of total data demand[5] from the 20,000+ domains found for all households) were manually mapped to services and then categorised into activities. We take the view that it is not particularly revealing to explore the 'long tail' 10% of least data demanding domains, which would also require manually mapping the remaining tens of thousands domain names. To provide an example of our mapping strategy (similar to that used by previous work [72]), *'pc-nowtv-ak.vod.sky.com'* mapped to the service *'Now TV'* and was categorised into the *'Watching'* activity. This process was carried out with other non-watching domains, e.g. *'i.instagram.com'* i.e. *'Instagram'* falls into *'Social News and Networking'*. Special case domains such as *'video.xx.fbcdn.net'*, where the service is Facebook but the content is video, the category chosen is *'Watching'*; domains associated with a watching device (e.g. *'yv1-api.youview.tv'*) are also categorised as this activity. If a

[2]OpenWrt routers were used: `https://openwrt.org/`
[3]Flows were captured using Cisco NetFlow: `https://www.cisco.com/c/en/us/products/ios-nx-os-software/ios-netflow/`
[4]Both interview schedules are provided as supplementary material.

[5]Only data demand which goes beyond the home network is explored in this paper, i.e. the data transmitted between a device in the home and a network domain outside the home. The internal traffic (total: 3 GB) is omitted.

domain outside the 90^{th} percentile of data demand had the same high-level domain name as a suffix, it was also included with the high-level domain as the same activity in order to fully represent the demand of each watching service.

A total of 1,547 domains were classified as *'Watching'*; these are the domains used within the analysis of this paper. These values could *potentially be under-represented* due to: 1) some domain services being difficult to decipher or their traffic/URL is ambiguous; and 2) participants' freedom to choose not to conduct certain activities during the study, such as watching pornography. It is important to note that watching data demand may not always be directly linked to immediate use by the end-user: due to background processes (e.g. for a watching device), or a user not looking at the screen whilst it is demanding data (e.g. if the TV has been left on). Determining this would require undesirably intrusive study methods such as video recording our participants for the full study period. Furthermore, we clarify that the data discussed in this paper is associated with the home network and therefore is Wi-Fi only. We do not discuss mobile data, however this has been covered in-depth previously [39, 43, 72]. We acknowledge that our sample size is small in comparison with larger scale studies of network use, but the purpose of our more detailed study is to uncover a nuanced understanding of contemporary watching practices indicative of wider trends in everyday life [12] and identify how this links explicitly to data demand.

4 WATCHING DEMAND IN THE HOME

All households (and 78% of devices shown in table 1) watched some form of video content in the study (table 2). The services used for this activity (e.g. YouTube, Netflix etc.) contributed to 72% (558.57 GB) of the households' total data demand (777.09 GB). This activity typically occured every day of the week (figure 1). There were peaks early morning (07:00) and late at night (22:00), with an early evening peak at 18:00. Demand also occured in 'prime time' TV watching hours (20:00–22:00 [68]); this prime time watching is facilitated by devices other than smartphones, tablets and laptops, as demand from portable devices dips at this time (figure 3)—a trough consistent with mobile devices [43, fig. 7].

Watching occurs across different device types (table 3). Smartphones were the most commonly owned devices, 18 of which accessed watching content, contributing 186 GB (33% of total watching data demand). The most data-intensive devices consist of H9's games console (79 GB in the month-long study) and the TV dongles (avg. 20 GB per device).

Figure 2 shows the top ten services which compose the largest share of watching-related data demand. YouTube was found to be the most data demanding service. Other significant services consisted of Now TV, Netflix, Sky TV and TV Player, followed by more social-media related videos on Facebook and Twitch. Domains associated with video from Akamai also made this content delivery network a top contributor. From this quantitative data we have uncovered: 1) when watching occurs; 2) the device types used; and 3) the streaming services accessed. To understand how watching related demand is formed; why, and how, this demanding activity growing; and what parts of it are most meaningful to users, we turn to our qualitative data.

