



# Research & Development

## White Paper

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

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*BRITISH BROADCASTING CORPORATION*

**BBC Research & Development  
White Paper WHP 393**

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**Abstract**

There are various studies investigating the energy footprint of digital technology and services, including streaming, broadcast television, telecommunications and consumer electronic devices. However, there are currently no complete studies estimating the electricity consumption of radio broadcast and listening. This paper presents our approach to modelling the energy required to prepare, distribute and consume BBC radio services, exploring both the current usage and how this may change over 20 years under a variety of scenarios. Our methodology applies the principles of lifecycle assessment to evaluate the energy intensity of each radio delivery platform and highlight key 'hotspots' within the end-to-end radio chain.

We show the total mean energy consumption for our 2018 baseline to be 325 GWh, equivalent to 0.1% of UK electricity use. Per device-hour, we determine DAB to be the least energy-intensive platform (9.3 Wh/device-hour) and DTV radio services to be the most (80.6 Wh/device-hour). Of all future scenarios modelled, we estimate that switching off AM, FM and DTV radio services, and retaining DAB and IP, leads to the largest energy saving – almost twice as much as moving to IP-only distribution. We show consumer devices to be the dominant driver of energy use, comprising 73.4%-81.0% of the total energy across our baseline and scenario results. We identify smart speaker and radio set standby power to be the key parameters impacting energy. As a result, we simulate the removal of smart speaker and radio set standby power from 2021 in our model which leads to a mean energy reduction of 38.3% across scenarios. This demonstrates the value of reducing standby power through regulation, manufacturers and audience education. Moreover, we highlight the importance of sustainable decision-making when choosing devices to access radio.

**Additional key words:** Sustainability, Radio, Distribution, IP Distribution, Internet, Energy Intensity, Environmental Impact, Lifecycle Assessment

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## Abbreviations

ADSL	Asymmetric Digital Subscriber Line
AM	Amplitude Modulation
AWS	Amazon Web Services
BARB	Broadcasters Audience Research Board
BAU	Business As Usual
BEIS	Department for Business, Energy and Industrial Strategy
CAGR	Compound Annual Growth Rate
CCM	Centralised Coding and Multiplexing
CDN	Content Delivery Network
CO <sub>2</sub> e	CO <sub>2</sub> -equivalent
CPE	Customer Premise Equipment
DAB	Digital Audio Broadcasting
DCMS	Department for Digital, Culture, Media and Sport
Defra	Department for Environmental, Food and Rural Affairs
DSO	Digital Switchover
DTT	Digital Terrestrial Television
DTV	Digital Television
E&M	Entertainment and Media
FM	Frequency Modulation
FTTC	Fibre to the Cabinet
FTTP	Fibre to the Premises
GHG	Greenhouse Gas
HTTP	Hypertext Transfer Protocol
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IP	Internet Protocol
ISP	Internet Service Provider
IPCC	Intergovernmental Panel on Climate Change
LCA	Lifecycle Assessment
LW	Long-wave (radio)
MIDAS	Measurement of Internet Delivered Audio Services
MW	Medium-wave (radio)
NICAM	Near Instantaneous Companded Audio Multiplex
ONS	Office for National Statistics
PVR	Personal Video Recorder
R&D	Research and Development
RAJAR	Radio Joint Audience Research
RDS	Radio Data System
STB	Set-top Box

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## **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<sub>2</sub>-equivalent (CO<sub>2</sub>e) 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<sub>2</sub>e 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, national 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 Section 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 1<sup>st</sup> January to 31<sup>st</sup> 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 1<sup>st</sup> January 2018 to 31<sup>st</sup> December 2037 – was used, with switch-off occurring immediately on 1<sup>st</sup> 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<sup>1</sup>, 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<sup>1</sup>, two-thirds of which were attributed to TVs, STBs and broadcast networks. The CO<sub>2</sub>e emissions for the ICT and E&M sectors were calculated to be approximately 1.5% and 1.2%<sup>2</sup> 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 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<sup>5</sup>, 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

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<sup>1</sup> Calculated using Statistica record of global electricity consumption in 2015

<sup>2</sup> Calculated using The World Bank data for CO<sub>2</sub>, methane, nitrous oxide and HFC gas emissions in 2014

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 (Kooimey *et al.*, 2004; Taylor & Kooimey, 2008; Malmmodin *et al.*, 2014; Krug *et al.*, 2014; Malmmodin & 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<sub>2e</sub> emissions in 2018, stated to be equivalent to the annual CO<sub>2e</sub> emissions of Spain (The Shift Project, 2019b). This widely shared study suggested that an hour of streaming generated approximately 3.20 kgCO<sub>2e</sub> 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<sub>2e</sub> 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<sub>2e</sub> 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<sub>2e</sub> 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<sub>2e</sub> 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 Mbps 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 Mbps and 3.5 Mbps 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 1 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.

