International Telecommunication Union

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Radiocommunication Sector of ITU

Report ITU-R BT.2385-1

(03/2022)

Reducing the environmental impact of terrestrial broadcasting systems

BT Series

Broadcasting service (television)

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

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***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

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REPORT ITU-R BT.2385-1

Reducing the environmental impact of terrestrial broadcasting systems

(2015-2022)

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Keywords

Environmental impact, energy efficiency, terrestrial broadcasting, environment

Introduction

The environment and climate change are global issues. ITU Plenipotentiary Resolution 182 ("The role of telecommunications/information and communication technologies in regard to climate change and the protection of the environment"), approved in Guadalajara in 2010 and revised in Busan in 2014, notes that "the development and deployment of telecommunications/ICTs has resulted in innovative outcomes, including, but not limited to, better energy management, recognition of the contribution of the entire lifecycle of telecommunications/ICTs on climate change, and the benefits that accrue from the comprehensive deployment of telecommunications/ICTs". *Resolves* 2, 3 of Resolution 182 encourage energy efficiency and *resolves* 7 of Resolution 182, the adoption of green energy sources. The Secretary-General, in collaboration with the Directors of the three Bureaux, is also instructed to "encourage the use of renewable energy technologies and systems, and to study and disseminate best practices in the field of renewable energy".

Resolution ITU-R 60 (Reduction of energy consumption for environmental protection and mitigating climate change by use of ICT/radiocommunication technologies and systems) resolves "that ITU R Study Groups should develop Recommendations, Reports or Handbooks on best practices in place to reduce energy consumption within ICT systems, equipment or applications operating in a radiocommunication service" and "possible development and use of radio systems or applications which can support reduction of energy consumption in non-radiocommunication sectors" (*resolves* 1*)* and that "that ITU R Study Groups, when developing new ITU R Recommendations, Handbooks, or Reports or reviewing existing Recommendations or Reports, take into account, as appropriate, energy consumption as well as best practices to conserve energy" (*resolves* 2). Resolution ITU-R 60 highlights the importance of close cooperation and regular liaison between the Sectors (*resolves* 3) in order to avoid duplication, but also considers that "that the ITU T work programme developed on the basis of WTSA Resolution 73, does not contain specific studies focusing on energy consumption related to radio transmission technology or planning characteristics of radio networks" (*further considering b).*

Like all industries, the broadcasting sector has a responsibility to improve its environmental performance. The main environmental impacts of the broadcasting industry are greenhouse gas (GHG) emissions, energy use, raw material consumption and electronic waste. Studies suggest that 2% of global GHG emissions result from Information and Communication Technology (ICT) (~800 Mt CO2e). Television sets and related peripherals are responsible for ~1.8% of global emissions (~700 Mt CO2e)[1].

Methodology for assessing environmental impact of Broadcasting delivery

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.

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[1] EBU Tech Fact Sheet – Sustainable Broadcasting – 17 September 2014.

This methodology demonstrates 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.

Life Cycle Assessment (LCA) is a methodology that permits the estimation of the environmental burden associated with the production and use of a product or service. By adopting the GHG Protocol Life Cycle Reporting standard (Greenhouse Gas Protocol, 2011) and more specifically working 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 the system, and extending it by the 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, details of the methodology used and decisions made are provided.

The following steps are used:

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. 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. For Internet access, detailed user analytics data are used. 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).

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 this 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 this 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 this case, these are process elements such as coding and multiplexing which are shared between many users and unaffected by choice of configuration.

Where LCA is to be undertaken that extends beyond the scope of the limited Lifecycle assessment described above for Broadcast programme delivery; the methodology for LCA, which includes the production of, and end of life disposal of, broadcast receivers etc., the methodology outlined in Recommendation ITU-T L.1410 may be more appropriate.

Annex 1

Mega solar plans at high power radio transmitting station in Japan

1 Introduction

In Japan, there has been considerable interest in harnessing sustainable sources of energy since the Great East Japan Earthquake in 11 March 2011. Natural sources of energy and the environment are major issues of public concern. The broadcasters in Japan try to provide their service which is environment-friendly by suppressing an increase in energy consumption by the development and installation of broadcasting facilities with energy saving. In the case of using natural sources of energy, solar power generating facilities are installed into not only broadcasting halls, but high-power radio transmitting stations. This facility is playing its part in helping protect the environment by reducing carbon-dioxide emissions. The power purchase has been reduced by installing a solar power generating facilities.

2 The list of radio transmitting stations with solar power generating facilities

The solar power generating facilities were installed into the radio transmitting stations of public and private broadcasters. The list of radio transmitting stations with solar power generating facilities in Japan is shown in Table 1.

TABLE 1

Radio transmitting stations with solar power generating facilities

Broadcaster	Radio transmitting station	Start date	Output power (kW)	Annual output power (MWh)	Number of panels
NHK (Japan Broadcasting Corp.)	Shobu-Kuki	August 2012	2,000	2,800	8,124
Kyushu Asahi Broadcasting Co., Ltd.	Kitakyusyu	February 2013	730	730	2,548
Broadcasting System of San-in Inc.	Yonago	April 2013	1,750	1,840	700
RKB Mainichi Broadcasting Corp.	Kitakyusyu	August 2013	900	890	3,100
	Yukuhasi	August 2013	280	290	1,180
CBC Radio Co., Ltd.	Nagashima	August 2013	1,645	1,684	6,800
Yamanashi Broadcasting System Inc.	Futaba	August 2013	1,150	1,000	4,700
Asahi Broadcasting Corp.	Takaishi	September 2013	1,990	2,800	10,000
Mainichi Broadcasting System, Inc.	Takaishi	October 2013	600	700	2,884
Nippon Broadcasting System, Inc.	Kisarazu	October 2013	1,908	2,102	7,634
"RKK" Kumamoto Broadcasting Co., Ltd.	Arao	October 2013	890	950	3,626
Yamagata Broadcasting Co., Ltd.	Numagi	October 2013	725	741	3,024

3 Example of mega solar system at a radio transmitting station

The following provides overall details about installation of the 2MW solar power generating facilities into the Shobu-Kuki Radio Transmitting Station, which is one of the largest radio transmitting stations in Japan. The technical problems that had been overcome for the installation of the facility and the amount of power it has produced are described in the following sections.

3.1 Overview of the Shobu-Kuki radio transmitting station

The Shobu-Kuki radio transmitting station broadcasts NHK's Radio 1 service (594 kHz) at 300 kW and NHK's Radio 2 service (693 kHz) at 500 kW. These services can reach approximately 20 million households (or some 40 percent of the total households in Japan). A height of 245 m antenna is used for NHK Radio 1, while a 215 m antenna is used for NHK Radio 2. These transmitters are solid-state digital. The facility as a whole normally consumes 1,100 kW of power. The 30 hectare site has copper wires for grounding running underneath it in radial patterns from the antenna. The grounding radials ensure the efficient radiation of the radio wave. The solar panels were established on the southern side of the site so that they would not come under the shadow of the antennas. Enough panels were installed to supply all of the facility’s power needs when the panels are operating at full capacity. There are a total of 8,120 panels, each capable of generating up to 247 W, or a total of 2 MW. They are arranged in 145 blocks or series, consisting of 14 × 4 panels, which occupy about 3 hectare of site. They generate an estimated 2,000 MWh of power per annum, achieving a 1,000 tons of reduction in carbon-dioxide emissions. The solar power generating facility was first considered in its construction in 2009, and was completed in 2012. Installation of the solar power generating facility into the Shobu-Kuki Radio Transmitting Station is summarised in the following sections.

3.2 Prior considerations

Solar power is looked upon a source of energy for the future. It is clean, sustainable, and does not rely on fossil fuels, but it does require space for the installation of solar panels. As the solar power generating facility was to be established at a radio transmitting station, there had to be prior consideration of the possible impact the radio wave might have on the extensive solar panels, and vice versa. Particular consideration was given to the possible effect on the grounding radials, given that the panels would have to be installed above the undergrounding radiating copper wires. Another important issue was safeguarding the transmitters from any negative impact by connecting the solar power generation facility to the existing power facilities.

3.2.1 Examinations with actual equipment

A system of actual, minimum-scale equipment was created to consider the possible effects that the strong field strength might have on the different components of the solar power generating facility. It consisted of a 10 kW power-conditioning subsystem (the smallest industrial version available) and a module of 9 × 200 W solar panels. The solar panels were moved within the site of the Shobu-Kuki Radio Transmitting Station to examine the impact of the strong field strength (see Fig. 1). Main considerations were as follows:

– Impact on the solar panels.
– Unwanted signals in the cabling for the solar panels.
– Unwanted signals in the cabling between the solar panels and the power-conditioning subsystem (CPS).

FIGURE 1

Examinations with actual equipment

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A series of tests were conducted by progressively shifting the panels into stronger field strength. No trouble was found to generate power even when they were positioned in strong field strength right near the antenna, and when the cables extended for a length of 200 m, the distance expected for the solar power generation system.

3.2.2 Electromagnetic simulations

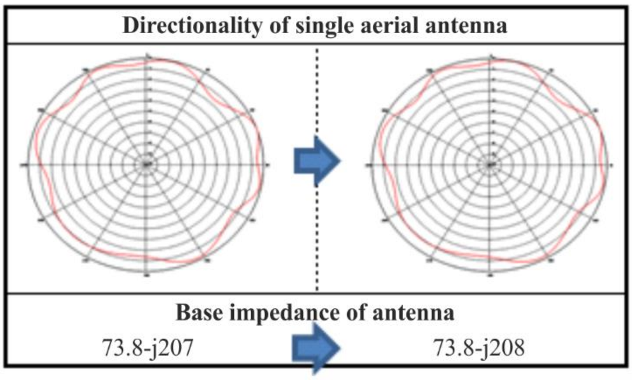
Electromagnetic simulations were carried out with a model of the solar panels for the proposed the solar power generation system. The considerations were as follows:

- Impact on radio waves.
- Impact on the transmitters.
- Impact of unwanted signals in the solar panels.

The solar power generation system would have to be placed at the maximum possible distance from the antenna, given concerns about the possible effect the panels might have on the medium-wave signals. The amount of unwanted signals in the solar panels was smaller than that in the minimum-scale system. Moreover, there was no effect on the directivity of the antenna and impedance. The results of the simulations are shown in Fig. 2.

FIGURE 2

Simulation result of electric field



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3.2.3 Extended test

An extended operational test in strong field strength was carried out with a 12 kW solar power generating facility, which was built by adding more solar panels to the PCS (Power Conditioning Subsystem) in the minimum-scale system. The 12 kW facility consists of 63 × 200 W panels (see Fig. 3). It generated power without any troubles during its test.

FIGURE 3

12 kW solar power generating facility

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3.2.4 Construction test

A study of the subsurface of the proposed site of the solar power generating facility was carried out. There was also a test to consider the possible impact that the ensuing construction work might have on broadcasts. This was done by cutting a number of wires in the grounding radials. A maximum of up to 15 wires had been cut in the event the solar power generation facility had 4 power-conditioning subsystems and extend over a quarter of the radials. A number of wires were cut during broadcast service suspension at night. The operating data from the transmitters and electromagnetic measurements revealed no impact, even when 15 wires had been cut (see Figs 4 and 5).

FIGURE 4

Cutting points of grounding radial system

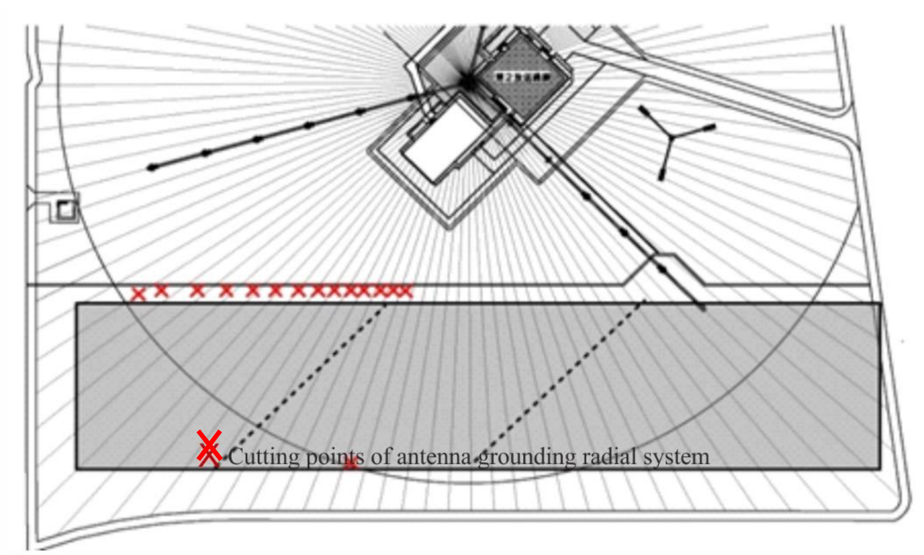

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FIGURE 5

Cutting off grounding radials

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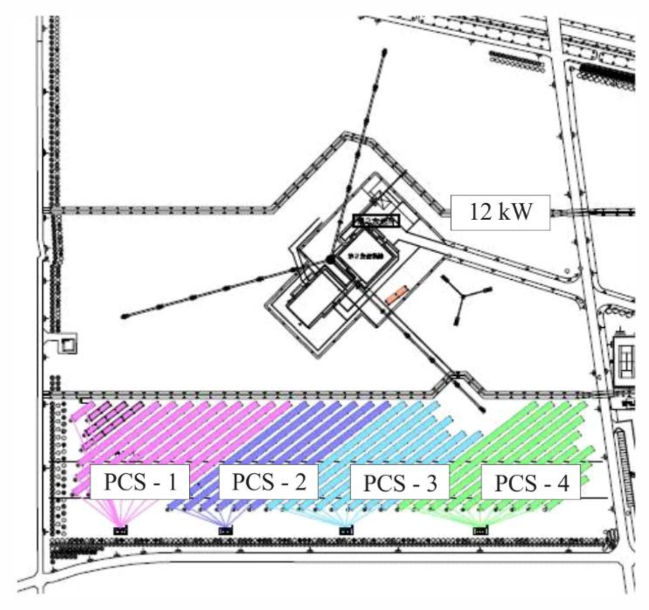
3.3 Arrangement of solar panels

The overall positioning of the solar panels focused on two issues: the shade coming from the tall trees abutting the southwest boundary of the site; and space required for new feeder cables. The angling and the spacing of the mounts for the solar panels are shown in Fig. 6.

FIGURE 6

Positioning of solar panels



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3.4 Grounding

3.4.1 Grounding radials

The wires that extend from the antennas to provide the grounding radials are situated about 40 cm below the surface. The piling and other interfering components were therefore installed beforehand to avoid them. Grounding wires in the form of twisted copper wires were laid around each mount for the solar panels, and connected to the existing grounding radials (see Figs 7 and 8).

FIGURE 7

Grounding radials

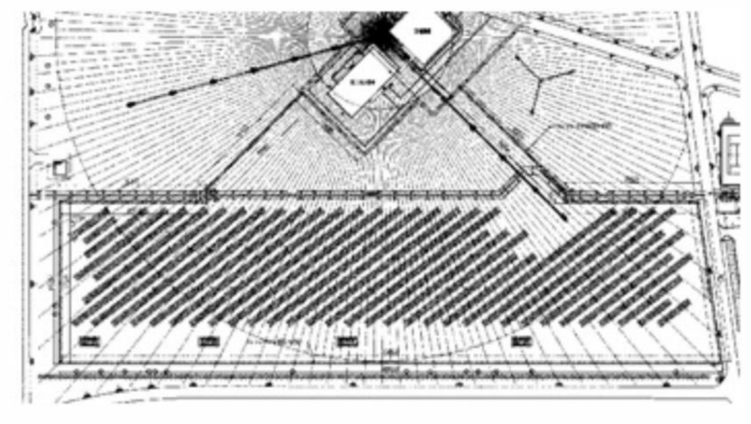

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FIGURE 8

Connection to the existing grounding radials

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3.4.2 Grounding for the solar panels

Protection equipments were connected to the mounts to protect the solar panels against lightning strikes. They run from above the panels to the foundations and to the grounding wires (see Fig. 9).

FIGURE 9

Lightning protection equipment

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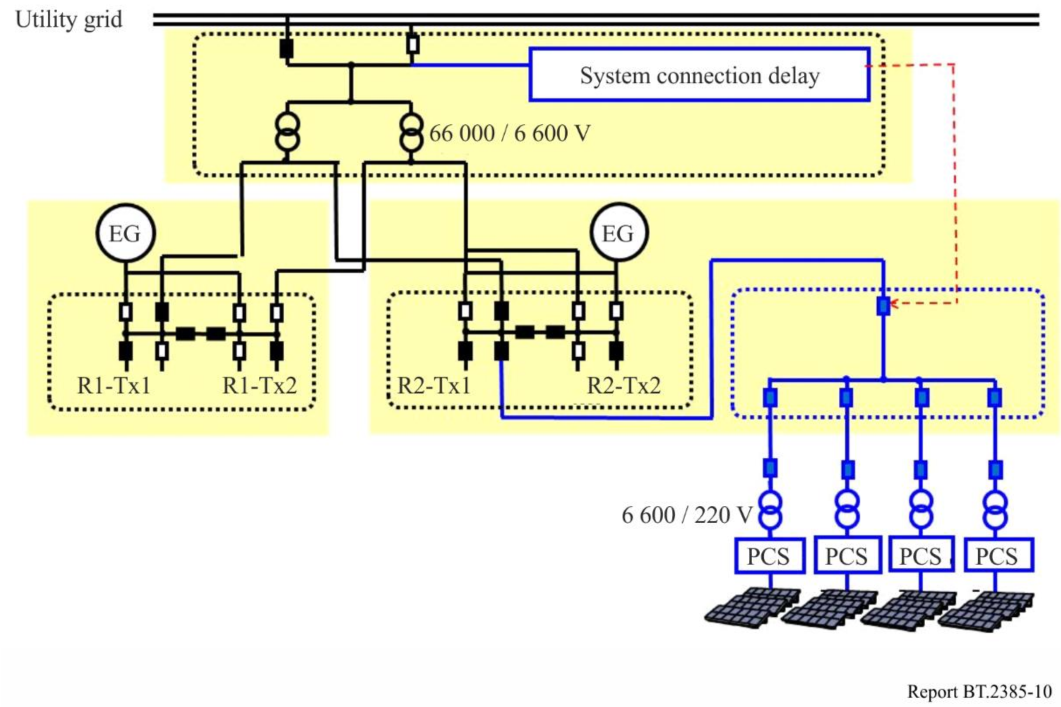
3.5 Electrical systems

3.5.1 Solar facilities

Figure 10 shows the electrical network for the solar power generation facility.

FIGURE 10

Connecting to the grid



The panels near the radio transmitting station for NHK Radio 2 generate approximately DC 430 V, which is converted outside to AC 6,600 V. The current passes through the solar power sub-station inside the building for the NHK Radio 2 transmitter to an auxiliary circuit breaker, and thence to the high-voltage substation where it is connected to the mains grid. The solar panels generate enough power for the transmitters and other facilities at the Shobu-Kuki Radio Transmitting Station. The system is designed to backfeed any surplus to the electric power company. Shortfalls at night-time and other occasions are accommodated by purchasing power from the power company.

3.5.2 Solar panels

The solar panels are arranged in series of 14 panels to ensure that the 41.12 V upper limit of the open-circuit voltage comes within the 600 V input-voltage ranges of the power-converting subsystems (CPS).

PCS-1, PCS-2, and PCS-4 have 144 parallel circuits, while PCS-3 has 148.

3.5.3 Electrical network for the solar farm

The direct current generated by the solar panels is converted into an alternating current at the power-converting subsystems (CPS). Four CPS have been established; each can handle up to 500 kW. The voltage is raised outside to 6,600 V to accommodate loss and suchlike from the cables that extend a distance of more than 200 m to the radio transmitting station for NHK Radio 2. A circuit breaker was established at the high-voltage substation so that the solar power generating facility can be disconnected from the mains grid in the event of parallel operation. It runs to the auxiliary breaker at the radio transmitting station for NHK Radio 2. Figure 11 shows an outside power distributor. Table 2 shows the specification of each PCS:

TABLE 2

Specification of PCS

Capacity (kW)	500
Rated input voltage (V)	DC 350
Input voltage range (V)	DC 310 – 600
Maximum power point tracking range (V)	DC 320 – 550
Output voltage (V)	AC 210
Conversion efficiency (%)	97.1 (1)

(1) Maximum conversion efficiency of 97.7% at 40% rated capacity.

FIGURE 11

External power panels

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3.5.4 Grid connection

In order to avoid back feeding to the commercial power grid, the solar power generating facility must be disconnected without delay if there is any earthing at the utility side. A relay for the mains grid was established in the upper part of the extra-high voltage transformer. As the transformer relies on dry compressed air for insulation, the modifications, including the airtight tests and compression, took four days. The placement of the relay is shown in Fig. 12.

FIGURE 12

Placement of grid connection

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The relay was installed for backfeeds to the mains grid. It does not control the electrical networks for the transmitters and other facilities, only the breaker for the solar power generating facility.

3.6 Power generation and impact

One sunny day, the solar generates more power than that consumed by the Shobu-Kuki radio transmitting station; the surplus can be sold to the electric power company. The amount of power generated by the solar power generating facility is shown in Figs 13 and 14. The broadcasts from the transmitter continue without interruption, as the electric power company can cover any momentary drop in power generation owing to cloudy skies or other factors. Sunny conditions saw the solar farm generate approximately 316 000 kWh in May 2013. Moreover, electromagnetic measurements have not revealed any major fluctuations in the directivities of the antennas, which had been major concerns (see Fig. 15). The facility has been generating power in a stable manner without any effect on the radio broadcasts.

FIGURE 13

Solar power generation

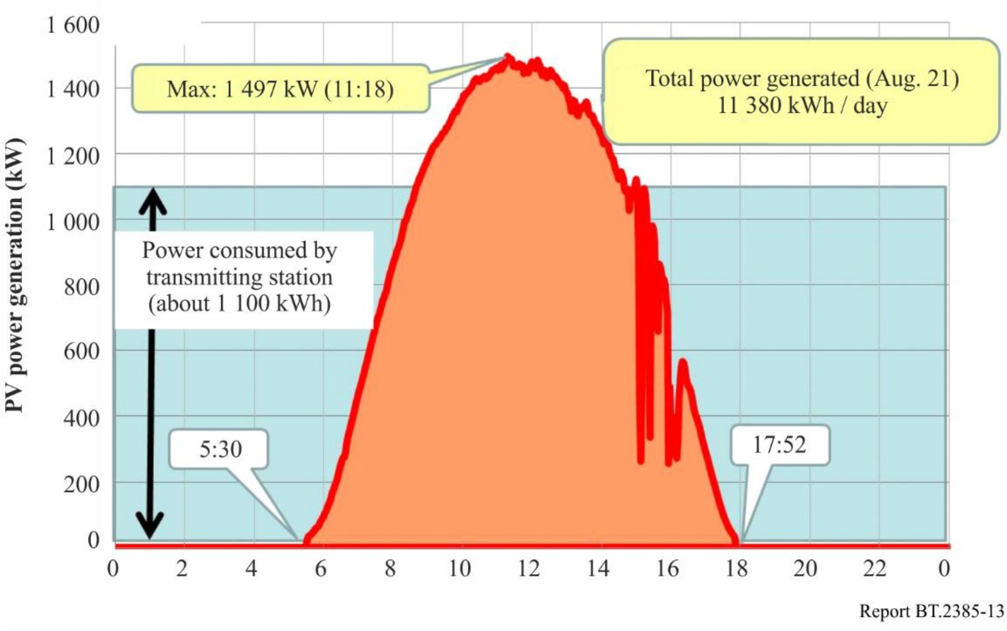

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FIGURE 14

Monthly total generated powers (kWh)

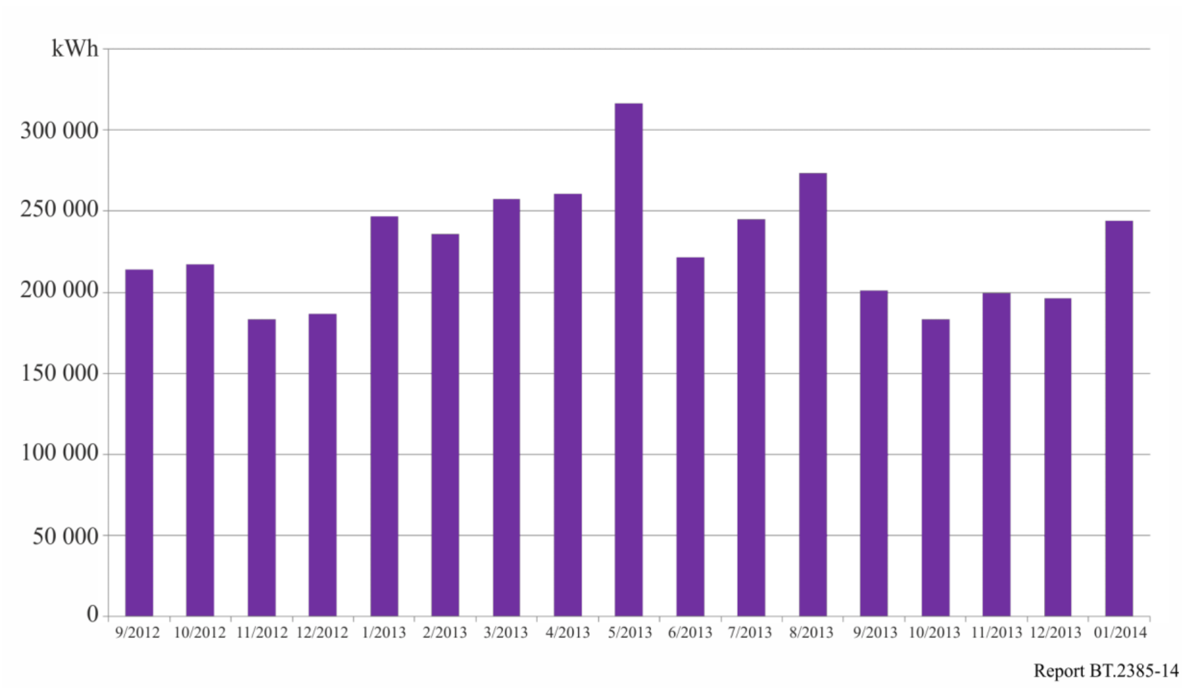

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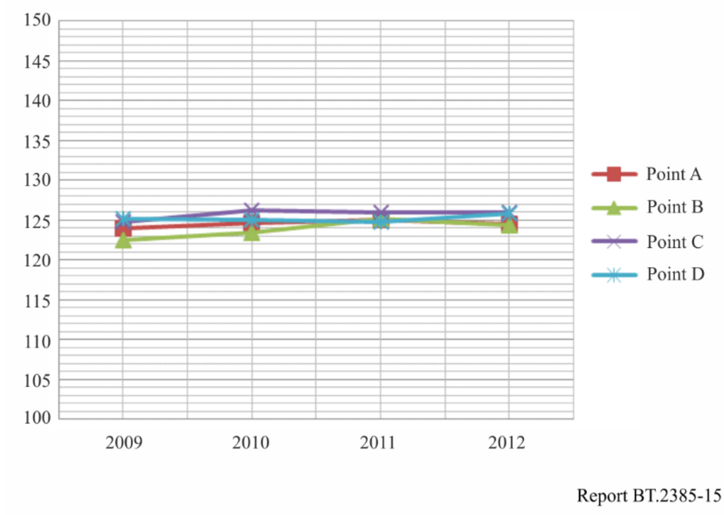
FIGURE 15

Fluctuation of field strength in measurement points



4 Summary

The solar power generating facilities were established at some of the radio transmitting stations in Japan. The objective was to reduce the demand for electricity during peak periods in the day and reduce carbon-dioxide emissions without any interruption of the broadcast services. This Report provides the list of radio transmitting stations with solar power generating facilities and the example of installation into the one of the largest radio transmitting stations. It also describes the simulations and examinations with actual equipment to study the possible impacts of solar system installation on radio wave and the possible impacts of broadcast signals on solar system. Based on the results of these prior considerations that showed that the mutual impacts were extremely small, the installation of the solar power generating facilities was conducted. This system has been generating environment-friendly power without any impact on the radio broadcasts.