H#	Avg. Daily MB	No. of Days	Top Watching Services (Avg. Daily MB, No. of Days)
H1	892	55	YouTube (803, 55), ITV Hub (184, 8), Akamai (128, 8)
H2	5	31	Facebook Videos (7, 17), YouTube (0.8, 26), Brightcove (2, 8)
H3	1287	36	Warner Bros UltraViolet (1962, 6), YouTube (310, 32), Watching Device Unknown IPs (964, 10)
H4	17	29	Brightcove (19, 10), YouTube (6, 28), BBC iPlayer (7, 11)
H5	2272	29	Now TV (3589, 13), Netflix (1658, 8), Facebook Videos (176, 27)
H6	5145	28	YouTube (4882, 28), Facebook Videos (79, 28), Sky Sports (2120, 1)
H7	1690	32	Sky (1472, 32), YouTube (286, 24), Facebook Videos (10, 5)
H8	2749	27	TV Player (2480, 17), All 4 (747, 15), ITV Hub (421, 14)
H9	5738	24	YouTube (3370, 24), Netflix (2285, 16), Twitch (910, 15)

Table 2: Each household's daily watching demand, the number of days spent watching, and their top services.

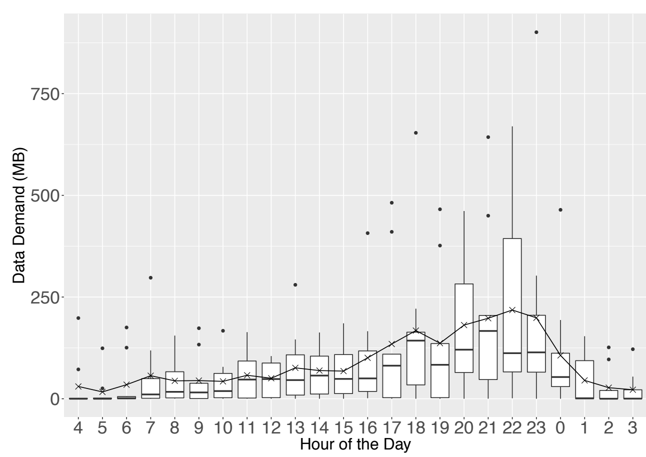

Figure 1: The average hourly data demand for watching for all households. The overlaid line and crosses represent the mean; the dots represent the outliers. The figure is supported by 9 months of fine-grained network logs. Some samples lie outside the inter-quartile range because data demand is non-normally distributed.

Device Type (No. of Devices)	Avg. GB per device (total devices' GB)	Contributing Households
Smartphone (18)	10.34 (186.17)	All households
Tablet (12)	6.96 (83.63)	All but H5
Laptop (7)	9.4 (65.85)	H2, H5, H6, H7, H8, H9
TV Box (5)	10.2 (51)	H1, H3, H7
TV Dongle (4)	20.46 (81.84)	H3, H6, H8
PC (4)	1.09 (4.37)	H1, H3, H5, H6
Smart TV (3)	2.23 (6.71)	H3, H6, H9
Games Console (1)	78.98 (78.98)	H9

Table 3: The different device types used for watching.

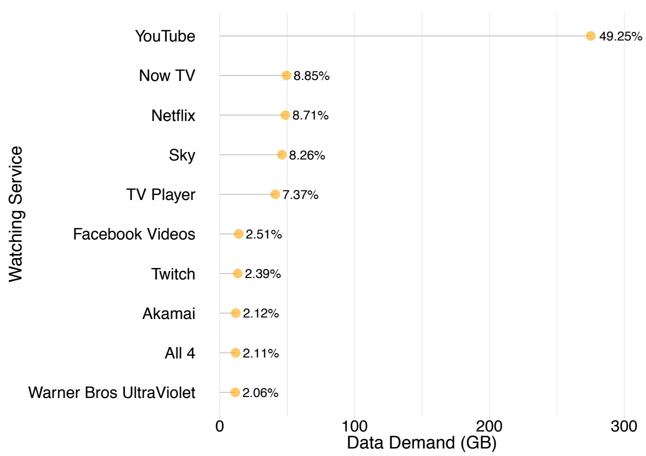

Figure 2: The total households' data demand (GB) for the top 10 watching services and their % of watching demand. Other watching services totalled to 35.5 GB (6.37%).

5 THE NEW WAYS OF WATCHING

To uncover why watching is such a large category of home Internet use, this section explores the participants' accounts, exposing new trajectories of watching-based data demand.

