BBC

Research & Development White Paper

WHP 372

September 2020

Using Behavioural Data to Assess the Environmental Impact of Electricity Consumption of Alternate Television Service Distribution Platforms

Daniel Schien (University of Bristol), Paul Shabajee (University of Bristol), Jigna Chandaria (BBC R&D), Dan Williams (BBC R&D), Chris Preist (University of Bristol), Chloe Fletcher (BBC R&D)

BRITISH BROADCASTING CORPORATION

BBC Research & Development
White Paper WHP 372

Using Behavioural Data to Assess the Environmental Impact of Electricity Consumption of Alternate Television Service Distribution Platforms

Daniel Schien (University of Bristol), Paul Shabajee (University of Bristol), Jigna Chandaria (BBC R&D), Dan Williams (BBC R&D), Chris Preist (University of Bristol), Chloe Fletcher (BBC R&D)

Abstract

Digital technology and entertainment is a significant driver of electricity use globally, resulting in increased greenhouse gas emissions. Research has been conducted on electricity use associated with digital services, but no complete study of television distribution has been conducted to date.

Here, we present the first assessment of electricity used for distribution and viewing of television over different distribution platforms - terrestrial, satellite, cable and online streaming. We use a novel methodology that combines life cycle assessment techniques with models of the diversity of actual user behaviour, derived from detailed audience monitoring and online behaviour analytics data. This can be applied to assess overall electricity usage for a given media company's services and allows comparison of the electricity demanded per viewer-hour of each distribution platform.

We apply this to a representative national TV provider – the British Broadcasting Corporation (BBC) – and show the mean estimate for BBC distribution and viewing electricity use in 2016 to be 2,000 GWh, resulting in emissions of 1.03 $MtCO_2e$. We show that viewing over streaming, cable and satellite platforms used a mean of 0.15-0.19 kWh per device-hour (78-98 gCO_2e) while terrestrial broadcast used a mean of 0.06 kWh (31 gCO_2e). We identify set-top boxes and televisions as key hotspots in the system. We also show that though streaming is similar in impact to cable and satellite, this is due to smaller viewing devices – meaning the networking equipment in and beyond the home has a higher impact than the end device.

The results of this white paper were amended in June 2021 to align with ongoing BBC energy modelling and benchmarking. The overall conclusions remain the same.

Additional key words: Broadcasting, Digital, Energy Efficiency, Environmental Impact Assessment, Life Cycle Assessment, Streaming, User Analytics

White Papers are distributed freely on request.

Authorisation of the R&D Section Head or Head of Standards is required for publication.

BBC Research & Development
White Paper WHP 372

Using Behavioural Data to Assess the Environmental Impact of Electricity Consumption of Alternate Television Service Distribution Platforms

Daniel Schien (University of Bristol), Paul Shabajee (University of Bristol), Jigna Chandaria (BBC R&D), Dan Williams (BBC R&D), Chris Preist (University of Bristol), Chloe Fletcher (BBC R&D)

1 Introduction

Digital technology and entertainment is a significant driver of electricity consumption globally (Malmodin et al., 2010), and service use is both growing and changing in nature. Research has been conducted on understanding and quantifying residential electricity use, including that associated with home entertainment equipment (Yohanis, 2012; Drysdale et al., 2015; Stankovic et al., 2016). However, there is little research which studies the electricity use of the entire television system end-to-end. Such work could identify opportunities to reduce electricity use in the short term, help understand the impacts on electricity demand due to future changes in the system, and allow electricity consumption to be incorporated in both technical and strategic decisions regarding the design of associated transmission and distribution systems.

In this paper, we provide a methodology for conducting such work, together with an example. We demonstrate how to quantify the total electricity used to distribute ("transmit") and consume ("view") television services by a provider who offers diverse distribution platforms to their customers. We illustrate this by applying it to the British Broadcasting Corporation (BBC), and calculate the electricity used to deliver and view BBC services over different distribution platforms throughout the UK for the year 2016. The BBC is a representative large broadcasting organisation serving a national audience, and offers services using terrestrial and satellite broadcast, cable and streamed video technologies. We identify hotspots in this system which would enable electricity use reductions in the short term, and provide guidance for large broadcasting organisations, media providers and policymakers for where to focus reduction efforts. We also provide insights as to how such hotspots might change in the future as a result of changing service usage patterns.

Life Cycle Assessment (LCA) has been identified as a key methodology to assist in understanding the environmental impacts of industrial processes and the products they produce. It has been widely used to assess the environmental impacts of both consumer electronics (Subramanian & Yung, 2016), and ICT products (Arushanyan et al., 2014). It has also been used to assess digital services and the associated greenhouse gas (GHG) emissions from electricity used to provide those services (Moberg et al., 2010; Weber et al., 2010; Moberg et al., 2011; Coroama et al., 2012; Schien et al., 2013b; Hischier et al., 2014; Shehabi et al., 2014; Mayers et al., 2015). Often, this is in comparison with

alternative traditional forms of services such as a printed paper vs. digital, critically reviewed in Bull & Kozak (2014), or a physical vs. virtual conference (Toniolo et al., 2017). It can also be for specific classes of services, such as Internet advertising (Pärssinen et al., 2018). Most relevant to our work is that of that of Chandaria et al. (2011) who conducted a scoping LCA for emissions associated with electricity use for one hour of BBC viewing for a typical viewer via terrestrial broadcast and digital platforms.

These studies tend to focus on a functional unit of a single service (e.g. one hour of viewing) to a customer. In doing this, they often identify that user practices and choices can make a significant difference to the actual impact, therefore making general conclusions difficult to draw. It is particularly difficult to make conclusions about the impact of the entire community of customers. To do so requires a model of behaviour for such customers. One approach is to model the "typical" customer and their choices, an approach adopted by Achachlouei et al. (2015). Yet, as they observe in their section on limitations and follow-on work, such an approach may miss important subtleties – it may be that a small number of "atypical" customers might have a disproportionately large impact. As Schien et al. (2013b) demonstrate, this variability can have a significant effect on the impact associated with digital services. In order to reduce uncertainty of an assessment, the inherent variability in the behaviour of users and the characteristics of the system infrastructure need to be adequately accounted for.

This is an area where digital technology has an advantage. Digital systems allow for detailed analytics that can be used to identify the behavioural choices made by each user. This, combined with an LCA model that is parameterised according to such choices, can give a more detailed and nuanced picture of the overall footprint of a service than assuming a "typical" user does. This approach has been used by Schien et al. (2013a) to calculate the carbon footprint of the Guardian News and Media website over a period of a month, and to estimate the global footprint of YouTube using publicly available aggregate data (Preist et al., 2019).

We extend this approach in this article to allow for the assessment of large media organisations with heterogeneous methods of distribution. We can use information such as user analytics, audience monitoring data, and sales data to help build a model of heterogeneous behaviour for a given media organisation. In turn, this allows for the creation of a bottom-up model of the impacts of viewing by summing the consequences of each individual decision across the whole of the consumer population. As Chan et al. (2013) demonstrate in the context of mobile networks, this bottom-up approach can avoid errors that result from dealing with aggregate data in models.

The contributions of this paper can be summarised as follows. We present the first comprehensive assessment of electricity usage for the distribution and viewing of television by a large media company. The analysis incorporates a variety of distribution platforms, from traditional terrestrial broadcast to on-demand streaming over the Internet, and allows comparison of the electricity demanded per viewer-hour for each. Our method combines LCA techniques with models of the diversity of actual user behaviour, derived from detailed audience monitoring and online analytics data. The process model and secondary data we

present are general, and can be applied to any large media company. We offer insights for TV service providers and policymakers to reduce current hotspots. We also offer insights with regard to the potential impacts of future changes in TV distribution and viewing, and provide a baseline against which these changes can be assessed.

Note, this white paper was re-published in June 2021 with amendments to the results and figures. These edits were made in line with the updated model used for ongoing energy modelling in the BBC, which differed slightly to the model used in the original publication. The changes were made to provide a consistent benchmark to compare future energy consumption against. Whilst the resulting values altered – for example, the total energy reduced by approximately 8% – the overall methodology, messages and conclusions remained the same. As such, the text used throughout align with, and are largely identical to, the original.

2 Methodology

LCA is a methodology that permits the estimation of the *environmental burden* associated with the production and use of a product or service. We adopt the GHG Protocol Life Cycle Reporting standard (Greenhouse Gas Protocol, 2011) and more specifically we work within the guidelines of the GHG Protocol ICT Sector Guidance (Greenhouse Gas Protocol, 2012) Chapter 4 'Guide for assessing GHG emissions of Cloud Computing and Data Center Services' in relevant areas of our system. We go beyond it in our use of detailed behavioural data, obtained from online and in-home audience monitoring, to produce a model of the heterogeneous behaviour of users. This is used to parameterise the LCA such that the total electricity usage (and associated GHG emissions) can be calculated for a given service.

In the following sections, we provide details of the methodology used and decisions made. Firstly, we provide a summary of the steps involved, focusing on the novel aspects of our approach. These steps are to:

1. Develop a detailed process model of the system under study, ensuring that it is parameterisable and the multiple processes involved in different patterns of user behaviour are captured within. In our case, the process model includes terrestrial, cable and satellite broadcast, and Internet access both in the home and over mobile networks. Parameterisation allows variation in factors such as TV screen size, time of viewing and image bit rate.
2. Collect user behaviour data and from this identify the different configurations of the system they use – in other words, different 'pathways' through the process model. In our case, the data we use comes from two sources. For Internet access, we use detailed user analytics data. From this, it is possible to determine different devices used, how long they were used for and their data bit rate, and the type of connection (Wi-Fi, mobile, landline). For broadcast viewing, we use detailed data extracted from the Broadcasters Audience Research Board (BARB) survey. This survey monitors in real-time the viewing behaviours of a representative sample of UK households, and is used to produce authoritative and independent audience viewing figures. The more detailed data behind this allowed tailored reports on the different

viewing configurations, and parameters such as distribution of TV size and viewing hours, to be obtained.

3. Cluster the user data for each of these configurations, and aggregate the data to give a total system usage in the given configuration. In our case, this consists of the total viewer-hours for the population, the mean screen size and image bit rate of that configuration.
4. Use the LCA process model to calculate the total material flow (or, in our case, electricity usage) for each configuration and sum these.
5. Assess parts of the process model which are independent of user configuration and add to the configuration result. In our case, these are process elements such as coding and multiplexing which are shared between many users and unaffected by choice of configuration.

Having provided an overview of the approach we use, we now give a detailed description of the method and document the choices made within.

2.1 Goal, Functional Unit, Scope and System Boundaries

The goal of this study is to calculate the electricity consumption associated with the distribution and use (i.e. broadcast and viewing) of a national-scale television service, identify hotspots within this, and determine the current energy intensity of different distribution platforms. As noted above, we use the BBC as a representative case study. In presenting our results, we adopt two functional units. To assess the demand placed on the UK electricity system, our functional unit is the delivery and viewing of one year of BBC television to the UK population. To assess the energy intensity of different distribution platforms, our functional unit is the provision of one hour of video content to a viewer.

The scope of the study includes mainstream means of distribution and viewing. Distribution includes digital terrestrial broadcast (via Freeview), cable TV multicast, satellite broadcast (via Freesat or Sky) and distribution over the Internet (via the BBC iPlayer service). Each of these involve different delivery platforms that lead to different infrastructure and reception equipment in a viewer's home. Viewing can be on a television set or on a portable consumer electronic device such as a laptop or smartphone. Further information about what is included are provided in the Process Description.

As our goal is to understand the electricity consumption associated with distribution and viewing technologies, we do not consider energy usage resulting from the production of TV content, manufacturing and use of DVDs, manufacturing of infrastructure and devices, or launching of broadcast satellites.

2.2 Process Description

The process model defines the diverse ways in which viewers can receive and watch television content. Figure 1 gives a simplified version of the process model. It consists of three stages: **preparation**, **distribution,** and **consumption**.

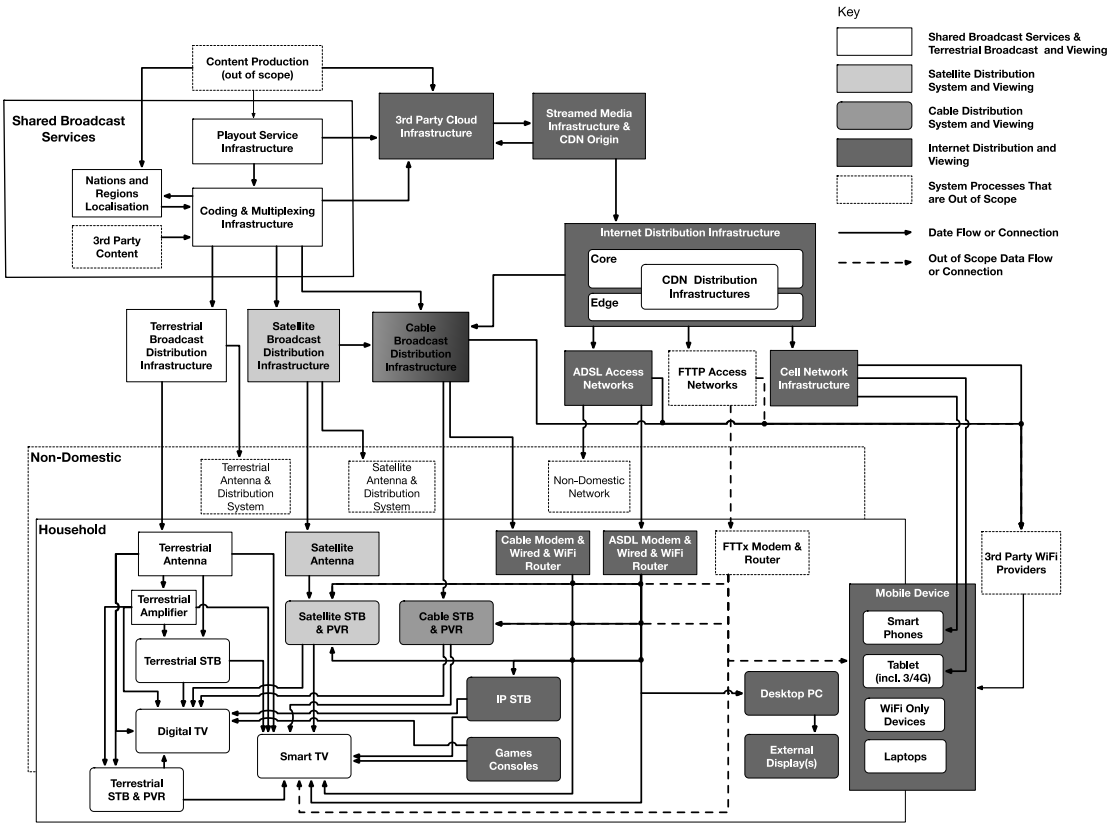

Figure 1: Processes involved in Television Distribution and Viewing

2.2.1 Preparation

Firstly, live or pre-recorded content is sequenced as needed for transmission through digital equipment responsible for *playout*. This is then converted (through a process of *encoding and multiplexing*) into forms appropriate for broadcast. Encoding reduces the bit rate of the content through the use of audio and video compression techniques. Multiplexing is the process that bundles together multiple encoded streams of video, audio and data prior to distribution. The final multiplexes are then sent to the appropriate broadcast distribution infrastructure. A high-quality feed is also sent to digital storage for Internet distribution. In the case of the BBC, this is cloud storage hosted by Amazon Web Services.