Annex 2

Evaluations of energy consumption associated with terrestrial television broadcasting

1 Introduction

Terrestrial television broadcasting is a radiocommunication service that provides information, entertainment, culture and instruction to virtually all the populations in the world, through a multiplicity of emission channels of diversified thematic vocations.

The ITU has stressed the need to establish best practices to reduce energy consumption within information and communication technology (ICT) systems, equipment or applications operating in radiocommunication services in order to reduce their impact on climate change. Mindful of this need, CBS and Rai Way, which both operate terrestrial television broadcasting services respectively in the USA and in Italy, have coordinated an inquiry to assess how efficiently they use electric energy to distribute television broadcasting programs to their audiences.

2 Energy efficiency of terrestrial television broadcasting emissions

The parameter chosen in this document to estimate the energy efficiency of terrestrial television broadcasting emissions is the daily energy used by a transmitter to deliver one digital television channel to each household in its service area (a channel carries a multiplex of one or more HDTV and/or SDTV program schedules).

The parameter value is computed on the following premises:

– the energy used by the broadcaster is the one required for the emission of one channel, irrespective of the number of television program schedules carried in the channel;

– the used energy, in Watt-hours is the one measured at the output of the transmitter, not the one radiated by the antenna;

– the channel is broadcast 24 hours a day: the used energy is the total daily energy;

– the potential audience is the total number of households directly served by the main transmitter;

– it is assumed that on average, each household is made up of three persons.

The approach taken in this annex correctly uses the ‘potential audience’ as the audience parameter, rather than using a parameter derived from audience polls, since the values of audience polls depend upon the audience appreciation of the content of the programs, while the potential audience is defined as the size of the audience that a broadcast transmitter can serve, irrespective of the programme content. The parameter of potential audience is particularly appropriate for those countries in which public broadcasters are under a charter obligation to serve a given percentage of the population in a given territory, irrespective of the population density.

Tables 3 and 4 show the case studies relevant respectively to the CBS and the Rai Way operation. The rightmost column in the Tables shows the electric energy, in Watt-hours, that their terrestrial television broadcast transmitters use each day to provide each household of their potential audience with the programme schedules carried in one digital television emission channel.

TABLE 3

Case study for CBS (USA)

Transmitting centre	**Frequency band**	**Type of service area**	**Power per channel (kW)**	**Potential audience**	**Daily energy per household (W-h)**
New York	UHF	A metropolis and a very wide area	88	19 400 000	0.33
Los Angeles	UHF	A metropolis and a very wide area	100	17 000 000	0.42
Chicago	VHF-Hi	A metropolis and a very wide area	13	9 200 000	0.10
Baltimore	VHF-Hi	Two large cities over a wide area	27.5	2 700 000	0.73

TABLE 4

Case study for Rai Way (Italy)

Transmitting centre	Frequency band	Type of service area	Power per channel (kW)	Potential audience	Daily energy per household (W-h)
Paganella (in the Alps)	VHF	A city and many villages	0.25	175 000	0.10
Venda (the Po river valley)	VHF	Several cities and many towns	2.5	4 240 000	0.04
Eremo (the city of Turin)	UHF	A large city and its surroundings	2.5	2 075 000	0.09

The Tables show that broadcasters typically use a small fraction of one (1) Watt-hour per day to deliver one terrestrial television channel to each household in their audience[2]. Furthermore, it can be expected that improvements in the energy efficiency of broadcast transmitters and in the ways broadcasting networks are managed will further reduce the energy currently used by digital terrestrial television broadcasters to deliver their program schedules to their audiences.

3 Energy required by television consumer receivers

The receiving devices for broadcasting are not directly under the control of the broadcast industry. The broadcasting industry will always encourage manufacturers of these devices to make them as energy efficient as possible. Reception of broadcasting is on a variety of devices ranging from laptops, tablets, portable receivers and static television receivers.

The following tables are provided for information purposes to give the necessary information on the domestic receiving end of the television broadcast service.

Table 5 recalls the power consumption of typical television consumer receivers.

TABLE 5

Power consumption of typical television consumer receivers of various screen sizes

Screen size of the television set	52”	46”	40”	32”
Power used in the ‘bright’ (‘shop’) mode (W)	260	220	170	100
Power used in the ‘home’ mode (W)	200	160	140	90
Power used in the ‘quick start’ mode (W)	17			
Power used in the ‘standby’ mode (W)	0.2			

Table 6 gives the typical total daily energy consumption used by each household, on the assumption it watches television in the ‘home’ mode for an average of four hours per day and that the television set is kept in the ‘quick start’ mode in other hours, or in the ‘standby’ mode, or it is switched off.

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2 It can be noted that CBS stations in the USA use a higher daily energy per household than Rai Way stations in Italy. This is not surprising since the average population density over the USA is about one sixth of the average population density over Italy (about 32 persons per square kilometre in the USA, and about 200 persons per square kilometer in Italy).

TABLE 6

Daily energy consumption of a typical television consumer receiver watched 4 hours per day

Screen size of the television set	52”	46”	40”	32”
Daily energy used if the TV set switches to the ‘quick start’ mode when not in use (W-h)	1 140	980	900	700
Daily energy used if the TV set switches to the ‘standby’ mode when not in use (W-h)	804	644	564	364
Daily energy used if the TV set switches off when not in use (W-h)	800	640	560	360

4 Conclusions

The analysis shows that broadcasters typically use a small fraction of one (1) Watt-hour per day to deliver one terrestrial television channel to each household in their audience. The overall power consumption of the broadcasting chain is dominated by consumer receivers. Nevertheless, further improvements can be expected in order to further reduce the overall energy consumption.

Annex 3

Power consumption of DVB-T broadcast networks in Germany

1 Introduction

ITU is studying how the information and communications technology (ICT) contributes to the effect of climate change and how ICT could be used to reduce this effect (ref. for example to Resolution ITU-R 60 “Reduction of energy consumption for environmental protection and mitigating climate change by use of ICT/radiocommunication technologies and systems”, which, in turn, makes reference to Resolution 182 of the ITU Plenipotentiary Conference (Guadalajara, 2010) entitled “The role of telecommunications/information and communication technologies in regard to climate change and the protection of the environment”.

The transition from analogue to digital television has led to a dramatic reduction in energy consumption needed for the terrestrial television service. On one hand, the number of transmit stations could be significantly reduced (from a few thousand to about 150 per national TV network) owing to the immunity of DVB-T and DVB-T2 to multipath propagation. Practically all fill-in stations could be shut down. On the other hand, the transmit power of a TV station could be reduced significantly due to the lower $C/(N+I)$ requirements for digital modulation (from up to 500 kW ERP for one analogue TV programme to typically 34.5 kW ERP for a multiplex of four TV programmes).

The following analysis deduces the consumption of electrical energy for the total of the German DVB-T networks and puts it in relationship to the annual personal energy consumption of the DVB-T users. The power consumption of broadcast networks is often overestimated. The conclusion, however, is that the percentage of electrical energy needed for DVB-T per user is negligible in practice.

2 Input power and radiant power of transmitters

The input power is used to produce a signal whose strength is called radiated power of the transmitter. The ratio between radiated power and input power is the efficiency. The radiated power can be increased by focusing the electrical energy on a certain spatial segment. The result is the effective radiated power (ERP) as product of the radiated power and the antenna gain.

Consequently, the following equation is valid:

$$\text{ERP} = (\text{input power}) \times \text{efficiency} \times (\text{antenna gain})$$

Usually, only the ERP of a transmitter is made public and the input power has to be determined by backwards calculation.

3 Power consumption of an existing DVB-T network in Germany

As an example, an existing TV coverage in Germany is considered: four TV programmes (ZDF, 3sat, KiKa and ZDFneo) are transmitted together in a DVB-T multiplex. The network consists of 143 transmitters with an average ERP of 34.5 kW. The efficiency of today's DVB-T transmitters is about 25%-30%. For new transmitters, it is around 30%. Prototypes of transmitters with an efficiency of 40% were already presented. The antenna gain is about 10 dB.

There is no relevant overhead to be taken into consideration to cope with potential failures of transmit equipment. Effectively, redundancy is provided by the fact that a power amplifier consists of several modules.

A failure of one of them causes only a weakening of the signal until the module is replaced. Of course, major transmission facilities include a replacement transmitter which, however, requires only a small fraction of normal input power in standby mode.

The average ERP of a transmitter of the DVB-T network mentioned above is 34.5 kW. From an antenna gain of 10 dB (including cable loss) it can be concluded that the output power of the power amplifier is one-tenth of that value (3.45 kW). For an efficiency of 30%, an electrical power of 11.5 kW is required to produce an amplifier output power of 3.45 kW. Consequently, the overall electrical power for 143 transmitters is thus 1.645 MW (= 143 × 11.5 kW). This corresponds to an annual consumption of electrical energy of the transmission network of 14.4 GWh.

4 Comparison with overall power consumption

There are usually six (6) DVB-T multiplexes in Germany, so the overall consumption of electrical energy of the DVB-T networks is about 86 GWh/a (= 6 × 14.4 GWh/a). However, three of these multiplexes (private stations) are restricted to urban areas. Consequently, the overall consumption of electrical energy of the DVB-T networks is less than 86 GWh/annum. But for sake of simplicity, let us assume 86 GWh/a. About 10% of the population receives TV via the DVB-T networks (primary and secondary TV receivers) corresponding to around 8 million people. Hence the electrical energy consumption of the DVB-T networks per user is 10.8 kWh/a (= 86 GWh/annum / 8 million).

Annex 4

Wind power generation in the South Atlantic

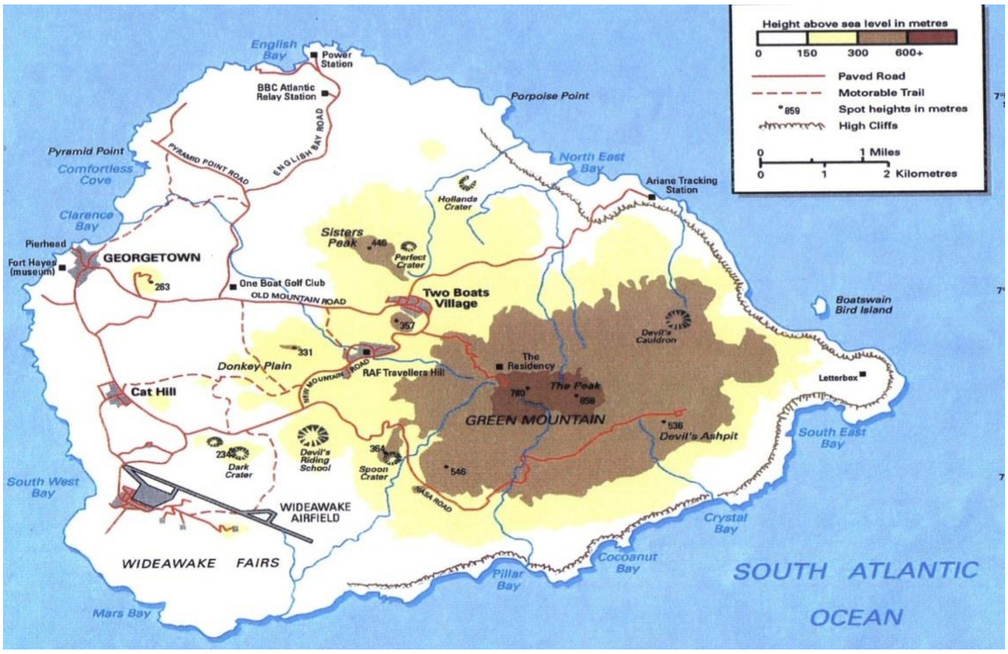
1 Introduction

BBC World Service operates a high power AM short-wave relay station on Ascension Island in the South Atlantic Ocean. Ascension Island is part of a British Overseas Territory, together with St. Helena and Tristan da Cunha, and is geographically ideally located for short-wave coverage of Africa and South America.

The transmitting station, together with a new diesel fired power station, were opened at English Bay on the northern coast of the island in 1966, together with a village of bungalows at Two Boats to accommodate the staff.

Both the transmitting station and power station are owned by the BBC, currently operated and maintained on its behalf by Babcock International.

Today, the BBC broadcasts from Ascension to Africa in English, Hausa, and French. The site continues to be strategically important to delivering radio services to the BBC's large short-wave audiences in Africa.



However, its disadvantages include its remoteness and the lack of any natural resources.

The major operating costs to BBC on Ascension Island are electricity costs – which is generated using diesel fired generators. In a re-engineering project that began in 2004, the BBC commenced a two-phase programme to reduce operating costs:

– replacement of ageing Marconi BD272 AM transmitters (45% efficient) with modern RIZ AMC transmitters (80% + efficient) together with a new station automation system allowing unattended operation of the transmitting station;

– an investigation into powering the transmitting station and the other British interests on the island using renewable energy sources.

This paper will describe how the BBC has brought environmental "green" benefits to this remote island, and at the same time reduced its electricity bill.

2 BBC power station

2.1 Overview

The BBC Power Station at English Bay is a diesel fired power station originally built in 1966. It supplies electricity and fresh water to all British interests on the island.

– Consists of 7, W H Allen V12 diesel generators
– Rated at 1,417 kW typically run on Ascension at 1,350 kW
– Between 2 and 3 diesels operate depending on forecasted load
– Major load is the atlantic relay transmitting station
– Supply an 11kV island network, mostly overhead transmission cable
– Compliance UK Grid code: 50 Hz

2.2 Renewable energy options

In 2005, the BBC commissioned work to investigate the use of renewable energy to reduce the environmental impact of our operation on the island.

Five options were initially reviewed:

– solar;
– wave/Tidal;
– geothermal;
– biomass;
– wind.

Table 7 summarises the 2005 review.

TABLE 7

Summary of the 2005 review

Technology	Relative cost	Resource	Advantages	Disadvantages
Geothermal	Low	Potencially high	Supply whole island with heat and power	Exploration costly, several years and financially risky
Solar power	High	High	Light weight, easy to install, proven technology	Very expensive, variable energy yield
Wind power	Low	High	Cost effective, proven technology	Integration with wind diesel and effect on water production
Wave and tidal power	High	Low	None	Resource and technology not proven
Biomass	High	Low	None	Small energy yield and expensive

2.2.1 Geothermal

Given the volcanic nature of the island geothermal power was an option, and research conducted previously by US researchers had demonstrated a potential resource on the island. But costly and time consuming exploration work would need to be conducted at risk to identify the suitability of the resource. If available, the potential reward is a continuous supply of economically attractive electrical power and heat in sufficient quantity for the whole island.

2.2.2 Solar

Although the solar irradiance resource is likely to be high, a large quantity of photovoltaic equipment would be required, at considerable cost, just to fulfil the base load. Given the variability of solar power it is likely to create significant engineering obstacles, and given the 24/7 nature of the transmitting operation considerable additional energy storage devices would be required.

2.2.3 Wave and tidal

In 2005, wave and tidal technologies were largely undeveloped, and an unproven technology is not suited for a remote island.

2.2.4 Biomass

Given the population of the island the biomass resource potential will not be large enough to impact on the energy requirement of the island.

2.2.5 Wind

Of the technologies reviewed, it was concluded that wind power was the cheapest, lowest risk exploitable renewable energy technology. The island benefits from an excellent wind regime, dominated by the consistent south-easterly trade winds. Ergo, on balance it was concluded that the installation of wind turbines was the most attractive option.

2.3 Wind power feasibility study

In 2006, a Feasibility study evaluated potential locations:

– consulted with local administration, environment officer, conservation department, the US Air force regarding aerodrome safeguarding, other internal and external companies / organisations;

– wind resource;

– access;
– grid connection;
– physical space;
– geology.

The chosen site was at English Bay close to the BBC Power Station. This site provided good wind resource, good grid connection, good access, suitable physical space, clear of seabird nesting grounds and acceptable geological conditions. The risk of RF interference was mitigated by choice of location of the turbines.

FIGURE 16

Chosen wind farm location

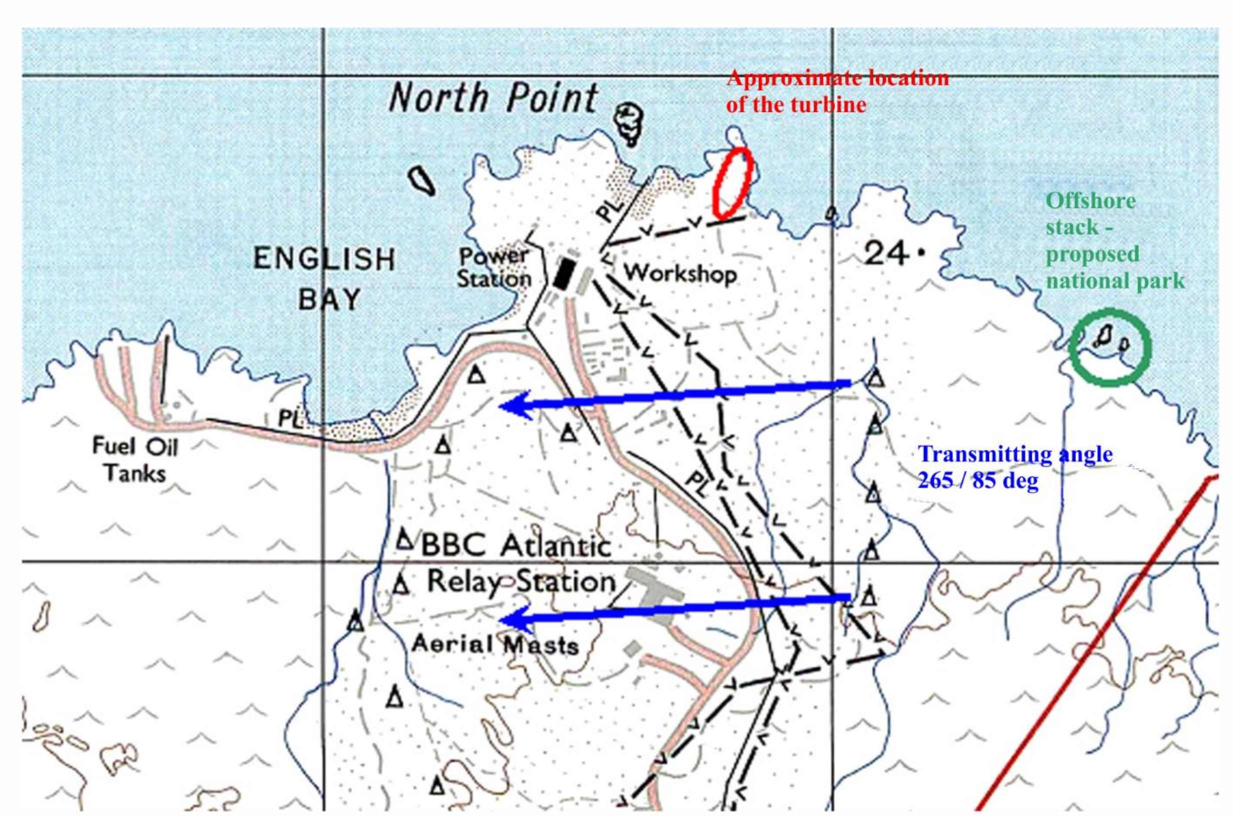


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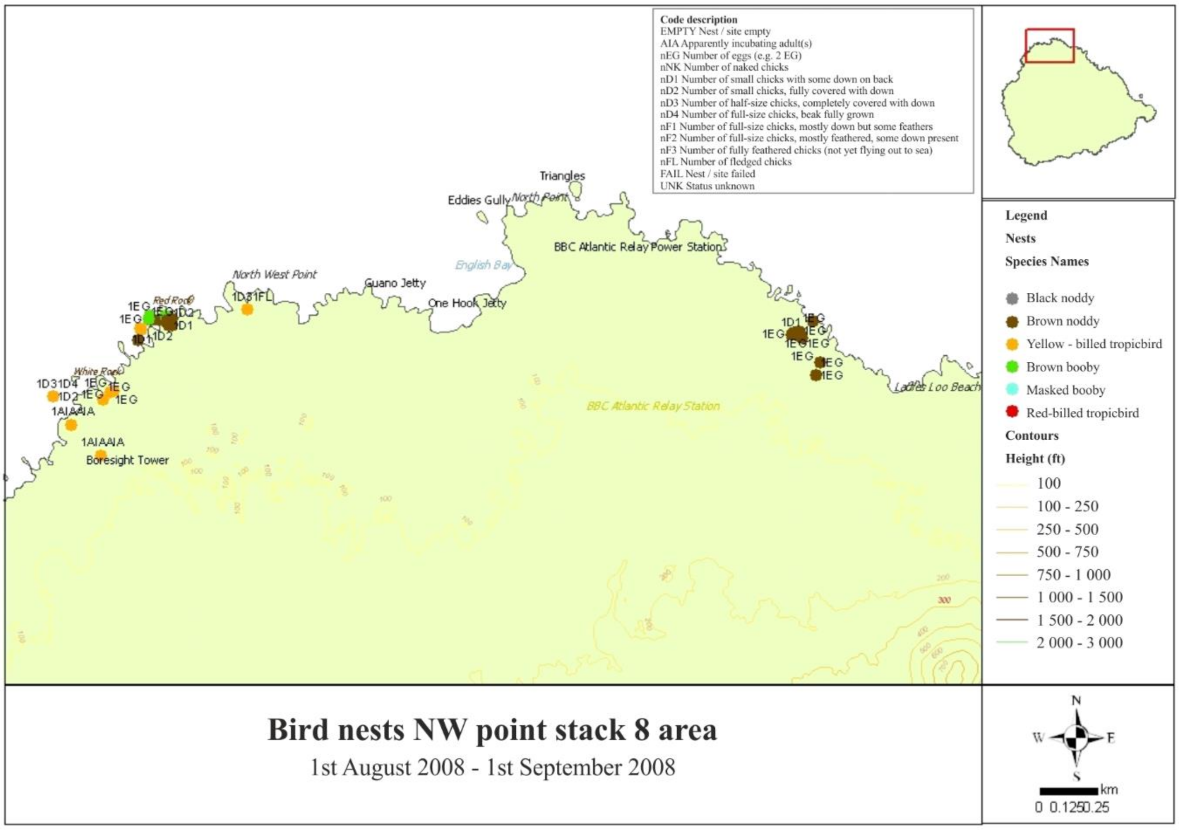
FIGURE 17

Bird nesting sites on north coast of Ascension



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2.3.1 Geological conditions at site

On this volcanic island there was concern about ground conditions. Initial investigations were carried out at the proposed site to explore ground conditions. Three trial pits were excavated at site, and revealed rock at variable depths < 1 m. The 'rock' comprises of volcanic cobbles and boulders, silt and sand. Loose volcanic material and cobbles cover the surface, as shown below.

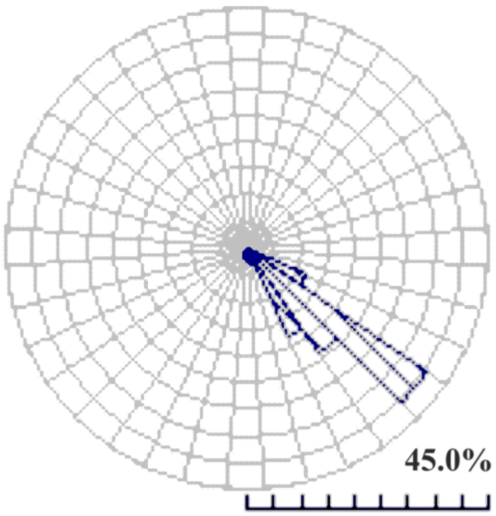
2.3.2 Wind resource monitoring

To confirm the wind resource on the site, a 50 m high wind monitoring mast was erected, equipped with anemometers and wind vanes at 30 m, 40 m and 50 m. The monitoring system was powered by

Solar PV, and data retrieved from a memory card periodically. Over a nine-month period, recorded data was closely analysed and this was correlated with long term data obtained from the weather station at Ascension Airfield. The results proved that there is a relatively constant SE wind resource with very low wind shear.

FIGURE 18

Wind Rose showing prevalent SE trade wind



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Wind Rose showing prevalent SE trade wind
Long term wind climate is 8.84 m/s at 50 m
Long term wind climate is 8.81 m/s at 40 m
Long term wind climate is 8.77 m/s at 30 m

The initial design considered the use of two wind turbines up to 900 kW each with up to 50 m hub heights. These plans were later modified due to difficulties of offloading at Ascension and erection on site to use of five turbines each of 330 kWp at 36 m hub height. Calculated figures predict a wind resource capable of producing circa 5 GWh.