Streaming as the primary way of watching

Video-on-demand provides a high-level of flexibility for watching activities: users can watch what they want, when they want to, and on a multitude of devices at their choosing. Subsequently, the nature of watching and what can be expected from this form of entertainment has changed, as Ella states below. Her household's watching habits have become more finicky since on-demand viewing (facilitated by their laptops, Google Chromecast and Now TV Box) entered their lives:

> *"Years ago you'd sit just for hours and watch Come Dine with Me or something on repeat on a Sunday, erm, but now we will start a series, if we don't like it after 1 or 2 episodes we will quit it and we'll start watching something else, and we're the same with movies, like we constantly just turn movies off half way through, and I never would've done that like a few years ago, I would've selected something, sat down and watched it, even if it was rubbish... there's always something else that you could erm be watching"* (Ella, H5).

Ella and Kevin no longer have access to broadcast television and describe it as *"mundane"*. Instead they pay monthly subscriptions to access the *"massive amount of options"* on three popular streaming services: Netflix, Now TV and Amazon Prime. Whilst all other households had access to broadcast television, some of them showed signs that follow the trajectories of H5: Rachel and Sally (H8) only have access to content provided by Amazon Fire Sticks in their bedrooms; H9 has access to broadcast TV but *"always stream*[s]*"*; Gemma (H1) believes *"you need the Internet for a telly"*; H3 have access to some Internet-only BT channels; and Tim (H3) reflects on whether broadcast television is even needed:

> *"I'd still watch the same programs I watch I suppose, yeah, I don't like, I sit down to put the telly on and I don't just watch whatever's on at the time. If there's nothing I wanna watch I just put something on on-demand. I suppose it wouldn't really matter if there was no broadcast telly."* (Tim, H3).

Furthermore, users default to streaming TV programmes or films instead of accessing content through more traditional mediums. Alan (H4) tends to watch catch-up TV programmes rather than pre-recording them as it's *"just as easy"* to do; and in H6, Fred chooses to stream films rather than finding his own DVD copy from his large collection at home.

YouTube: the most demanding watching service

YouTube is used by all of the households and was found to be the largest contributor to data demand—consuming 49.25% (figure 2) of demand for watching across all households (275.12 GB / 558.57 GB). For personal devices (i.e. devices that are owned by one participant), the average daily total demand for YouTube was 648.25 MB for Generation Z (participants born early 2000s onwards), 410.63 MB for the Millennials (1980s-2000s), and 186.02 MB for Generation X (pre-1980s). This was evident in the interview discussions too for Ben (H1) and Xavier (H9) (Millenials), alongside Heather (H6), Nick (H7) and Sally (H8) (Generation X).

While Heather (H6) knew the study was about device and Internet use, she distinctly picked out YouTube to describe herself: *"I'm 13, I play with my cats a lot, I go to school, and I spend quite a lot of time on YouTube"*. Furthermore, Connie and Tim's (H3) YouTube demand is extended by their 5 and 3 year-old children watching *"ridiculous things where people are like playing with dolls"* (Connie, H3).

For all generations, music was a particularly popular video type: Tim (H3) will watch music playlists with his family;

Julie (H6) watched old music videos one night in the study; and Sally (H8) accesses new music videos: *"I let the music play and I sing to it"*. Yet, some participants do not always *watch* the YouTube music videos they stream. Whilst Heather (H6) does a *"bit of both"* watching and listening, Nick (H7) will only listen to music videos via his phone whilst he plays on H7's Xbox or researches online for school: *"I don't watch them I just put them aside to listen to music."* (Nick, H7).

Nick's listening of YouTube videos for music began when he got his first smartphone, but these habits can emerge in other ways. H1's free 3-month trial to Apple Music, listened to through their Sonos speaker, led Martin to develop a new way of listening; this was continued after the trial via a new Bluetooth speaker and streamed YouTube playlists due to the paid-subscription nature of Sonos:

> *"The Sonos system, I'm a bit disappointed with"..."you can't just stream things to it from Bluetooth, you've gotta pay for a subscription to a music service"..."so we've got a cheaper music speaker in there"..."I was using my phone and sending it via Bluetooth to that speaker, and it was, and it was fine, from, on YouTube, which is pretty good."* (Martin, H1).

Listening to music this way is much more data-intensive due to the video content involved. Whilst audio-only options are available on YouTube Red/ Premium[6] (a paid YouTube service), Martin highlighted that they *"don't listen to* [music] *frequently enough to pay a fee for it"*.