2.2.2 Broadcast Distribution

Distribution of content for broadcast takes place in three main ways:

1. Digital terrestrial television (DTT) distribution consists of relaying the signal to a network of transmission stations over the service area. For the BBC, there are over one thousand transmission stations across the UK. Relaying is carried out by a dedicated high-performance distribution

network carrying a number of multiplexes, each of which is associated with a specific antenna at each transmission station. This transmitter network is managed by a third-party company, Arqiva. The BBC uses a share of three multiplexes which are internally and publicly referred to as PSB1, PSB3 and COM7. Some homes will have aerial amplifiers to boost the DTT signal.

2. Satellite distribution consists of relaying the signal to an Earth Station Uplink, which transmits the signal to the satellite for broadcast. At the BBC (and most other broadcasters), there are two of these with one acting as a hot backup (i.e. working and ready to take over in case of failure of the primary).
3. Content for cable distribution is fed to the cable providers via two routes depending on the content type:
    a. High Definition (HD) channels are provided via a fibre link of uncompressed audio, video and subtitle streams that are encoded and multiplexed centrally by the cable network operator.
    b. Standard Definition (SD) channels are received from the direct-to-home satellite feed described above.

    In both cases, the channel feeds are transmitted over the cable operator's private fibre data network to a number of regional cable head-end sites across the service area, and thence to local cable hubs on street corners, which, in turn, relay the signals on to individual subscriber homes via a co-axial final drop cable.

2.2.3 Internet Preparation and Distribution

Internet distribution can take place for both live and on-demand viewing via the BBC iPlayer service. Unlike broadcast distribution, Internet distribution today occurs through unicast Internet Protocol packet switching, which means an individual stream of data packets is generated for each viewer.

BBC content served across the Internet in the UK shares the initial playout process with the other delivery modes, but otherwise is an entirely separate set of processes.

Both storage of master content and video encoding for streaming are carried out using datacentre facilities. For the BBC, this is cloud-based and presently provided by Amazon Web Services. The elastic nature of cloud services – meaning they can be scaled up at times of higher demand and reduced at other times – is helpful in dealing with peak periods such as the preparation of multiple early-evening regional news bulletins, and reduces overall energy consumption for encoding.

Prepared content is transferred and stored temporarily in a set of caching servers which act as the origin for online content. For the BBC, as with most large media providers, these are in-house within the BBC's datacentres. This, in turn, is distributed using *Content Delivery Networks* (CDNs). CDNs are effectively distributed datacentres allowing the storage ("caching") of copies of the origin content at a number of locations around the country. This means that customer requests are satisfied by local servers, reducing the demand on the core network

and the latency in serving a request. The BBC uses several CDNs, one of which (BIDI) they operate themselves.

CDNs acquire content across the *core* and *edge* network segments of the Internet for both fixed and mobile Internet Service Providers. It is then served from a CDN edge cache to the user's receiver device via the Internet Service Provider's local *access network* equipment. For domestic installations, the access network is terminated at a home modem or router with in-home distribution to receiver devices typically over Wi-Fi. Outside the home, a mobile cellular network (3G, or 4G) provides access directly to the user's terminal equipment such as a smartphone. A simplifying assumption made is that all Wi-Fi reception is within home network environments rather than third party out-of-home Wi-Fi providers, like cafés or transport companies.

2.2.4 Consumption

Viewing content can take place on a number of different devices. Most common is the traditional *television set* which encompasses a number of different screen sizes and resolutions, and which may have other features such as high dynamic range (HDR). Often, the TV set is fed from a set-top box (STB) that decodes broadcast (terrestrial, satellite or cable) or Internet signals. In some cases, the STB also acts as a personal video recorder (PVR). In modern TV sets, some of this functionality may be built in. For example, most modern sets include at least one terrestrial receiver; some can be extended to add in recording capabilities; and a few include an integrated satellite (Freesat) receiver. Furthermore, new smart TVs also allow direct reception of Internet services such as BBC iPlayer. In some cases, games consoles are used to access such services and display them on a TV set.

Although the traditional TV set is the most commonly used device to view TV services, other types of consumer electronics device are also being used to access Internet streaming services such as iPlayer. These devices can be personal computers (desktops and laptops), which may have external displays attached to them, or mobile devices such as smartphones and tablets. Although viewing often takes place at home, the use of streaming over mobile networks means viewing can also take place outside of the home.

3 Assumptions

3.1 Data Sources and Allocation

In this subsection, we give a detailed overview of the various data sources used and approaches adopted to allocate burden within the parts of the system described above. We present this information in terms of the process stages. Details of all data, together with a measure of data quality for each, are provided in the appendix. With the exception of the BBC-specific primary data, this can be applied to any media company.

3.1.1 Preparation

3.1.1.1 Playout and Injection of Localised Content

The third-party provider of linear channel playout services provided primary power data for the overall playout datacentre, allowing its yearly energy

consumption to be calculated. BBC is not the only customer of this. A share of the yearly energy consumption of the playout datacentre is allocated to BBC services based on an estimate of the BBC share of the service calculated by BBC R&D (Research & Development) staff from confidential service documentation. In addition to the datacentre, there are several other less energy-intensive sub-processes involved in playout. Electricity use figures for these processes are not available and have been estimated by BBC R&D engineers to be of the order of 12-24% of the energy use of the datacentre.

In addition to primary playout, localised programming (e.g. local news) is produced in three national and 15 regional or sub-regional studios. This uncompressed high-definition video is injected via a private internal network that transfers content to the national and regional locations where local content is injected into the feed and returned for encoding and multiplexing (see Encoding and Multiplexing section). The energy in this network transfer is modelled as a standard Internet data transfer based on the estimated data volume.

3.1.1.2 Encoding and Multiplexing

Primary energy data for 2015/16 was provided for the BBC's encoding and multiplexing datacentres. This included power, cooling, power supply losses, and, most significantly, the maintenance of a geographically separate "hot spare" datacentre to ensure continual service.

3.1.2 Terrestrial Broadcast Distribution

The private distribution network and transmitters for terrestrial distribution are run by a third party, Arqiva, as a service to the BBC and other UK terrestrial broadcasters. Arqiva provided primary data on energy use for equipment associated with the PSB1 and PSB3 multiplexes, including an allocation of energy from networking equipment shared with other broadcasters. The BBC's share of each multiplex is calculated as the BBC's proportion of the overall average bit rate of a given multiplex. Primary energy data for COM7 was not provided, but an estimate has been calculated as 70% of the average of PSB1 and PSB3, because COM7 provides service coverage of approximately 70% that of the other two multiplexes.

3.1.3 Satellite Broadcast Distribution

An estimate of the power, and therefore yearly energy requirements, of the satellite uplink equipment was obtained from BBC engineers. Energy expended by the satellite itself is outside the scope of this study.

3.1.4 Cable Distribution

We calculate the electricity associated with cable distribution by using the Scope 2 emissions reporting data for the main cable provider in the UK (Virgin Media, 2017). The Scope 2 emissions correspond to the quantity of electricity purchased by the company, which can be calculated using the UK emissions factor for the given year. We have attempted to separate out electricity use associated with running the company offices, based on likely upper and lower bound values of Scope 2 per occupant from BBC and University of Bristol corporate reporting.

The cable network operator also reports on the total number of STBs and broadband modems they serve in the UK. We allocate a share of their total electricity used for TV provision based on this ratio. Finally, we allocate a share of electricity used for TV provision to the BBC based on the ratio of BBC to total viewer hours on cable platforms. This gives the energy used per cable household for the cable company. We use this figure for all households with a cable connection, including those served by other companies.

3.1.5 Internet Preparation and Distribution

Data from Amazon Web Services gives hourly figures for the number of virtual server instances of different classes used by the BBC. From this, the total number of physical machines of different classes was estimated, and industry power data was used to estimate the energy used in a typical week. Not all of this is used for storage and processing of BBC iPlayer television content: some is used for other BBC services. There is no direct data available for an estimate of the relative proportion of usage for iPlayer. We therefore modelled this with high uncertainty where the total energy was used as an upper bound, half of the total as a lower bound and the mean set to 75%.

Primary data is used for the daily mean power consumption per server. This enables the calculation of overall energy use by the origin servers. In addition, the BBC has provided daily data for the average power consumption and data volumes served by the BIDI Content Delivery Network which they own and manage. From this, it is possible to calculate the energy required to download a gigabyte (GB) of data from the BIDI CDN. This is used as proxy data for the third-party CDN services that the BBC also uses.

There are divergent estimates for energy use associated with transfer of data through the core and edge segments of networks, as reviewed in Coroama & Hilty (2014). Subsequent work by Schien & Preist (2014) has shown that reconstruction of assumptions in earlier work can reduce this level of divergence, and hence come up with a consensus estimate from the different approaches. We adopt this figure to estimate energy usage of the Internet Service Provider's (ISP) network, extrapolated to the reference year.

We adopt a similar approach to handling access over mobile cellular networks, and use estimates of the energy required per GB transferred over 3G and 4G from Andrae and Edler (2015). iPlayer analytics data provides an estimate based on ISP networks on the percentage of requests that are over cellular networks. This accounts for approximately 9% of smartphone viewing. We do not have direct estimates of the proportion of iPlayer viewing over 3G (LTE) relative to 4G. It seems likely that 3G and 4G iPlayer use takes place outside of the home, with Wi-Fi used inside the home. Ofcom (2016) reports that overall data volumes of 3G and 4G usage were approximately 40:60, respectively. We use this ratio in the model to estimate the amount of data transferred over 3G and 4G networks.

We use power data for fixed broadband access network equipment, such as Digital Subscriber Line (DSL) Access Network equipment, shared between multiple households and home Wi-Fi routers, and allocate this based on data volume transferred. The full list of sources of input parameters is included in the appendix.

3.1.6 Home Equipment and End-User Devices

The majority of UK households view BBC TV services through at least one of the delivery modes available, but how this is done can vary widely. These differences can impact energy consumption. Past assessments of digital services have estimated energy consumption of user devices by assuming a homogeneous distribution of devices across the population. For example, an average value for the power draw of television sets is used across the entire population. Yet, it might be that those in the population with larger, more energy-intensive sets watch more TV than those with smaller ones, meaning an estimate of energy consumption using a simple mean power value for the whole population would underestimate the overall energy. For this reason, we avoid adopting an approach where we model a statistically "average" household as representative, and instead aim to capture this diversity in our estimate. We represent populations of devices and demographics at a much higher granularity than in previous work. This makes our estimate more robust.

Detailed demographic and TV viewing device population data is provided to us by BARB. This is obtained through in-home continuous monitoring of viewing behaviours of a representative sample of the UK population. The BARB Establishment Survey (BARB, 2018) provides data on population profiles, access to TV viewing platforms, and ownership of television reception equipment.

Using this, we are able to model households as three types based on primary TV viewing platform.[1] Those that:

1. Only receive DTT
2. Receive Satellite (Sky, Freesat or other) TV, a proportion of which also receive DTT
3. Receive Cable TV, a proportion of which also receive DTT

(less than 1% of households have both satellite and cable)

An analysis of the BARB Establishment Survey demonstrates that these different types of households have substantially different demographic and device profiles. For example, the mean size of DTT-only households is 2.0 people, with 43% of those being single-person households and 41% of households' main TV screen size being over 40 inches, whereas for satellite households, there are on average 2.6 people, with 20% single-person households and 66% of TVs over 40 inches.

The value of these distinctions can be illustrated in our approach to modelling energy consumption. We identify several a number of different equipment *configurations* a customer can have when viewing BBC services. Each configuration consists of a choice of viewing device, and equipment associated with reception or access. To illustrate, we provide a few example configurations:

[1] Households which have no primary television and watch BBC content only over digital devices ("cord cutters") are not captured in the BARB Establishment Survey but are captured in the iPlayer analytics data (see below).

- A TV and STB recording from a satellite broadcast and viewed later;
- A laptop connected to iPlayer through a home cable modem and Wi-Fi router;
- An integrated TV set including a built-in Freeview receiver receiving terrestrial television;
- A tablet device using the BBC iPlayer app over the cellular mobile network.

We estimate the number of *device viewing hours* (i.e. hours that devices are actively receiving, displaying or recording content as distinct from viewer or "eyeball" hours) using each configuration over a period of a year by using viewer data from two sources:

- For viewers watching television channels via the three main broadcast distribution platforms, the BARB Establishment Survey, a BARB commissioned report of total *viewing hours*[2] and proportion of BBC viewing by device type, and the BARB "quality control" report used to estimate "uncovered viewing".
- For iPlayer consumption, the BBC user analytics data from this service provides rich data. It can tell us the distribution of devices used, how long viewing took place for, the mean bit rate by device type, and estimates of numbers of Internet connections via Wi-Fi and cellular mobile networks. This can be used to estimate how many device-hours took place in any given configuration and how much data was transferred.

From the Establishment Survey data, it is then possible to characterise these household types in terms of their television viewing configurations, including average sizes of main and non-main TV sets, percentages of satellite and cable households that have DTT receivers, and use of STBs. It is also possible to characterise the distribution of household sizes.

Combined with the data for viewing durations by device types, this modelling gives an estimate of the number of people who view different BBC programmes using different equipment configurations. This can also be used to give a reasonably accurate estimate of the number of viewer-hours that have taken place in the UK over a period of a year for each configuration. These can be converted to *device viewing hours* based on estimates of shared viewing. We model shared viewing based on household size profiles by household type, weighted by estimates of shared viewing ratios: 1.0 for one-person households, 1.5 for two-person households, and 2.0 for household sizes greater than three. We consider the significance of this assumption in the sensitivity analysis of the results.