FIGURE 19

Offloading at Ascension Island

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2.4 Wind farm implementation

BBC World Service signed a contract in 2009 with Enercon for the supply of 5 off 330 kW wind energy converters (WEC's) to be located at English Bay adjacent to the BBC Power Station. Civil works associated with this project were carried out by Morrison Construction.

Project work was started on the island in July 2009 with project completion in April 2010.

The E 33 WEC's are a gearbox-less variable pitch machine, ideally suited to use in the Wind Diesel Hybrid application.

FIGURE 20

WEC 1 and 2 Ascension Island

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FIGURE 21

WEC 3, 4 and 5 Ascension Island

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2.4.1 Wind farm results

Year	Total wind farm output (MWh)	Grid penetration (%)	Average wind speed (m/s)	Average availability (%)	Co2 offset (tonnes)
10/11	2,411	N/A	N/A	90.08	603
11/12	2,924	23.19	7.18	97.70	731
12/13	2,768	23.05	7.37	99.09	692
13/14	2,802	25.48	7.36	98.34	701
14/15	2,081	25.97	7.54	95.02	520

2.4.2 Pre wind farm

Peak power load

Transmitting station: 3.2 MW – Using six original Marconi BD272 AM transmitters

Island load: 1 MW

– consumed circa 6M litres diesel p.a.

– required four bulk storage tanks holding 10 M litres of fuel

– refueling every 18 months using floating hose to offshore tanker.

2.4.3 Post wind farm

Peak power Load

Transmitting station: 2.2 MW – 4 Riz AMC transmitters plus 2 Marconi BD272 AM transmitters

Island load: 1 MW

– consumed circa 3M litres diesel p.a.

– require two bulk storage tanks holding 6 M litres of fuel

– refueling reduced to every 24 months.

Conclusions

Whilst Wind Diesel hybrid systems can deliver substantial green benefits to operators of high power short-wave broadcasting from remote islands, the challenges should not be underestimated.

The choice of wind as the renewable resource on Ascension Island was proven to be correct and has fully justified the investment. On an island with near constant wind resource this was not a difficult choice. A wind-based solution will not necessarily be correct in all locations.

As the owner of the HV grid on the island the BBC was able to re-engineer and approve the new grid design without reference to a third party "utility operator".

The lobby from other environmental groups should not be underestimated. Considerable challenge from the island's conservation department were faced, who were concerned with the impact of the turbines on the island's birdlife.

In closing, a respectable 25% grid penetration is now being achieved, with a wind diesel hybrid system without energy storage. Only around half of the available wind resource from the wind farm is being utilised. In the future, given suitable battery technology, there appears to be scope to develop this solution to deliver 50% grid penetration.

Annex 5

Solar powered FM broadcasting

1 Introduction

For local and rural VHF FM broadcasting to small communities the widest coverage area can be achieved through having the transmitting aerial as high as possible but there can be many difficulties associated with this objective.

In a city, mast and towers are often available; however this is not always economically possible or practical where the service is in a rural location with a lack of infrastructure. Transmitters can be installed on a local high building or on top of a hill but this prime position can bring complications with a lack of a public electricity supply; a diesel generator could be used but has the problem of refueling.

For locations where a public electricity supply is expensive, unreliable or would cost too much to install and maintain, the possibility of using renewable energy is attractive to provide an autonomous power supply with low routine maintenance. An off-grid photovoltaic (PV) system may be a solution to consider; PV panels convert solar energy to charge batteries and the stored energy in these batteries can be used for low power FM transmitters.

2 System design

The design an off-grid PV system is done in a certain order and each step often dictates the decisions made in the next step. At a high level, the steps are to determine the:

– energy consumption and consumption pattern of the load;

– size of the energy storage required;

– amount of energy that needs to be generated by the PV array.

In PV systems the design considerations include.

Location – Based on the location meteorological data is available for the system calculation, the most significant factors is the available solar radiation energy (available from NASA's Atmospheric Science Data Centre https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi) and the daytime ambient temperature (available from a number of sources including Weather base http://www.weatherbase.com/.) The angle of incidence of the sunlight on the PV panel is also determined from the location and the variance of incident (and so energy conversion) over the year is also location dependent.

System load – this includes transmitter load, equipment such as rebroadcast or satellite receivers, system inefficiencies in the power conversion and I^2R power loss in the cables. Consideration needs to be given to using equipment that will connect directly to the batteries, for example a 24V DC exciter to a 24V battery system. Efficiency of the overall system is a prime consideration.

Days of Autonomy – The number of days the system can operate without the battery array being re-charged contributes to the battery capacity required; a power saving mode to reduce or inhibit the transmitter power may reduce the number of batteries and panels needed to a more acceptable cost.

Depth of Discharge – The amount batteries are allowed to discharge before the broadcast system (the load) is switched off varies between different types of panels and batteries.

As the aim is to design an off-grid system, all of the energy used by the relay system must be generated by the PV array. In months of the year where there is less solar radiation available there will be less energy generated from the array. The PV system must be designed to support the relay system during the darker winter months. By tailoring the load to match the amount of available solar radiation, a smaller PV array will be able to be used, and less energy will be wasted.

When planning a PV system, it is possible to make reasonable predictions about the solar energy available, as the sun's radiation is fairly consistent. Meteorology, however, is not. To enable the PV power system to cope with unpredictable weather, cloud cover for example, sufficient reserve must be available, data is available about the weather patterns but this is an average and short term variations will occur.

The 'smart' system can be used; under control of a simple timer or a single board computer (such as an Arduino based unit or Raspberry Pi) the transmitter can be switched off at times, for example overnight when there are fewer listeners or switched to a 'low power' mode. If a single board computer is used then other functions can be added, for example remote monitoring of the system charge and discharge and sending SMS text messages to show the state of the installation.

3 Modelling a PV system

System design can be aided using one of the many software tools available for analysis, planning, and economic evaluation and monitoring of PV systems. Some tools are available free of charge and can be downloaded from the internet, for example HOMER, the Hybrid Optimization Model for Electric Renewables designed by the National Renewable Energy Laboratory (NREL). Any modelling needs to have the variables defined and a Microsoft Excel spreadsheet can be used as a front end to the HOMER simulation software and guide the user to select system inputs and variables. The Excel spreadsheet is designed to be adaptable by the user; units such exciters, receivers etc. have their specifications in the model spreadsheet and can be selected through drop down menu selection and these can be easily updated to include new or different units.

Macros in the spreadsheet produces the input files for the simulation software defining parameters such as load, sunshine and incident angles of sunshine. The final output from the simulation software shows the appropriate photovoltaic solar power system components required to power the off-grid FM system as defined.

4 Routine maintenance and replacements

Like any system, PV is not completely maintenance free; the main points are:

Batteries – these have a limited number of charge/discharge cycles and will probably need to be replaced after about five years. Flooded batteries need to be checked regularly to make sure electrolyte levels are full; the chemical reaction releases gases, as water molecules are split into hydrogen and oxygen. This, in turn, consumes water and creates the need to replace it regularly with pure distilled water. The connections from battery to battery and to the charging and load circuits should always be kept clean and free of corrosion.

PV Panels – during long periods without rain the loss in energy production caused by dust over a daily period can be up to 20% though this depends on the angle of the panels.

5 BBC World Service systems

The BBC World Service has installed a number of solar/PV FM relay systems; the first was in Hargeisa in November 2001 and was followed by seven in Afghanistan and two in Sierra Leone. The Afghan relays are designed to provide power for two 30 W transmitters and the others for a single 30 W transmitter; the only other item of equipment for the BBC services is a satellite receiver used as part of the global programme distribution network. The systems were supplied by different UK companies and include:

Batteries – different types have been used; the first systems had 2 volt flooded cell batteries and the later ones 12 volt sealed batteries with a capacity between 150 and 300 amp-hour. Batteries have rigorously enforced arrangements for freight shipping which is not a problem as long as the correct documentation is available from the manufacturer.

PV/solar panels – panels are becoming larger, higher capacity and producing higher voltages but there are often limitations in shipping and the maximum size that can be accommodated in smaller air freight routes.

Battery charger and inverters – chargers need to be set to match the type of PV panel and battery used; different types of batteries need to have different charge settings.

Transmission equipment – transmitters provided work directly from 24V DC but the satellite receivers have to use a DC to 240V AC inverter as a DC version isn't available.

This system has two 30W transmitters and 16 deep discharge batteries. The control wiring (on the black board fixed to the wall) has been pre-wired for installation. A separate battery charger (blue wall unit) allows the batteries to be charged from a small petrol generator.

The roof mounted PV array has been spaced to prevent one set of panels being in the shadow of the other.

This shows a system and the rugged and remote environment in which it operates as an autonomous off-grid installation.

6 Conclusions

A practical installation to produce about 50W of RF power, with deep-discharge batteries for a reasonable length of autonomy, solar panels and other parts including frames for the solar panels, charge controllers and installation will cost around $ 20,000 in addition to the usual cost of installation. A connection to a public supply will (almost) always be the most effective means of powering broadcast transmitters; the supply can be for higher power services which would normally be beyond an economic value from solar or wind power.

Off-grid systems start to produce benefits and provide coverage to communities in remote locations which are beyond coverage from main broadcasting stations. In this way sustainable energy provides the means for broadcasters to reach out these communities and provide coverage that was previously not possible. An ideal solution may be difficult and expensive to implement and careful thought needs to be given to a compromise design which may not provide the same availability as a grid-connected design but that does deliver the sought after services to very remote locations; adding a small percentage of increased availability may bring a large percentage increase in costs.

Annex 6

Application of LCA modelling to television broadcasting

1 Introduction

This Study takes the LCA analysis and applies it to the BBC national TV distribution in the United Kingdom as a representative case study for the electricity consumption associated with the distribution and reception of Television content.

1.1 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. The BBC television platforms in the UK are used as a representative case study. To assess the demand placed on the UK electricity system, the 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, the 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, cable TV multicast, satellite broadcast and distribution over the Internet (via the BBC's OTT 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.

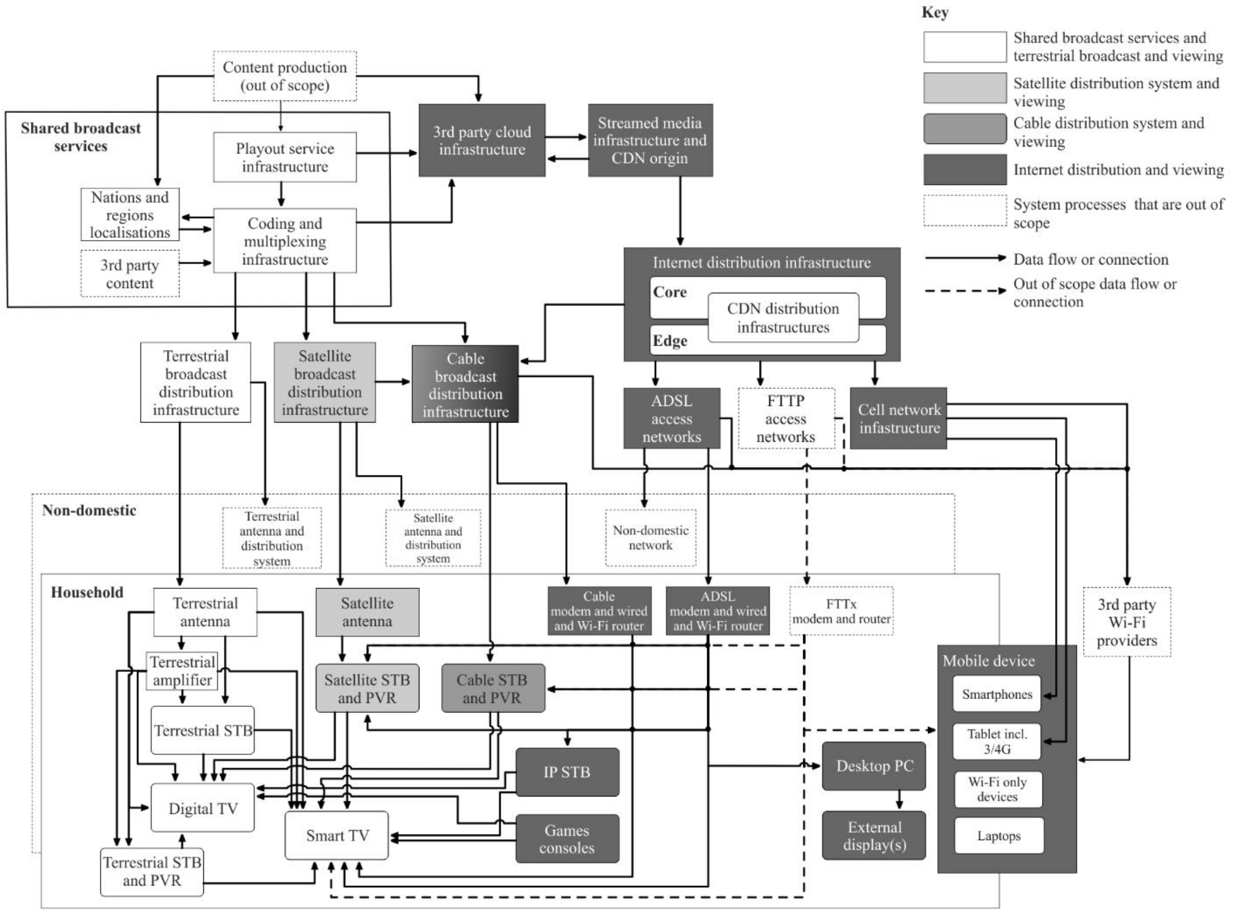
The goal is to understand the electricity consumption associated with distribution and viewing technologies, energy usage resulting from the production of TV content, manufacturing and use of DVDs, manufacturing of infrastructure and devices, or launching of broadcast satellites is excluded.

1.2 Process description

The process model defines the diverse ways in which viewers can receive and watch television content. Figure 22 gives a simplified version of the process model. It consists of three stages: preparation, distribution, and consumption.

FIGURE 22

Processes involved in television distribution and viewing



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1.2.1 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.

1.2.2 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.

1.2.3 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.

1.2.4 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 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 BBC iPlayer. These devices can be personal computers (desktops and laptops), which may have external displays attached to them, or mobile devices such as smart phones 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.

2 Assumptions

2.1 Data sources and allocation

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

2.1.1 Preparation

2.1.1.1 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 playout datacentre. 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 and 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 to 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.

2.1.1.2 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.

2.1.2 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.

2.1.3 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.

2.1.4 Cable distribution

Calculating 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. An attempt 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 has been made.

The cable network operator also reports on the total number of STBs and broadband modems they serve in the UK. A share of their total electricity used for TV provision is based on this ratio. Finally, a share of electricity used for TV provision to the BBC was allocated 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. This figure was used for all households with a cable connection, including those served by other companies.

2.1.5 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 BBC iPlayer. This was therefore modelled 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. This figure was adopted to estimate energy usage of the Internet Service Provider's (ISP) network, extrapolated to the reference year.

A similar approach was adopted to handle access over mobile cellular networks, and use estimates of the energy required per GB transferred over 3G and 4G from Andrae and Edler (2015). BBC 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 smart-phone viewing. There are no direct estimates of the proportion of BBC 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. This ratio was used in the model to estimate the amount of data transferred over 3G and 4G networks.

The 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 was used, and allocated based on data volume transferred. The full list of sources of input parameters is included in the Attachment.

2.1.6 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, an approach was adopted which avoids modelling a statistically "average" household as representative, and instead aims to capture this diversity in the estimate. Detailed demographic and TV viewing device population data was provided 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, it was possible to model households as three types based on primary TV viewing platform.[3] 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. Several different equipment *configurations* that a customer can have when viewing BBC services were identified. Each configuration consists of a choice of viewing device, and equipment associated with reception or access. To illustrate, a few example configurations are provided:

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[3] 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.

The number of *device viewing hours* were estimated (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*[4] 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. Shared viewing is modelled 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. The significance of this assumption is considered 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 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, the typical power consumption of the equipment involved is calculated. 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, it is necessary 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, a linear regression using the EnergyStar database for the BARB screen size bands was conducted. To this, an uplift of 18.5% to the power value (highly uncertain and so modelled with lower bound 0% and upper 37%) was added,

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[4] Including recorded content viewed within 28 days.

based on the knowledge that not all TVs are EnergyStar certified[5] and that not all TVs are set by users in their optimal energy mode. BARB data was used 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. This figure was used to set our "main to secondary TV viewing ratio" appropriately.

For other equipment, 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 was used.

For all end-user equipment, a simplified version of the EnergyStar power state model approach was used. They were modelled 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). It was assumed 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.
- STBs and PVRs mostly use all three distinct states.

Where a configuration uses the Internet, 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 was determined.

To ensure 'energy-balance', an allocation of the proportion of the energy associated with periods when equipment is in an idle but energy-consuming state must be made. 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, no allocation of any idle time is made. 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-BBC 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, it is understood 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.

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5 EnergyStar estimate that EnergyStar TVs are, on average, 27% more energy efficient (EnergyStar, 2018).

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 BBC 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.
- It was assumed that 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, Fibre to the Premises (FTTP) networking was not included as uptake levels in domestic settings were approximately 1% at that time.

2.2 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 are ongoing where there is no information available. These processes are epistemically uncertain. Both aleatory variability and epistemic uncertainty are handled 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 the aim is to model much of the variability endogenously, in particular through our use of configurations described above, it is not possible 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. Sensitivity analysis can be used to decide on that trade-off by calculating the relative effect of input variability on the output variability.

To illustrate, an estimate is made for the number of people using cable STBs or TV sets, but it is not known exactly which models they are using. To handle this, an estimate is made for mean power-use profiles for each type of device and assigned a probability distribution based on the knowledge of the values associated with different models. These are necessarily approximate, and therefore conservative bounds are taken rather than underestimating uncertainties.

The distribution function that fits the available data is chosen. 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, a normal distribution is used with some context-dependent assumption for the standard deviation.

Epistemic uncertainty occurs when there is an imperfect knowledge about the variable within the model. This is often based on expert knowledge, so again conservative bounds are used. For example, a wider range for a variable such as Satellite Uplink energy was used, which is estimated by BBC R&D staff based on their knowledge, rather than playout datacentre energy use, where there is primary data based on energy bills. Similarly, a range was used 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 Attachment.

3 Results

Figure 23 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 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 whisker marks the distance to the smallest value that is at least 1.5 times the inter-quartile range below the first quartile. And respectively for the upper whisker above the third quartile. Small circles mark outliers, which are points outside the whisker range.

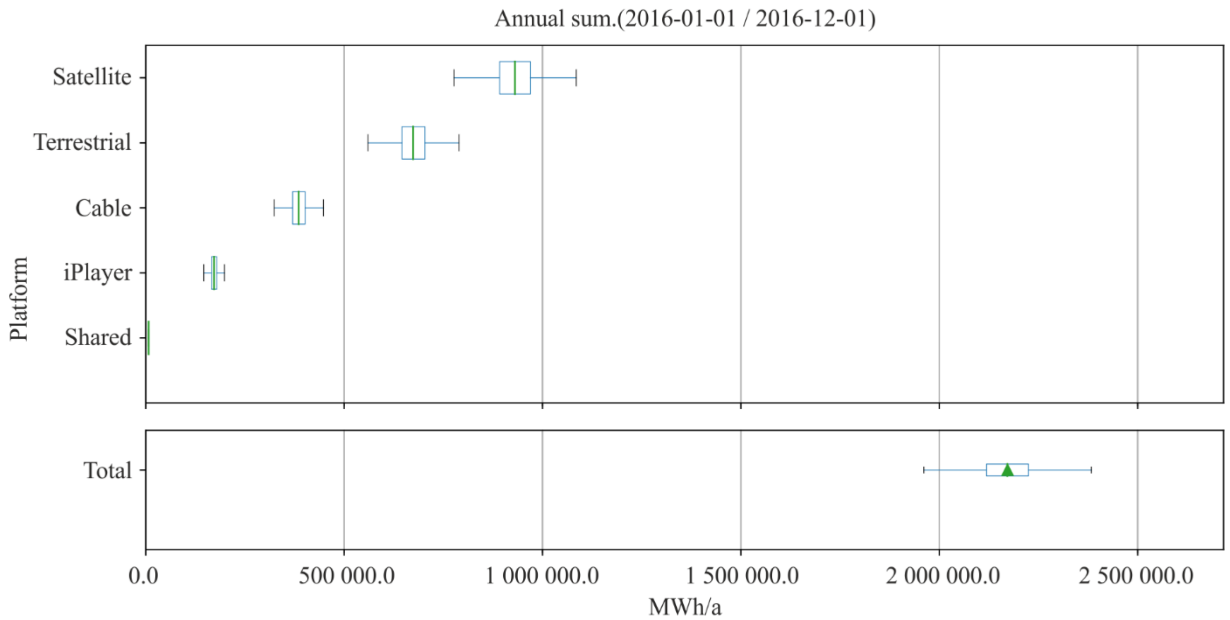
Our analysis estimates overall energy used for the delivery and viewing of BBC television services in the UK in 2016 to be 2,171 GWh (0.6% of total UK electricity use; UK Department for Business Energy & Industrial Strategy, 2017). This results in an average power consumption of 248 MW.

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, total energy used for the delivery and viewing of BBC television services in 2016 produced approximately 1.12 MtCO_2e (million tonnes of CO_2 equivalent emissions), equivalent to 0.24% 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. Total energy use associated with satellite viewers was greatest at 931 GWh (43%) [0.48 MtCO_2e], terrestrial viewers was 675 GWh (31%) [0.35 MtCO_2e], cable viewers was 386 GWh (18%) [0.20 MtCO_2e], and iPlayer viewers was 172 GWh (8%) [0.09 MtCO_2e]. Shared denotes those processes, such as playout, that are common to all platforms.

FIGURE 23

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

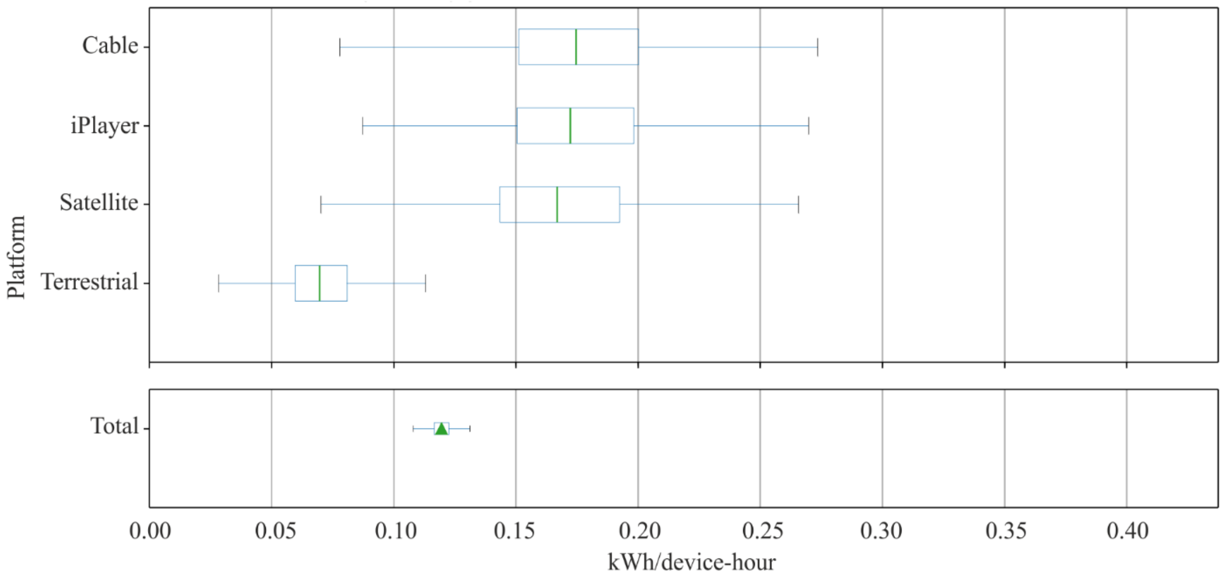


Report BT.2385-23

Now consider electricity used per device-hour of viewing. Energy use associated with shared infrastructure is allocated between platforms based on their proportion of overall device-hours of BBC viewing. Figure 24 gives an average per device-hour figure for different platforms, with iPlayer at 0.18 kWh/device-hour [93 gCO_2e/device-hour], cable also at 0.18 kWh/device-hour [93.0 gCO_2e/device-hour], satellite at 0.17 kWh/device-hour [88 gCO_2e/device-hour], and terrestrial at 0.07 kWh/device-hour [36 gCO_2e/device-hour].