Multi-watching in the home

Watching separate content via different mediums at the same time (e.g. through broadcast TV, on-demand services, DVDs etc.) is a common activity for householders. We define this everyday life reality as *multi-watching*, i.e. *multiple, separate watching activities occurring simultaneously in a given space.* This is enabled by devices (e.g. smartphones, tablets) existing in the home alongside the TV—for multi-watching to occur previously, households would've had to own multiple TVs.

Multi-watching occurs in: different rooms of the home, e.g. Fred (H6) will stream Sky Go football on his study PC when the lounge TV is in-use by his family; and in the same room, e.g. Fred described that Heather is *"happy sitting on the settee with us with her headphones in watching something on YouTube"*. Same room multi-watching has taken place in H3 too: Tim decided to stream BT Sport on his laptop since his children were watching the TV. Household members are also *streaming* video for 'solo entertainment'. H5's Internet-only watching allows Ella and Kevin to sit separately for this activity–partially aided by Netflix's profiles feature.

Table 4 shows each household's daily number of streamed multi-watching sessions; these occur when more than (any)

H#	No. of Sessions per Day			Durations of Sessions		
	Mean	Med	Max	Mean	Med	Max
H1	0.1	0	2	2.3	2.2	4.4
H3	10.1	8	54	112.3	32	853.4
H4	0.03	0	1	0.7	0.7	0.7
H5	1	0	6	6.9	4	41.5
H6	12.5	11.5	23	38.4	9.9	441.6
H7	16	16	43	27	13.3	323.2
H8	3.6	3	9	3.9	2.6	17.1
H9	4.7	4	14	30.5	4	198.6

Table 4: The daily number and durations (mins) of multi-watching sessions. H2 did not multi-watch. H3's max duration means they streamed for a full day.

one device is streaming from any watching domain at a given time. Sessions are concatenated if they occur within 1 minute of each other, and must be at least 30 seconds in duration (filtering out extremely short overlaps).

For some, multi-watching is a rare or non-existent activity (H1, H2, H4). However, it does happen at least once daily for other households (H3, H6, H7, H8, H9). This is partly related to the number of people living in the home: H3, H6 and H7 (the most frequent multi-watchers) are three of the largest households (three or four occupants each). Yet multi-watching can also happen in a single-person household, as with H9 (table 4); Fred (H6) also discussed watching YouTube whilst watching TV–a data intensive activity via his Amazon Fire Stick:

> *"I might be watching an episode or a film or something, if my phone's there I might every now and then go on and just look at Facebook or, I might look at YouTube or something because I've short attention span of watching..."* (Fred, H6).

Multi-watching via streaming is not yet routine. However, as we are increasingly turning to online content for watching, it is more than plausible to expect that multi-watching will be further accomplished by streaming in the future–particularly as Internet speeds grow and allow for even more simultaneous streams in higher qualities. (For example, the UK Government aims for premises to have *"full fibre"* access i.e. fibre to the home by 2021 [26]).

More devices, more watching demand

The variety of devices available has created new possibilities for how and when watching can be carried out. Portable devices (i.e. mobile devices and laptops) are easily accessible and able to integrate *"in areas of the home where computing was previously unacceptable"* [65, pg. 2642], allowing for watching activities to follow. *"Communality and Portability"* has been found to be the motivation behind mobile device video watching [35] and we extend this to laptops too; e.g.

[6] `https://www.youtube.com/red`

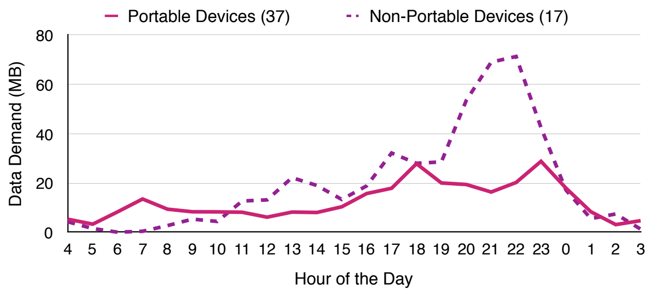

Figure 3: Average hourly watching MB by device portability.

when prompting Ella (H5) about her large data demand on Wednesdays, she responded with: *"you know what, Wednesday is my cleaning day, that sounds ridiculous, but erm I watch, I watch things while I'm tidying"*. This was facilitated by her laptop, which she carries round the house to 'wind down' when cleaning or doing other chores.