Account also needs taken of *digital waste* (Preist & Shabajee, 2010), where a service is provided but not used. This takes two forms: *uncovered viewing* where a TV set is left on with no viewer, and *over-recording*, where a STB records content that is never viewed. The former is estimated from BARB's quality control reports for "uncovered viewing". The latter is modelled via an "over

[2] Including recorded content viewed within 28 days.

recording ratio", which is a ratio of total duration of recorded content viewed to duration of content viewed. Currently, this is modelled as a mean value of two based on expert opinion via BBC R&D.

For each configuration, we calculate the typical power consumption of the equipment involved. The power consumption of television sets can vary significantly and, in particular, is affected by the screen size and resolution. Hence, to calculate the power consumption of TV sets in the population, we need to account for screen size and resolution variation. The BARB Establishment Survey gives data about the relative number of sets with different screen sizes in households of each types listed above, and distinguishes between main and (usually smaller) secondary TVs within a household. The sizes are grouped into four bands: under 20", 20"–29", 30"–39", over 40", and "don't know". To determine the power consumption of TVs with different screen sizes, we conducted a linear regression using the EnergyStar database for the BARB screen size bands. To this, we added an uplift of 18.5% to the power value (highly uncertain and so modelled with lower bound 0% and upper 37%), based on the knowledge that not all TVs are EnergyStar certified[3] and that not all TVs are set by users in their optimal energy mode. We then used the BARB data to calculate the weighted average power consumption from these figures to determine the overall average power consumption of a main and secondary TV set in each household type.

BARB standard reports provide viewing in a household but do not report whether a given viewing takes place on the main or secondary TV set. A special report for 2017 (BARB, 2017b) estimates that 14% of viewing overall is on secondary TV sets. We use this figure to set our "main to secondary TV viewing ratio" appropriately.

For other equipment, we use a combination of EnergyStar data, direct measurements of a number of different equipment models made at the BBC R&D labs, industry, and community reporting of power use.

For all end-user equipment, we use a simplified version of the EnergyStar power state model approach. We model them as having three power states: on (displaying or feeding the display with a picture and sound), active standby (recording but not displaying or feeding the display or sound), and passive standby (on at the socket, but not recording or playing content, and awaiting control signals). We assume that they are not switched off at the mains supply and so drop to passive standby when not providing a service.

In practice, energy-using behaviour is quite specific by device type and may or may not use all three states. For example:

- Domestic modem and Wi-Fi routers are always "on" and operate at relatively constant power consumption levels that vary little according to workload.
- Most flat screen TVs have fairly constant "on" power and very low passive standby.

[3] EnergyStar estimate that EnergyStar TVs are, on average, 27% more energy efficient (EnergyStar, 2018)

- STBs and PVRs mostly use all three distinct states.

Where a configuration uses the Internet, we determine the quantity of data downloaded and use estimates of the energy intensity of data transport for the core and edge ISP network segments and cellular mobile access network as appropriate for the given configuration.

To ensure "energy-balance", we must allocate a proportion of the energy associated with periods when equipment is in an idle but energy-consuming state. For equipment exclusively involved with consumption, such as TV sets and STBs, it is possible to use the BARB viewing data to determine the average time these devices are idle in the UK. This, together with idle (passive standby) power consumption data from the sources listed above, can be used to estimate the energy consumed by such equipment nationally in their idle state. This is allocated proportionally to the BBC based on its share of UK viewing time.

For generic smart devices, including laptops, smartphones and tablets, we do not allocate any idle time. These devices tend to be on for a different function, such as the reception of email, phone calls and social media updates, or are in a very low-powered idle state.

Key modelling limitations, aside from the modelling assumptions mentioned above, include the following:

- Only domestic non-iPlayer television consumption is included, not, for example, viewing in hotels, gyms, offices, bars, and other public spaces. This is because BARB viewing and establishment surveys do not cover these; however, we understand that a small BARB study (BARB, 2017a) indicates that viewing, other than in other people's homes (already captured as device viewing), is of the order of less than 5 minutes per day on average. In addition, BARB viewing figures do not include some categories of accommodation, such as student residences or care homes.
- The hosting and distribution of non-video iPlayer web assets, such as web pages, stylesheets, JavaScript libraries and static images, are not included due to lack of data availability. The data volumes and hardware required, however, are small compared with providing the video content itself.
- We assume all Wi-Fi access is from home, rather than modelling differences in consumption in out-of-home access venues such as café and office infrastructure.
- In the 2016 model, we have not included Fibre to the Premises (FTTP) networking as uptake levels in domestic settings were approximately 1% at that time.

3.2 Representing Uncertainty and Variability

As with all models used in LCA, our understanding of the system is subject to both aleatory variability and epistemic uncertainty. In our model, the most common cases of aleatory variability are with system processes that represent a set of several alternative models of infrastructure, all of which are well understood. An example is our assumption of an average cellular network energy

efficiency that in fact varies with cell size and cellular base station utilisation. On the other hand, there are system processes that we know of, the details of which, however, we have no information about. These processes are epistemically uncertain. We handle both of these by representing variables in the model as distributions, rather than working with average values alone, and performing a Monte Carlo simulation (Weidema & Beaufort, 2001) on the whole model that draws from these distributions. The final result is a distribution with a mean value identical to the result of a scalar model that also represents confidence intervals wherein the true energy consumption and carbon emissions value will likely lie.

Variability occurs based on choices made by the user population, such as what device to view on or which STB box model to purchase. Although we aim to model much of the variability endogenously – in particular, through our use of configurations described above – we cannot do so completely. It is possible to reduce the variability of the system processes by representing them in more detail; however, this results in greater model complexity and requires additional data collection, thus forming a trade-off. We can use sensitivity analysis to decide on that trade-off by calculating the relative effect of input variability on the output variability.

To illustrate, we have an estimate of the number of people using cable STBs or TV sets, but we do not know exactly which models they are using. To handle this, we estimate mean power-use profiles for each type of device and assign a probability distribution based on the knowledge of the values associated with different models. These are necessarily approximate, and we tend to take conservative bounds rather than underestimating uncertainties.

We chose the distribution function that fits the available data. In cases where only minimum and maximum values (and, possibly, a most likely value) are known, we sample from a triangular distribution. In cases where only an assumption for the average value is available, we commonly use a normal distribution with some context-dependent assumption for the standard deviation.

Epistemic uncertainty occurs when we have imperfect knowledge about the variable within the model. This is often based on expert knowledge, so again we use conservative bounds. For example, we use a wider range for a variable such as Satellite Uplink energy, which is estimated by BBC R&D staff based on their knowledge, rather than playout datacentre energy use, where we have primary data based on energy bills. Similarly, we use a range to represent the energy use of cellular access via 3G and 4G based on different values reported in the literature. Full details of the ranges adopted are provided in the Appendix.

4 Results

Figure 2 presents a boxplot of the overall results based on a Monte Carlo simulation of 10,000 runs. It presents the distribution of total energy consumed to deliver and view BBC television services over a year, and the results broken down according to delivery platform. The vertical lines at the centre of the boxes represent the median values. The left and right borders of the boxes represent the first and third quartiles, respectively, defining the inter-quartile range. The lower and upper whisker marks represent the 5th and 95th percentiles, respectively.

Our analysis estimates overall energy used for the delivery and viewing of BBC television services in the UK in 2016 to be 2,000 GWh (0.6% of total UK electricity use; UK Department for Business Energy & Industrial Strategy, 2017). This results in an average power consumption of 228 MW.

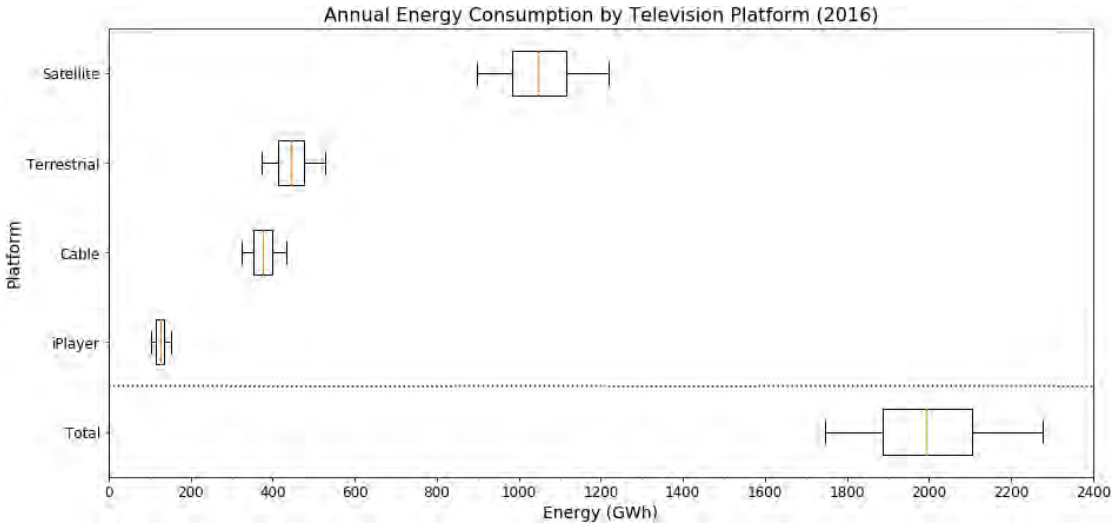

Figure 2: Estimate of total 2016 electricity use per annum by the BBC distribution and consumption, and electricity use by each distribution platform, based on a 10,000 run Monte Carlo simulation

Using the UK Government emission conversion factors for greenhouse gas company reporting for 2016 (UK Department for Business Energy & Industrial Strategy, 2016), we include the Scope 2 factor of 0.412 $kgCO_2e/kWh$, the Scope 3 factors for transmission losses and 'Well to Tank' factors for both generation and transmission that total 0.105 $kgCO_2e/kWh$ to establish a total emissions factor of 0.517 $kgCO_2e/kWh$. Therefore, the total energy used for the delivery and viewing of BBC television services in 2016 produced approximately 1.03 $MtCO_2e$ (million tonnes of CO_2 equivalent) emissions, equivalent to 0.2% of total UK emissions in 2016 (467.9 $MtCO_2e$; UK Department for Business, Energy & Industrial Strategy, 2018).

In the results that follow, the figures in square brackets are $MtCO_2e$ figures based on the emissions factor above. Energy use associated with shared infrastructure is allocated between platforms based on their proportion of overall device-hours of BBC viewing.

The total energy use associated with satellite viewing was greatest at 1052 GWh (53%) [0.54 $MtCO_2e$], followed by terrestrial viewing at 446 GWh (22%) [0.23 $MtCO_2e$], cable viewing at 377 GWh (19%) [0.19 $MtCO_2e$], and iPlayer viewing at 126 GWh (6%) [0.07 $MtCO_2e$].

We now consider electricity used per device-hour of viewing. Figure 3 gives an average per device-hour figure for different platforms, with iPlayer at 0.19 kWh/device-hour [98 gCO_2e/device-hour], satellite at 0.16 kWh/device-hour [82 gCO_2e/device-hour], cable at 0.15 kWh/device-hour [78 gCO_2e/device-hour], and terrestrial at 0.06 kWh/device-hour [31 gCO_2e/device-hour].

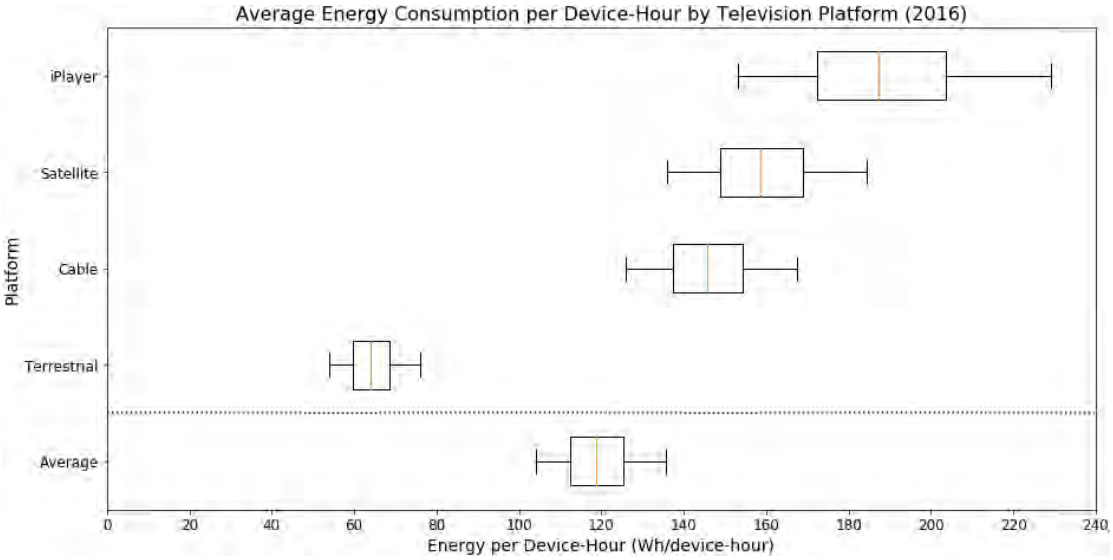

Figure 3: Estimate of energy use of distribution and consumption for one device-hour of BBC content over different distribution platforms (2016-01 to 2016-12).

If we consider the different processes and devices involved in the delivery of the overall service, we see that the bulk of electricity use occurs within the home (including mobile devices). Home equipment was responsible for around 1,852 GWh [0.96 $MtCO_2e$] in 2016 (0.5% of total national and 1.4% of domestic electricity consumption in the UK; UK Department for Business, Energy & Industrial Strategy, 2017), and distribution for around 142 GWh [0.07 $MtCO_2e$] (0.04% of total electricity consumption; UK Department for Business, Energy & Industrial Strategy, 2017).

Figure 4 shows a breakdown of total energy consumed according to the different processes and devices. It can be seen that STBs and PVRs dominate (1047 GWh [0.54 $MtCO_2e$]), followed by TVs (737 GWh [0.38 $MtCO_2e$]).