FIGURE 24

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



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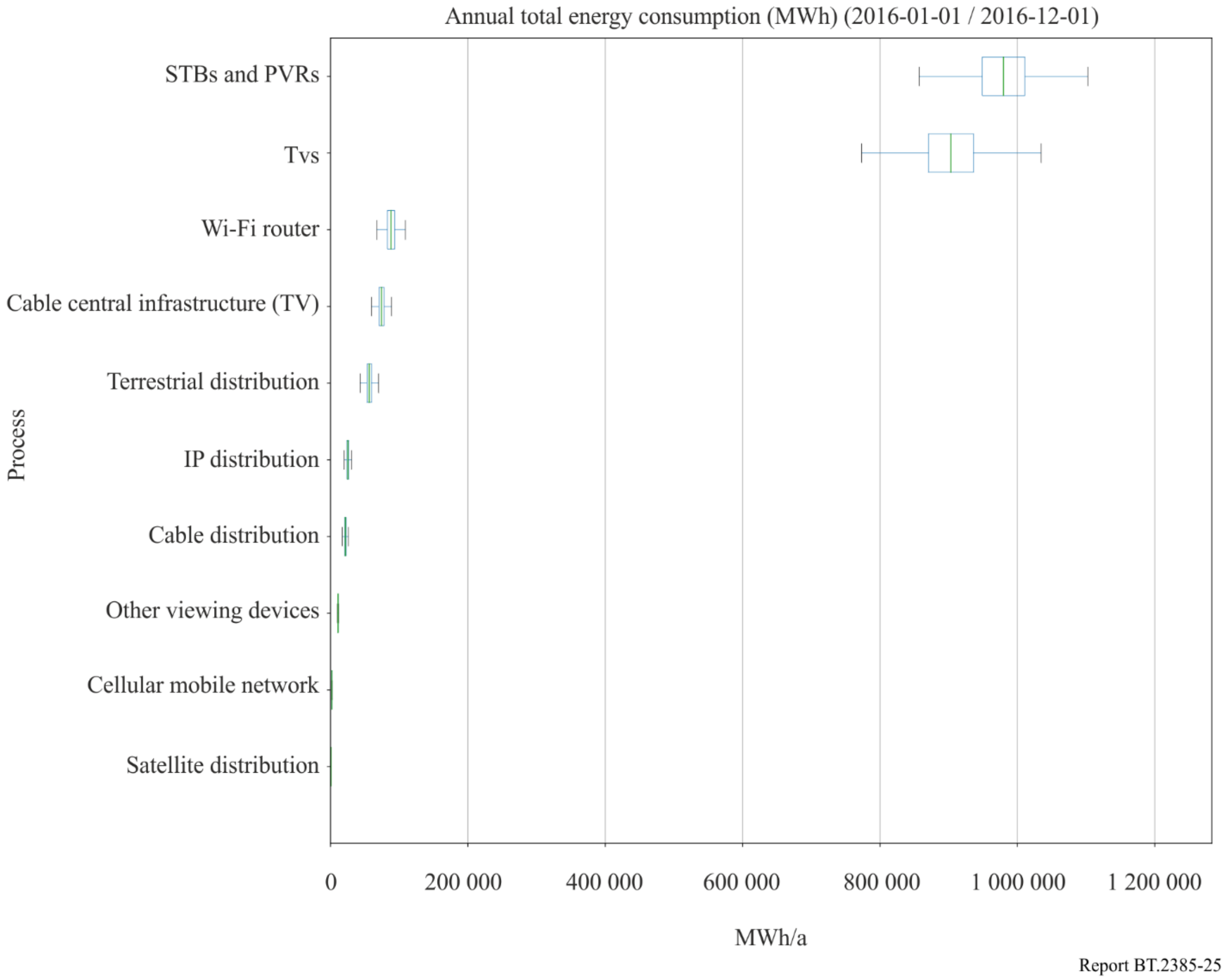
Considering the different processes and devices involved in the delivery of the overall service, it can be seen that the bulk of electricity use occurs within the home (including mobile devices). Home equipment was responsible for around 1,982 GWh [1.02 $MtCO_2e$] in 2016 (0.56% of total national and 1.5% of domestic electricity consumption in the UK; UK Department for Business, Energy & Industrial Strategy, 2017), and distribution for around 180 GWh [0.09 $MtCO_2e$] (0.05% of total electricity consumption; UK Department for Business, Energy & Industrial Strategy, 2017). Figure 25 shows a breakdown of total energy consumed according to the different processes and devices. It can be seen that STBs and PVRs dominate (980 GWh [0.51 $MtCO_2e$]), although TVs in total consume nearly as much energy (903 GWh [0.47 $MtCO_2e$]).

FIGURE 25

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

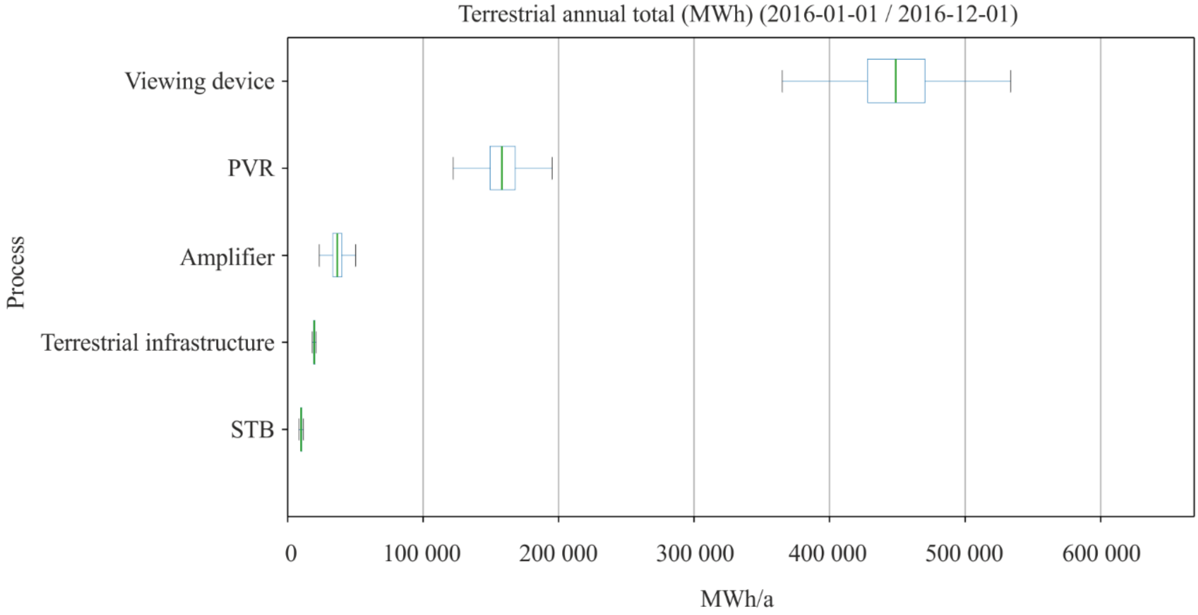


Figures 26 to 29 give more detail on the breakdown of electricity use per delivery mode, excluding shared infrastructure.

Figure 26 shows the breakdown for terrestrial broadcast delivery. Viewing device (almost always a TV set) is dominant here at 449 GWh (67%) [0.23 $MtCO_2e$], larger than the STB and PVR contribution combined at 158 GWh (23%) [0.08 $MtCO_2e$]. The broadcast preparation and distribution infrastructure took a small share at 20 GWh (3%) [0.01 $MtCO_2e$]. Aerial amplifiers which are often fitted in the loft of a house to amplify the DTT signal consumed 37 GWh (5%) [0.02 $MtCO_2e$]. There is very limited data available on their deployment, hence the very large uncertainty.

FIGURE 26

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

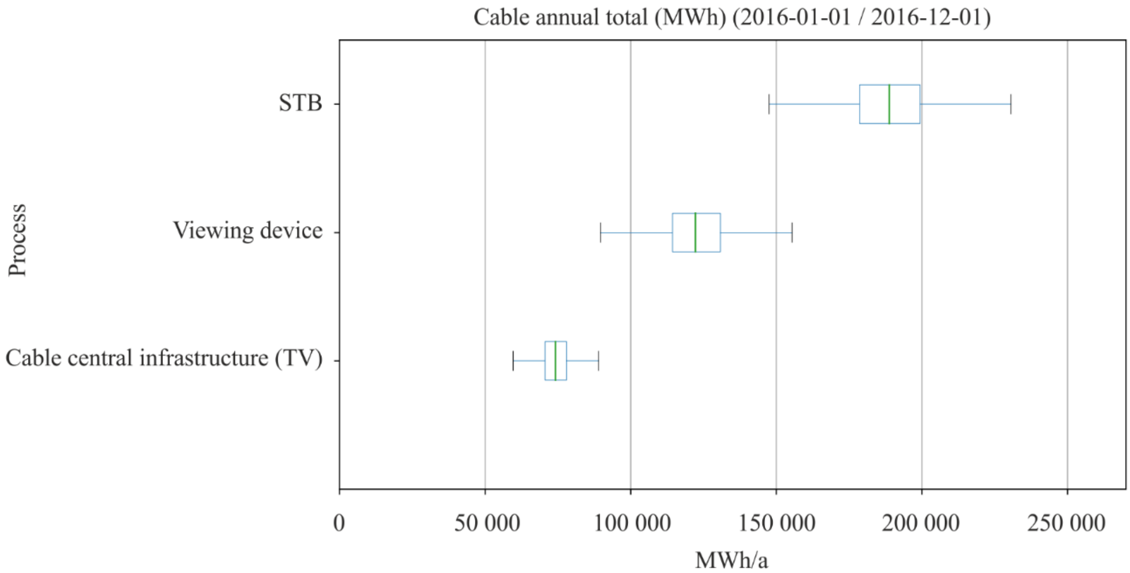


Report BT.2385-26

Figure 27 gives the breakdown for cable distribution. Energy consumption is more evenly spread through the different components compared to terrestrial distribution. STBs are highest at 189 GWh (49%) [0.10 $MtCO_2e$], TV sets and other viewing devices consumed 122 GWh (32%) [0.06 $MtCO_2e$], and the cable infrastructure 74 GWh (19%) [0.04 $MtCO_2e$].

FIGURE 27

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



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Satellite, shown in Fig. 28, similarly shows STB consumption at 621 GWh (67%) [0.32 $MtCO_2e$] to be higher than viewing devices at 308 GWh (33%) [0.16 $MtCO_2e$] but, unlike cable, electricity for the broadcast infrastructure is small at 661 MWh (<0.1%) [<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 28

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

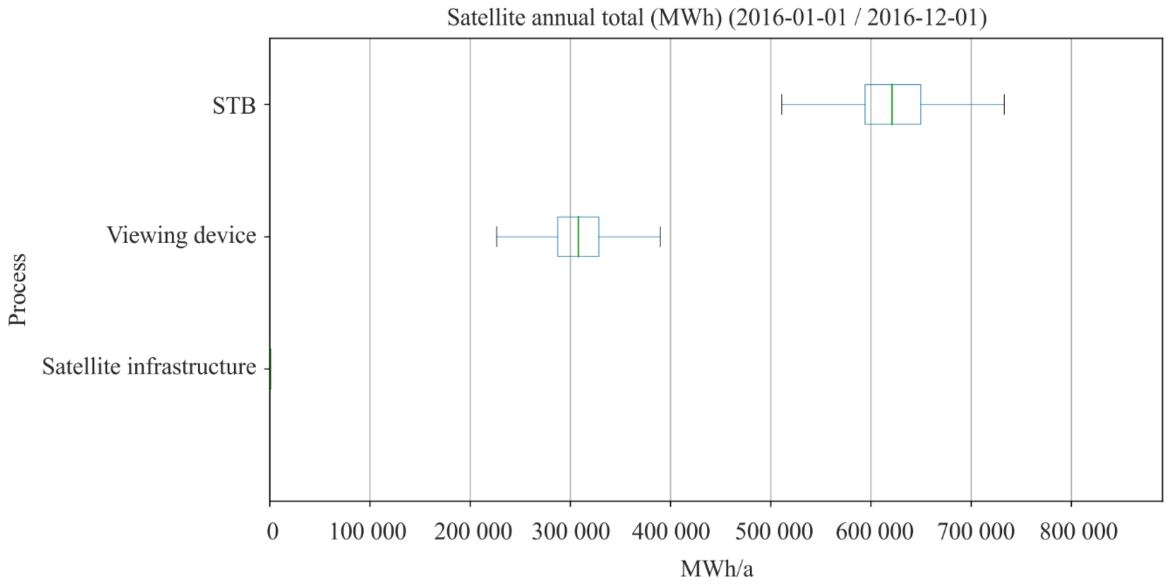

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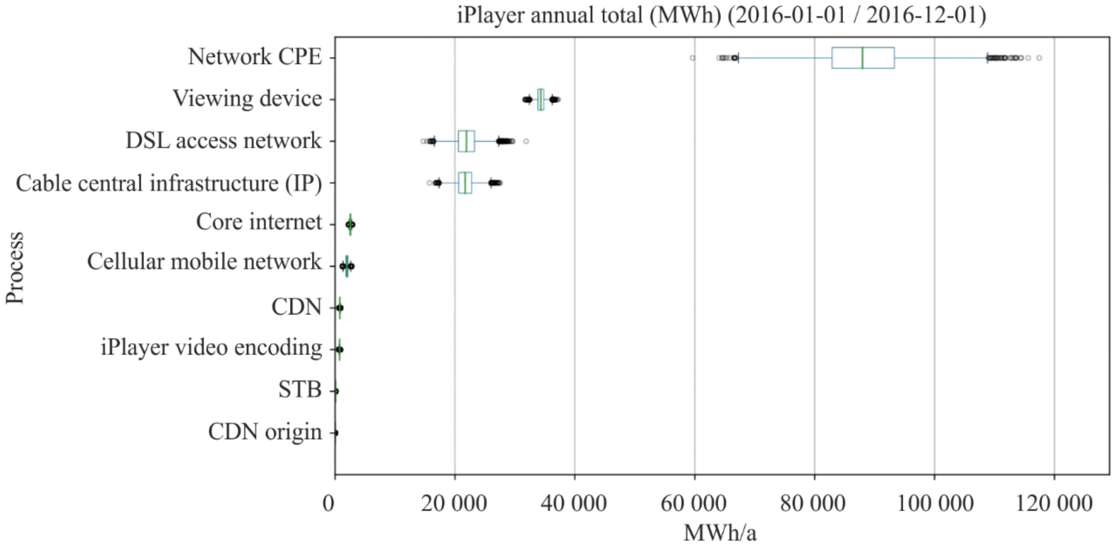
Figure 29 gives the breakdown for BBC iPlayer viewing on all devices, including smart TVs, satellite and cable STBs, tablets and smart phones. This shows a very different pattern of energy use compared to the other delivery platforms. Viewing device is a relatively small share at 34 GWh (20%) [0.02 $MtCO_2e$], network customer premises equipment (CPE), such as home Wi-Fi, modems, and routers, is greatest at 88 GWh (51%) [0.05 $MtCO_2e$] and network energy use outside the home (including cable, access and cell networks) is a significant share at 48 GWh (28%) [0.02 $MtCO_2e$]. Server usage, namely BBC iPlayer video encoding and CDNs to prepare, store, and transmit content, is almost negligible at 1.6 GWh (1%) [0.001 $MtCO_2e$].

FIGURE 29

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



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3.1 Uncertainty and sensitivity analysis

The coefficient of variation (the standard deviation relative to the mean) of the estimate of energy consumption is 12.5%. The interquartile range of the overall energy consumption has a 25th percentile value at 2,083 GWh and a 75th percentile value at 2,241 GWh.

In order to understand which processes contribute most strongly to the variability of the outcome, sensitivity analysis was performed 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. One-at-a-time sensitivity analysis (Iooss & Saltelli, 2015) was performed. Here, all model variables are fixed to their mean values and only allow a single variable to vary according to its original distribution. With this approach, approximately 48% of the variability of estimated energy consumption can be explained. 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.

4 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, a process-based LCA was used 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 is viewed on smaller, lower powered personal devices, approximately 60% of the time, instead of TV sets. 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. As 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 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. By identifying 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 the energy and environmental impacts of the manufacture and deployment of the infrastructure required to deliver the services was omitted, 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. The impact of software development was omitted 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).

5 Conclusions

This study 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 2,171 GWh [1.12 MtCO2e] in 2016, approximately 0.6% of total UK electricity use in that year and 0.24% of the UK GHG emissions. It has been 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, there is a need for future scenarios exploring the implications on electricity consumption of this and other technology trends.

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8 Attachment

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 ~70-170 W power_on (assume connected to a 'secondary' TV = 30 W). 2013 cited paper out of date but other sources also point to order 70 W. 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 ~70-170 W power_on (assume connected to a 'secondary' TV = 30 W). 2013 cited paper out of date but other sources also point to order 70 W. 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
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
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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 internet traffic	Estimated share of Virgin Cable's internet 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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 infrastructures (TV and IP). Based on Virgin Corporate Reporting number of STBs Vs number of Modems calculated 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 infrastructures (TV and IP). Based on Virgin Corporate Reporting number of STBs Vs number of Modems calculated 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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
cable infrastructure total	Calculated from Virgin 2016 CSR report of Scope 2 carbon based on UK Grid Carbon Intensity for 2016	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
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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 Wi-Fi 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 Wi-Fi 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 Wi-Fi 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 operational 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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 Browsers 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 Browsers per month from iPlayer Analytics and estimated proportion of laptops Vs desktops	normal	916262	91626			0	2016-01-01 00:00:00	iPlayer Analytics

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 Browsers 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 Browsers 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 Browsers 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 Browsers 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 Browsers 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 Browsers 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	normal	937109	93711			0	2016-01-01 00:00:00	iPlayer Analytics

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
	on Unique Browsers per month from 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 Browsers 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 Browsers 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 Browsers 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 Browsers 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 Browsers per month from iPlayer Analytics	normal	480506	48051			0	2016-01-01 00:00:00	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 Browsers 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	normal	31270000	3127000			0	2016-01-01 00:00:00	iPlayer Analytics

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
	Cable internet connections. Based on Unique Browsers per month from 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 Browsers 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 Browsers 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
proportion 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
proportion 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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 DTT amplifier	Power when device in 'active standby' state	normal	5	0.5		W	0	2016-01-01 00:00:00	Expert Opinion (BBC R&D and redated)
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 measurements 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 measurements on two Sky + HD boxes and Freesat + FoxSat
Power Cable Router	Estimate of mean power of Cable Internet Wi-Fi/Router over iPlayer viewing households	normal	11.4	1.14		W	0	2017-01-01 00:00:00	Measurements of Virgin Wi-Fi 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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 Wi-Fi/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 Opinion (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 measurements 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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 Opinion (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 measurements 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 measurements on two Sky + HD boxes and Freesat + FoxSat

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 measurements 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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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)

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 internet 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

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
requests GamesConsole Cable	Mean number of requests for device per month over Cable internet 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 internet 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 internet 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 internet 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 internet 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 internet 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 internet 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 internet 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 internet connection	normal	2881479	288148			0	2009-01-01 00:00:00	iPlayer Analytics

Variable name	Comment	Random distribution	A	B	C	Unit	CAGR	References date for CAGR	Source
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 overall 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 multiplexing 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)
energy 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 platform but BARB indicate 2017 figures that 14% of viewing overall is on Secondary TVs. That comes out using this parameter at approx. 0.77.	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/
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

Variable name	Comment	Random distribution	min	max	mode	unit	CAGR	References date for CAGR	Source
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 TV viewing per platform dcab 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 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 Opinion (BBC R&D and redacted)

Variable name	Comment	Random distribution	min	max	mode	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 infrastructure non IP TV	Estimate of cable infrastructure scope 2 emissions that are not due to either internet 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

Annex 7

The energy footprint of BBC radio services: now and in the future

1 Introduction

1.1 Background

Anthropogenic climate change conceivably poses the greatest threat to humanity, and is driven primarily by fossil fuel combustion and industrial processes (IPCC, 2014). The ratification of the Paris Agreement – since the United Nations Conference of the Parties (COP21) in 2015 – has emphasised the importance of ensuring mean global temperature rise does not exceed 1.5°C above pre-industrial levels (United Nations, 2015). In 2020, human activities were estimated to have caused an average increase of 1.0°C since c.1880, two-thirds of which have occurred over the last 45 years (NASA, 2020). To date, nine of the 10 warmest years on record have taken place since 2005 (Lindsey & Dahlman, 2020). This trend of global heating is posited to continue at an exponential rate if solid interventions are not made.

Energy generation and industry account for approximately 56% of greenhouse gas (GHG) emissions; therefore, effective reduction, mitigation and adaptation strategies must be implemented across all public and private sectors for this 1.5°C objective to be met (IPCC, 2014). It has been estimated that, by 2020, the Information and Communication Technology (ICT) and Entertainment and Media (E&M) sectors may account for up to 1.9% and 2.0% of global CO_2-equivalent (CO_2e) emissions, respectively (Malmodin *et al.*, 2013). Whilst these footprints appear small, they are comparable to that of the global aviation sector (ATAG, 2020) and, in an increasingly data-driven world, are susceptible to rapid growth in the absence of efficiencies and decarbonisation.

The BBC "Greener Broadcasting" strategy is committed to reducing BBC carbon emissions by 24% and energy consumption by 10% between 2015 and 2022 (BBC, 2018). Although targets primarily focus on emissions the BBC has direct control over, such as those from on-site generators and company vehicles, and indirectly from the electricity purchased and consumed across its sites, it is also important for the BBC to consider its wider footprint. As the UK's largest public service broadcaster, the BBC has audiences in the order of millions for its core services – television, radio and online. The preparation, distribution and consumption of these services, particularly when scaled up by vast audiences, have an inevitable impact on the environment. In 2016, it was estimated that the BBC's television services alone accounted for 0.6% of UK electricity used that year, equivalent to 0.2% of CO_2e emissions (Schien *et al.*, 2020). At present, there is limited research looking into the energy impact of radio.

BBC radio is an integral service consumed, on average, by 35.6 million people per week in the UK (MIDAS, 2018). At present, there are 62 network, nations and local BBC radio stations available across a multitude of delivery platforms – AM (amplitude modulation) services on long-wave (LW) and medium-wave (MW); FM (frequency modulation) services; DAB (digital audio broadcasting); DTV (digital television) including terrestrial, satellite and cable; and IP (Internet Protocol) streaming services like BBC Sounds and Spotify.

Network radio stations are available at scale with coverage across the majority of the UK. There are 11 domestic network channels – BBC Radio 1, BBC Radio 1Xtra, BBC Radio 2, BBC Radio 3, BBC Radio 4, BBC Radio 4 LW, BBC Radio 4 Extra, BBC Radio 5 Live, BBC Radio 5 Live Sports Extra, BBC Radio 6 Music, BBC Asian Network – and one international network station, BBC World Service. There are nine stations available within the three devolved nations: Wales (BBC Radio

Wales, BBC Radio Cymru, BBC Radio Cymru 2), Scotland (BBC Radio Scotland, BBC Radio nan Gàidheal, BBC Radio Orkney, BBC Radio Shetland), and Northern Ireland (BBC Radio Ulster, BBC Radio Foyle), known as *nations* radio channels. Local radio stations, which represent counties across England and the Channel Islands, are available locally and within the surrounding region. There are a vast range of devices capable of accessing these radio services in the home, in-car and outside such as radio receivers, TVs, set-top boxes (STBs), smart speakers and portable devices.

In 2012, the UK completed its TV digital switchover (DSO) where analogue terrestrial television was replaced by digital terrestrial television (DTT). Subsequently, the Department for Digital, Culture, Media and Sport (DCMS) conducted a review to evaluate the economic, infrastructural and environmental effects a radio DSO could have on the UK (DCMS, 2013). It was concluded that a radio DSO would most likely have an overall negative impact if implemented before 2020 due to insufficient DAB coverage and the costs associated with replacing analogue technology. According to the UK Government's Digital Radio Action Plan (DCMS, 2014), the criteria required for reconsideration of a radio DSO were for: (i) 50% of radio consumption to occur via digital platforms, and (ii) national DAB coverage to be comparable to FM. These criteria were met in 2018 therefore a review is now underway.

Separate to government policy, the BBC and other media organisations have been investigating the feasibility of migrating television and radio services to IP-only distribution. The implementation of either a radio DSO or IP-only services would have notable environmental impacts due to changes in infrastructure, data traffic and user behaviour; however, these are yet to be quantified. It is important that the environmental impacts of these core services are understood to provide a benchmark for which future consumption can be measured against, aid decision-making in emissions reduction efforts, and embed sustainability into relevant architectural design processes.

1.2 Research objectives

The objectives of this study are:

– to quantify the total energy required to prepare, distribute and consume BBC radio services for the baseline year of 2018;

– to establish the energy used by each radio delivery platform for the 2018 baseline year;

– to model how the energy consumption of BBC radio may change under various future scenarios (as outlined in § 1.3.2) over 20 years, from 2018 to 2037; and

– to identify the largest drivers of electricity use within the end-to-end radio chain, both now and in the future.

1.3 Scope

This study explores the energy required to prepare, distribute and consume BBC radio services. Radio is defined in this study as live broadcasting, podcasts and 'listen again' (also known as 'catch-up') services. For live and listen again radio outputs, only network radio has been modelled to reduce system complexity. Solely infrastructure and listening within the UK have been investigated. With approximately 35% of radio consumed outside of the home (MIDAS, 2018), both domestic and non-domestic consumption have been considered, including listening in the home, in vehicle (e.g. car or lorry), at a place of work or study, on public transport, walking or elsewhere.

Neither music production nor radio production have been considered in this study. It has also been assumed that the infrastructure required to provide radio services has already been established, meaning the energy associated with manufacturing, transportation and installation of equipment has not been included. Furthermore, the energy associated with equipment disposal has been excluded. Lastly, the independent recording of radio onto a CD, tape, personal video recorder (PVR) or otherwise was assumed to be minimal and has therefore been not considered.

1.3.1 Baseline

The baseline reference period used to quantify the energy of preparing, distributing and consuming BBC radio services was the year 2018, from 1st January to 31st December. Metrics used to evaluate energy performance for this reference period were total system energy, total energy per delivery platform, and total energy per platform per device-hour.

1.3.2 Scenarios

The scenarios selected for consideration within this study were:

– Scenario 0: Business as Usual – All platforms retained.

– Scenario 1: Digital Only – Switch off LW, MW and FM from 2030.

– Scenario 2: DAB/IP Only – Switch off LW, MW, FM and DTV radio from 2030.

– Scenario 3: IP Only – Switch off LW, MW, FM, DTV radio and DAB from 2030.

It is important to note that these scenarios are for illustrative purposes, and do **not** represent the intentions of the BBC.

The scenario reference period of 20 years – from 1st January 2018 to 31st December 2037 – was used, with switch-off occurring immediately on 1st January of the stated year. Metrics used to evaluate energy performance for this reference period were total system energy and mean monthly energy.

2 Literature review

In Malmodin & Lundén (2018), the ICT sector is characterised as the intersection of information technology and telecommunications, encompassing a range of infrastructure and devices such as computers, phones and tablets; modems and routers; datacentres; and broadband, telephony and cellular networks. Similarly, the E&M sector is the union of the entertainment and media sectors, which includes TVs, peripherals and networks; other consumer electronic devices; content production; and paper media.

The research of Malmodin & Lundén (2018) quantified the global energy and carbon footprints of the ICT and E&M sectors between 2010 and 2015. It was deduced that ICT accounted for 3.8% of global electricity in 2015[6], with the largest contributor – user devices – responsible for approximately 45% of energy use. The E&M sector consumed 2.8% of global electricity in 2015[6], two-thirds of which were attributed to TVs, STBs and broadcast networks. The CO_2e emissions for the ICT and E&M sectors were calculated to be approximately 1.5% and 1.2%[7] of global emissions, respectively, with the latter reducing to 0.8% if paper media were excluded. TVs were shown to have the largest carbon footprint of all user devices – vastly higher than that of smartphones, which were almost twice as prevalent in the global population.