Watching demand is greatest at 20:00–22:00 and is predominately provided by non-portable devices (figure 3), yet there are points in the day where watching on portable devices is more prominent: 07:00, 18:00, and 23:00. These times coincide with the mobile device watching demand peaks [72, fig. 5]. Watching here is not necessarily used to *fill* "dead time" [39] but rather to *spend* downtime. For example, Fred (H6) has a particular YouTube routine on his phone:

> *"Usually when I get home from work I'll sit down for 10 minutes or so, about quarter of an hour, and just sort of like right, before I do anything else, have a choc ice [laughs], and go on YouTube for a bit."* (Fred, H6).

The characteristic of portability alongside device quality can lead users to borrow devices from others for watching; this is described by Kevin (H5) regarding his wife's streaming, despite Ella owning a laptop herself: *"Occasionally* [Ella would] *borrow my laptop to watch some Netflix thing whilst she's cooking, just cause it had a bigger and better screen."*.

Other ways of watching can be more situational and spatially determined. As the log data indicated that Rachel's (H8) Amazon Fire Stick demands more data on Tuesdays and Wednesdays, she described how going to bed early is the cause of this. These days involve her using the TV dongle located in her bedroom (rather than her lounge TV) due to specific activities she routinely does or does not do:

> *"Tuesday, erm I don't see my boyfriend, he doesn't come round, so I go to bed when Sally goes to bed, and she comes in my bed for a bit and we watch telly, erm, and then Wednesday erm I go to my boyfriend's for tea and then we come back here and I don't see the point in sitting in the front room, especially in winter, so we just go to bed."* (Rachel, H8).

H3 arguably has the most complex watching setup of the households. Alongside their mobile devices, they own a Google Chromecast, an Android box, a smart LG TV and two YouView boxes—all of which facilitate H3's watching in some way. Tim therefore has multiple options of how to watch the same TV programme or film, yet he chooses a particular device configuration in order to watch in HD:

> *"...I get BT Sport, erm I only get standard definition on the YouView player, high definition on the mobile app, so I tend to watch high definition channels by connecting* [his smartphone] *to the Google Chromecast and watching that on the telly in high-def."* (Tim, H3).

Throughout the study, Tim only ever accessed BT Sport through his Google Chromecast and smartphone. These scenarios of how users go about watching sum up the complexity of device setups—yet one thing is clear: they all lead to more demand. Participants extend watching hours through portable devices (and hence embed watching more into their everyday lives); Ella will watch streamed content on larger devices; Fred will stream football matches instead of watching them on H6's (in-use) broadcast-enabled TV; Rachel will default to on-demand watching on specific days of the week in order to watch from the comfort of her bed; and Tim will use specific device configurations in order to watch in HD.

Media-multitasking

The TV has been described *"as a resource that can be dipped into and out of as different activities come to dominate"* [5, pg. 15:14], leading to the accomplishment of other activities whilst the TV is on. More recently, *"media-multitasking"* [47] has become familiar; many users access their mobile devices whilst watching TV for both *"media-meshing"* i.e. interaction involving the TV program in view, and *"media-stacking"* i.e. interaction for other means unrelated to the TV [47]. Daily media-multitasking activities were common for 14/20 participants, consisting of: viewing social notifications (Ella, H5); checking emails (Ian, H7); shopping (Julie, H6); playing games (Sally, H8); gathering news updates (Alan, H4); discovering information on TV shows (H5); smartphone use during TV adverts (Heather, H6); multi-watching (Fred, H6); and other browsing (Laura, H2; H3; Denise, H4; Rachel, H8).

Five participants (i.e. Martin, Laura, Connie, Fred, Sally) mentioned that their media-multitasking occurs due to their disengagement with what they, or their household members, are 'watching'. Such multi-tasks can even cause conflict between householders, as Ella said that *"Kevin tells* [her] *off all the time"* when she checks notifications during TV watching. However, some participants do not media-multitask; despite

Alan (H4) having his iPad to hand while the TV is on, he points out that he is not using them simultaneously:

> *"I'm not doing both, I can't multitask, so I might be concentrating perhaps on a newsfeed on the iPad and the television's on, or I'm watching the television and I'm just looking for an alternative source of information or something."* (Alan, H4).