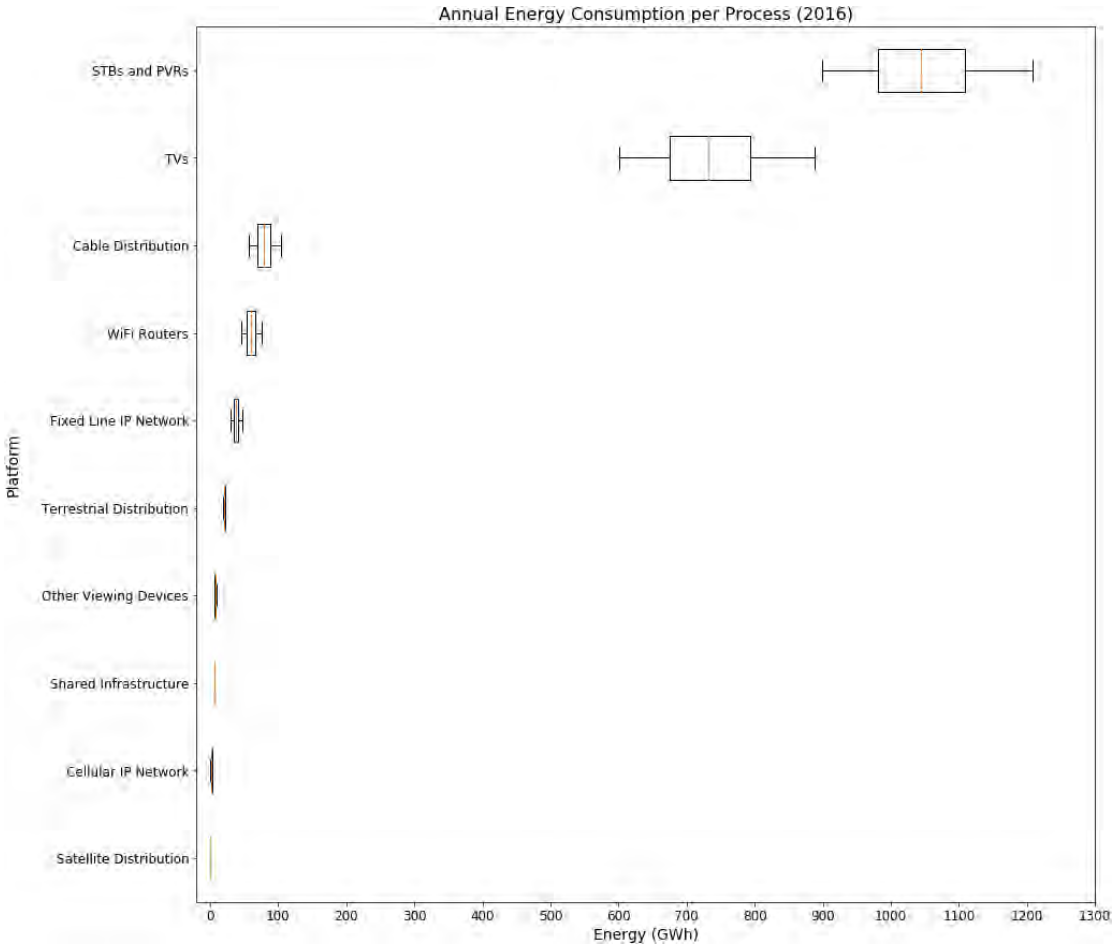

Figure 4: Breakdown of total BBC distribution and consumption energy use in 2016, based on process groupings.

Figures 5 to 8 give more detail on the breakdown of electricity use per delivery mode, including the allocation of shared infrastructure per platform.

Figure 5 shows the breakdown for terrestrial broadcast delivery. Viewing device (almost always a TV set) is dominant here at 296 GWh (66%) [0.15 $MtCO_2e$], larger than the STB and PVR contribution combined at 95 GWh (21%) [0.05 $MtCO_2e$]. The broadcast distribution infrastructure and allocation of shared infrastructure collectively took a small proportion at 24 GWh (5%) [0.01 $MtCO_2e$]. Aerial amplifiers which are often fitted in the loft of a house to amplify the DTT signal consumed 31 GWh (7%) [0.02 $MtCO_2e$]. There is very limited data available on their deployment, hence the very large uncertainty.

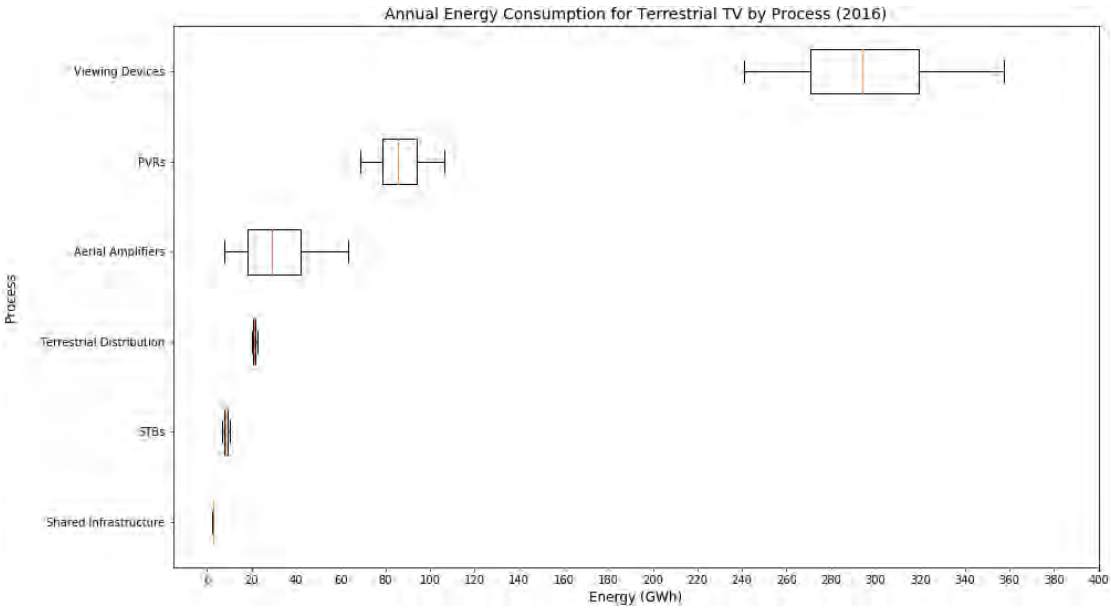

Figure 5: Breakdown of BBC distribution and consumption energy use associated with consumption of terrestrial broadcast in 2016, based on process groupings.

Figure 6 gives the breakdown for cable distribution. Energy consumption is more evenly spread across the different components compared to terrestrial distribution. STBs are highest at 186 GWh (49%) [0.10 $MtCO_2e$], followed by TV sets and other viewing devices at 110 GWh (29%) [0.06 $MtCO_2e$], the cable distribution infrastructure at 79 GWh (21%) [0.04 $MtCO_2e$] and the allocation of shared infrastructure for cable at 972 MWh (0.3%) [<0.001 $MtCO_2e$].

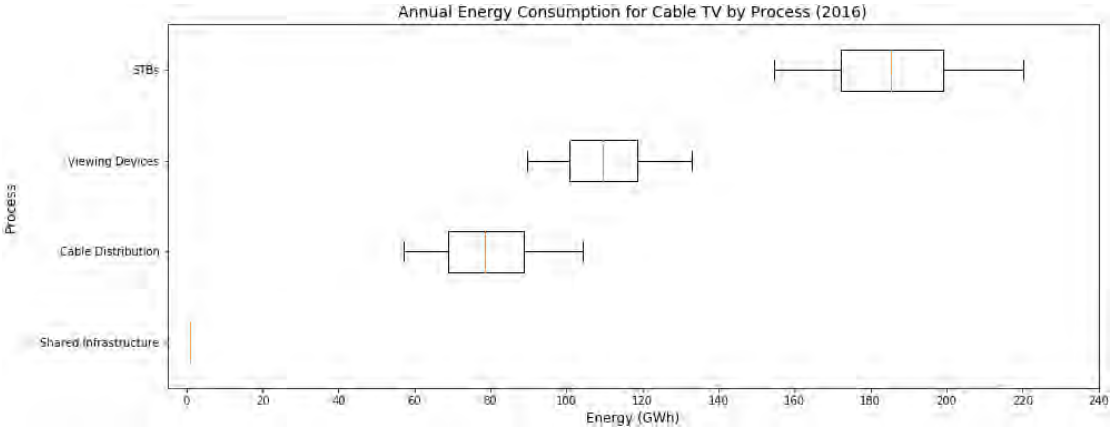

Figure 6: Breakdown of BBC distribution and consumption energy use associated with consumption of cable broadcast in 2016, based on process groupings.

Satellite, presented in Figure 7, similarly shows STB consumption at 766 GWh (73%) [0.40 $MtCO_2e$] to be higher than viewing devices at 282 GWh (27%) [0.15 $MtCO_2e$] but, unlike cable, electricity for the broadcast infrastructure is small at 661 MWh (<0.1%) [<0.001 $MtCO_2e$] with the allocation of shared infrastructure for satellite at 2 GWh (0.2%) [0.001 $MtCO_2e$].

Both cable and satellite platforms generally use more complex STBs than those used by DTT. For example, cable and satellite STBs generally include PVR functionality. Over 80% of TV sets used to consume DTT services use built-in decoders rather than STBs.

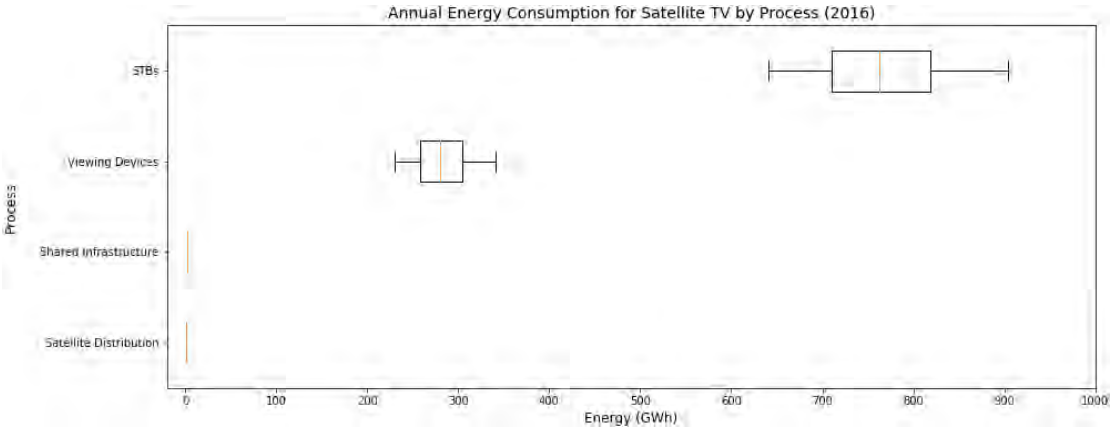

Figure 7: Breakdown of BBC distribution and consumption energy use associated with consumption of satellite broadcast in 2016, based on process groupings.

Figure 8 gives the breakdown for iPlayer viewing on all devices, including smart TVs, satellite and cable STBs, tablets, smartphones and computers. This shows a very different pattern of energy use compared to the other delivery platforms. The viewing device is a relatively small share at 25 GWh (20%) [0.01 $MtCO_2e$], whereas network customer premises equipment (CPE), such as home Wi-Fi modems and routers, is greatest at 60 GWh (48%) [0.03 $MtCO_2e$]. Network energy use outside the home (including cable, access and cell networks) is a significant share at 39 GWh (31%) [0.02 $MtCO_2e$]. Server usage, namely iPlayer video encoding and CDNs to prepare, store, and transmit content, is almost negligible at 1 GWh (1%) [0.001 $MtCO_2e$].

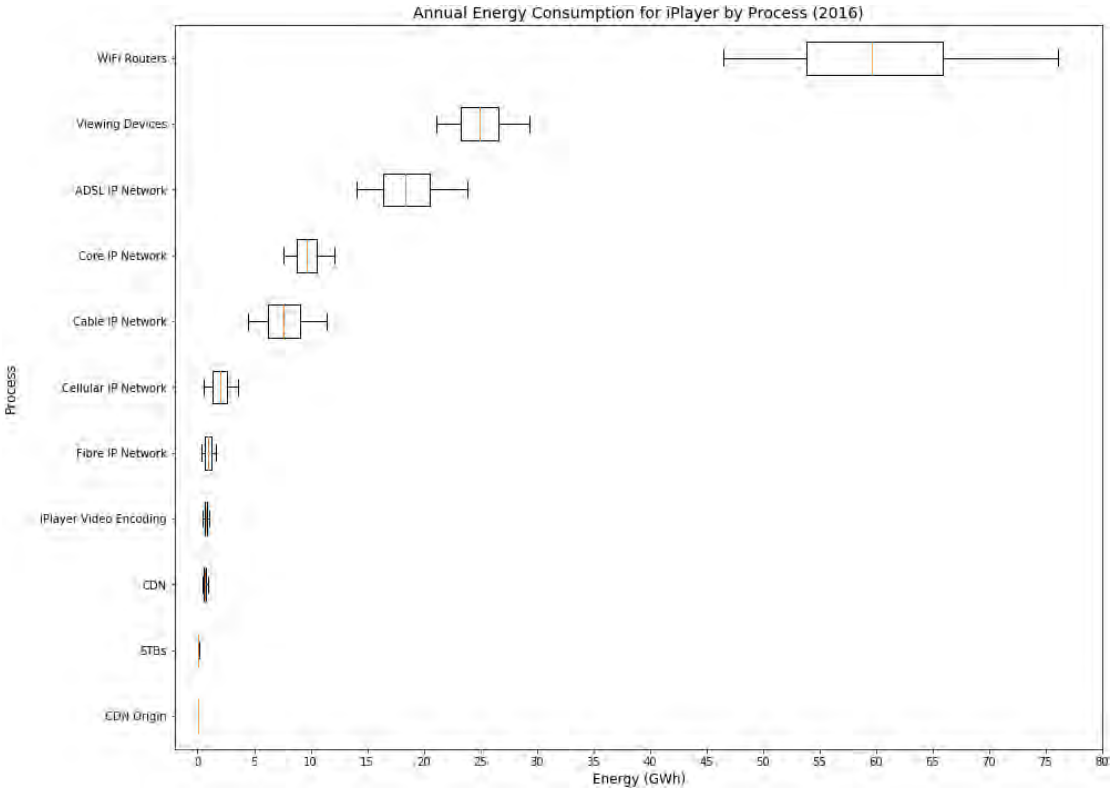

Figure 8: Breakdown of BBC distribution and consumption energy use associated with consumption of iPlayer services in 2016, based on process groupings.

4.1 Uncertainty and Sensitivity Analysis

The coefficient of variation (the standard deviation relative to the mean) of the estimate of energy consumption is 12.4%. The interquartile range of the overall energy consumption has a 25th percentile value at 1,791 GWh and a 75th percentile value at 2,192 GWh.