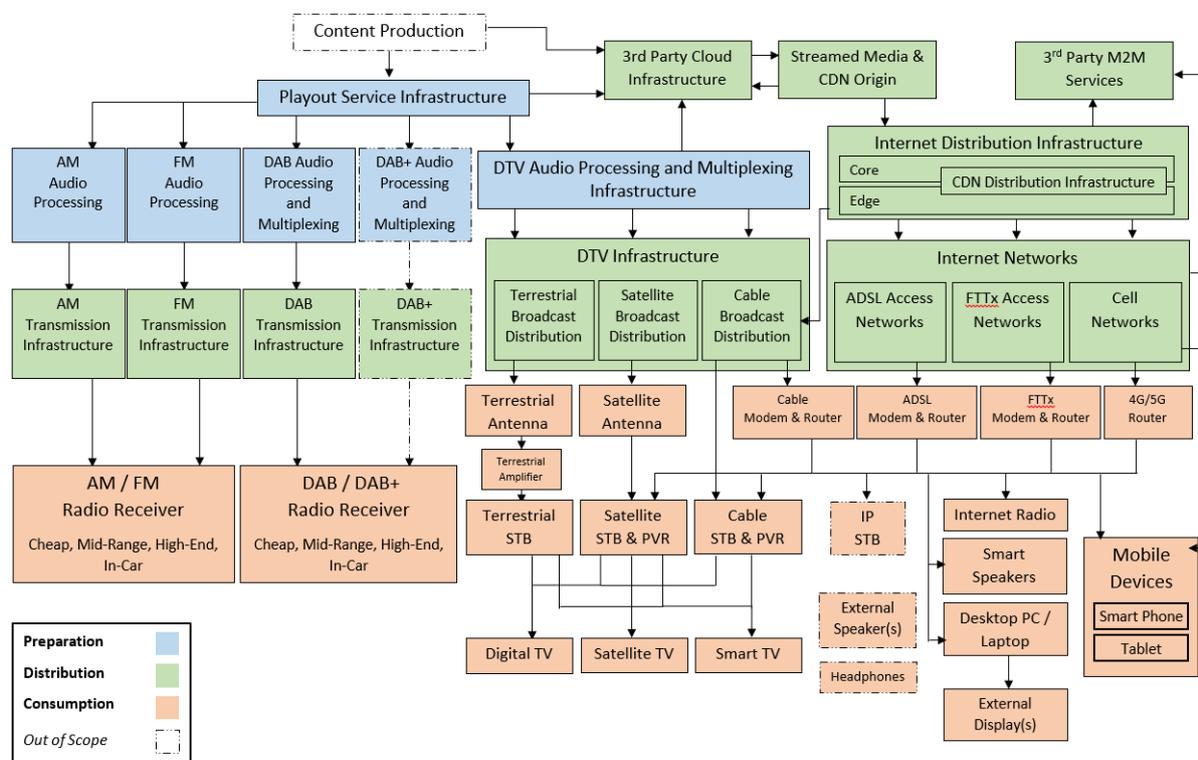


Figure 1: System map of the end-to-end BBC radio chain from production to consumption

##### 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, national 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 WiFi 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 WiFi 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<sub>2e</sub> 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 at 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<sup>3</sup>, 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 Appendix 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 Section 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

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<sup>3</sup> Amazon Echo (1<sup>st</sup> Generation), Amazon Echo Show, Amazon Echo (2<sup>nd</sup> Generation), Amazon Echo Plus

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 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 Section 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 Section 4.2 and Section 4.4.

## 4. Results

### 4.1. Results: Baseline

Figure 2 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<sup>th</sup> to 95<sup>th</sup> percentiles. Shared infrastructure energy was distributed by the unique listening hours per platform.