It is important to note that the carbon footprints in Malmodin & Lundén (2018) were calculated using a full lifecycle approach, whereas energy footprints only included operational and use-phase consumption. Lifecycle assessment (LCA) is a methodology used to evaluate the environmental effects of products or services at every stage of its lifetime, including raw material acquisition, manufacturing, distribution, use and waste management. In Malmodin & Lundén (2018), the embodied energy from mining, manufacturing, transportation and waste were not included. As a result, the energy footprints of these sectors were not fully realised. Malmodin *et al.* (2018) provide a more detailed analysis of the material and carbon footprints for the mining and end-of-life stages of

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6 Calculated using Statistical record of global electricity consumption in 2015.

7 Calculated using The World Bank data for CO_2, methane, nitrous oxide and HFC gas emissions in 2014.

the ICT and E&M sectors, but, due to a lack of publicly available data, this research still omits a comprehensive overview of energy use.

Results from Malmodin & Lundén (2018) concluded that global energy consumption for both the ICT and E&M sectors peaked between 2010 and 2015, and has demonstrated subsequent decline despite increases in data traffic. This is consistent with a similar study of ICT and E&M for Sweden, conducted by the same authors, which determined a peak in electricity consumption around 2010 (Malmodin & Lundén, 2016). The sectorial reductions in energy consumption globally from 2010 to 2015 were shown to be primarily attributed to the increased efficiency of TVs, STBs and broadcast networks as well as other user devices. Fixed and mobile networks demonstrated an increase in total energy by 30.8% in 2015, relative to 2010. This was significantly lower than the estimated compound annual growth rate (CAGR) of 29.0% for Internet data traffic (Cisco, 2012), which, from 2010 to 2015, could have theoretically led to a 257.2% increase in energy use in absence of efficiency improvements.

Aslan *et al.* (2018) conducted a review of 14 studies to establish a trend in the electricity intensity of Internet data transmission – in kilowatt-hours per gigabyte (kWh/GB) – over time. The studies under consideration covered a variety of system boundaries, methodologies, reference years and locations. Estimates of electricity intensity varied by up to 10^5, with the highest estimate being 136 kWh/GB in 2000 (Koomey *et al.*, 2004) and the lowest 0.004 kWh/GB in 2008 (Baliga *et al.*, 2009). To ensure studies were comparable, Aslan *et al.* (2018) recalculated estimates after applying a common system boundary and deriving averages from eight different configurations. After computing new estimates in line with this common framework, differences of up to three orders of magnitude were observed. Moore's Law implies that electricity intensity values should approximately halve every two years due to efficiency gains. With estimates spread over 15 years, Moore's Law would imply differences of up to two orders of magnitude, indicating disparities between values. As a result, the authors undertook a critical analysis to determine which studies satisfied a minimum set of criteria, of which five of them met (Koomey *et al.*, 2004; Taylor & Koomey, 2008; Malmodin *et al.*, 2014; Krug *et al.*, 2014; Malmodin & Lundén, 2016). An additional sixth estimate was deduced from updated data applied to the methodology in Krug *et al.* (2014). These six estimates exhibited consistency with Moore's Law, with a coefficient of determination (R^2) equal to 0.98.

However, it is unlikely for electrical efficiency to improve in line with Moore's law indefinitely. Andrae & Edler (2015) presented estimates of the global energy use for communication technology – including the production and use of devices, networks and datacentres – from 2010 to 2030. Their work considered three scenarios – the best, expected and worst cases. For each scenario, the annual electrical efficiency improvement from 2022 onwards was set to the worst-case value of 5% per year. Estimates for the proportion of global energy attributed to communication technology were highly disparate across scenarios. In 2020, the best, expected and worst cases were estimated to be 6%, 11% and 21%, respectively; these further diverged to 8%, 21% and 51% by 2030. Despite the authors concluding that the worst-case scenario was "dramatic", and that the most likely outcome would be between the best and expected-case scenarios, significant attention has been drawn to the 51% figure for 2030. This was the focal point of the paper's abstract, along with its associated 23% share of global GHG emissions.

The Shift Project (2019a) adopted the methodology presented in Andrae & Edler (2015) to determine the environmental impact of digital technologies, using estimates between the expected and worst-case scenarios as the closest approximation to real-world values. It was concluded that online video streaming produced over 300 $MtCO_2e$ emissions in 2018, stated to be equivalent to the annual CO_2e emissions of Spain (The Shift Project, 2019b). This widely shared study suggested that an hour of streaming generated approximately 3.20 $kgCO_2e$ emissions, despite only including portable devices such as smartphones and laptops within their scope. This grossly overestimated emissions compared to congruent studies. For example, analysis conducted by the Carbon Brief (2020) across a range of user devices – primarily TV sets – determined the emissions from streaming video on Netflix to be between 0.056 and 0.114 kgCO_2e per hour. Chandaria *et al.* (2011) estimated the carbon footprint of video-on-demand via BBC iPlayer to be between 0.030 and 0.086 kgCO_2e per viewer-hour. Similarly, a more recent study investigating the footprint of BBC television services via IP distribution in 2016 estimated emissions to be approximately 0.078 kgCO_2e per viewer-hour (Schien *et al.*, 2020). Both BBC-focused studies included a large range of consumer devices – primarily TVs and STBs, which typically require higher amounts of power than the portable devices considered by the Shift Project. Preist *et al.* (2019) estimated the carbon footprint of YouTube video streaming in 2016 based on publicly available data. The design of this study was the most comparable to the Shift Project research as phones, laptops and computers comprised 84% of user devices; however, their estimate of 0.028 kgCO_2e per viewer-hour was two orders of magnitude lower.

Differences in the proportion of carbon within the UK energy mix between years would account for some variation in results, but these would be marginal. The average bitrate of 24 Mbit/s used by the Shift Project was considered to be six times larger than the global average bitrate for Netflix (Carbon Brief, 2020). In Schien *et al.* (2020), the mean bitrates for BBC iPlayer on smartphones and laptops were estimated to be 1.8 Mbit/s and 3.5 Mbit/s and thus, respectively, a thirteenth and seventh of the estimates used by the Shift Project. Furthermore, the energy intensity of datacentres, content delivery networks (CDNs) and data transmission networks were found to be approximately 6 to 18 times higher than that claimed in other literature (Carbon Brief, 2020). The adoption of methodologies in line with the expected and worst-case scenarios from Andrae & Edler (2015) also led to inaccurate emissions estimates. Andrae (2019) has subsequently published a paper acknowledging that the real-world trends in global energy use of communication technology have been more in line with the best-case scenario, and are projected to do so until at least 2023.

Despite vast overestimations in most system components, the Shift Project study considerably underestimated the energy associated with consumer devices by a factor of 4 to 7 (Carbon Brief, 2020. This is likely due to the omission of high-powered devices, such as TVs and STBs. The Shift Project (2019b) concluded that consumer devices comprised the smallest amount of energy across the end-to-end IP distribution chain; however, this conclusion is contested by multiple studies. Schien *et al.* (2013) conducted an analysis of the emissions produced by Guardian News & Media Limited in the distribution and consumption of their digital media services in 2012, in which it was deduced that consumer devices were responsible for 75% of emissions. Similarly, in Chandaria *et al.* (2011), user equipment for the consumption of BBC television services via DTT on a TV set and via IP on a desktop computer accounted for 76% and 78% of emissions, respectively. It was however noted that when IP-delivered services were consumed via a laptop, equipment constituted only 37% of emissions due to the comparably lower power. In Preist *et al.* (2019), where consumption was predominantly via smartphones, laptops and tablets, devices used approximately 30% of the total system energy. In Schien *et al.* (2020), user equipment comprised 67% of the overall energy for the consumption of BBC television services over IP. Interestingly, this was dominated by network customer premise equipment (CPE) – such as modems and routers – which contributed 72% of energy for equipment compared to 28% for viewing devices. For the consumption of BBC television via terrestrial, cable and satellite broadcast platforms – where a TV and STB was the predominant viewing set-up – user equipment respectively accounted for 97%, 80% and just under 100% of the total energy per platform. High standby power for STBs was the highest contributor to these results, followed by the *on* power of TV sets and STBs. Across all platforms, user equipment accounted for 92% of the total system energy.

With greater prominence given to television and video streaming, limited research has been conducted on the energy or carbon footprints of radio services. Between 2010 and 2013, the UK Government Department for Environment, Food and Rural Affairs (Defra) and DCMS jointly commissioned a three-phased study to determine the power consumption of radio sets (Defra, 2010; Defra, 2011; Defra, 2013). The aim of this research was to monitor the power consumption of radio devices and inform the impact on energy, were a radio DSO to have been implemented in 2015. A total of 299 devices – including FM, DAB and Internet radio devices – were selected to represent the market. Significant reductions in mean power were exhibited between Phase 1 (2010) and Phase 3 (2013) across all device types. FM radio sets demonstrated a 26% reduction in on power, whereas the mean power for FM listening on DAB radio sets decreased by 45%. The average on power for DAB and Internet radio devices decreased by 46% and 66%, respectively. Additionally, standby power reduced by 66% across all devices. This study considered only operational energy associated with consumer devices, specifically radio receivers, and not energy attributed to the preparation or distribution of radio, or the manufacturing or disposal of equipment.

3 Methods

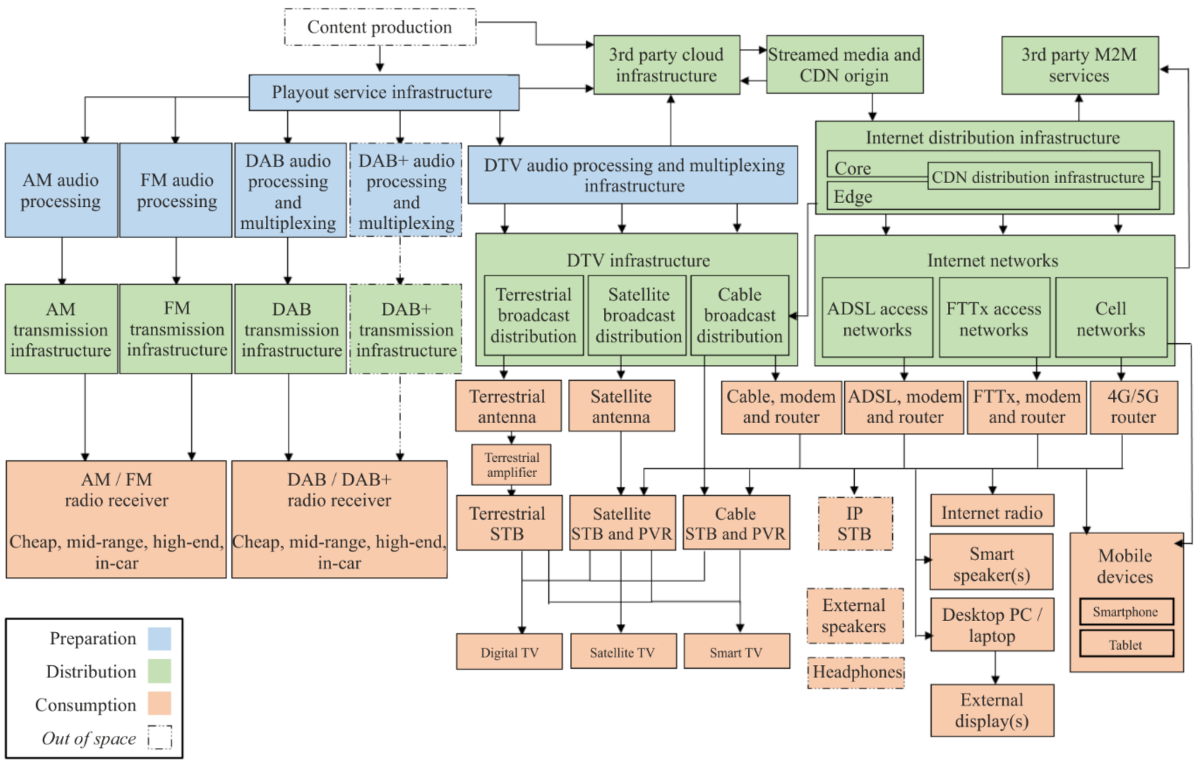
This study adopts the approach of Schien *et al.* (2020) to establish the energy associated with preparing, distributing and consuming BBC radio services. Our methodology applies the principles of LCA to calculate energy for the lifecycle distribution and use phases, and to identify ‘hotspots’ within the radio system. Cumulative energy has been determined for the whole system and per platform and, where appropriate, converted to estimated GHG emissions. Other inputs, lifecycle stages and outputs have not been considered.

3.1 Radio system overview

Figure 30 provides a system overview of BBC network radio from production to consumption. This map represents the flow of data across various delivery methods and consumer devices. Each component is characterised by its stage in the system: preparation, distribution or consumption.

FIGURE 30

System map of the end-to-end BBC radio chain from production to consumption



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3.1.1 Preparation

Playout for audio content is managed by the *dira!* digital playout system, which is used across network, nations and local BBC radio stations for both live and pre-recorded programmes. *dira!* handles recording, editing, scheduling and reporting as well as the storage of media and metadata. Depending on the platform used, the audio is encoded (compressed to reduce bitrate) and multiplexed (packaged alongside other services to a single stream).

Analogue network radio services are encoded through NICAM (Near Instantaneous Companded Audio Multiplex) for subsequent distribution via a national network which also carries dynamic RDS (Radio Data System) – such as station identification, programme type and radio text. For DAB and DTV services, encoding and multiplexing are carried out at Centralised Coding and Multiplexing (CCM) facilities in the UK. The BBC has one national DAB multiplex for network radio. For radio via DTV, there are three multiplexes which bundle together local, nations and network radio channels along with television services – two for satellite (DSAT2 and DSAT5) and one for terrestrial (PSB1), the channels of which vary by location.

3.1.2 Distribution

Distribution for network radio services via LW, MW, FM, DAB and DTT involves relaying the respective signals to networks of transmitters across the UK. Platforms require different numbers of transmitters for national coverage. For example, AM radio, which occupies lower frequencies, is characterised by a small number of transmitters, whereas DAB operates at higher frequencies and uses a higher number of typically lower-powered transmitters. A transmission site may carry multiple transmitters for different delivery platforms. These transmitter networks are managed by a third-party contractor, Arqiva.

Distribution via satellite television requires signals to be sent via earth station uplinks (one main and one back-up) to one of the broadcast satellites in the Astra 2 constellation, where it is received by the DSAT2 and DSAT5 transponders. These signals are then rebroadcast to Earth via downlinks and picked up by CPE (i.e. satellite dishes). For radio services on cable television, this satellite feed is received and re-multiplexed for distribution over a private fibre-optic network to street-side cabinets, which is then routed to customers via coaxial cable service drops.

Podcasts, listen again and live radio are also available via Internet distribution. Digital audio input streams are carried to the *BBC Audio Factory* for encoding, storage, packaging and transcoding in the cloud. Cloud infrastructure for the BBC is currently provided by Amazon Web Services (AWS). The Audio Factory system encodes BBC radio content via three codecs – AAC-LC, HE-AACv1 and MP3 – at various bitrates (BBC, 2020a). Content is packaged into short (3 to 8 second) chunks and delivered individually via HTTP streaming protocols – HLS, HDS and MPEG-DASH (BBC, 2020b).

Origin content is stored on a number of servers within BBC datacentres and delivered via Content Delivery Networks (CDNs). CDNs cache copies of the origin content across the UK so that requests can be managed locally, thereby minimising latency and network traffic. These CDNs usually distribute content from edge networks to home equipment via access networks – dependent on the Internet Service Provider (ISP) – which reach consumer devices over Wi-Fi or a fixed line. Alternatively, content is distributed from the edge to the consumer device directly through mobile cellular networks, including 3G, 4G and 5G.

3.1.3 Consumption

Radio listening can take place on a range of consumer devices which vary according to the preferred delivery platform. Typical radio sets may contain circuitry that decodes AM, FM, DAB or IP signals, or a combination thereof. These devices range in size, quality and functionality, and can be powered via different means, including mains electric, rechargeable batteries, dry cells or in-car. Many listening devices also support connection to external headphones or speakers.

Radio consumption via DTV requires a television set which may be accompanied by a STB or PVR. These STBs or PVRs decode terrestrial, satellite, cable or Internet signals. For radio listening over IP, there are a variety of additional consumer devices available. Among these are smart speakers, desktop computers, laptops, smartphones and tablets. These devices may receive Internet via either a wired or Wi-Fi connection, and may require network CPE such as a modem or router, or access to the cellular network. Network CPE typically receive Internet via either an Asymmetric Digital Subscriber Line (ADSL), fibre, cable, 4G or 5G connection.

3.2 Data acquisition and modelling

3.2.1 Playout infrastructure

Due to COVID-19, direct measurements of radio playout power usage could not be obtained, as planned. Therefore, with a lack of available data, a rough estimate was made using the playout energy calculated in Schien *et al.* (2020) for BBC television. A scaling factor, dubbed the *ratio of radio to TV bitrate*, was multiplied to this figure to give a ballpark estimate for the playout energy of BBC radio services. This ratio – originally calculated for CCM energy use – was established by summing distribution bitrates for network radio channels across DSAT2, DSAT5, PSB1 and DAB, and dividing by the sum of distribution bitrates for TV and radio services across all multiplexes.

Whilst BBC television and radio services have largely different playout infrastructure, the total power of these system components was small compared to other components. From discussions with internal experts, it is likely the energy derived in this study is an overestimate and has been included for a sense of the scale. In future, a clamp meter would be used to measure the power consumption of relevant playout equipment and provide a more accurate estimate of energy use.

3.2.2 Audio encoding and multiplexing

Power attributed to the CCM for DAB, DTT and satellite were calculated individually in the model and broken down into the number of multiplexes, the number of channels per multiplex, and the power per channel per multiplex to provide model flexibility. These power values were aggregated to derive the mean power of CCM, and then multiplied by time to obtain the energy.

To estimate the power per channel per multiplex for each platform, the mean power for each of the two CCM facilities – which includes lighting, cooling and IT – was obtained internally. Bitrates were used to estimate the mean power for each multiplex (including those dedicated to television). A *ratio of radio to TV bitrate*, tailored to each multiplex, was then used to find the mean power per multiplex specifically for radio. Lastly, this was divided by the number of channels per platform.

3.2.3 Broadcast infrastructure

Energy data for AM, FM, DAB and DTT broadcast infrastructure – used to inform billing – were made available by Arqiva. These datasets provide per-transmitter granularity of energy consumption. For each platform, the mean power was calculated and broken down into the number of channels, the number of transmitters and the mean power per channel per transmitter. For AM broadcast infrastructure, the mean power of LW and MW were calculated separately and aggregated to establish the mean power of AM.

To estimate the energy for radio services available on satellite, the mean power for the satellite uplink was adopted from Schien *et al.* (2020). In their study, the back-up site was directly measured, and the main site energy estimated. The *ratio of radio to TV bitrate* was used to represent the energy allocation for BBC radio services.

For cable television infrastructure, estimates were based on Virgin Media corporate sustainability reporting of Scope 2 emissions for 2018 (Virgin Media, 2018). General operational energy was estimated by multiplying the total number of full-time equivalent (FTE) Virgin Media employees with an average estimate of 2.3 tCO_2e per FTE employee, as used in Schien *et al.* (2020), and removed. The 2018 UK carbon factor was then used to approximate energy use (BEIS, 2018). The ratio of IP to TV services was estimated from the reported number of modems to STBs. The energy consumption of cable television services was separated out using this proportion, with the *ratio of radio to TV bitrate* then used to estimate energy for radio services. Lastly, the proportional share of BBC radio listening hours was applied to represent the BBC allocation of energy.

Despite likely increases in the efficiency of transmitter and delivery networks over time, all broadcast infrastructure energy was assumed constant over 20 years. In a scenario where a platform was switched off, the infrastructure energy associated with that platform was set to zero from the date of switch-off.

3.2.4 Internet distribution

Cloud infrastructure was modelled using AWS billing data, which estimates energy usage to be of the order of 1.0 GWh per year for all BBC streamed media services. The radio allocation was estimated to be 30%, with a triangular distribution of 15% to 45% to represent uncertainty. This was presumed to be a cautious overestimate due to a lack of granular data for the total energy consumption or the proportion dedicated to radio services. For the CDN origin, an estimate for the proportion of servers dedicated to radio was made by an internal expert. The power consumption of CDN origin servers was measured in Schien *et al.* (2020) and adopted in this research, with the radio proportion applied. Both the cloud and CDN origin infrastructure were assumed to have a constant power consumption over the 20-year period.

The national IP networking infrastructure was broken down into components – ADSL access, ADSL backhaul, cable, cellular, CDN, core, fibre access, fibre backhaul and metro. Not all data passes through each component; the infrastructure required depends upon the network used. Therefore, we estimated the data traffic through each IP networking component. Data was categorised as either *cellular* (for 3G, 4G, 5G and core), *non-cellular* (for core), *cable* (for cable), *non-cellular-non-cable* (for metro) or *all* (for ADSL and fibre). Data traffic per network was estimated by taking the average bitrate per device, categorising data flows as above based on MIDAS (2018) location analytics and multiplying by the consumption time.

For cellular, cable, core, metro and CDN, the data traffic was multiplied by the relevant network energy intensity. For 3G, 4G and 5G, the energy intensities were estimated from Andrae & Edler (2015), where the expected case scenario was used to quantify the intensity in 2018 and the average CAGR of −8.7% from 2018 to 2037 (assuming an annual improvement of 22% up to 2022 and 5% thereafter). Cable energy intensity was estimated from corporate reporting (Virgin Media, 2020). Metro, core and CDN energy intensities were adopted from Schien *et al.* (2020). The shared CAGR for cable, metro and core networks was estimated to be –7.3% using a combination of Krug *et al.* (2014) which estimates an annual improvement of 16% and Andrae & Edler (2015) which indicates an annual improvement of 5% from 2022.

The ADSL and fibre access and backhaul networks were calculated by multiplying the average power per line – adopted from Krug *et al.* (2014) – with the total number of subscriber lines which access IP radio per network. The latter was estimated by using the number of UK households from the Office for National Statistics (ONS), the proportion of radio listening via IP delivery from MIDAS, and the proportion of ADSL and fibre connections in 2018 from the 2019 Ofcom Communications Market Report (Ofcom, 2019). Here, fibre includes both fibre to the cabinet (FTTC) and fibre to the premises (FTTP). The BBC data allocation was estimated by calculating the total data traffic for BBC radio services and dividing that figure by the total UK data traffic as quantified by Cisco (2016).

3.2.5 Consumer devices

The power consumption of TVs, STBs, smartphones, tablets, laptops, and desktop and monitors were adopted from Schien *et al.* (2020). For smart speakers, Amazon represented 75% of the UK market in 2018 (Ofcom, 2018), thus the on power was averaged across four Amazon devices[8], assuming an equal market share. Each device offers three standby power modes – low power mode (off), networked standby (microphones on/camera off) and networked standby (microphones/camera on) – an average was taken across these three standby modes and four devices, assuming equal use of each mode and device. For radio receivers, classed here as analogue, DAB and Internet radio sets, the mean on and standby power figures were averaged from direct measurements. Our methodology is outlined in Attachment A (note: due to COVID-19, we were unable to measure the power consumption of car radios, as planned). All power values were assumed constant over 20 years – with the exception of TVs and STBs, which were modelled in line with Schien *et al.* (2020). Parameter sensitivities have been explored in §§ 4.2 and 4.4.

MIDAS (2018) data was used to estimate the proportion of the UK population who listen to radio and the average number of listening hours per person per day. Furthermore, MIDAS was used to establish the proportional share of listening hours per device type in 2018, with future projections based upon the UK future consumption of audio report (Mediatique, 2019) and extrapolated from 2035. Note, this report is likely to be updated to reflect recent changes in listener behaviour. However, listening hours are not unique, meaning that MIDAS datasets do not account for multiple people listening on the same device at the same time. This needs to be taken into account to ensure device *on* hours are not incidentally duplicated. Therefore, a *shared listening ratio* was determined for each device type using MIDAS (2018) 'who listened with' data to ascertain the unique listening hours per person per platform per day. The BBC share of radio consumption at 45%, also deduced from MIDAS (2018), was assumed constant over 20 years.

To calculate the energy consumption of smartphones, laptops, desktops and tablets, the unique listening hours for BBC content per device was multiplied by the device on power, and further multiplied by the representative population of listeners who access BBC radio via the specific device. The standby energy associated with these devices was not taken into account in our estimates. As smartphones, laptops, desktops and tablets generally offer a wide range of non-audio or radio-related services, we assumed the standby power attributed to radio listening on these devices to be negligible. Contrarily, radio listening was considered to be a core function for radio sets, TV sets, STBs and smart speakers; therefore, for these devices, the standby energy was taken into consideration. For radio sets, standby energy was calculated by subtracting the unique listening hours per person per day from 24 hours and multiplying by the standby power. This was similarly multiplied by the representative population, as well as the BBC share of listening at 45%. This however assumes one radio per listener; whereas MIDAS (2018) estimates approximately 1.4 radios per listener. Therefore, the estimated standby energy was further upscaled by 1.4 to account for additional device standby power. Smart speaker standby energy was similarly calculated, but with an additional parameter for the proportion of smart speaker energy allocated to radio listening. It was estimated that 90% of energy was attributed to audio streaming, with MIDAS (2018) data indicating 55% of smart speaker audio streaming to be for radio. As TV sets and STBs are predominantly used for television services, the *ratio of radio to TV bitrate* was applied to represent the radio allocation of device standby energy.

User analytics and device power data for AM and FM radio services are often collected as a single metric. Therefore, the energy associated with AM and FM consumer devices were modelled as a single output, 'analogue radio sets'. To estimate the energy apportioned to each platform separately, MIDAS (2018) analytics data were used to classify listening hours by network radio stations, where BBC Radio 5 Live and BBC Asian Network were classed as AM, and BBC Radio 1, BBC Radio 2

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8 Amazon Echo (1st Generation), Amazon Echo Show, Amazon Echo (2nd Generation), Amazon Echo Plus.

and BBC Radio 3 were classed as FM. BBC Radio 4 and BBC World Service broadcast on both AM and FM, therefore it was estimated that 10% of listening on these channels were on AM with a triangular distribution of 5% to 15%.