Furthermore, Ben (H1) stated that: *"if I'm watching something I'm watching"*, ensuring focus on the content he is viewing. Gemma (H1) even mentioned she has to have the TV turned off to *"concentrate"* on her online tasks:

> *"I don't even like the telly on when I'm, if I'm using* [my phone] *or texting cause it'll distract, the telly will distract me from doing it"..."it's a bit like reading the same, when somebody's talking to you and you're reading the same page of a book, it just gets annoying doesn't it?"* (Gemma, H1).

As media-multitasking overlaps data demand from other online activities, the demand linked to watching may be more than we present. With streaming becoming more prominent, the participants accounts of TV disengagement and the need to focus on single online tasks, indicate that not all watching demand will be fully absorbed or appreciated.

Trivial watching?

The participants have varying perspectives on what types of watching provides meaning to their lives, e.g. YouTube is useful for learning to play instruments (Fred, H6; H7) or for finding new musicians (Fred). However, general YouTube viewing can be distracting:

> *"You can lose track of time sometimes"..."you go on* [YouTube] *for something to do and you realise you've been on there for half an hour because one video of funny cats lead to another"..."sometimes it's easier just to watch another video, 'oh I'll do the ironing in a minute, oh there's another video of cats, I'll watch that'"* (Fred, H6).

Despite Ben (H1) and Xavier (H9) regularly using YouTube, they seemed somewhat dissatisfied with the site's content. For example, Xavier falls asleep while watching YouTube videos he describes as *"mundane"* and as *"background noise"*—the video content of which isn't meaningful to him:

> *"Most of it's just junk content, people playing games and then making jokes over the top of it"..."it's almost like a podcasty thing, I don't really watch it for the content itself but it's more about the, the voice overs..."* (Xavier, H9).

Xavier further explains how this YouTube watching contrasts to Netflix: *"When I'm watching Netflix, I don't really wanna go to sleep, I wanna watch the show"*. Like Xavier, Ben is also more content with Netflix than YouTube:

> *"I noticed when I had the Netflix subscription that I was way more satisfied with the entertainment that I had, whereas YouTube entertainment is very like basic"..."it's a bit like a slot machine isn't it? Like yeah, it's a bit of a gamble, like 'you might get something good, you might not'"* (Ben, H1).

Ben reflected that services like YouTube are *"designed to hold your attention as long as possible"*. As a result, he uses productivity tools and has edited a system file on his PC to block access to sites he gets distracted by. Distractions are not subject to YouTube alone, as Reddit can lead Kevin (H5) to watch many short videos on the site. This 'binge-watching' can occur with longer forms of video too, as Ella points out with her Netflix streaming: *"I'll be like 'I'll just watch one more'"*.

6 DISCUSSION

Considering how technology is impacting watching norms, we see a number of clear opportunities where HCI can challenge these new practices. We suggest we urgently need to confront 'all-you-can-eat' and 'binge' watching more broadly, as the shift to Internet based services has an increasing impact on people, society and the planet. We point to the need for a broad framing to address political activism [37], radical societal transformation [36], and policy [67], to tackle this increasingly signficant concern. But we also acknowledge the need to *evaluate* SHCI designs with care [54] given the potential for unwanted rebound effects when addressing streaming in future work, as users could end up replacing streaming with more energy-intensive activities; we note our current discussion is limited in this regard.

The new norms

Shifts towards streaming and YouTube generation gaps. Our findings, coinciding with UK [50] and US [66] statistics, show that there have been significant shifts towards streaming as a default. H5 no longer have a TV license. With Fred and Alan, online content is emphasized as the primary medium for watching, with more traditional forms of viewing (i.e. broadcast TV, DVDs) becoming a secondary, if not obsolete, form of entertainment. Unsurprisingly the shift to streaming is more prominent with younger generations (Generation Z, Millennials) accessing YouTube. Despite these shifts, the energy cost linked to these older infrastructures (e.g. broadcast TV) is not necessarily removed; meaning streaming norms create another layer of energy impact.

Watching as a distraction. Watching can become trivial: users can become disappointed with the time they spend watching (Ben, Fred, Kevin); and YouTube in particular, the most common [55] and demanding watching service, can sometimes only provide *"mundane"* or *"distracting"* entertainment. Whilst paid streaming services can provide 'better' content (Ben), they can also promote binge-watching (Ella). This shows how different watching services and their content can greatly change in meaning for users.