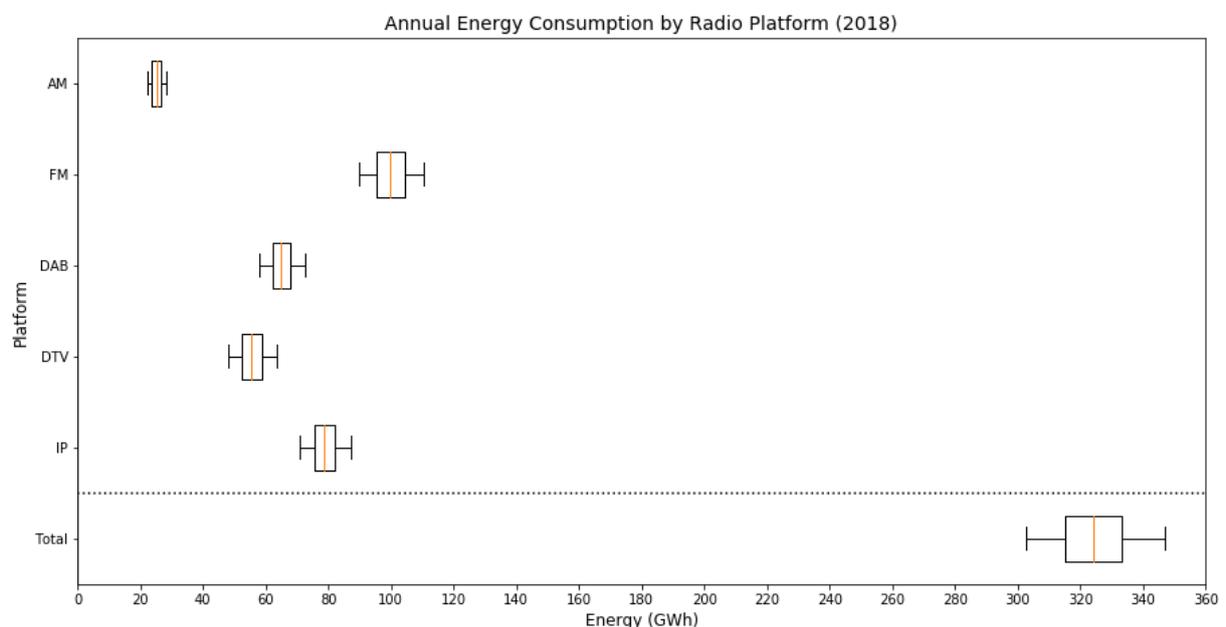


Figure 2: Estimated energy used to prepare, distribute and consume BBC radio in 2018 per platform and in total

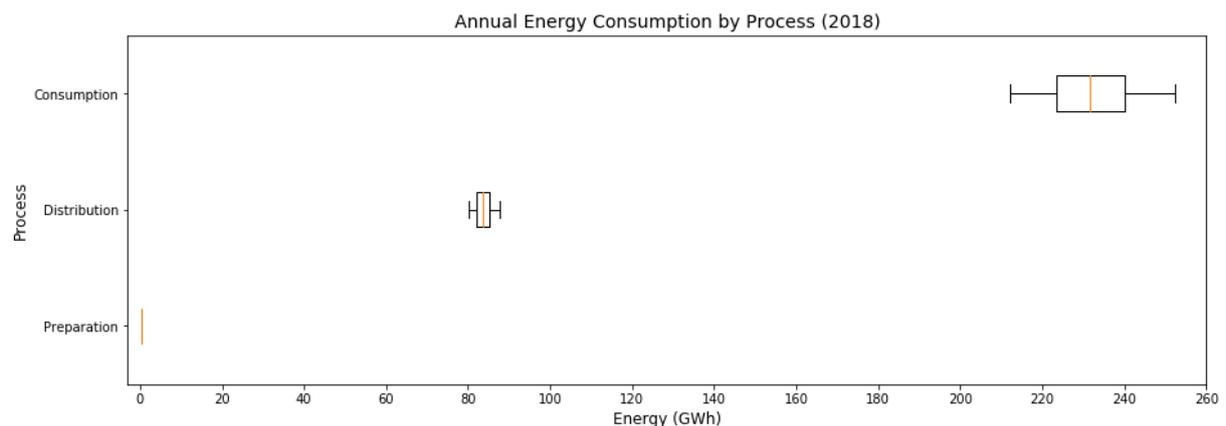
The energy required to prepare, distribute and consume BBC radio services in 2018 was 325 GWh. This equated to a mean power consumption of 37 MW. Across delivery platforms, the mean energy for AM was 25 GWh (7.7%), FM was 100 GWh (30.8%), DAB was 65 GWh (20.0%), DTV was 56 GWh (17.2%) and IP was 79 GWh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