In order to understand which processes contribute most strongly to the variability of the outcome, we perform sensitivity analysis based on Monte Carlo simulation. An analytic approach based on error propagation (Finnveden et al., 2009) is too involved given the large number of variables (261). Our model structure is monotonic with non-linear, multiplicative random variables. We perform a one-at-a-time sensitivity analysis (Iooss & Saltelli, 2015). Here, we fix all model variables to their mean values and only allow a single variable to vary according to its original distribution. With this approach, we can explain approximately 48% of the variability of estimated energy consumption. The remaining variability is due to interactions between two or more of the input variables and has not been studied. Among the variables affecting the overall uncertainty of energy consumption estimate, most are the variables related to power draw and time of use for terrestrial, satellite, and cable receivers – each individually, affecting between 1 and 5 percent of output variability. These are the variables that additional research effort should be directed in order to most effectively reduce outcome uncertainty.

5 Discussion

The distribution and consumption of digital services, such as entertainment, provided by a single large organisation such as the BBC can alone be responsible for non-trivial quantities of energy. In this research, we have used a process-based LCA to demonstrate that the distribution and consumption of BBC television services accounted for approximately 0.6% of UK electricity use in 2016. Hence, choices made by such organisations and their partners regarding which delivery platforms to support and which technologies to adopt will have implications for energy consumption patterns in the regions they operate.

The majority of this electricity consumption occurs within the home. Of this, the majority is from set-top boxes, rather than television sets and other viewing devices. This contrasts with the scoping study conducted by Chandaria et al. (2011) which found that TV sets dominated. This reversal is a consequence of technology trends within domestic electronics. Television technology has become increasingly efficient in the last few years, particularly as a consequence of efficiency improvements in flat-screen technology. Despite increases in average screen size, models draw lower power when operating, and use almost no energy when in standby mode.

In the case of set-top boxes, the trend has been the opposite. Complex STBs, used for cable and satellite services, are becoming more widespread in the home and have more sophisticated functionality than the simple STBs they are replacing, resulting in higher energy usage both when on and in standby mode. Voluntary agreements in both the European Union and the United States have resulted in reductions of energy use by complex STBs (D+R International, 2017) but, among BBC viewers in the UK, this has been offset by an increased number of people

using such devices. This is likely to also hold in other regions where terrestrial broadcast, rather than cable, has traditionally been dominant. However, in the USA, the penetration of cable TV was already far higher and so the same technology improvements are likely to result in absolute reductions in overall STB energy usage.

Our analysis suggests it is important to continue this focus as this is the main hotspot within the current delivery footprint. This can be reduced further either through technology improvements within the set-top boxes, or by moving to a "thin client" model where the processing occurs elsewhere and is shared with a number of households.

Newer delivery platforms offer more convenience and choice but at the price of increased electricity use compared with terrestrial broadcast. The electricity use per device-hour of delivery over the Internet is comparable to satellite and cable but, due to the small proportion of content currently delivered in this way, the overall electricity footprint of the service is significantly smaller. This pattern is likely to hold for other traditional broadcast companies which also offer their content online. It is interesting to note that the pattern of energy consumption is different from those of other delivery modes. Electricity use is dominated by the networking equipment, inside and outside the home, while the viewing device is responsible for a relatively small share. This is partly because the iPlayer service has a higher proportion of viewing on smaller, lower powered personal devices than other platforms, comprising 40% of the viewing hours. It is likely that consumption of on-demand television services such as BBC iPlayer will increase in future years, which would lead to an increase in both the overall electricity footprint of TV distribution and alteration of energy hotspots within the footprint. This will continue and magnify the trend identified in global energy use of Entertainment, Media and IT sectors (Malmodin et al., 2010; Malmodin et al., 2018;). It appears that network energy consumption is increasing while energy associated with end-user equipment is decreasing, meaning that the overall consumption is stabilising.

To anticipate and prepare for the impact of changes in service use, it is valuable to conduct scenario analyses based on possible future trends. We note that, because the analysis presented above is an attributional LCA, determining the impact of increased use of on-demand services and reduced use of other services is more complex than simply taking the "per device-hour" figures we have calculated and multiplying it by the new usage figures. It requires running the entire model under a new set of assumptions.

Other trends likely to impact the overall footprint of the TV involve the potential introduction of new technologies such as higher resolution video (such as 4K or 8K) and high dynamic range (HDR) in the home. We identify analysis of such future scenarios and trends as future work and have prepared our model to have sufficiently fine granularity to do this. Such work can contribute quantitative examples of the impacts of changes alongside qualitative scenario modelling to explore the impacts of digital technology in the future (Picha Edwardsson, 2014; Fauré et al., 2017; Pargman et al., 2017).

In addition to exploring scenarios, there is the opportunity for future work to understand the implications on electricity consumption of the design decisions

for digital services. Two classes of decision can have a significant impact on energy usage. The first is that of the software architecture, particularly regarding the delivery architectures used. For example, the structure and location of the CDN caches used by a TV distribution system or the adoption of multicasting over IP for the efficient distribution of linear channels to many receivers simultaneously. Approaches from Green Software Design of cloud systems can be of benefit here (Baliga et al., 2011; Procaccianti et al., 2014; Hintemann & Clausen, 2016). The second class of decision is with regard to the user interaction and what practices and behaviours it encourages (or not). Here, approaches from Sustainable Interaction Design applied to large-scale systems can be used (Blevis, 2007; Preist & Shabajee, 2010; Preist et al., 2016). It is also beneficial to understand how such practices interact with the wider set of entertainment and IT practices in the home and their resulting energy impacts (Bates et al., 2014; Lord et al., 2015; Widdicks et al., 2017). Such work, together with scenario analysis, could provide valuable insights resulting in long-term reductions in both cost and environmental impact. This can form part of a more general effort to design digital services while taking sustainability factors into account (Lundström & Pargman, 2017; Kern et al., 2018; Remy et al., 2018).

The work presented in this article, like many other analyses of digital systems, has electricity consumption during the use phase as its scope, and so is not a complete LCA. This is a deliberate choice, as the results are intended for use when considering the impact of TV services on electricity consumption. As we omit the energy and environmental impacts of the manufacture and deployment of the infrastructure required to deliver the services, results presented in this article should not be taken as a definitive statement of which delivery modes are "environmentally best." For example, electricity use associated with satellite broadcast is very low in our model, using simply what is necessary to create a narrow beam transmission of content to the satellite. Broadcast is then dealt with using solar power harnessed by the satellite. A full environmental analysis would include a share of the impacts of manufacture and launch of the satellite, and the rocket carrying it to orbit. An extension of system boundaries to provide a more complete analysis is an option for future work. It would be possible to do this very coarsely for home equipment using the approach of Teehan et al. (2010), but data on the specification and lifetime of distribution equipment is much harder to obtain. The work of Chan et al. (2016) provides a promising approach to incorporating network equipment. Such an analysis is likely to be significantly more uncertain than the work presented here. We also omit the impact of software development in line with GHG protocol guidance, but note that the approach of Kern et al. (2015) to provide this.

Our analysis identifies the total annual electricity consumption to provide BBC television services. For energy policy planning, it is also helpful to have data about the likely peak demand of energy from TV services both currently and under potential future technology scenarios. This is outside the scope of traditional LCAs, which consider quantity rather than rate of resource consumption, but there is potential for future work to extend the model to allow the peak rate of electricity use (i.e. peak power consumption) to be determined. Current practices mean that "peak entertainment demand", and therefore the timing of peak electricity use, is later in the evening than the overall peak

electricity use. This, however, has potential to change and such changes can be influenced by design choices in the provision of entertainment services (Morley et al., 2018).

6 Conclusions

In this article, we have presented a methodology for the assessment of energy use by TV distribution and viewing. It combines the use of detailed behavioural data obtained through user monitoring and analytics with an LCA approach. We have presented a detailed process model of television distribution and viewing, and applied the method to assess energy use associated with a representative national TV company, the BBC. In doing so, we have demonstrated that TV distribution and viewing can account for a non-trivial share of national electricity use, with BBC services responsible for 2,000 GWh [1.03 $MtCO_2e$] in 2016, approximately 0.6% of total UK electricity use in that year and 0.2% of the UK GHG emissions. We have shown that digital terrestrial broadcast is the least electricity-intensive distribution platform and that cable, satellite and streaming are of a similar order. As on-demand streaming media consumption is likely to increase, we have identified the need for future scenarios exploring the implications on electricity consumption of this and other technology trends.

7 Acknowledgements

This work was funded in part through the EPSRC Impact Acceleration programme, and by BBC R&D.

8 References

Ahmadi Achachlouei, M., Moberg, Å., & Hochschorner, E. (2015). Life Cycle Assessment of a Magazine, Part I: Tablet Edition in Emerging and Mature States. *Journal of Industrial Ecology*, *19*(4), 575–589. https://doi.org/10.1111/jiec.12227

Andrae, A., & Edler, T. (2015). On Global Electricity Usage of Communication Technology: Trends to 2030. *Challenges*, *6*(1), 117–157. https://doi.org/10.3390/challe6010117

Arushanyan, Y., Ekener-Petersen, E., & Finnveden, G. (2014). Lessons learned – Review of LCAs for ICT products and services. *Computers in Industry*, *65*(2), 211–234. https://doi.org/10.1016/j.compind.2013.10.003

Baliga, J., Ayre, R. W. A., Hinton, K., & Tucker, R. S. (2011). Green cloud computing: Balancing energy in processing, storage, and transport. *Proceedings of the IEEE*, Vol. 99, pp. 149–167. IEEE.

BARB. (2017a). *personal e-mail communication*.

BARB. (2017b). The primary role of secondary TV sets. Retrieved from http://www.barb.co.uk/tv-landscape-reports/the-primary-role-of-secondary-tv-sets/

BARB. (2018). Establishment Survey. Retrieved April 12, 2018, from http://www.barb.co.uk/resources/establishment-survey/

Bates, O., Hazas, M., Friday, A., Morley, J., Clear, A. K., Bates, O., … Clear, A. K. (2014). Towards an holistic view of the energy and environmental impacts of domestic media and IT. *Proceedings of the 32nd Annual ACM Conference on Human Factors in Computing Systems - CHI '14*, 1173–1182. https://doi.org/10.1145/2556288.2556968

Blevis, E. (2007). Sustainable interaction design. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '07*, 503. https://doi.org/10.1145/1240624.1240705

Bull, J. G., & Kozak, R. A. (2014). Comparative life cycle assessments: The case of paper and digital media. *Environmental Impact Assessment Review*, *45*, 10–18. https://doi.org/10.1016/j.eiar.2013.10.001

Chan, Chien A., Gygax, A. F., Wong, E., Leckie, C. A., Nirmalathas, A., & Kilper, D. C. (2013). Methodologies for Assessing the Use-Phase Power Consumption and Greenhouse Gas Emissions of Telecommunications Network Services. *Environmental Science & Technology*, *47*(1), 485–492. https://doi.org/10.1021/es303384y

Chan, Chien Aun, Gygax, A. F., Leckie, C., Wong, E., Nirmalathas, A., & Hinton, K. (2016). Telecommunications energy and greenhouse gas emissions management for future network growth. *Applied Energy*, *166*, 174–185. https://doi.org/10.1016/J.APENERGY.2016.01.007

Chandaria, J., Hunter, J., & Williams, A. (2011). The carbon footprint of watching television, comparing digital terrestrial television with video-on-demand. *Sustainable Systems and Technology (ISSST), 2011 IEEE International Symposium On*, 1–6. Chicago: IEEE.

Coroama, V. C., & Hilty, L. M. (2014). Assessing Internet energy intensity: A review of methods and results. *Environmental Impact Assessment Review*, *45*, 63–68. https://doi.org/10.1016/J.EIAR.2013.12.004

Coroama, V. C., Hilty, L. M., & Birtel, M. (2012). Effects of Internet-based multiple-site conferences on greenhouse gas emissions. *Telematics and Informatics*, *29*(4), 362–374. https://doi.org/10.1016/J.TELE.2011.11.006

D+R International. (2017). *2016 Annual Report Voluntary Agreement for Ongoing Improvement to the Energy Efficiency of Set-Top Boxes*.

Drysdale, B., Wu, J., & Jenkins, N. (2015). Flexible demand in the GB domestic electricity sector in 2030. *Applied Energy*, *139*, 281–290. https://doi.org/10.1016/j.apenergy.2014.11.013

EnergyStar. (2018). Certified Products-Televisions. Retrieved April 25, 2018, from https://www.energystar.gov/products/electronics/televisions

Fauré, E., Arushanyan, Y., Ekener, E., Miliutenko, S., & Finnveden, G. (2017). Methods for assessing future scenarios from a sustainability perspective. *European Journal of Futures Research*, *5*(1), 17. https://doi.org/10.1007/s40309-017-0121-9

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., … Suh, S. (2009). Recent developments in Life Cycle Assessment. *Journal of Environmental Management*, *91*(1), 1–21.

https://doi.org/10.1016/j.jenvman.2009.06.018

Greenhouse Gas Protocol. (2011). *Product Life Cycle Accounting and Reporting Standard*.

Greenhouse Gas Protocol. (2012). *Product Life Cycle Accounting and Reporting Standard ICT Sector Guidance*.

Hintemann, R., & Clausen, J. (2016). Green Cloud? The current and future development of energy consumption by data centers, networks and end-user devices. *Proceedings of ICT for Sustainability 2016*. https://doi.org/10.2991/ict4s-16.2016.13

Hischier, R., Achachlouei, M. A., & Hilty, L. M. (2014). Evaluating the sustainability of electronic media: Strategies for life cycle inventory data collection and their implications for LCA results. *Environmental Modelling and Software*, *56*, 27–36. https://doi.org/10.1016/j.envsoft.2014.01.001

Iooss, B., & Saltelli, A. (2015). Introduction : Sensitivity Analysis. In R. Ghanem, D. Higdon, & H. Owhadi (Eds.), *Springer Handbook on Uncertainty Quantification* (pp. 1–31).