A screen (or two), each, anytime of the day. Our participants in shared houses illustrate how each person is becoming more focused on their own watching devices (H3, H6, H7, H8, H9). This is even occurring whilst users are the same room (H6)—an activity that Ofcom found for a third of UK households [48]. The act of domestic multi-device watching, i.e. *multi-watching*, is contributing to exaggerated evening peaks (figure 1) and overlaid demand (table 4). One of the big challenges for HCI to overcome when considering how to tackle multi-watching is that interactivity can be core in these experiences. At a basic level, most online services aim to keep users engaged for longer, leading to more demand.

Reducing the data demand of watching through HCI

Limiting watching to the least data demanding configurations. Interventions could steer users away from the new watching possibilities that the multitude of household devices allow [6]. A greater shared understanding of devices and their capabilities may help constrain users to watch content in the least data demanding way. Take the example of Tim (H3) and his choices of either watching BT Sport in standard definition on his YouView player, or in high definition on his Google Chromecast via his smartphone: Tim chooses the latter, yet devices and services could be designed to encourage the former (least data-intensive) device setup. Whilst previously discussed 'nudge' approaches for opt-in high definition video [51] may encourage standard definition viewing for some users, these are less likely to be effective for streaming 'connoisseurs' [6] like Tim. As a result, further encouragement *across devices* will be required.

Co-creating what amount of streaming is 'enough'. Our findings show that household members are watching separately; and some streamed content can be trivial for users. The emergence of smart home devices could be used to combat the associated demand: users' current Internet activities could be shared or made more visible (through displays, apps, or dis-aggregated views) in the household. Media-multitasking could be omitted by prompting users to choose between watching and the secondary activity; and multi-watching could be removed by bringing household members together for group-only streaming [72]. Both of these examples could exploit predictive algorithms to present options of what households could do or watch at a particular point in time, helping them to avoid any difficult activity choices or potential conflicts in content preferences between household members. Co-creating these guidelines and technologies *with* users could help them shift their streaming activities in more meaningful, family-orientated and sustainable directions; moving away from watching "alone together" [69].

Confronting 'all-you-can-eat' and 'binge-watching'

'All-you-can-eat' contracts for home broadband and cellular data have become common, enabling multiple devices and media-rich interactions. Some contracts include unlimited data for streaming (e.g. Three's *"Go Binge"* deal[7]) and bundle media subscriptions with contracts (e.g. EE customers can get free BT Sport [19], Sprint customers can access Hulu [20]); this encourages media consumption, further propagating default streaming norms and growing data demand. 'Binge-watchers' and perhaps less disciplined consumers (e.g. Ella, Ben, Fred, Kevin) are aware that that they are captured by auto-play [14] and the infinite availability of video on YouTube, Netflix and other forums e.g. Reddit.

How is it that *excess* is valued as neutral or even positive, in this context? Taking health as an analogy ('all-you-can-eat' food, binge drinking), overload is seen negatively [1, 4, 38]. Yet, binge use drives major selling points of Internet contracts. Ultimately, if binge-ing is bad for our health, why are ISPs and service providers allowed to promote data gorging? There is a real need to rethink regulations (e.g. caps) on what data demand or screen time providers can responsibly encourage, for the good of the user and the environment. Whilst previous HCI research has suggested that streaming services should help users gain more control over their watching sessions (e.g. by informing users when their 'optimal' viewing time has been reached or passed [14]), contributions to over-watching are much more pervasive than the design of a particular app. Our findings point towards a need for a more responsible stance on the 'all-you-can-eat' philosophies and business models of ISPs and cellular providers—all of which enable the prevalence of streaming in everyday life.

7 IMPLICATIONS FOR HCI

Rethinking UX and Quality of Experience

Within HCI, media-multitasking is looked upon as a positive user experience [18, 24, 44]. With our participants, this multitasking means that streamed content is not always fully utilised (or "consumed") and inherently makes watching more data demanding. Here lies a tension: HCI promotes innovative and improved user experience (UX), whereas SHCI highlights the need to be conscious of the utilisation and promotion of data demanding services [51, 72]. What if Quality of Experience (QoE) considered reducing data demand?