Peripheral equipment, such as headphones and external speakers, would have an inevitable impact on device power consumption. However, due to a lack of available data, these impacts are not in scope. It is also worth noting that radio listening can be a secondary activity on an in-use device, such as a laptop being used for work purposes. This additional radio listening would have a small impact on additional power consumption. Therefore, listening as a non-primary activity on desktops and laptops was identified through MIDAS (2018) 'activities' data and the proportional energy removed.

For our scenarios, some devices were modelled to be redundant after platforms were switched off, implying that individuals would need to move to other devices to consume radio. Listening 'location' data (MIDAS, 2018) was used to predict device migration using matrix multiplication.

3.2.6 Home networking equipment

Home networking equipment, such as modems and routers, were assumed to be continuously on. The on power for cable CPE was obtained from corporate reporting (Virgin Media, 2018), whereas ADSL, fibre and 4G/5G routers were based upon alternative online sources (ISPreview, 2017; Genexis, 2016; HUAWEI, 2020). These figures were assumed constant over our 20-year reference period.

Although both domestic and non-domestic radio consumption have been included, for simplicity, CPE energy was modelled on a household basis, assuming one router per household. The number of households per broadband type for 2018 were deduced from Ofcom (2018), with future projections adopted from Schien *et al.* (2020). The proportion of households that access radio via IP devices was determined through MIDAS (2018) data. As CPE is not solely used for radio consumption, the BBC allocation was estimated by calculating the total data traffic for BBC radio services (as in § 3.2.4) and dividing by the total UK data traffic (Cisco, 2016).

3.3 Uncertainty and Sensitivity Analysis

Models are impacted by the accuracy, assumptions and availability of data. Capturing every intricacy of a system is virtually impossible, making models inherently imperfect. Therefore, uncertainty and sensitivity analysis have been used to explore the robustness of our results.

In this research, all input variables were represented as distributions to account for parameter uncertainty. The Monte Carlo method, which randomly selects input values based upon these distributions, was performed on the whole model over 10,000 simulations. This permits the evaluation of output uncertainty, represented as a range within which the 'true' result may lie.

Sensitivity analysis is the process of changing parameter values or testing alternative assumptions to evaluate the impact on model outputs. This gives insight into how specific variables affect results. This methodology is effective when performed on variables with high uncertainty or high model dependency. The latter can be identified by determining the components with the highest energy consumption and the parameters which contributed the most to that result, as shown in §§ 4.2 and 4.4.

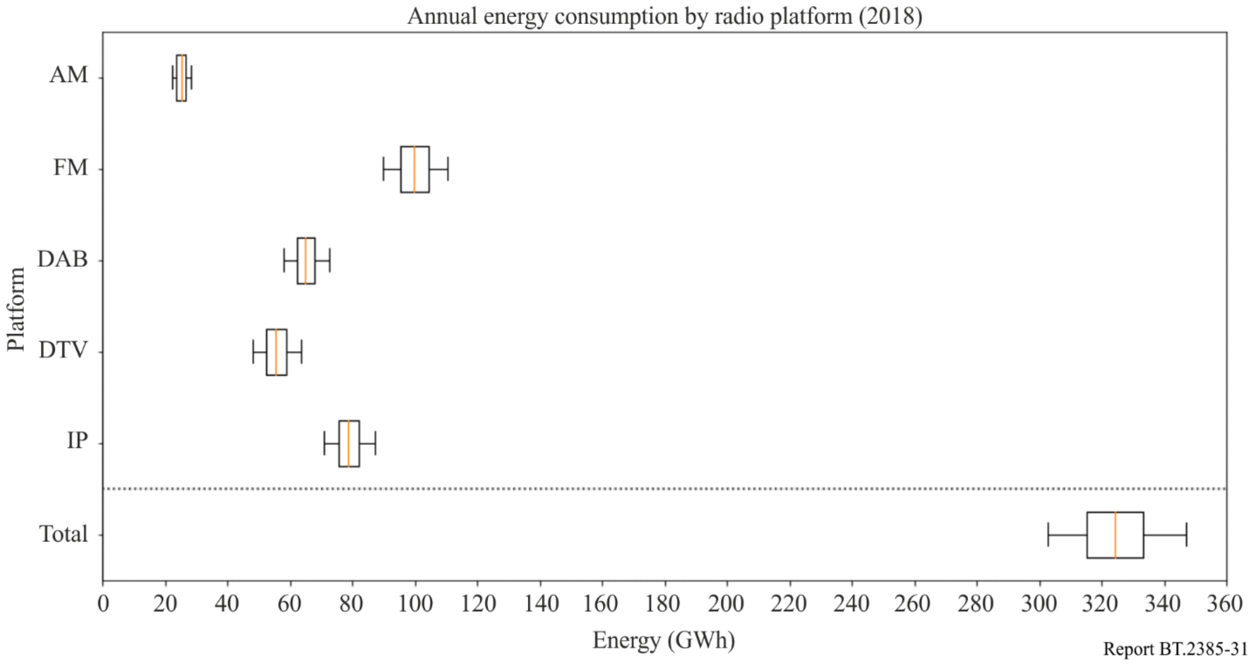
4 Results

4.1 Results: Baseline

Figure 31 presents the estimated energy to prepare, distribute and consume BBC radio in the UK per delivery platform and in total for the baseline year of 2018. The boxplots display the medians and interquartile ranges, with flyers representing the spread from the 5^{th} to 95^{th} percentiles. Shared infrastructure energy was distributed by the unique listening hours per platform.

FIGURE 31

Estimated energy used to prepare, distribute and consume BBC radio in 2018 per platform and in total



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The energy required to prepare, distribute and consume BBC radio services in 2018 was 325 GWh. This equated to a mean power consumption of 37 MW. Across delivery platforms, the mean energy for AM was 25 GWh (7.7%), FM was 100 GWh (30.8%), DAB was 65 GWh (20.0%), DTV was 56 GWh (17.2%) and IP was 79 GWh (24.3%).

Table 8 shows the five components with the highest mean energy for 2018. Collectively, these constituted nearly two-thirds of the overall system energy at 213 GWh (65.6%). The top three – analogue radio sets, DAB radio sets and TV sets – are all consumer devices and cumulatively represented more than half of the system energy at 170 GWh (52.3%).

TABLE 8

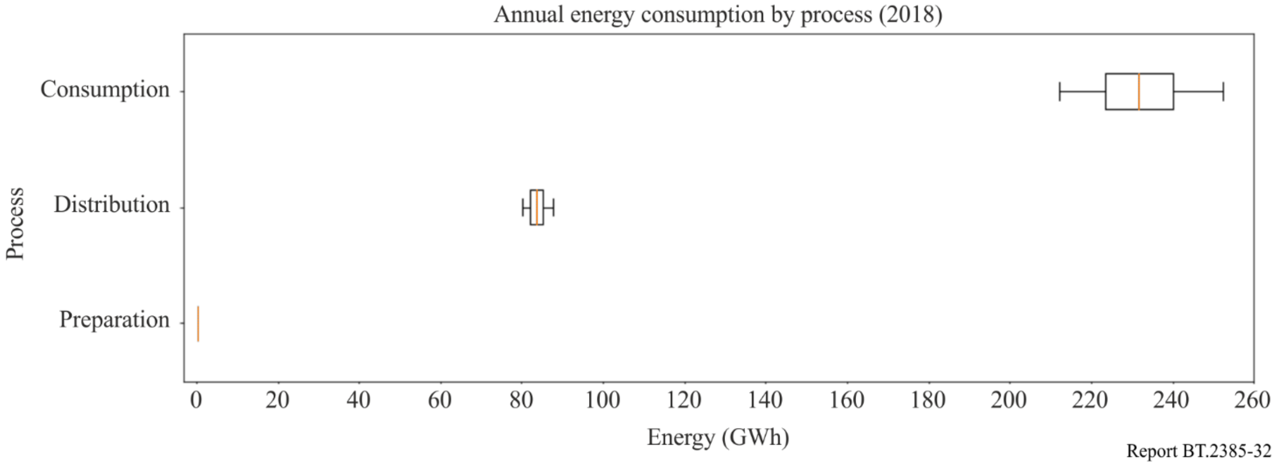
Top five components with the highest energy consumption in the BBC radio system for 2018

Radio system component	Annual energy (GWh)	Proportion of total (%)
Analogue radio set	82	25.2
DAB radio set	55	17.0
TV set	33	10.1
FM broadcast infrastructure	26	8.1
AM broadcast infrastructure	17	5.2

Figure 32 shows the energy per process: preparation, distribution and consumption. Consumer devices were the dominant component with an estimated mean energy of 239 GWh (73.4%), almost three times that of distribution at 86 GWh (26.5%). Playout, encoding and multiplexing contributed a mean energy of 0.3 GWh (0.1%).

FIGURE 32

Estimated energy for BBC radio in 2018 by preparation, distribution and consumption

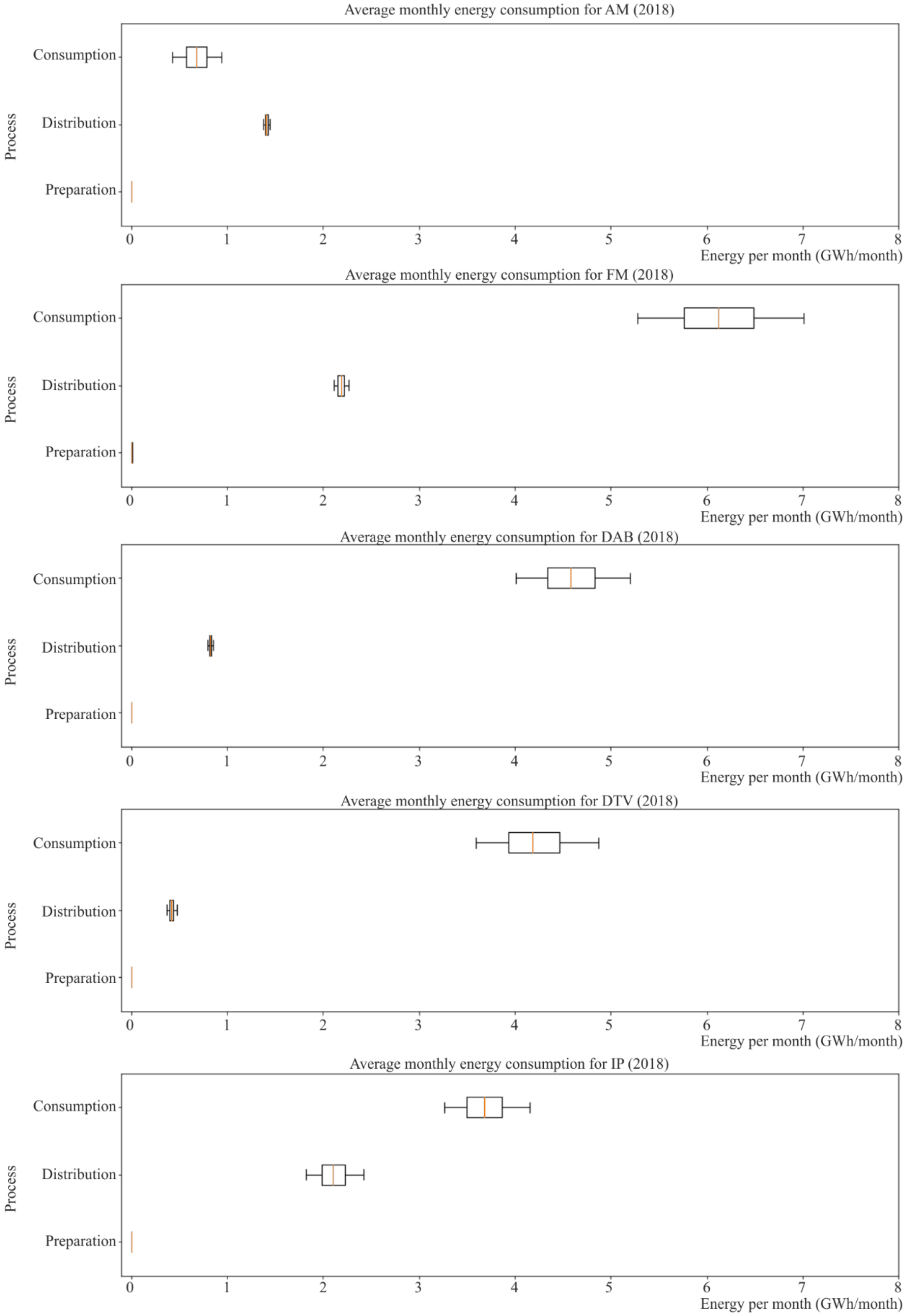


The mean energy breakdown per process per platform are presented in Fig. 33. Across all platforms, preparation contributed the least at 0.1% of total energy, with the exception of DTV at 0.02% and AM at 0.4%. Consumer devices and equipment almost consistently exhibited the highest mean annual energy, with FM at 73.6%, DAB at 84.6%, DTV at 90.9%, and IP at 63.5%. For AM, however, distribution was over twice as large (67.4%) as consumption (32.6%) due to the energy-intensive transmitter network and small listenership for MW and LW. Uncertainty was highest in consumer devices across all platforms. For distribution, IP had the largest spread of results due to error propagation from the cellular infrastructure, where energy intensities and shares of the 3G, 4G and 5G networks had high uncertainty.

Of all IP consumer devices, desktops and monitors represented the highest share of energy in 2018 at 9.2 GWh, followed by Internet radio sets at 9.1 GWh and smart speakers at 8.1 GWh. For all radio sets and smart speakers, the mean energy resulting from device standby power was considerably higher than the on power by a factor of 1.9 to 6.2. The same was not true of TV sets due to the vastly higher on power compared to standby. Furthermore, only a small proportion of TV and STB standby energy was attributed to radio services.

FIGURE 33

Estimated energy for BBC radio in 2018 by preparation, distribution and consumption for each platform: a) AM, b) FM, c) DAB, d) DTV and e) IP



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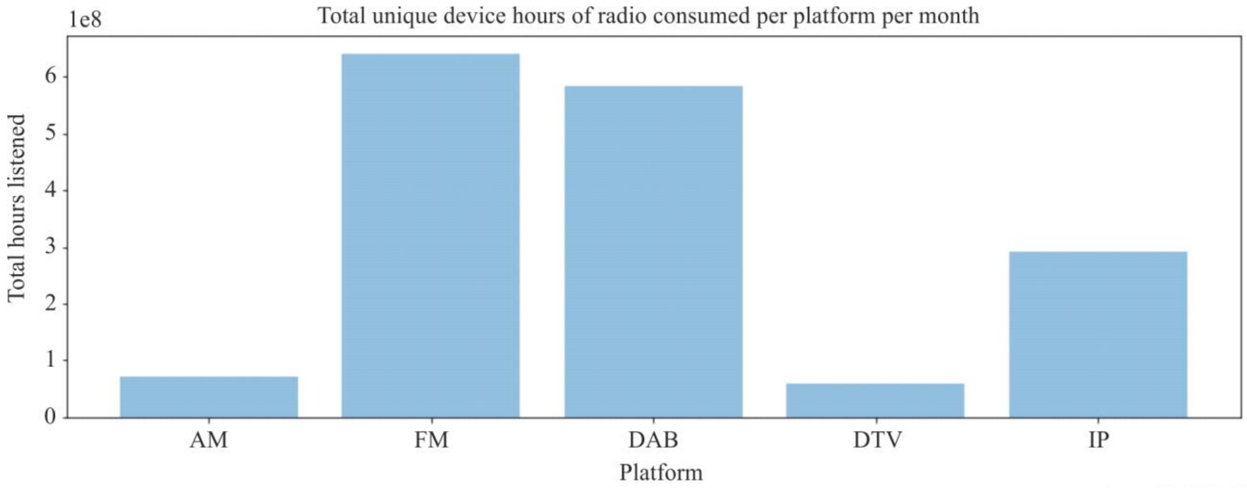
As shown in Fig. 34, the distribution of unique listening hours per platform per month in 2018, which accounts for shared listening, was not equal across platforms. For AM, the total unique device hours was estimated to be 71 million (4.3%), whereas FM was 642 million (39.0%), DAB was 584 million

(35.5%), DTV was 58 million (3.5%) and IP was 292 million (17.7%). Thus, differences in total energy per platform were to be expected.

FIGURE 34

Mean number of unique listening hours for BBC radio in 2018 per platform per month



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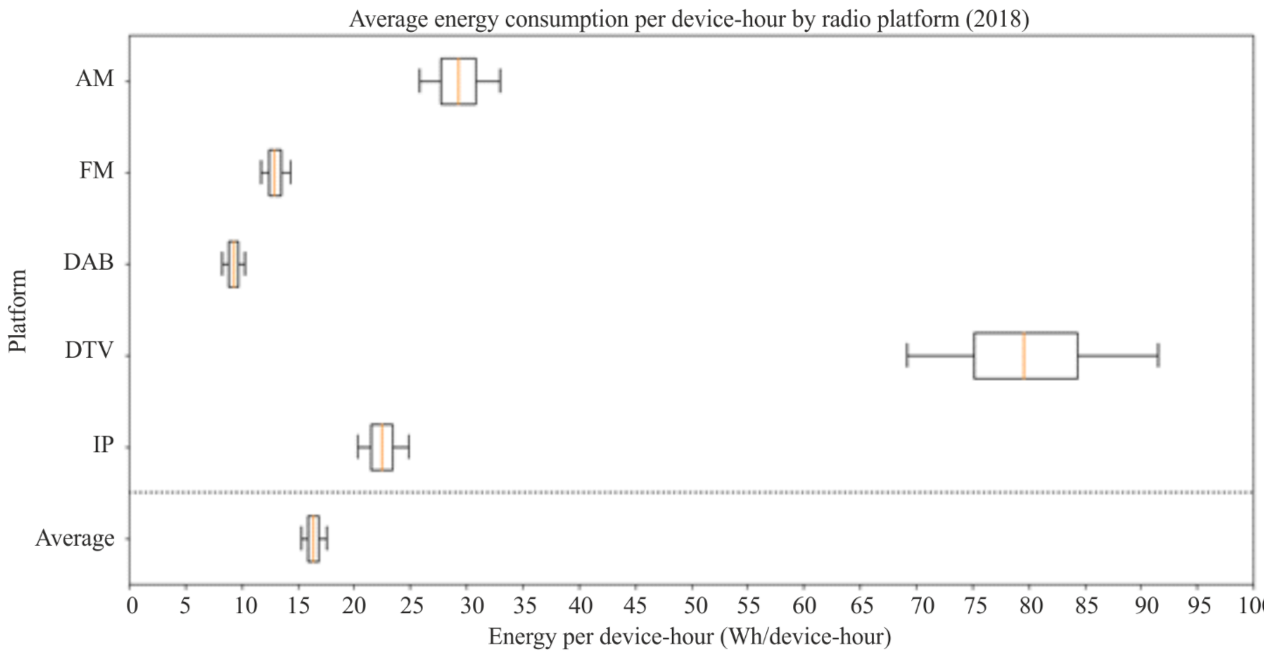
However, increased listenership did not account for all variation in mean energy per platform. This is demonstrated in Fig. 35, which displays the mean energy per device-hour per delivery platform. The average energy across all platforms in 2018 was 16.4 Wh/device-hour. The lowest was DAB with a mean energy of 9.3 Wh/device-hour, followed by FM with 13.0 Wh/device-hour. The most energy intensive platform was DTV with a mean of 80.6 Wh/device-hour (almost nine times more than DAB), followed by AM at 29.3 Wh/device-hour and IP at 22.5 Wh/device-hour.

FIGURE 35

Estimated energy per device-hour to prepare, distribute and consume BBC radio in 2018 per platform



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4.2 Sensitivity analysis: Baseline

As shown in Table 8, the components with the highest energy expenditure for 2018 were analogue radio sets, DAB radio sets, TV sets, FM broadcast infrastructure and AM broadcast infrastructure. Energy attributed to both the AM and FM transmitter networks were based on Arqiva electricity data used for billing and were considered to have low uncertainty. For the remaining components, the parameters with the highest uncertainty values were the on and standby power figures for the respective devices. Estimates for TV set on and standby power were adopted from Schien *et al.,* (2020), where regression analysis was conducted from BARB Establishment Survey data (BARB, 2018). Contrarily, the on and standby power values for all radio sets were based on measurements from a small sample size, and had high uncertainty.

Both the on and standby power of analogue radio sets, DAB radio sets, Internet radio sets and smart speakers were collectively amended over four model runs to evaluate the impact on energy. Results are presented in Table 9. The first row shows the original baseline results. Subsequent rows represent the results where the average on and standby power for all radio sets and smart speakers were adjusted to be 50% higher or lower than the baseline. All other parameters remained the same.

TABLE 9

Estimated energy and proportional share per platform for BBC radio in 2018 if on and standby power of radio sets and smart speakers were adjusted by 50% from the baseline

	Total energy (GWh)		**Share of annual energy (%)**			
		AM	**FM**	**DAB**	**DTV**	**IP**
Baseline	325	7.7	30.8	20.1	17.1	24.3
On power (+50%)	345	7.6	31.5	21.6	16.1	23.2
On power (-50%)	303	7.9	29.9	18.3	18.3	25.5
Standby power (+50%)	380	7.4	33.6	21.8	14.6	22.6
Standby power (-50%)	268	8.2	27.0	17.3	20.7	26.7

Table 9 shows that standby power has a greater impact on the mean energy than on power. An increase in mean standby power by 50% across radio devices and smart speakers increased the total system energy by 16.9%, with a 50% decrease in standby power causing a 17.5% reduction. Contrarily, a 50% increase in mean on power across radio devices and smart speakers only contributed to a 6.2% rise in the total energy, with a 50% decrease in on power prompting a reduction of 6.8%. If on and standby power values were increased or decreased simultaneously, the total system energy would have varied by +23.1% or −24.3%, respectively.

The share of annual energy per delivery platform remained relatively stable across this analysis. For increases in on and standby power, the proportion of energy attributed to FM and DAB platforms increased due to larger audiences. Similarly, when on and standby power values were reduced, FM and DAB shares of energy decreased. Furthermore, across these four cases, consumption remained the most energy intensive part of the chain, representing 67.9% to 79.2% of the total energy.

4.3 Results: Scenarios

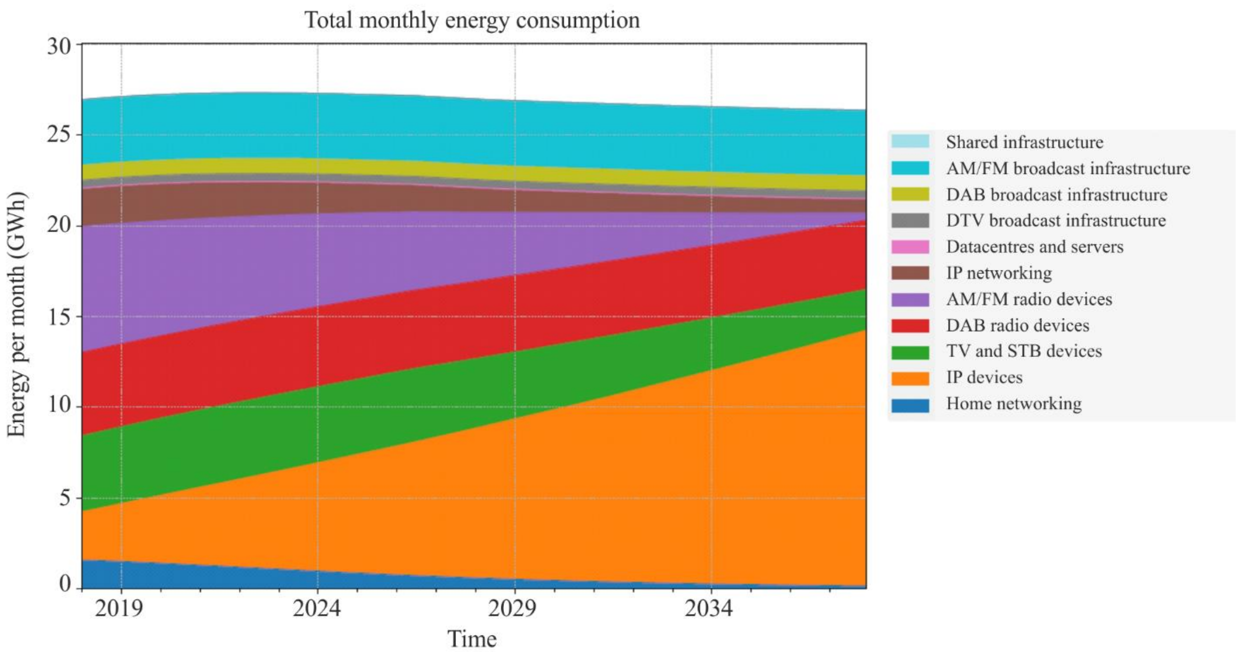
This section presents results for the energy usage of BBC radio services under the scenarios outlined in § 1.3.2. It is important to emphasise that these results are based on a series of assumptions that exhibit increasing uncertainty over time. Furthermore, the immediate switch-off of infrastructure across scenarios is unrealistic but has been presented for illustrative purposes. Therefore, these results should be treated as indicative and not as direct projections for future energy consumption. Result sensitivity is investigated in § 4.4.

4.3.1 Scenario 0: Business as Usual

Figure 36 shows the electricity consumption under the BAU case, where all delivery platforms are retained to the end of 2037. Mean annual energy was estimated to be 323 GWh/year, indicating minimal deviation from the total energy in the 2018 baseline. Energy reductions were exhibited in the IP networking infrastructure due to efficiency gains in network energy intensities outweighing population increase. Reductions were also seen in home networking equipment due to a modelled increase in overall household data traffic growing faster than data traffic from radio over IP, meaning the proportional energy allocated to BBC radio services decreased. Similarly, there were decreases in energy use associated with analogue radio devices, TVs and STBs due to projections of reduced listening on these platforms. However, these reductions were largely negated by the surge in IP device consumption, particularly smart speakers. Consumer devices were the largest contributor of energy, averaged at 76.3% of total energy across the 20-year timeframe.