Kern, E., Dick, M., Naumann, S., & Hiller, T. (2015). Impacts of software and its engineering on the carbon footprint of ICT. *Environmental Impact Assessment Review*, *52*, 53–61. https://doi.org/10.1016/J.EIAR.2014.07.003

Kern, E., Hilty, L. M., Guldner, A., Maksimov, Y. V., Filler, A., Gröger, J., & Naumann, S. (2018). Sustainable software products—Towards assessment criteria for resource and energy efficiency. *Future Generation Computer Systems*, *86*, 199–210. https://doi.org/10.1016/J.FUTURE.2018.02.044

Lord, C., Hazas, M., Clear, A. K., Bates, O., Whittam, R., Morley, J., & Friday, A. (2015). Demand in My Pocket. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*, 2729–2738. https://doi.org/10.1145/2702123.2702162

Lundström, A., & Pargman, D. (2017). Developing a Framework for Evaluating the Sustainability of Computing Projects. *Proceedings of the 2017 Workshop on Computing Within Limits - LIMITS '17*, 111–117. https://doi.org/10.1145/3080556.3080562

Malmodin, J., Bergmark, P., & Matinfar, S. (2018). A high-level estimate of the material footprints of the ICT and the E&M sector. *Proceedings of the 5th International Conference on Information and Communication Technology for Sustainability, ICT4S 2018*, 168–148. https://doi.org/10.29007/q5fw

Malmodin, J., Moberg, Å., Lundén, D., Finnveden, G., & Lövehagen, N. (2010). Greenhouse Gas Emissions and Operational Electricity Use in the ICT and Entertainment & Media Sectors. *Journal of Industrial Ecology*, *14*(5). https://doi.org/10.1111/j.1530-9290.2010.00278.x

Mayers, K., Koomey, J., Hall, R., Bauer, M., France, C., & Webb, A. (2015). The Carbon Footprint of Games Distribution. *Journal of Industrial Ecology*, *19*(3), 402–415. https://doi.org/10.1111/jiec.12181

Moberg, Å., Borggren, C., & Finnveden, G. (2011). Books from an environmental perspective—Part 2: e-books as an alternative to paper books. *The*

International Journal of Life Cycle Assessment, *16*(3), 238–246. https://doi.org/10.1007/s11367-011-0255-0

Moberg, Å., Johansson, M., Finnveden, G., & Jonsson, A. (2010). Printed and tablet e-paper newspaper from an environmental perspective — A screening life cycle assessment. *Environmental Impact Assessment Review*, *30*(3), 177–191. https://doi.org/10.1016/j.eiar.2009.07.001

Morley, J., Widdicks, K., & Hazas, M. (2018). Digitalisation, energy and data demand: The impact of Internet traffic on overall and peak electricity consumption. *Energy Research & Social Science*, *38*, 128–137. https://doi.org/10.1016/J.ERSS.2018.01.018

Ofcom. (2016). *Connected Nations 2016*.

Pargman, D., Eriksson, E., Höjer, M., Östling, U. G., & Borges, L. A. (2017). The (Un)sustainability of Imagined Future Information Societies. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 773–785. https://doi.org/10.1145/3025453.3025858

Pärssinen, M., Kotila, M., Cuevas, R., Phansalkar, A., & Manner, J. (2018). Environmental impact assessment of online advertising. *Environmental Impact Assessment Review*, *73*, 177–200. https://doi.org/10.1016/j.eiar.2018.08.004

Picha Edwardsson, M. (2014). Environmental aspects of media scenarios for the future ICT society. *Proceedings of the 2014 Conference ICT for Sustainability*, (Ict4s), 218–225. https://doi.org/10.2991/ict4s-14.2014.26

Preist, C., Schien, D., & Blevis, E. (2016). Understanding and Mitigating the Effects of Device and Cloud Service Design Decisions on the Environmental Footprint of Digital Infrastructure. *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, 1324–1337. https://doi.org/10.1145/2858036.2858378

Preist, C., Schien, D., & Shabajee, P. (2019). Evaluating sustainable interaction design of digital services: The case of YouTube. *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. https://doi.org/10.1145/3290605.3300627

Preist, C., & Shabajee, P. (2010). Energy Use in the Media Cloud. *2nd IEEE International Conference on Cloud Computing Technology and Science*. Indianapolis, USA: IEEE Comput. Soc.

Procaccianti, G., Lago, P., & Lewis, G. A. (2014). A Catalogue of Green Architectural Tactics for the Cloud. *2014 IEEE 8th International Symposium on the Maintenance and Evolution of Service-Oriented and Cloud-Based Systems*, 29–36. https://doi.org/10.1109/MESOCA.2014.12

Remy, C., Bates, O., Dix, A., Thomas, V., Hazas, M., Friday, A., & Huang, E. M. (2018). Evaluation Beyond Usability. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems - CHI '18*, 1–14. https://doi.org/10.1145/3173574.3173790

Schien, D., & Preist, C. (2014). A review of top-down models of internet network energy intensity. *ICT for Sustainability 2014, ICT4S 2014*.

Schien, Dan, & Preist, C. (2014). Approaches to energy intensity of the internet. *IEEE Communications Magazine*, *52*(11), 130–137. https://doi.org/10.1109/MCOM.2014.6957153

Schien, Daniel, Shabajee, P., Wood, S. G., & Preist, C. (2013). A Model for Green Design of Online News Media Services. *22nd International Conference on World Wide Web*, 1111–1121. https://doi.org/10.1145/2488388.2488485

Schien, Daniel, Shabajee, P., Yearworth, M., & Preist, C. (2013). Modeling and assessing variability in energy consumption during the use stage of online multimedia services. *Journal of Industrial Ecology*, *17*(6), 800–813. https://doi.org/10.1111/jiec.12065

Shehabi, A., Walker, B., & Masanet, E. (2014). The energy and greenhouse-gas implications of internet video streaming in the United States. *Environmental Research Letters*, *9*(5), 054007. https://doi.org/10.1088/1748-9326/9/5/054007

Stankovic, L., Stankovic, V., Liao, J., & Wilson, C. (2016). Measuring the energy intensity of domestic activities from smart meter data. *Applied Energy*, *183*, 1565–1580. https://doi.org/10.1016/J.APENERGY.2016.09.087

Subramanian, K., & Yung, W. K. C. (2016). Review of life cycle assessment on consumer electronic products: Developments and the way ahead. *Critical Reviews in Environmental Science and Technology*, *46*(18), 1441–1497. https://doi.org/10.1080/10643389.2016.1245550

Teehan, P., Kandlikar, M., & Dowlatabadi, H. (2010). Estimating the Changing Environmental Impacts of ICT-Based Tasks : A Top-Down Approach. *Sustainable Systems and Technology (ISSST), 2010 IEEE International Symposium On*. https://doi.org/10.1109/ISSST.2010.5507676

Toniolo, S., Mazzi, A., Fedele, A., Aguiari, F., & Scipioni, A. (2017). Life Cycle Assessment to support the quantification of the environmental impacts of an event. *Environmental Impact Assessment Review*, *63*, 12–22. https://doi.org/10.1016/j.eiar.2016.07.007

UK Department for Business Energy & Industrial Strategy. (2016). *Greenhouse gas reporting - Conversion factors 2016*.

UK Department for Business Energy & Industrial Strategy. (2017). Digest of UK Energy Statistics (DUKES) 2016: Chapter 5: Electricity. In *Digest of United Kingdom Energy Statistics (DUKES)*.

UK Department for Business Energy & Industrial Strategy. (2018). *Annual statement of emissions for 2016.*

Virgin Media. (2017). *Growing Responsibility & Doing More with Digital*.

Weber, C. L., Koomey, J. G., & Matthews, H. S. (2010). The Energy and Climate Change Implications of Different Music Delivery Methods. *Journal of Industrial Ecology*, *14*(5), 754–769. https://doi.org/10.1111/j.1530-9290.2010.00269.x

Weidema, B., & Beaufort, A. S. H. De. (2001). Framework for Modelling Data Uncertainty in Life Cycle Inventories. *International Journal Life Cycle Assessment*, *6*(Lci), 127–132. https://doi.org/10.1007/BF02978728

Widdicks, K., Bates, O., Hazas, M., Friday, A., & Beresford, A. R. (2017). Demand Around the Clock. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 5361–5372. https://doi.org/10.1145/3025453.3025730

Yohanis, Y. G. (2012). Domestic energy use and householders' energy behaviour. *Energy Policy*, *41*, 654–665. https://doi.org/10.1016/J.ENPOL.2011.11.028

9 Appendix

Variable Name	Comment	Random Distribution	A	B	C	unit	CAGR	References Date for CAGR	Source
Power GamesConsole Cable	For both Console and TV. Games Console highly variable ~70W - 170W power_on (assume connected to a 'secondary' TV = 30W). 2013 cited paper out of date but other sources also point to order 70W. Includes both Console and TV	choice	200	140	100	W	0	2016-01-01 00:00:00	Webb, a., Mayers, K., France, C., & Koomey, J. (2013). Estimating the energy use of high definition games consoles. Energy Policy, 61, 1412–1421. doi:10.1016/j.enpol.2013.05.056
Power GamesConsole DSL	For both Console and TV. Games Console highly variable ~70W - 170W power_on (assume connected to a 'secondary' TV = 30W). 2013 cited paper out of date but other sources also point to order 70W. Includes both Console and TV	choice	200	140	100	W	0	2016-01-01 00:00:00	Webb, a., Mayers, K., France, C., & Koomey, J. (2013). Estimating the energy use of high definition games consoles. Energy Policy, 61, 1412–1421. doi:10.1016/j.enpol.2013.05.056
Variable Name	**Comment**		**Value**			**unit**	**CAGR**	**References Date for CAGR**	**Source**
proportion have stb per platform dcab hh	Proportion of households of DSAT households that have STB/PVRs for the main platform		1				0	2016-01-01 00:00:00	Virgin Media STB required for service & BARB Establishment Survey
total bb hh	Total number of Broadband Households		22567000				0	2016-01-01 00:00:00	Barb establishment 2016

Variable Name	Comment	Random Distribution	mean	std dev		unit	CAGR	References Date for CAGR	Source
barb bbc viewing share per platform dcab hh	BBC's share of viewing on DCAB platforms	normal	redacted	redacted			0	2016-01-01 00:00:00	BARB Special Report
barb bbc viewing share per platform dsat hh	BBC's share of viewing on DSAT platforms	normal	redacted	redacted			0	2016-01-01 00:00:00	BARB Special Report
barb bbc viewing share per platform dtt hh	BBC's share of viewing on DTT platforms	normal	redacted	redacted			0	2016-01-01 00:00:00	BARB Special Report
barb uncovered tv viewing proportion dcab hh	This is the proportion of the time that a TV is switched on but no one is viewing/watching	normal	0.084	0.0168			0	2016-01-01 00:00:00	BARB Quality Control Documents 2016
barb uncovered tv viewing proportion dsat hh	This is the proportion of the time that a TV is switched on but no one is viewing/watching	normal	0.084	0.0168			0	2016-01-01 00:00:00	BARB Quality Control Documents 2016
barb uncovered tv viewing proportion dtt hh	This is the proportion of the time that a TV is switched on but no one is viewing/watching	normal	0.084	0.0168			0	2016-01-01 00:00:00	BARB Quality Control Documents 2016
BBC iplayer share of Virgin UK nternet traffic	Estimated share of Virgin Cable's interntet traffic allocated to BBC iPlayer viewing. Based on Domestic Estimates of Allocation to BBC	normal	0.1	0.01			0	2016-01-01 00:00:00	Based on estimates of BBC iPlayer's share of IP data volume in average households

bbc national viewing share proportion	Mean TV Viewing share of BBC over all TV viewing platforms	normal	0.321	0.0321			0	2016-01-01 00:00:00	BARB (https://www.barb.co.uk/download/?file=/wp-content/uploads/2017/04/Barb-Viewing-Report-2017.pdf)
BBC TV channel share of viewer hours cable	BARB BBC Vs Total Viewer Hours by Device	normal	redacted	redacted			0	2016-01-01 00:00:00	BARB Special Report
bitrate DCAB main tv	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate DCAB secondary tv	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Desktop and Screen Cable	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Desktop and Screen DSL	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate DSAT main tv	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate DSAT secondary tv	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate DTT amplifier	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate DTT main tv	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team

bitrate DTT pvr	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate DTT secondary tv	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate GamesConsole Cable	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	8000000	800000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate GamesConsole DSL	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	8000000	800000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate IP STB Cable	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate IP STB DSL	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Laptop Cable	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	3500000	350000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Laptop DSL	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	3500000	350000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate PO STB Cable	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate PO STB DSL	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Smart TV Cable	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Smart TV DSL	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	5000000	500000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate SmartPhone	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	1800000	180000		b/s	0	2016-01-01 00:00:00	Estimates made by project team

bitrate SmartPhone Cable	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	1800000	180000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate SmartPhone DSL	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	1800000	180000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Tablet	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	1800000	180000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Tablet Cable	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	1800000	180000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
bitrate Tablet DSL	Bit rate for BBC iPlayer TV Content. Based on standard profile for device types	normal	1800000	180000		b/s	0	2016-01-01 00:00:00	Estimates made by project team
cable infrastructure share IP	Allocation based on total number of devices (number of modem-routers and cable STBs) and proportions allocated by number of each type of device to the two infrastrures (TV and IP). Based on Virgin Corporate Reporting number of STBs Vs number of Modems calcualted from Scope 3 reporting	normal	0.47	0.047			0	2016-01-01 00:00:00	Virgin media CSR report http://assets.virginmedia.com/resources/pdf/VM_Sustainability.pdf
cable infrastructure share TV	Allocation based on total number of devices (number of modem-routers and cable STBs) and proportions allocated by number of each type of device to the two infrastrures (TV and IP). Based on Virgin Corporate Reporting number of STBs Vs number of Modems calcualted from Scope 3 reporting	normal	0.53	0.053			0	2016-01-01 00:00:00	Virgin media CSR report http://assets.virginmedia.com/resources/pdf/VM_Sustainability.pdf
cable infrastructure total	Calculated from Virgin 2016 CSR report of Scope 2 carbon	normal	528333940	105666788		kWh/year	0	2016-01-01 00:00:00	Virgin media CSR report http://assets.virginmedia.com/resources/pdf/VM_Sustainability.pdf

	based on UK Grid Carbon Intensity for 2016								
duration per request mins Desktop and Screen Cable	Mean duration per iPlayer request for device over Cable internet connection. Assume Laptop and Desktop same	normal	24.5	2.45		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins Desktop and Screen DSL	Mean duration per iPlayer request for device over DSL internet connection. Assume Laptop and Desktop same	normal	24.5	2.45		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins GamesConsole Cable	Mean duration per iPlayer request for device over DSL internet connection.	normal	21.5	2.15		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins GamesConsole DSL	Mean duration per iPlayer request for device over Cable internet connection.	normal	21.5	2.15		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins IP STB Cable	Mean duration per iPlayer request for device over DSL internet connection.	normal	21.5	2.15		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins IP STB DSL	Mean duration per iPlayer request for device over Cable internet connection.	normal	21.5	2.15		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins Laptop Cable	Mean duration per iPlayer request for device over Cable internet connection. Assume Laptop and Desktop same	normal	24.5	2.45		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins Laptop DSL	Mean duration per iPlayer request for device over DSL internet connection. Assume Laptop and Desktop same	normal	24.5	2.45		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics

duration per request mins PO STB Cable	Mean duration per iPlayer request for device over DSL internet connection.	normal	21.5	2.15		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins PO STB DSL	Mean duration per iPlayer request for device over Cable internet connection.	normal	21.5	2.15		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins Smart TV Cable	Mean duration per iPlayer request for device over DSL internet connection.	normal	21.5	2.15		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins Smart TV DSL	Mean duration per iPlayer request for device over Cable internet connection.	normal	21.5	2.15		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins SmartPhone	Mean duration per iPlayer request for device over Cell internet connection. Assumed both Cell and WiFi are the same	normal	17.25	1.725		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins SmartPhone Cable	Mean duration per iPlayer request for device over Cable internet connection. Assumed both Cell and WiFi are the same	normal	17.25	1.725		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins SmartPhone DSL	Mean duration per iPlayer request for device over DSL internet connection. Assumed both Cell and WiFi are the same	normal	17.25	1.725		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins Tablet	Mean duration per iPlayer request for device over DSL internet connection.	normal	20	2		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
duration per request mins Tablet Cable	Mean duration per iPlayer request for device over DSL internet connection.	normal	20	2		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics

duration per request mins Tablet DSL	Mean duration per iPlayer request for device over Cable internet connection.	normal	20	2		mins/request	0	2016-01-01 00:00:00	iPlayer Analytics
energy intensity core network	Estimated energy intensity of core internet (j/bit)	normal	9.00E-06	9.00E-08		j/b	-0.2	2014-01-01 00:00:00	IEEE Magazine article, Schien and Preist 2014
energy intensity CDN	Based on estimates from opperational power use data from BBC BIDI CDN	normal	redacted	redacted		j/b	0	2017-07-01 00:00:00	BBC BIDI Team
mean barb tv viewing per individual per day per platform mins dcab hh	Mins of TV viewing per person per day in DCAB household	normal	199	19.9		mins	0	2016-01-01 00:00:00	BARB 2016 data reported by Ofcom UK Television and Audio-Visual 2017 https://www.ofcom.org.uk/__data/assets/pdf_file/0016/105442/uk-television-audio-visual.pdf
mean barb tv viewing per individual per day per platform mins dsat hh	Mins of TV viewing per person per day in DSAT household	normal	209	20.9		mins	0	2016-01-01 00:00:00	BARB 2016 data reported by Ofcom UK Television and Audio-Visual 2017 https://www.ofcom.org.uk/__data/assets/pdf_file/0016/105442/uk-television-audio-visual.pdf
mean barb tv viewing per individual per day per platform mins dtt hh	Mins of TV viewing per person per day in DTT Only household	normal	242	24.2		mins	0	2016-01-01 00:00:00	BARB 2016 data reported by Ofcom UK Television and Audio-Visual 2017 https://www.ofcom.org.uk/__data/assets/pdf_file/0016/105442/uk-television-audio-visual.pdf
mean number of tvs per household dcab hh	Mean number of TVs per DCAB household	normal	2.15	0.215			0	2016-01-01 00:00:00	BARB Establishment Survey 2016

mean number of tvs per household dsat hh	Mean number of TVs per DSAT household	normal	2.24	0.224			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
mean number of tvs per household dtt hh	Mean number of TVs per DTT Only household	normal	1.77	0.177			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
num devices cable modem hh	Estimate of households with cable modem installed	normal	4170000	417000			0	2016-01-01 00:00:00	Virgin Media Data Number of Devices and Power from Corporate Reporting 2016
num devices Desktop and Screen Cable	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics and estimated proportion of laptops Vs desktops	normal	201130	20113			0	2016-01-01 00:00:00	iPlayer Analytics
num devices Desktop and Screen DSL	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique Browers per month from iPlayer Analytics and estimated proportion of laptops Vs desktops	normal	916262	91626			0	2016-01-01 00:00:00	iPlayer Analytics
num devices GamesConsole Cable	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	72219	7222			0	2016-01-01 00:00:00	iPlayer Analytics

num devices GamesConsole DSL	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	328998	32900			0	2016-01-01 00:00:00	iPlayer Analytics
num devices IP STB Cable	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	34017	3402			0	2016-01-01 00:00:00	iPlayer Analytics
num devices IP STB DSL	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	154970	15497			0	2016-01-01 00:00:00	iPlayer Analytics
num devices Laptop Cable	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics and estimated proportion of laptops Vs desktops	normal	402261	40226			0	2016-01-01 00:00:00	iPlayer Analytics
num devices Laptop DSL	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique Browers per month from iPlayer Analytics and estimated proportion of laptops Vs desktops	normal	1832525	183253			0	2016-01-01 00:00:00	iPlayer Analytics

num devices PO STB Cable	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	937109	93711			0	2016-01-01 00:00:00	iPlayer Analytics
num devices PO STB DSL	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	1669024	166902			0	2016-01-01 00:00:00	iPlayer Analytics
num devices Smart TV Cable	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	536917	53692			0	2016-01-01 00:00:00	iPlayer Analytics
num devices Smart TV DSL	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	2445955	244596			0	2016-01-01 00:00:00	iPlayer Analytics
num devices SmartPhone	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	20000000	2000000			0	2016-01-01 00:00:00	iPlayer Analytics
num devices SmartPhone Cable	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique	normal	480506	48051			0	2016-01-01 00:00:00	iPlayer Analytics

	Browers per month from iPlayer Analytics								
num devices SmartPhone DSL	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	2188974	218897			0	2016-01-01 00:00:00	iPlayer Analytics
num devices Tablet	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	31270000	3127000			0	2016-01-01 00:00:00	iPlayer Analytics
num devices Tablet Cable	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over Cable internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	662534	66253			0	2016-01-01 00:00:00	iPlayer Analytics
num devices Tablet DSL	Estimate of mean number of devices per month, of this type, that are used to access iPlayer over DSL internet connections. Based on Unique Browers per month from iPlayer Analytics	normal	3018211	301821			0	2016-01-01 00:00:00	iPlayer Analytics
number hh per platform dcab hh	Number of households with DCAB as primary platform	normal	4140000	621000			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
number hh per platform dsat hh	Number of households with DSAT as primary platform	normal	10935000	1640250			0	2016-01-01 00:00:00	BARB Establishment Survey 2016

number hh per platform dtt hh	Number of households with DTT Only as platform	normal	11280000	1692000			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
porportion hh dcab only	Proportion of DSAT households that only have DCAB as a platform	normal	0.417	0.0417			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
porportion hh dsat only	Proportion of DSAT households that only have DSAT as a platform	normal	0.426	0.0426			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
Power AccessNetwork port		normal	3.2	0.32		W	0	2016-01-01 00:00:00	Krug, L., Shackleton, M., & Saffre, F. (2014). Understanding the Environmental Costs of Fixed Line Networking. Proceedings of the 5th International Conference on Future Energy Systems, 87–95
Power active standby DCAB main tv	Power when device in 'active standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power active standby DCAB secondary tv	Power when device in 'active standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power active standby DSAT main tv	Power when device in 'active standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power active standby DSAT secondary tv	Power when device in 'active standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power active standby	Power when device in 'active standby' state	normal	5	0.5		W	0	2016-01-01 00:00:00	Expert Opinon (BBC R&D and redated)

DTT amplifier									
Power active standby DTT main tv	Power when device in 'active standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power active standby DTT pvr		normal	16	3.6		W	0	2016-01-01 00:00:00	Estimate based on measurments of various STBs at BBC and domestic environments and analysis of Complex STB voluntary agreement data from 2011-2017
Power active standby DTT secondary tv	Power when device in 'active standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power active standby STB cable	Power when device in 'active standby' state	normal	20	5.45		W	0	2016-01-01 00:00:00	Complex STB voluntary agreement data from 2011-2016 and direct measurements of Virgin Media Tivo (Samsung SMT-C7100)
Power active standby STB freeview	As not recording the device is not in active standby, set to same as 'passive standby'	normal	1	0.1		W	0	2016-01-01 00:00:00	Based on Ecodesign rules for simple set-top boxes (https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products/setupboxes)
Power active standby STB satellite	Power when device in 'active standby' state	normal	20	3.18		W	0	2016-01-01 00:00:00	Based on mix of analysis of Complex STB voluntary agreement data from 2011-2016 and direct measurments on two Sky + HD boxes and Freesat + FoxSat
Power Cable Router	Estimate of mean power of Cable Internet Wifi/Router over iPlayer viewing households	normal	11.4	1.14		W	0	2017-01-01 00:00:00	Measurements of Virgin WiFi Router
Power DCAB main tv	Power when device is in 'on' state	normal	47	4.7		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power DCAB secondary tv	Power when device is in 'on' state	normal	30	3		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016

Power Desktop and Screen Cable	Average PC values (for active standby and standby) taken from EU energy calculator, adjusted to represent more likely mean 'on-power' average consumption under load	normal	77	7.7		W	0	2016-01-01 00:00:00	https://www.eu-energystar.org/calculator.htm
Power Desktop and Screen DSL	Average PC values (for active standby and standby) taken from EU energy calculator, adjusted to represent more likely mean 'on-power' average consumption under load	normal	77	7.7		W	0	2016-01-01 00:00:00	https://www.eu-energystar.org/calculator.htm
Power DSAT main tv	Power when device is in 'on' state	normal	47	4.7		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power DSAT secondary tv	Power when device is in 'on' state	normal	30	3		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power DSL Router	Estimate of mean power of DSL Internet Wifi/Router over iPlayer viewing households	normal	9.7	0.97		W	0	2017-01-01 00:00:00	http://www.ispreview.co.uk/index.php/2017/01/energy-usage-uk-home-broadband-routers-big-isps-compared.html/3
Power DTT amplifier	Power when device is in 'on' state	normal	5	0.5		W	0	2016-01-01 00:00:00	Expert Opinon (BBC R&D and redacted)
Power DTT main tv	Power when device is in 'on' state	normal	40	4		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power DTT pvr		normal	18	4		W	0	2016-01-01 00:00:00	Estimate based on measurments of various STBs at BBC and domestic environments and analysis of Complex STB voluntary agreement data from 2011-2016
Power DTT secondary tv	Power when device is in 'on' state	normal	26	2.6		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power IP STB Cable	IP set-top box	normal	3.5	0.35		W	0	2009-01-01 00:00:00	https://ting.com/blog/the-hidden-costs-of-cable-tv/
Power IP STB DSL	IP set-top box	normal	3.5	0.35		W	0	2009-01-01 00:00:00	https://ting.com/blog/the-hidden-costs-of-cable-tv/

Power Laptop Cable	Based on data from Energy Star Calculator for 'Average notebook 15-17" - that is based on Energy Start data.	normal	15	1.5		W	0	2016-01-01 00:00:00	https://www.eu-energystar.org/calculator.htm
Power Laptop DSL	Based on data from Energy Star Calculator for 'Average notebook 15-17" - that is based on Energy Start data.	normal	15	1.5		W	0	2016-01-01 00:00:00	https://www.eu-energystar.org/calculator.htm
Power passive standby DCAB main tv	Power when device in 'passive standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power passive standby DCAB secondary tv	Power when device in 'passive standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power passive standby DSAT main tv	Power when device in 'passive standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power passive standby DSAT secondary tv	Power when device in 'passive standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power passive standby DTT amplifier	Power when device in 'passive standby' state	normal	5	0.5		W	0	2016-01-01 00:00:00	Expert Opinon (BBC R&D and Redacted)
Power passive standby DTT main tv	Power when device in 'passive standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016

Power passive standby DTT pvr		normal	3	1.4		W	0	2016-01-01 00:00:00	Estimate based on measurments of various STBs at BBC and domestic environments and analysis of Complex STB voluntary agreement data from 2011-2018
Power passive standby DTT secondary tv	Power when device in 'passive standby' state	normal	0.31	0.031		W	0	2016-01-01 00:00:00	Energy Star & BARB Establishment Survey 2016
Power passive standby STB cable	Power when device in 'passive standby' state	normal	10	2.73		W	0	2016-01-01 00:00:00	Complex STB voluntary agreement data from 2011-2016 and direct measurements of Virgin Media Tivo (Samsung SMT-C7100)
Power passive standby STB freeview	1W upper end of eco-design rules with display on	normal	1	0.1		W	0	2016-01-01 00:00:00	Based on Ecodesign rules for simple set-top boxes (https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products/setupboxes)
Power passive standby STB satellite	Power when device in 'passive standby' state	normal	15	2.39		W	0	2016-01-01 00:00:00	Based on mix of analysis of Complex STB voluntary agreement data from 2011-2016 and direct measurments on two Sky + HD boxes and Freesat + FoxSat
Power PO STB Cable	STB & Main TV - Platform operator set-top box connected to main TV for watching iPlayer	normal	69	6.9		W	0	2016-01-01 00:00:00	Based on values above for platform STBS and TVs
Power PO STB DSL	STB & Main TV - Platform operator set-top box connected to main TV for watching iPlayer	normal	69	6.9		W	0	2016-01-01 00:00:00	Based on values above for platform STBS and TVs
Power Smart TV Cable	Power when device is in 'on' state - for those connected to the internet via Cable Networks	normal	47	4.7		W	0	2016-01-01 00:00:00	Energy Star TV population of models 2016 + distribution of screen size from BARB
Power Smart TV DSL	Power when device is in 'on' state - for those connected to the internet via DSL	normal	47	4.7		W	0	2016-01-01 00:00:00	Energy Star TV population of models 2016 + distribution of screen size from BARB