There is an opportunity to actively degrade QoE as a HCI intervention, deterring the data demanding forms of

[7] **http://www.three.co.uk/go-binge**, accessed 31st August 2018.

watching we present (e.g. multitasking and multi-watching) and helping users think about negotiable forms of watching [7]. HCI could work more closely with network systems researchers who are experts in, and drive the agenda of, QoE [22, 23, 25]. Through this partnership, HCI researchers and practitioners could: implement interfaces and services that nudge and shift users towards less demanding modes of watching [51]; be more instrumental in promoting network infrastructure running from renewable energy (e.g. data centres [8]); and help create Internet standards that support sustainability (e.g. IETF[8], ISO[9]). Collaborations like this could highlight the data impact of interaction changes in digital services prior to implementation, preempting effects on network operators (e.g. Facebook's effect by introducing video auto-play [59]).

Sustainable streaming contravenes net neutrality

One of the key points from our findings and discussion is that we might limit traffic in different ways to create less data demand, with potentially profound impacts on society (e.g. impacting the revenue of content creators using YouTube and Twitch). In particular, traffic limits are clearly at odds with ideas of net neutrality; this takes all traffic as equal and at an equal cost, guaranteeing a fair level of access and service to all. Our suggestions therefore coincide with the net neutrality repeal in the US [46] and conflict with policies such as the EU's Open Internet [13]. We are not against the social justice issues that EU policies protect; we suggest traffic limits for reasons of greater good (i.e. *environmental sustainability*) over increased profits for service providers. As a result, if video traffic should cost more to reflect its cost to the environment, these would have to be applied to *all* forms of video content; YouTube, Netflix, and the like would all have the same quota on watching traffic.

In some contexts, videos may still have to be treated differently (e.g. Emergency Broadcast System). This is a hard balance to maintain and cannot be resolved by HCI researchers alone. Policy makers are also required to consider the social, environmental and economic implications of surveilling, regulating and controlling portions of the Internet. HCI researchers should seek out policy makers for interdisciplinary investigations in this area. We are not the first researchers in SHCI to point out the need for wider political and societal involvement [10, 16, 17, 67]. To do this, HCI researchers could begin by approaching governmental departments (e.g. UK Department for Digital, Culture, Media, and Sport, US Department of Commerce's Digital Economy Agenda), or look to how previous HCI researchers have communicated with policy makers (e.g. International Policy Ideas Challenge [67]).

[8]`https://www.ietf.org/`
[9]`https://www.iso.org/`

Developing a robust evidence base for policy makers

Internet policies driving *"superfast"* and *"full fibre"* access [26] may only be fuelling more demand, as infrastructural capacity growth leads to an increase in demand [51, fig. 1]. From this standpoint, it is clear that policy makers have not made the connection between binge-watching and all-you-can-eat marketing and data demand. Possibly blinded by the utility of Internet, there has been little discussion on the energy impact of the Internet and its services within public policy (perhaps only a recent report by Policy Connect [42]). How can HCI researchers help policy makers consider the growing environmental impacts associated with data demand?

HCI researchers need to build robust knowledge bases and engage with creation of more *responsible* policy when it comes to ICT. Not only should new norms of everyday data demand be considered (e.g. the new ways of watching we present), but also emerging Internet-based technologies (e.g. cryptocurrencies, IoT, smart homes and connected cars) and broader SHCI topics that require policy engagement [10, 16, 17, 67]. This will involve HCI researchers providing policy makers with ideas (e.g. designs, interventions), and evidence of their sustainable effect, that affect different aspects of HCI e.g. users themselves, interfaces HCI practitioners create, and subscription designs that service providers introduce. How HCI researchers would then present these to policy makers is still in question, much like our net neutrality implication. Perhaps the largest hurdle here in HCI (and at CHI) is finding the appropriate venues to promote these discussions and affect change in systems, interfaces and policies.

8 CONCLUSION

In this paper, we have explored the most Internet-demanding activity in the home: watching. We have shown how video-on-demand activities are composed, how these link to streaming services, and how they continue to evolve in new 'data demanding' ways. We have identified opportunities for the HCI community to reduce watching data demand; highlighting broader implications for HCI and society—showing how HCI and other communities (e.g. policy makers, network engineers, service designers) do, and should, interlink. It is time that we, as a society, work together to redefine our watching futures and begin dealing head-on with the unsustainable trajectory of this data demand.

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