FIGURE 36

Estimated energy per month to prepare, distribute and consume BBC radio from 2018 to 2037 under BAU



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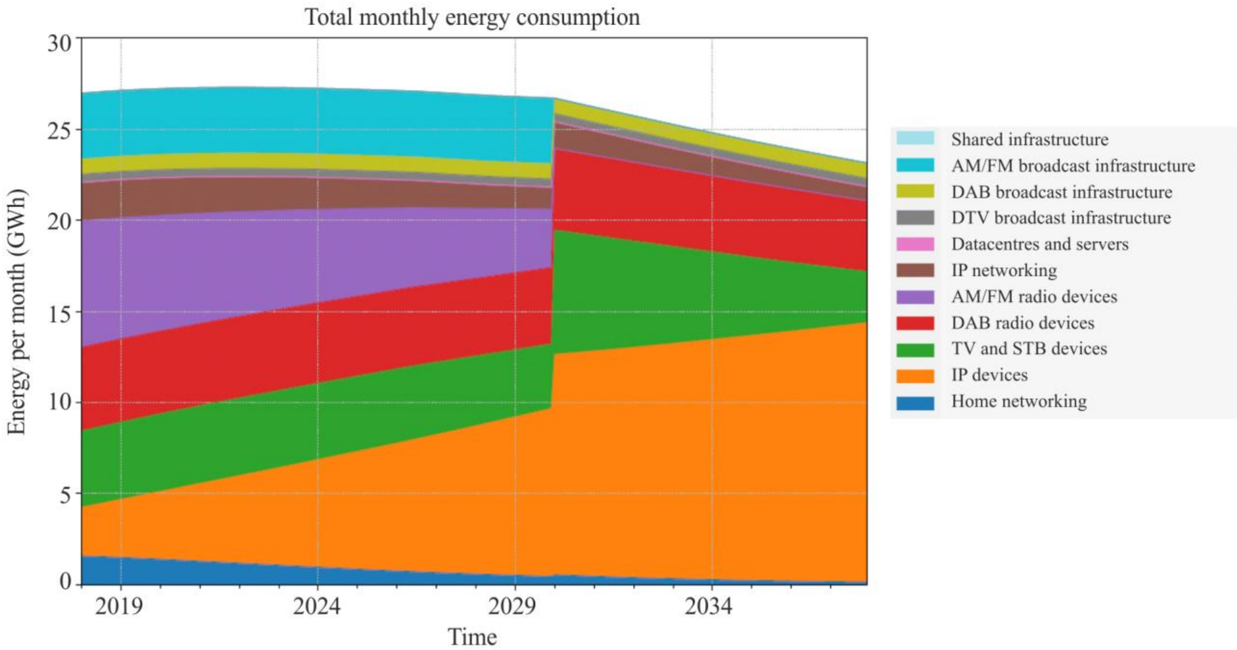
4.3.2 Scenario 1: Digital Only

Results for the digital only case, in which both AM and FM delivery platforms were switched off from 2030, are presented in Fig. 37. Mean annual energy was 315 GWh/year over the 20-year period. This represented a total decrease in system energy by 176 GWh between January 2030 and December 2037 compared to BAU, equivalent to a reduction of 1.8 GWh/month. At switch-off in 2030, the energy decreased by 0.03% despite the immediate removal of analogue devices and broadcast infrastructure. This was primarily due to the modelled uptake of smart speakers as well as additional listening via TV sets and STBs. The steady decline from 2030 to 2037 was attributed to the reduction in radio consumption via DTV in favour of IP. Consumer devices accounted for an even higher proportion of energy (80.9%) than in the BAU case.

FIGURE 37

Estimated energy per month to prepare, distribute and consume BBC radio from 2018 to 2037 for Scenario 1



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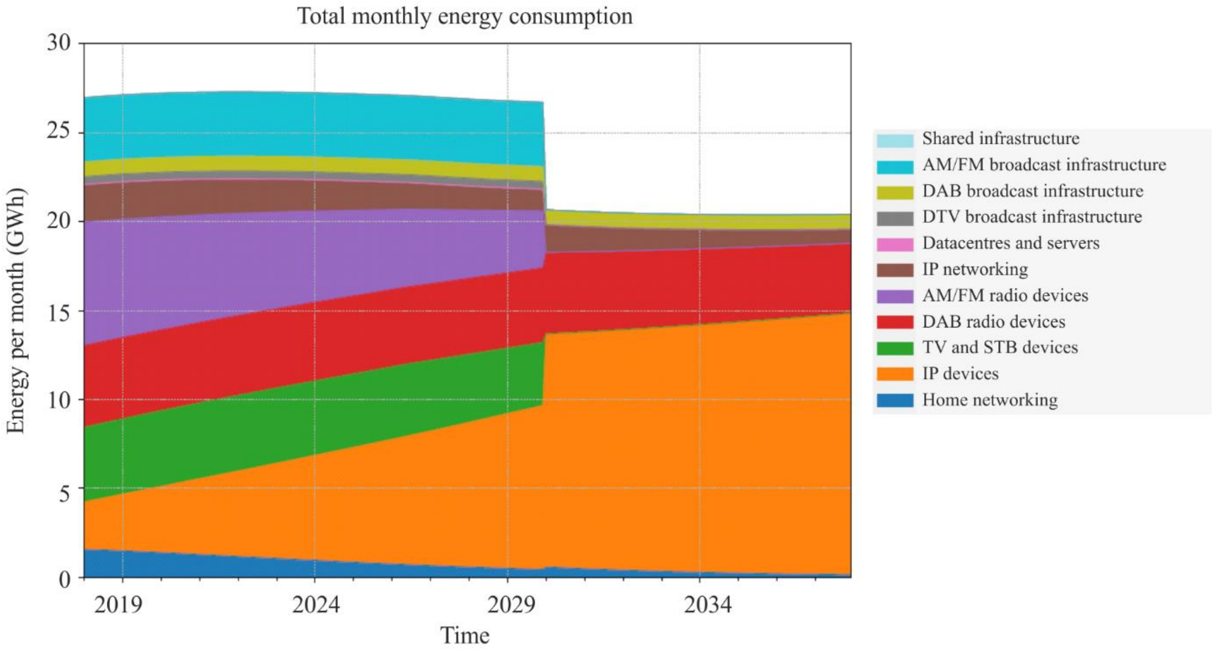
4.3.3 Scenario 2: DAB/IP Only

Figure 38 shows the estimated electricity consumption when AM, FM and DTV delivery platforms are switched off from 2030. Mean annual energy was calculated to be 293 GWh/year from 2018 to 2037. The total reduction in energy after switch-off was calculated to be 599 GWh compared to BAU, analogous to an average decrease of 6.2 GWh/month. There was an estimated 22.6% reduction in energy at 2030, which was largely maintained to December 2037. Despite an increased uptake of DAB radio sets and IP devices, the removal of TV sets, STBs, analogue devices and their associated infrastructure caused a substantial decrease in energy. At 80.1%, consumption remained the largest driver of energy.

FIGURE 38

Estimated energy per month to prepare, distribute and consume BBC radio from 2018 to 2037 for Scenario 2



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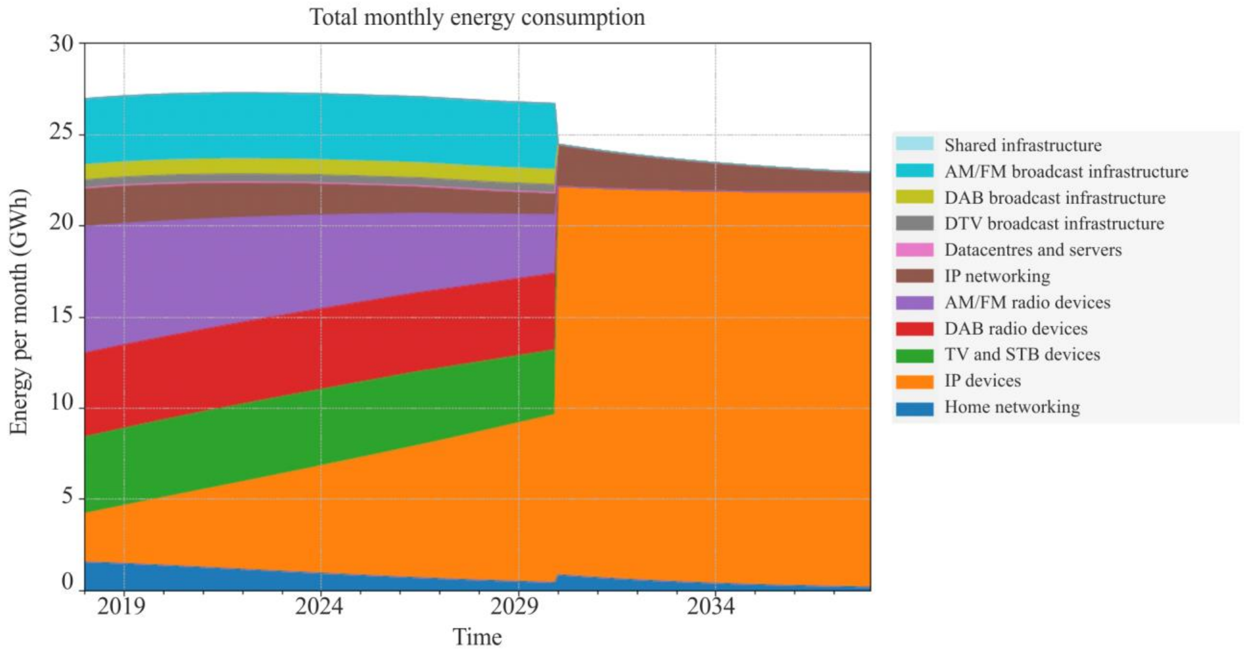
4.3.4 Scenario 3: IP Only

Figure 39 presents the energy consumption if the BBC were to migrate to IP-only radio services from 2030. The mean annual energy was calculated to be 308 GWh/year, which implies an estimated reduction of 301 GWh compared to BAU – approximately half the energy saving achieved in Scenario 2. At switch-off, a modest energy decrease of 8.4% was demonstrated. Both IP networking infrastructure and home networking equipment showed initial increases in energy due to higher data traffic, which subsequently reduced due to modelled electrical efficiency improvements. Over the reference period, smart speakers utilised the highest amount of energy at 1 726 GWh (28.0%), followed by analogue radio sets at 737 GWh (12.0%) and DAB radio sets at 635 GWh (10.3%). In total, consumer devices represented 81.0% of all energy.

FIGURE 39

Estimated energy per month to prepare, distribute and consume BBC radio from 2018 to 2037 for Scenario 3



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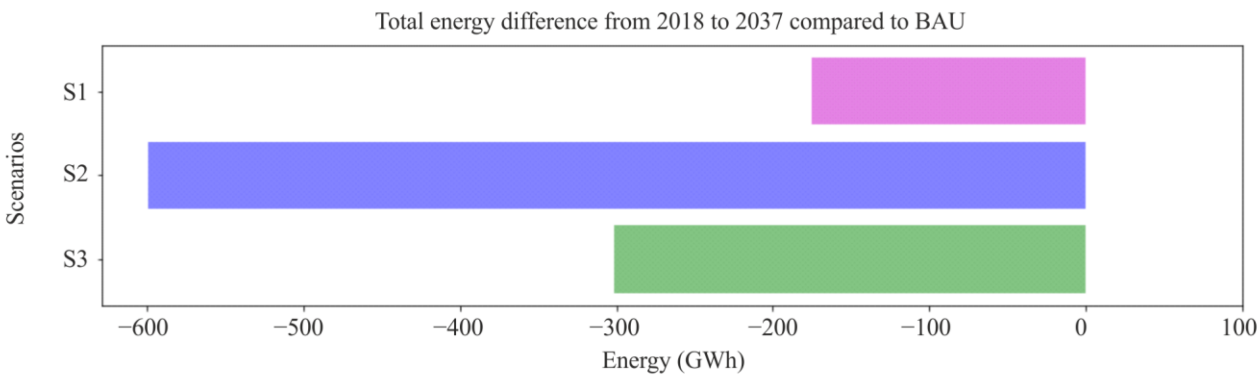
4.3.5 Summary

Figure 40 shows the mean energy saving for Scenarios 1 to 3 compared to BAU. Scenario 2 demonstrated the largest energy reduction relative to BAU by a factor of 2.0 (Scenario 3) and 3.4 (Scenario 1). This indicated that switching off AM, FM and DTV delivery platforms – and retaining both DAB and IP – led to the largest energy saving across all scenarios modelled. Contrarily, switching off only analogue platforms was estimated to save the least energy.

FIGURE 40

Estimated mean annual energy saving for each scenario compared to BAU from switch-off to 2037



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4.4 Sensitivity analysis: Scenarios

Consumption comprised the most energy-intensive part of the BBC radio chain across all scenarios, spanning 74.9% to 80.9% of the total energy. This share increased after switch-off in Scenarios 1-3 due to the removal of AM and FM broadcast infrastructure, identified to be the fourth and fifth largest contributors in the 2018 baseline. Therefore, our sensitivity analysis should focus on parameters used to determine the energy of consumer devices which also have high uncertainty. Three key areas were identified from these criteria – (i) the proportion of listeners per device type, (ii) the listening hours per person, and (iii) the device power figures, particularly for radio sets and smart speakers.

4.4.1 Device popularity

Device popularity for the scenario results were based upon Mediatique projections, with location used to determine which devices people migrated to after switch-off (Scenarios 1 to 3). There were two sources of uncertainty within this method – the future projections, and the use of location as a sole determinant for device migration. Thus, two further configurations which changed these components independently were tested.

Table 10 presents all three configurations simulated. Configuration A is the original case used in § 4.3, Configuration B omits the Mediatique projections, and Configuration C does not use location as a sole determinant for device migration.

TABLE 10

Different configurations used to model device popularity across scenarios for sensitivity analysis

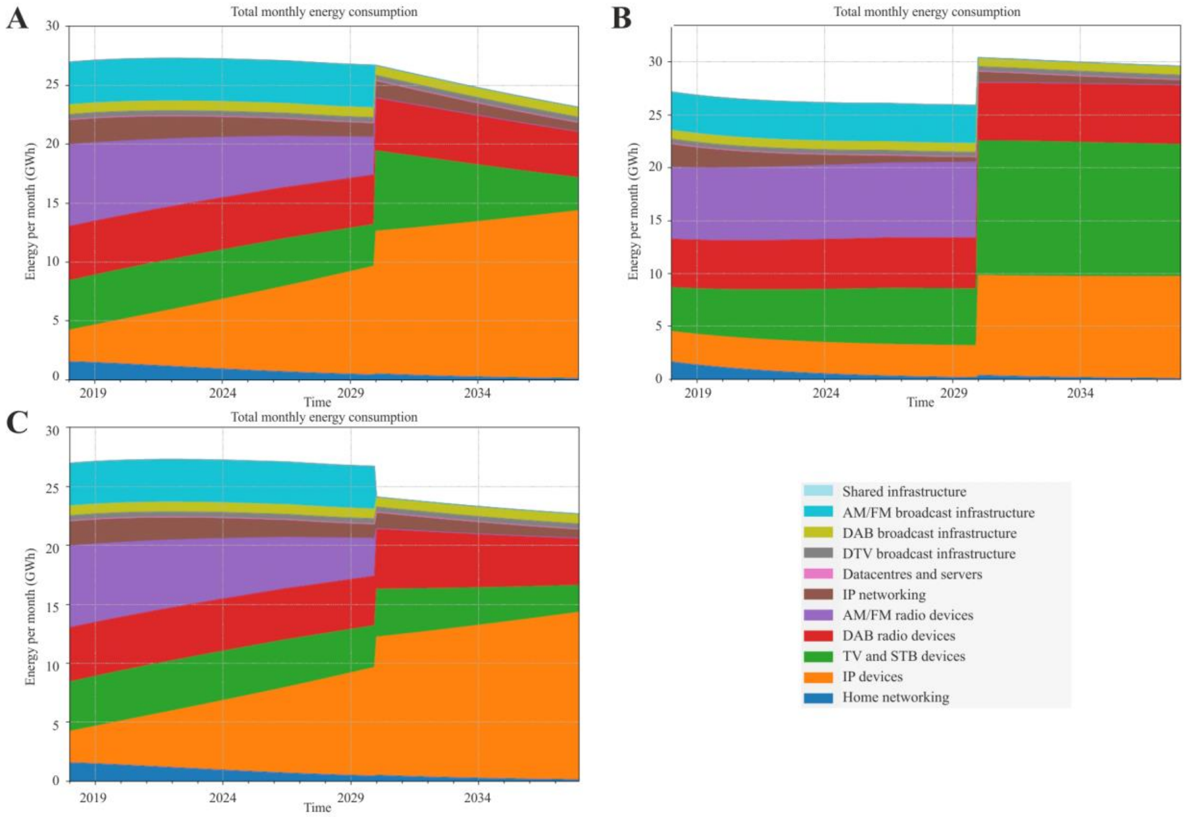
Configuration ID	Description
A	Device popularity is based upon Mediatique projections, with migration at switch-off based upon location of consumption
B	Device popularity is kept constant from 2018 until switch-off, with migration based upon location of consumption
C	Device popularity is based upon Mediatique projections, with migration at switch-off proportional to popularity at switch-off; except in-car listening, which was distributed equally between DAB and Internet radio, dependent on the scenario

Figures 41, 42 and 43 present a comparison of energy across Configurations A, B and C for Scenarios 1 to 3. Despite variations in device popularity across configurations, the mean energy prior to switch-off remained relatively consistent at 27.1 GWh/month for Configurations A and C, and 26.3 GWh/month for B. However, there was notable variation in modelled energy across configurations after switch-off.

For Scenario 1, Fig. 41 reveals significant differences in energy consumption at the point of switch-off. For A, there was a minimal reduction of 0.03%, whereas B showed an energy increase of 17.3% and C a decrease of 9.7%. It is evident that the estimated uptake of TVs and STBs was the dominant factor impacting energy, indicating that an increased radio listenership via DTV could lead to a notable rise in electricity use.

FIGURE 41

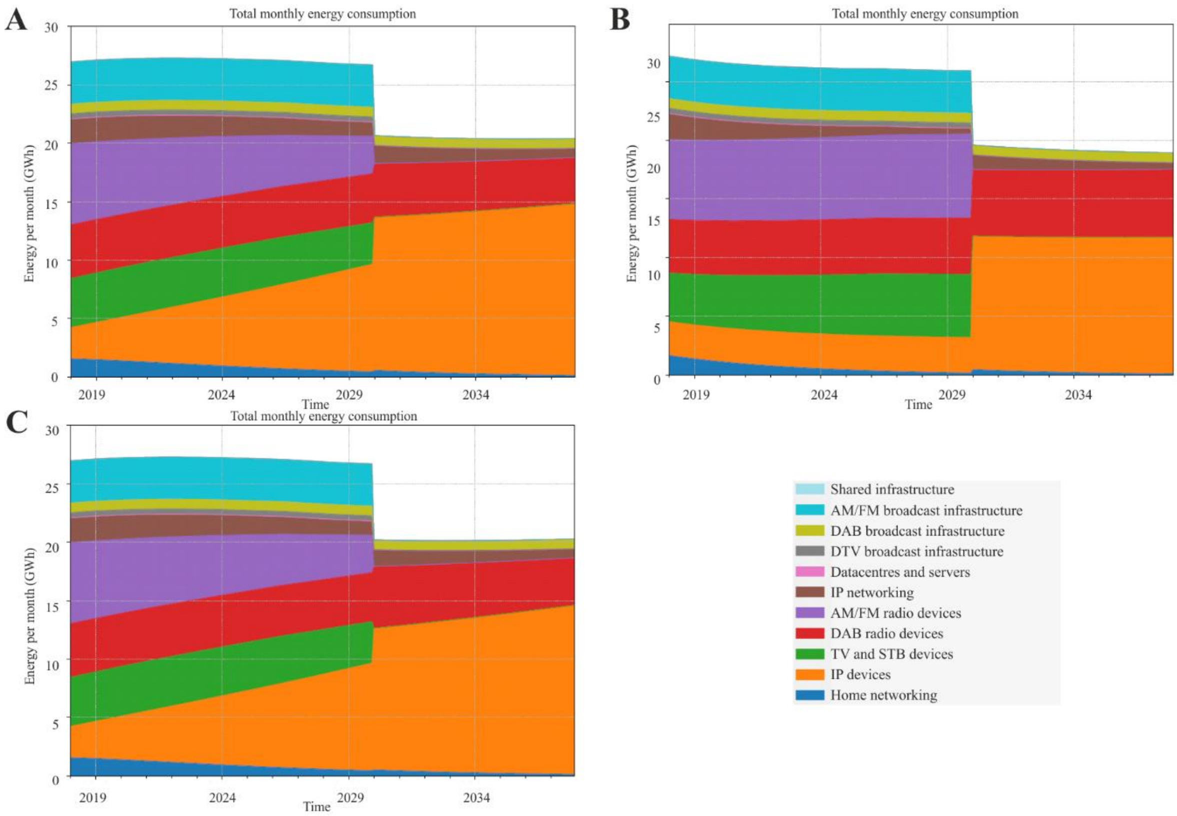
Comparative energy per month of BBC radio from 2018 to 2037 for Configurations A, B and C for Scenario 1



Report BT.2385-41

FIGURE 42

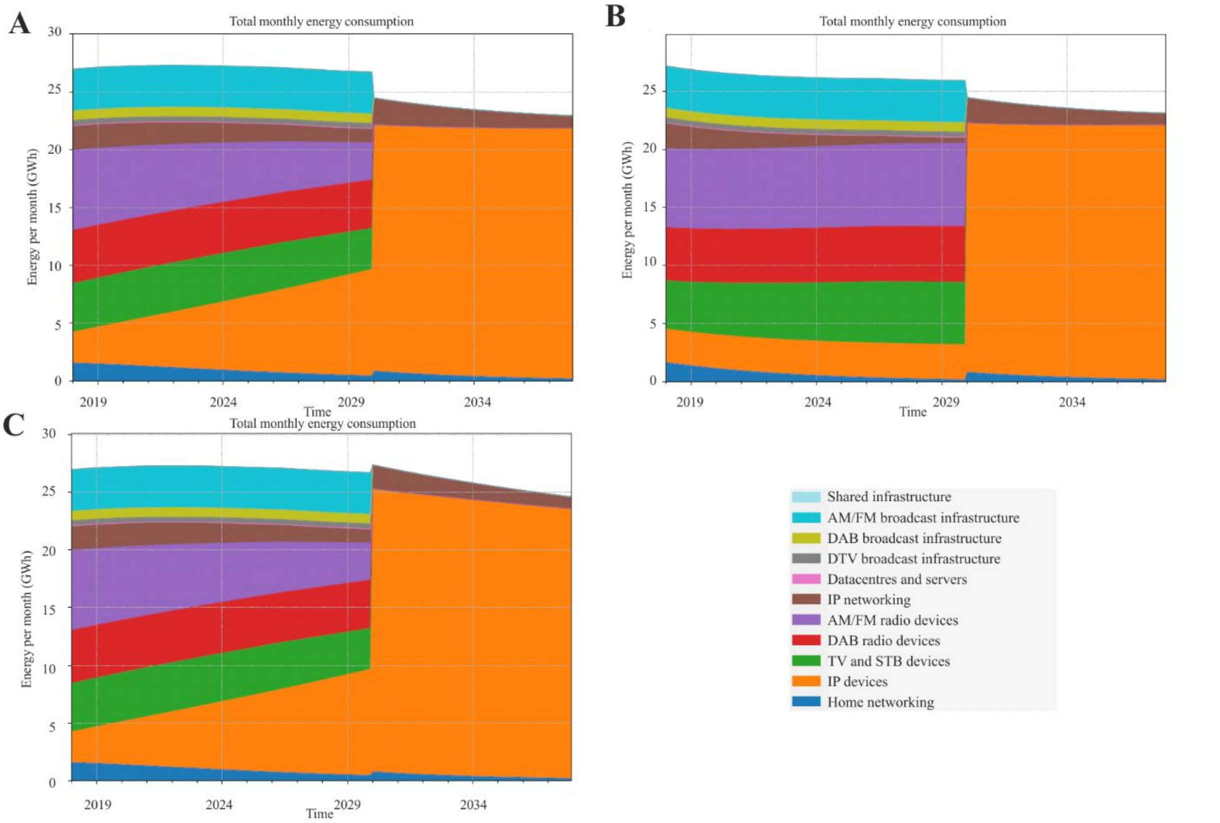
Comparative energy per month of BBC radio from 2018 to 2037 for Configurations A, B and C for Scenario 2



Report BT.2385-42

FIGURE 43

Comparative energy per month of BBC radio from 2018 to 2037 for Configurations A, B and C for Scenario 3



Report BT.2385-43

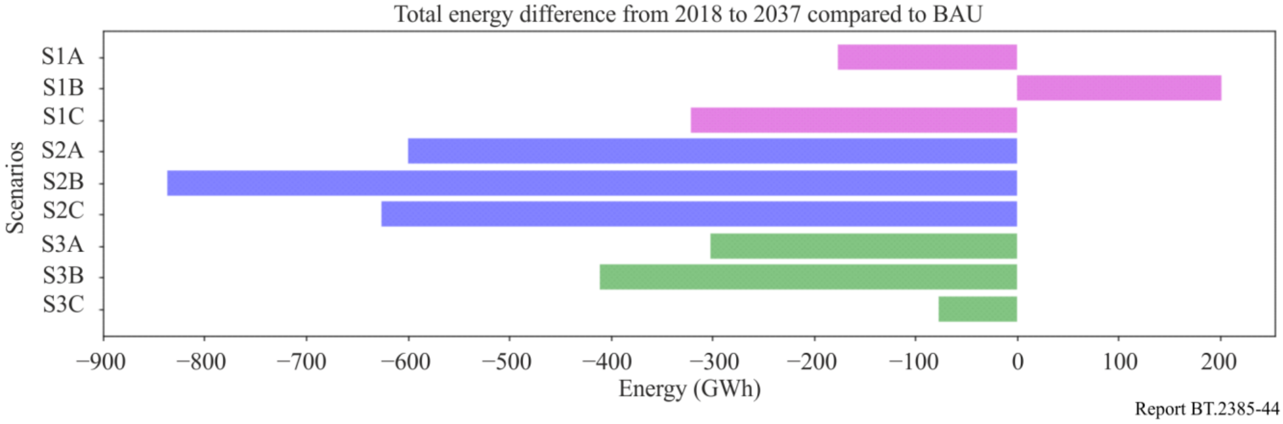
For Scenario 2, Fig. 42 shows minor differences in energy consumption at switch-off. All configurations led to an energy reduction in 2030 – 22.6% for A, 23.4% for B and 23.4% for C – regardless of variations in device popularity. Energy reductions were sustained until 2037 across all configurations. Evaluating the total energy across the 20-year period, both B and C showed an additional reduction relative to A, of 239 GWh 26 GWh, respectively.