Power SmartPhone	Power when device is in 'on' state - for those connected to the internet via a Cellular Network	normal	1	0.1		W	0	2016-01-01 00:00:00	Carroll, A., & Heiser, G. (2010). An Analysis of Power Consumption in a Smartphone. In USENIX annual technical conference (pp. 21-21). Berkeley, CA: USENIX Association and Apple environmental reports
Power SmartPhone Cable	Power when device is in 'on' state - for those connected to the internet via Cable Networks	normal	1	0.1		W	0	2016-01-01 00:00:00	Carroll, A., & Heiser, G. (2010). An Analysis of Power Consumption in a Smartphone. In USENIX annual technical conference (pp. 21-21). Berkeley, CA: USENIX Association and Apple environmental reports
Power SmartPhone DSL	Power when device is in 'on' state - for those connected to the internet via DSL	normal	1	0.1		W	0	2016-01-01 00:00:00	Carroll, A., & Heiser, G. (2010). An Analysis of Power Consumption in a Smartphone. In USENIX annual technical conference (pp. 21-21). Berkeley, CA: USENIX Association and Apple environmental reports
Power STB cable	Power when device is in 'on' state	normal	22	6.00		W	0	2016-01-01 00:00:00	Complex STB voluntary agreement data from 2011-2016 and direct measurements of Virgin Media Tivo (Samsung SMT-C7100)
Power STB freeview	Using 5W as conservative value (higher end)	normal	5	0.5		W	0	2016-01-01 00:00:00	Based on Ecodesign rules for simple set-top boxes (https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products/setupboxes)
Power STB satellite	Power when device is in 'on' state	normal	22	3.5		W	0	2016-01-01 00:00:00	Based on mix of analysis of Complex STB voluntary agreement data from 2011-2016 and direct measurments on two Sky + HD boxes and Freesat + FoxSat
Power Tablet	Power when device is in 'on' state - for those connected to the internet via a Cellular Network	normal	5.5	0.55		W	0	2016-01-01 00:00:00	https://www.eu-energystar.org/calculator.htm
Power Tablet Cable	Power when device is in 'on' state - for those connected to the internet via Cable Networks	normal	5.5	0.55		W	0	2016-01-01 00:00:00	https://www.eu-energystar.org/calculator.htm
Power Tablet DSL	Power when device is in 'on' state - for those connected to the internet via DSL	normal	5.5	0.55		W	0	2016-01-01 00:00:00	https://www.eu-energystar.org/calculator.htm
proportion 7 day recorded viewing dcab hh	Proportion of viewing of recorded content that was recorded within the last 7 days	normal	0.1	0.01			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report

proportion 7 day recorded viewing dsat hh	Proportion of viewing of recorded content that was recorded within the last 7 days	normal	0.1	0.01			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion 7 day recorded viewing dtt hh	Proportion of viewing of recorded content that was recorded within the last 7 days	normal	0.1	0.01			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion 8 28 day recorded viewing dcab hh	Proportion of viewing of recorded content that was recorded within the last 8-28 days	normal	0.02	0.002			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion 8 28 day recorded viewing dsat hh	Proportion of viewing of recorded content that was recorded within the last 8-28 days	normal	0.02	0.002			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion 8 28 day recorded viewing dtt hh	Proportion of viewing of recorded content that was recorded within the last 8-28 days	normal	0.02	0.002			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion broadcaster vod dcab hh	Proportion of viewing that is broadcaster Video on Demand (VoD), incl. iPlayer	normal	0.04	0.004			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion broadcaster vod dsat hh	Proportion of viewing that is broadcaster Video on Demand (VoD), incl. iPlayer	normal	0.04	0.004			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion broadcaster vod dtt hh	Proportion of viewing that is broadcaster Video on Demand (VoD), incl. iPlayer	normal	0.04	0.004			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion have pvr per platform dtt hh	Proportion of DTT Only households that have PVRs (or STBs with PVR functionality)	normal	0.373	0.0373			0	2016-01-01 00:00:00	BARB Establishment Survey - Q4-2016 (any kind of recorder in DTT only households)

proportion have stb per platform dtt hh	Proportion of households of DTT Only households that have STBs (assumed not to have PVR functionality)	normal	0.15	0.015			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
proportion only one tv per household per platform dcab hh	Proportion of households with DCAB as the primary platform with only one TV	normal	0.342	0.0342			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
proportion only one tv per household per platform dsat hh	Proportion of households with DSAT as the primary platform with only one TV	normal	0.313	0.0313			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
proportion only one tv per household per platform dtt hh	Proportion of households with DTT Only with only one TV	normal	0.5	0.05			0	2016-01-01 00:00:00	BARB Establishment Survey 2016
proportion SVoD dcab hh	Proportion of viewing that is Subscription Video on Demand (SVoD), i.e. Netflix, etc.	normal	0.04	0.004			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion SVoD dsat hh	Proportion of viewing that is Subscription Video on Demand (SVoD), i.e. Netflix, etc.	normal	0.04	0.004			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
proportion SVoD dtt hh	Proportion of viewing that is Subscription Video on Demand (SVoD), i.e. Netflix, etc.	normal	0.04	0.004			0	2016-01-01 00:00:00	Ofcom uk-television-audio-visual 2017 report
radix annual energy	Based on mean power values of servers over extended periods and number of servers in Radix data centres	normal	16792	1679.2		kWh/year	0	2017-09-01 00:00:00	BBC via BBC R&D

requests Desktop and Screen Cable	Mean number of requests for device per month over Cable interenet connection. . assume ration of 2:1 for laptops : desktop	normal	3294952	329495			0	2016-01-01 00:00:00	iPlayer Analytics
requests Desktop and Screen DSL	Mean number of requests for device per month over DSL internet connection. assume ration of 2:1 for laptops : desktop	normal	15010340	1501034			0	2016-01-01 00:00:00	iPlayer Analytics
requests GamesConsole Cable	Mean number of requests for device per month over Cable interenet connection	normal	1223963	122396			0	2016-01-01 00:00:00	iPlayer Analytics
requests GamesConsole DSL	Mean number of requests for device per month over DSL interenet connection	normal	5575834	557583			0	2016-01-01 00:00:00	iPlayer Analytics
requests IP STB Cable	Mean number of requests for device per month over Cable interenet connection	normal	1020033	102003			0	2016-01-01 00:00:00	iPlayer Analytics
requests IP STB DSL	Mean number of requests for device per month over DSL interenet connection	normal	4646819	464682			0	2016-01-01 00:00:00	iPlayer Analytics
requests Laptop Cable	Mean number of requests for device per month over Cable interenet connection. assume ration of 2:1 for laptops : desktop	normal	6589905	658991			0	2016-01-01 00:00:00	iPlayer Analytics
requests Laptop DSL	Mean number of requests for device per month over DSL internet connection. assume ration of 2:1 for laptops : desktop	normal	30020681	3002068			0	2016-01-01 00:00:00	iPlayer Analytics
requests PO STB Cable	Mean number of requests for device per month over Cable internet connection	normal	11610982	1161098			0	2016-01-01 00:00:00	iPlayer Analytics
requests PO STB DSL	Mean number of requests for device per month over DSL internet connection	normal	18051303	1805130			0	2016-01-01 00:00:00	iPlayer Analytics

requests Smart TV Cable	Mean number of requests for device per month over Cable interenet connection	normal	9180301	918030			0	2016-01-01 00:00:00	iPlayer Analytics
requests Smart TV DSL	Mean number of requests for device per month over DSL interenet connection	normal	41821373	4182137			0	2016-01-01 00:00:00	iPlayer Analytics
requests SmartPhone Cable	Mean number of requests for device per month over Cable interenet connection	normal	5244293	524429			0	2016-01-01 00:00:00	iPlayer Analytics
requests SmartPhone Cell	Mean number of requests for device per month over Cell interenet connection	normal	2881479	288148			0	2009-01-01 00:00:00	iPlayer Analytics
requests SmartPhone DSL	Mean number of requests for device per month over DSL internet connection	normal	23890669	2389066			0	2016-01-01 00:00:00	iPlayer Analytics
requests Tablet Cable	Mean number of requests for device per month over Cable internet connection	normal	9911288	991129			0	2016-01-01 00:00:00	iPlayer Analytics
requests Tablet Cell	Mean number of requests for device per month over Cellular internet connection	normal	1123728	112373			0	2009-01-01 00:00:00	iPlayer Analytics
requests Tablet DSL	Mean number of requests for device per month over DSL internet connection	normal	45151427	4515142			0	2016-01-01 00:00:00	iPlayer Analytics
satellite uplink energy	Based on 365days and 24hrs per day.	normal	661380	66138		kWh/year	0	2016-01-01 00:00:00	BBC via BBC R&D. Based on power measurements for main and backup sites
total energy terrestrial network	Based on estimates of oveall transmitter energy use for DTT Multiplexes that are used by the BBC and allocation by proportion of bit rate use by BBC	normal	redacted	redacted		kWh/year	0	2016-01-01 00:00:00	BBC R&D from service provider estimates and expert opinion (BBC R&D and Project Team)
total traffic Cable Router	Estimate of mean data volume per Cable household per month. Assume DSL and Cable the same	normal	1.1339E+12	113387136614		b/month	0	2016-01-01 00:00:00	Ofcom communications report 2017

total traffic DSL Router	Estimate of mean data volume per DSL household per month. Assume DSL and Cable the same	normal	1.1339E+12	113387136614		b/month	0	2016-01-01 00:00:00	Ofcom communications report 2016
Variable Name	**Comment**	**Random Distribution**	**min**	**max**	**mode**	**unit**	**CAGR**	**References Date for CAGR**	**Source**
bbc ccm and internal network annual energy	Estimated energy use for Coding and Multiplexing and localisation network (used to transfer content between sites for insertion of regionalised content). Based on mean power values for coding and mutliplexing sites and estimates of data volumes transferred and assuming energy intensity of networking is the same as for core internet	triangular	redacted	redacted		kWh/year	0	2016-01-01 00:00:00	BBC via BBC R&D and expert opinion (BBC R&D and Project Team)
bbc playout annual energy	Based on mean power (kW) estimates for playout data centres and estimated values for studio and other services	triangular	redacted	redacted		kWh/year	0	2017-08-01 00:00:00	BBC R&D from service provider estimates and expert opinion (BBC R&D and Project Team)
enery cloud infrastructure	Upper Bound estimate from BBC R&D (December 2017). Triangular distribution based on expert opinion BBC R&D and project team	triangular	redacted	redacted		kWh/year	0	2016-01-01 00:00:00	BBC R&D
main tv watching ratio per hh	Mean proportion of viewing that is on the main TV in a household - where there are more than 1 TV. Uncertain how this is distributed by plaform but BARB indicate 2017 figures that 14% of viewing overall is on Secondary TVs. That comes	triangular	0.64	0.77	0.9		0	2016-01-01 00:00:00	BARB http://www.barb.co.uk/tv-landscape-reports/the-primary-role-of-secondary-tv-sets/

	out using this parameter at approx. 0.77.								
num online TV HH	While a high percentage of households have internet connection, model needs to be based on access iPlayer via IP	triangular	3750000	7500000	15000000		0	2016-01-01 00:00:00	Estimates based on number of sources: number of HH that access TV online. https://www.ofcom.org.uk/__data/assets/pdf_file/0023/26393/uk_internet.pdf. Barb Establishment Survey for "Respondent uses Internet to watch TV". Upper limit from iPlayer Analytics number of unique browsers
number viewing groups per platform dcab hh	Number of 'viewing groups' in DCAB households. Derived from estimates of shared viewing ratio based on demographics of household size by platform	triangular	1903666	6230333	10557000		0	2016-01-01 00:00:00	BARB Establishment Survey 2016
number viewing groups per platform dsat hh	Number of 'viewing groups' in DSAT households. Derived from estimates of shared viewing ratio based on demographics of household size by platform	triangular	4806000	16727850	28649700		0	2016-01-01 00:00:00	BARB Establishment Survey 2016
number viewing groups per platform dtt hh	Number of 'viewing groups' in DTT households. Derived from estimates of shared viewing ratio based on demographics of household size by platform	triangular	7337666	14892433	22447200		0	2016-01-01 00:00:00	BARB Establishment Survey 2016
proportion have DTT tv amplifier	Proportion of DTT Households that have loft TV amplifiers. Highly uncertain. Based on expert opinion	triangular	0	0.2	0.4		0	2016-01-01 00:00:00	Expert opinion BBC R&D
proportion have stb per platform dsat hh	Proportion of households of DSAT households that have STB/PVRs for the main platform	triangular	0.95	0.975	1		0	2016-01-01 00:00:00	BARB Establishment Survey and Expert opinion
proportion over recording	Proportion of pre-recorded viewing (on STBs and PVRs) that is over recorded, 1 = no	triangular	1	2	3		0	2016-01-01 00:00:00	BBC R&D from expert opinion

TV viewing per platform dcab hh	over recording, 10=10x recorded content than viewed. A mean of 2 was provided by BBC R&D from expert opinion.								
proportion over recording TV viewing per platform dsat hh	Proportion of pre-recorded viewing (on STBs and PVRs) that is over recorded, 1 = no over recording, 10=10x recorded content than viewed. A mean of 2 was provided by BBC R&D from expert opinion.	triangular	1	2	3		0	2016-01-01 00:00:00	BBC R&D from expert opinion
proportion over recording TV viewing per platform dtt hh	Proportion of pre-recorded viewing (on STBs and PVRs) that is over recorded, 1 = no over recording, 10=10x recorded content than viewed. A mean of 2 was provided by BBC R&D from expert opinion.	triangular	1	2	3		0	2016-01-01 00:00:00	BBC R&D from expert opinion
tv power uplift	Power uplift (multiplier) over mean TV power values that are based on Energy Star data. Because not all TVs are Energy Star certified (EnergyStar estimate that Energy Star TV's are on average 27% more energy efficient (EnergyStar 2018)) and not all TVs are set by users in their energy optimal mode	triangular	1	1.185	1.37		0	2016-01-01 00:00:00	Expert Opinon (BBC R&D and redacted)
Variable Name	**Comment**	**Random Distribution**	**min**	**max**		**unit**	**CAGR**	**References Date for CAGR**	**Source**

energy intensity cellular 3G 4G mix	Calculated from estimates for intensity of 3G and 4G and proportion of 4G (0.6 based on Ofcom estimates - Ofcom. 2016. "Connected Nations 2016." https://www.ofcom.org.uk/research-and-data/infrastructure-research/connected-nations-2016.)	uniform	6.30E-04	1.26E-04		j/b	-0.22	2010-01-01 00:00:00	Andrae, Anders, and Tomas Edler. 2015. “On Global Electricity Usage of Communication Technology: Trends to 2030.” Challenges 6 (1): 117–57. doi:10.3390/challe6010117.
proportion cable infratructure non ip tv	Estimate of cable infrastructure scope 2 emissions that are not due to either interent or Cable TV provision. Estimate of Mean = 0.12 From estimates of CO2e per employee for more office based organisations. High uncertainty reflected in wide range and uniform distribution	uniform	0.05	0.19			0	2016-01-01 00:00:00	Virgin media CSR report http://assets.virginmedia.com/resources/pdf/VM_Sustainability.pdf and estimates of CO2e per employee for office based organisations