For Scenario 3, Fig. 43 highlights variation in energy after switch-off, although these were less pronounced than for Scenario 1. The decreases in mean monthly energy at switch-off were 8.4% and 5.7% for A and B, respectively. For C, there was a 2.5% increase. Compared to BAU, all configurations showed a decrease in total energy – but to varying extents. The biggest reduction was exhibited in B (410 GWh), followed by A (301 GWh) and C (77 GWh). In A and C, smart speakers comprised the largest share of the total energy at 28.0% and 29.8%.

Figure 44 presents the total energy change relative to BAU across configurations and scenarios.

FIGURE 44

Estimated mean annual energy saving for each scenario configuration compared to BAU from switch-off



Report BT.2385-44

4.4.2 Listening hours

Table 11 presents the changes in total energy if radio consumption were to linearly increase or decrease by 50% from 2018 to 2038. Ranges represent the changes across Scenarios 0 to 3.

TABLE 11

Estimated energy difference across all scenarios if listening hours were to increase or decrease by 50% by 2038

	Change in total energy (%)
Listening hours (+50%)	+7.3 to +9.2
Listening hours (−50%)	−9.2 to −7.3

These results indicate that radio consumption had a relatively low impact on total energy, possibly due to the sustained use of infrastructure as well as the standby energy.

4.4.3 Radio device power figures

Adopting the same process from § 4.2, the changes in total energy if the average on and standby power values across all radio devices and smart speakers were 50% higher or lower than estimated are presented in Table 12. Ranges represent the changes across Scenarios 0 to 3.

TABLE 12

Estimated energy difference across all scenarios if on and standby power of radio sets and smart speakers were adjusted by 50%

	Change in total energy (%)
On power (+50%)	+5.9 to +6.7
On power (−50%)	−6.1 to −5.3
Standby power (+50%)	+20.7 to +23.1
Standby power (−50%)	−23.1 to −20.7

Results show that standby power had a greater impact on energy than on power by a factor of 3.1 to 4.4. If both the on and standby power values were increased or decreased by 50% concurrently, the total system energy could vary by up to 29.8%. This indicates that results were highly sensitive to radio device and smart speaker power figures, particularly standby power.

4.4.3.1 Standby power intervention

As results were highly sensitive to standby power, it would be valuable to estimate the impact on the total energy if the standby power of all radio devices and smart speakers was equal to zero. In practice, this would mean devices were completed switched off when not in use (i.e. the connection between the device and its power supply were removed).

Table 13 presents the reductions in energy if all radio devices and smart speakers were both or individually switched off when not in use from January 2021. Results suggest that removing all radio devices and smart speakers from their power supply instead of leaving in standby could lead to substantial savings in energy across all scenarios, averaged at 38.3%. Switching off only radio devices or smart speakers individually could also lead to energy savings across scenarios by an average of 17.4% and 20.9%, respectively.

TABLE 13

Estimated energy difference across all scenarios if standby power of devices were set to zero from 2021

	Change in total energy (%)		
	Radio devices and smart speakers	**Radio devices only**	**Smart speakers only**
S0: BAU	−36.2	−17.3	−18.9
S1: Digital only	−36.5	−16.7	−19.8
S2: DAB/IP only	−39.9	−18.4	−21.5
S3: IP only	−40.7	−17.2	−23.5

5 Discussion

Results indicate that the preparation, distribution and consumption of BBC radio services had a notable impact on UK electricity use. For the 2018 baseline, an estimated 325 GWh of energy was consumed, equivalent to 0.1% of UK electricity for that year. The congruent study for BBC television services in 2016, conducted by Schien *et al.* (2020), established a result of 2 171 GWh, approximately 6.7 times that of radio. Note, whilst differences in reference years would account for some variation, for example reductions due to the increased efficiency of IP networks, the magnitude of this would be minor. Considering the estimated power consumption of TV sets was 14 times higher in Schien *et al.* (2020) compared to radio sets in this study, plus the additional energy attributed to STBs, this 6.7 magnitude may appear small. However, there were some key factors which contributed to this result.

Firstly, the total distribution energy of BBC television services was only 1.8 times larger than for BBC radio. In fact, the Arqiva transmitter network energy for radio services on AM, FM, DAB and DTT collectively used 2.5 times the energy of DTT transmitters for television services, whereas the energy from Internet, satellite and cable distribution for television was 4.1 times that of radio. In each study, the energy attributed to distribution was estimated to be 26.5% (radio) and 7.1% (TV) of the total. Secondly, the total number of devices in the population differed between studies. Schien *et al.* (2020) estimated there to be two television sets per household for 95% of UK households, equating to 52.1 million devices. In this study are estimated 1.4 radio sets per person for 90% of the UK population, which equates to approximately 83.7 million devices. The number of unique device hours per person per day, which accounts for shared listening, varied between studies, with approximately 0.78 for BBC television services and 0.91 for BBC radio services. Furthermore, the mean measured standby power figures of radio sets (0.316 W for DAB and 0.529 W for analogue) were slightly higher than the estimated standby power of TV sets at 0.3 W, which we showed to be a significant factor in our results. Lastly, the uptake of other consumer devices was larger and more diverse in the radio research than in Schien *et al.* (2020), implying that a like-for-like comparison between these two studies is challenging due to distinct differences in distribution methods and consumer behaviour. This demonstrates the value of taking a full system approach when modelling the energy consumption of media services.

The carbon footprint of BBC radio services was estimated using the 2018 UK Scope 2 carbon emissions factor and Scope 3 factor for transmission losses (BEIS, 2018), together with 'Well-to-Tank' factors for transmission and generation (LowCVP, 2019). This method estimated emissions to be approximately 0.11 $MtCO_2e$ in 2018, equivalent to 0.03% of annual UK emissions (BEIS, 2020). This, however, assumes a fuel mix in line with the UK average. Therefore, it does not account for the specific purchase of renewable energy for the operation of infrastructure such as BBC premises, transmitter networks or third-party datacentres. Nor does this account for the consumption of petrol or diesel to power car radios. If this work were to be replicated in the future, direct power measurements of car radios would be obtained, and the energy attributed to in-vehicle listening modelled separately. This would permit a more granular analysis of the energy footprint as the standby power for car radios could be better accounted for, as well as the carbon footprint where vehicle-specific carbon factors could be incorporated. The emissions in Schien *et al.* (2020) were estimated to be 1.12 $MtCO_2e$, or 0.24% of UK total in 2016. Emissions were approximately 9.8 times higher in Schien *et al.* (2020) than this study, larger than the difference between the electricity estimates. This is due to differences in carbon factors between 2016 and 2018, primarily from increasingly decarbonised electricity generation.

Across both studies, consumption was calculated to be the most energy-intensive part of the end-to-end chain, comprising 73.4% in this research and 92.6% for television in 2016 (Schien *et al.*, 2020). For BBC television services, the on power values for STBs, PVRs and TV sets led to high energy consumption, as well as the standby power of STBs and PVRs. Similarly, for BBC radio services, the standby power of radio sets and smart speakers were the dominant drivers of energy consumption. In 2013, the EU Regulation No 801/2013 (European Commission, 2014) was enforced to ensure that the standby power of new consumer electronic devices, including TVs and radio sets, did not exceed 0.5 W. Whilst the mean standby power of DAB radios measured in this study showed accordance with this regulation, the mean analogue radio standby power slightly exceeded this limit. This is primarily due to the high power consumption of legacy analogue radio devices, which generally have a longer lifespan. However, the sample of radios used for taking measurements in this research were not necessarily representative of those in the population, which may have skewed results. Furthermore, the power behaviour of car radios and battery-powered devices may differ considerably to those measured. Without conducting a robust analysis of individuals' radio set-ups, and the power consumption of those devices, results from this study should be treated with caution. Although, as our sensitivity analysis (see § 4.2) showed, re-simulating results with radio set and smart speaker power values 50% higher or lower than estimated consistently indicated consumer devices to be the most energy intensive part of the BBC radio chain, ranging from 67.9% to 79.2% of the total energy.

The contribution of analogue radio sets was pertinent to the baseline results as the AM and FM platforms combined had a higher amount of listening hours than each of DAB, DTV and IP. Whereas, in the scenarios analysis, smart speakers were the dominant contributor as uptake was projected to increase substantially over the 20-year period. The EU Regulation for the maximum standby power of 0.5 W does not apply to network-connected devices, such as STBs, smart speakers and Internet radios, which, since 2017, have been regulated to ensure that standby modes do not consume more than 3 to 12 W, dependent on the device (European Commission, 2014). Whilst the mean standby power of 2 W for smart speakers in 2018 satisfied this requirement, it is difficult to predict whether these devices will become more power intensive with time, particularly if household devices become increasingly Internet-connected and smart home technology more commonplace. Furthermore, this 2 W value was derived by taking an average across four Amazon devices with three standby power modes. It was assumed that these standby modes were used equally, which may not be realistic. Other smart speaker devices, which represent a smaller share of the UK market, use different amounts of power. For example, all Sonos smart speaker products had a higher power consumption in idle (standby) mode than our estimate, ranging from 2.2 W to 8.0 W (Sonos, 2020). Additionally, whilst the Apple HomePod standby power was toward the lower end of our uncertainty range at 1.8 W, the device on power has been reported to be over three times our estimate at 9.3 W (Apple, 2018). This could highlight a potential underestimation of smart speaker energy consumption from our modelling.

This study revealed that if all radio devices and smart speakers were switched off when not in use from 2021, such that the standby power was equal to zero, the 20-year energy footprint of BBC radio services could be reduced by approximately 38.3%. This would also have a subsequent impact on the energy footprints of other radio providers and streaming services, and collectively UK consumption. However, such an intervention may be difficult to effect. It may also be unfeasible in practice; for example, home-integrated smart speakers and clock radios serve alternative functions which require continuous power. Nevertheless, encouraging audience behavioural change where possible would lead to positive environmental outcomes. Furthermore, ensuring that regulations for the standby power of consumer electronic devices are maintained or, better yet, strengthened is critical, particularly once the UK has completed its transition from the European Union. Lastly, manufacturers who develop smart speakers and radio devices should be encouraged to decrease device power consumption, irrespective of regulation, to reduce their energy footprint and demonstrate their commitment to sustainability.

Investigation into the electricity consumption of BBC radio under the four scenarios modelled in this study revealed retaining both DAB and IP radio platforms (Scenario 2) to be the most energy-efficient. Although results in this research are only indicative, this scenario proved to be the most robust against parameter sensitivities such as device popularity. However, some providers have migrated radio services from DAB to DAB+. DAB+ radio is more spectrum-efficient with lower bit-rates than DAB (Cridland, 2017). This allows providers to offer more services within their multiplexes. Anecdotally, this could also mean reduced energy expenditure for transmission, although this is not definitive. It is also possible that any savings from distribution may be outweighed by greater energy expenditure in DAB+ radio receivers on account of their added complexity. DAB+ receivers could however be, on average, more power efficient than existing DAB-only devices due to their more recent emergence in the UK market (Cridland, 2017). However, many DAB devices, old and new, do not have DAB+ capability; in fact, nearly one-fifth of radios sold in October 2019 were not DAB+ compatible (GfK, 2019). This could equate to additional environmental impacts associated with the acquisition of new equipment and disposal of redundant technology, which has not been captured here. Over time, if more providers switched from DAB to DAB+, it is also possible that there could be an increased uptake of radio consumption via IP devices – such as smart phones or smart speakers – or other platforms than modelled, if existing DAB listeners have devices which are not DAB+ compatible.

In the context of IP-only distribution, DAB and DAB+ would both eventually be phased out. Whilst this case (Scenario 3) only demonstrated half the energy reduction capability of retaining both DAB and IP platforms, results signalled a decrease in energy compared to BAU, primarily due to reduced energy from distribution. This would indicate positive environmental and financial outcomes for the BBC. However, the electricity usage of consumer devices remained high after switch-off as a result of increased smart speaker uptake. This re-emphasises the importance of reducing device power consumption. Results from the IP-only scenario were highly sensitive to which devices people migrated to after switch-off, and even more so for the digital-only case (Scenario 1) which demonstrated a potential increase in energy if a high proportion of individuals were to adopt radio listening via TVs and STBs. This illustrates the potential impact that a radio DSO could have on UK energy consumption. Following the findings of this study, appropriate strategies and messaging regarding device migration would be required to encourage consumers to make more sustainable choices, particularly if either a radio DSO or a migration to IP-only services were to be implemented. For example, based on our findings, consumers should be encouraged to opt for DAB or low-powered IP devices in place of radio services via DTV. However, since this research was completed, the BBC Sounds app was launched on smart TVs, the impact of which has not been modelled here. This could reduce the listenership for DTV radio devices and potentially have a smaller footprint if viewers were to listen through a smart TV without a STB. Although, this is still likely to have a higher footprint than the current estimated energy intensity of radio over IP.

Technological changes could also impact energy consumption in ways that are difficult to quantify. With over one-third of listening occurring outside of the household (MIDAS, 2018), changes in transport and consumer habits could affect radio consumption. For example, if autonomous vehicles were to become commonplace within the near future, as is often declared by car manufacturers and news outlets (Piper, 2020), traditional audio consumption may see a decline. Autonomous vehicles could be integrated with more screen-based entertainment, meaning that video media may be favoured over audio-only. This could be further supported by the rollout of 5G, which has greater bandwidth than older generations of cellular networks, thereby facilitating a larger volume of data traffic. An increased uptake of autonomous lorries could, in theory, remove radio listenership from these vehicles altogether if passengers or operators are no longer required (BBC, 2019). In wake of both the COVID-19 pandemic and climate emergency, there are opportunities to increase bicycle traffic, which may lead to a decline in radio consumption. Contrarily, more individuals could be encouraged to opt for personal motorised transportation instead of public transport (Honey-Roses *et al.*, 2020). Despite results in this research showing that changes to the radio listening duration did not lead to drastic reductions in energy, this did not model the impact of listening hours in conjunction with device migration or disuse.

New audio devices destined for future markets could also have unprecedented impacts on energy consumption. For example, with the increasing prominence of smart technology, it is possible that products like independent smart headphones or glasses may become prevalent over time (IntelligentHQ, 2018). In this study, the energy associated with headphones, audio glasses and other peripheral devices were not considered due to a lack of available data. In some cases, headphone use can reduce energy, as was observed during our direct radio power testing. This impact however is highly likely to depend on both the audio device and headphones themselves. Contrarily, external speakers are likely to increase energy. Furthermore, this study assumed that the power consumption of existing devices would remain constant over 20 years, which is unlikely. Technological improvements could lead to increased energy efficiency, although the incorporation of additional features or changes in design could lead to the opposite. For example, trends in increasingly power-efficient television sets have been counteracted by a greater propensity toward larger screen sizes with a higher power consumption (Chandaria *et al.*, 2011).

Another key caveat to the results presented in this study is that only the impact of BBC network radio services has been investigated. If the infrastructure and consumption of local and nations radio stations – which comprised an additional 14.2% of listening in 2018 (MIDAS, 2018) – were considered, the BBC’s energy and carbon footprints for radio would be higher than estimated. The primary reason for omitting these stations from scope was due to the more complex nature of distribution. In total, there are nine national regional and 41 local stations (including Solent for Dorset); however, not all of these are available across each delivery platform. FM covers almost all channels with eight nations and 41 local, whereas MW covers four nations and 31 local; DAB covers seven nations and 38 local; and BBC Sounds covers six nations and 40 local. Furthermore, satellite and cable broadcast platforms provide seven nations and one local (only in London); and DTT provides seven nations and all local, but local stations are only available to consumers in surrounding areas, the amount of which is not consistent. Whilst MW, FM and DTV transmission of these stations are managed by Arqiva, local DAB multiplexes are auctioned out by Ofcom to various UK providers, making data collection a challenge. With consumption shown to be the largest contributor to energy in this study, the total energy of network, nations and local radio could be estimated by scaling up in proportion with the additional listening hours, leading to an estimated value of 371 GWh for 2018, equivalent to 0.13 $MtCO_2e$ emissions.

As a full-scale LCA has not been conducted, factors such as music and radio production, equipment manufacturing and waste disposal have not been considered. However, these elements are likely to have had a significant impact on energy. For radio production, internal staff calculated the carbon footprint of BBC Radio 5 Live via the BAFTA albert scheme (albert, 2020a), including news, sport, business, podcasts and independent productions (albert, 2020b). This assessment accounted for business travel and accommodation, office and studio energy use, materials, and on-location consumption. For February 2020, the carbon footprint was estimated to be 44.7 tCO_2e emissions, of which the largest components were business travel (80.8%) and office and studio use (15.9%). Assuming this was a representative estimate for the mean monthly footprint in 2018, the annual emissions of BBC Radio 5 Live would be approximately 536.4 tCO_2e. For scale, if we assumed BBC Radio 5 Live to be an 'average case' BBC network radio channel, the total emissions for all BBC stations would be approximately 0.006 $MtCO_2e$, around 5% of the total emissions calculated for our baseline. However, it should be acknowledged that the footprints of radio production across BBC network radio channels are likely to differ. For example, more studio-based stations, such as BBC Radio 1 and BBC Radio 2, may have smaller travel footprints than BBC Radio 5 Live. Contrarily, the concert performances on BBC Radio 3, international scope of BBC World Service, and various pre-recorded programmes on BBC Radio 4 may lead to higher carbon footprints.

For music production, Bottrill *et al.*, (2010) estimated that the UK music market generated around 0.54 $MtCO_2e$ emissions per year a decade ago, although 74% of this was due to live performances. The remaining 0.14 $MtCO_2e$ emissions were attributed to music recording and publishing. This figure appears to be comparable with the 2018 baseline emissions in this study; however, differences in carbon factors imply that the estimated energy of UK music production in the 2010 would have been lower at approximately 233 GWh. This also assumes that energy consumption has remained constant over eight years. Whilst this may be unrealistic, it helps to impart a sense of scale. Assuming that the energy did remain constant, and that the proportion attributed to BBC was in line with its share of radio listening hours (45%), music production would still comprise a smaller part of the chain (105 GWh) compared to consumption (239 GWh). However, there are flaws within this estimate. Namely, it does not consider the footprint of 'older' music and solely accounts for the BBC share of music produced that year, assuming all new music is played by the BBC. Furthermore, it does not consider the longevity or popularity of music. For example, a song played out frequently over several years would have a smaller footprint per play than a song played only once. It is also important to note that digital music is not immaterial (Kumar & Parikh, 2013). In the context of equipment, including broadcast infrastructure, radio studios and consumer devices, there are many lifecycle stages not accounted for – such as mining, manufacturing, transportation, purchasing, decommission and disposal.

Whilst not all elements have been captured, this research has provided a detailed analysis of the current BBC radio energy consumption. The scenarios selected provide an illustrative overview of how decision-making on the future of radio may impact the environment. The outlined methodology also enables the flexibility to model other potential scenarios.

6 Conclusion

In this Annex is presented an approach to modelling the energy required to prepare, distribute and consume BBC radio services, both now and under a variety of future scenarios. The methodology from Schien *et al.*, (2020) was adopted, which applies the principles of LCA to calculate energy used during the lifecycle distribution and use phases. This allowed us to identify energy hotspots within the end-to-end BBC radio system.

From the baseline results, the energy use in 2018 is estimated to be 325 GWh, equivalent to 0.1% of UK energy consumption. Per device-hour, DAB was shown to be the least energy-intensive platform (9.3 Wh/device-hour), and DTV the most (80.6 Wh/device-hour) with a footprint almost nine-times as large. Consumer devices were shown to be the dominant driver of electricity use, as was seen for BBC television services (Schien *et al.*, 2020), comprising 73.4% of the total energy. The three largest components – analogue radio sets, DAB radio sets and TV sets – consumed over half of the total energy at 52.3%.

In future modelling, all scenarios showed energy-saving potential but to varying magnitudes. Retaining only DAB and IP radio services from 2030 (Scenario 2), by far, led to the largest energy saving across all scenarios modelled – almost twice as much as switching to IP-only services from 2030 (Scenario 3). This scenario was also most robust under sensitivity analysis. In contrast, switching off only analogue services (Scenario 1) showed the smallest reduction in energy. Under sensitivity analysis, this scenario also showed a potential increase in energy resulting from a larger uptake in DTV radio services, which had the highest footprint per device-hour. This highlighted the impact consumer decisions have on energy use, and the importance of audience messaging if the BBC were to adapt its distribution strategy. These results indicate that, from an environmental perspective, consumers should be encouraged to steer away from DTV radio services in favour of DAB or IP devices.

Both the baseline and scenario results showed the significance of radio set and smart speaker standby power on energy consumption. For 2018, radio device and smart speaker standby power were identified as the principal parameters impacting energy in the BBC radio system. Similarly, for our future modelling, setting the standby power of smart speakers and radio sets to zero from 2021 showed an average energy reduction of 38.3%. This indicated that any reduction in standby power could lead to notable energy savings. Smart speaker and radio device power consumption could be influenced via regulation by reducing the maximum wattage for electronic consumer devices; manufacturers by innovating to reduce the device power consumption; and consumers by removing devices from their power source when not in use.

7 Acknowledgements

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Attachment A
to Annex 7

Radio device measurements

The joint Defra-DCMS research on the power consumption of radio devices between 2010 and 2013 were considered to be out of date for this study. Therefore, measurements across a sample of 19 radios available to BBC R&D (listed in Attachment B) were taken to estimate on and standby power for analogue, DAB and Internet radio sets. All 19 radio sets considered had FM functionality, of which 11 had DAB and one had IP. AM delivery methods, such as MW and LW, were not tested for simplicity. It was assumed the power consumption of AM platforms were the same as FM. It should be noted that this small sample size was not necessarily representative of the market. The sensitivity of these figures were tested as outlined in §§ 4.2 and 4.4.

The methodology used to measure the power output of devices combined techniques outlined in the IEC 62087-6 standard and the joint Defra-DCMS study, as well as adjustments for simplification made internally. The conditions were as follows:

– **Environmental conditions:** the ambient temperature was within 23 °C ± 5 °C

– **Acoustical environment:** acoustics such that the sound pressure level decreases with distance, r, from the sound source in accordance with 1/r ± 10%

– **Sound selection:** BBC Radio 1 was used as a reference to provide real-world application – one 2-min talking segment and two 2-min music segments

– **Volume control:** the volume was adjusted such that the sound pressure level recorded an average of 70 dBA ± 10% at a one-metre distance from the source, using a sound pressure meter, with background noise tested to ensure no other interference detected

– **Adjustment of controls:** all other device controls were set to neutral and batteries were removed from the device

– **Connection type:** all devices were connected to a watt-meter via mains power with the voltage not exceeding 230 V ± 2%

Measurements were recorded in the Radio Device Power Use Data Sheet (as in Attachment C). Characteristics of each device including model name, functionality, year of manufacture, wavebands and device type were also noted down. The procedure for taking power measurements was as follows:

1 Remove batteries from the device and plug into the watt-meter via mains connection.

2 Turn the device on and switch channel to BBC Radio 1.

3 Adjust the volume control as required and ensure all other controls are set to neutral.

4 Record the on power consumption:

a) Press *log* on the watt-meter and start timer for 2 minutes

b) Note down the ambient temperature

c) Stop logging after 2 minutes

d) REPEAT **a-c** twice more

e) Remove USB logger and connect to computer

f) Calculate the mean power and voltage per test

g) Record readings

h) Find average power across three readings.

5 Record the standby power consumption:

a) Turn the device to standby mode (if applicable)

b) Press *log* on the watt-meter and start timer for 30 minutes

c) Stop logging after 30 minutes

d) Press *log* on the watt-meter and start timer for 2 minutes

e) Repeat **d** twice more

f) Remove USB logger and connect to computer

g) Analyse 30-min log and note down whether any power fluctuations (representing different states of standby mode)

h) Calculate the mean power and voltage per 2-min test

i) Record readings

j) Find average power across three readings.

6 Record the off power consumption:

a) Turn the device to off mode (if applicable)

b) Press *log* on the watt-meter and start timer for 2 minutes

c) Repeat **b** twice more

d Remove USB logger and connect to computer

e) Calculate the mean power and voltage per test

f) Record readings

g) Find average power across three readings.

7 Calculate the mean on power for each FM, DAB and IP.

8 Calculate the mean standby power for each FM, DAB and IP, combining readings from both the standby and off modes.

Attachment B
to Annex 7

Radio devices

Table 14 presents the devices used to measure on and standby power consumption, as per Attachment A.

TABLE 14

Radio devices used to measure power consumption

ID	Radio device	Year of manufacture
1	Roberts Stream 93i	2014
2	Sony XDR-S40	2014
3	Goodmans GMR1886	2016
4	Panasonic RF-2400	2001
5	Pure One Mi Series 2	2012
6	Roberts Ecologic 1	2006
7	Steepletone Brighton	2011
8	Pure One Classic Series 2	2011
9	Sony XDR-S55	2008
10	Akai A61016	2015
11	John Lewis Spectrum Clock	2015
12	Roberts Classic 928	2004
13	Roberts Classic 993	2007
14	Roberts R 9962	2004
15	Trevi MB 741	2011
16	August MB400	2014
17	Roberts Gemini 7 RD-7	2006
18	Roberts Eco4 BT	2015
19	Sangean ATS 818cs	1993

Attachment C
to Annex 7

Radio device power use data sheet

DEVICE DETAILS

Date	Location
Device Name	Brand
Year of Manufacture	Model
Wavebands	Type
Key Features	
Test Signal Input	

OFF Mode

Test 1	Temp (°C)	Voltage (V)	Watts (W)
Test 2	Temp (°C)	Voltage (V)	Watts (W)
Test 3	Temp (°C)	Voltage (V)	Watts (W)

STANDBY Mode

Test 1	Temp (°C)	Voltage (V)	Watts (W)
Test 2	Temp (°C)	Voltage (V)	Watts (W)
Test 3	Temp (°C)	Voltage (V)	Watts (W)

ON Mode

Test 1	Temp (°C)	Voltage (V)	Watts (W)
Test 2	Temp (°C)	Voltage (V)	Watts (W)
Test 3	Temp (°C)	Voltage (V)	Watts (W)