Table 1 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 1:** 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

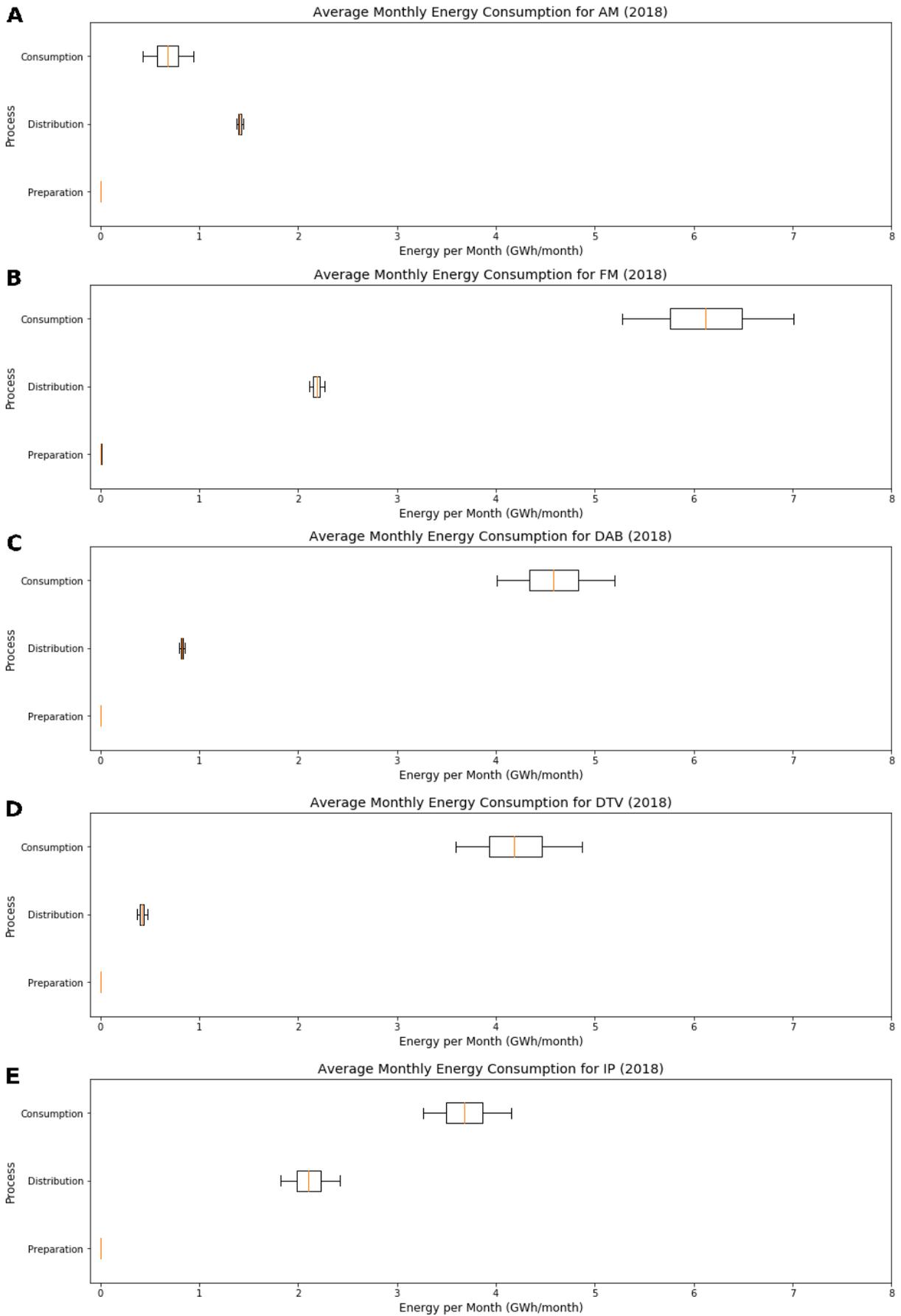
Figure 3 shows the energy per process: preparation, distribution and consumption. Consumer devices were the dominant component with an estimated mean energy of 239 GWh (73.4%), almost three times that of distribution at 86 GWh (26.5%). Payout, encoding and multiplexing contributed a mean energy of 0.3 GWh (0.1%).



**Figure 3:** Estimated energy for BBC radio in 2018 by preparation, distribution and consumption

The mean energy breakdown per process per platform are presented in Figure 4. 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.

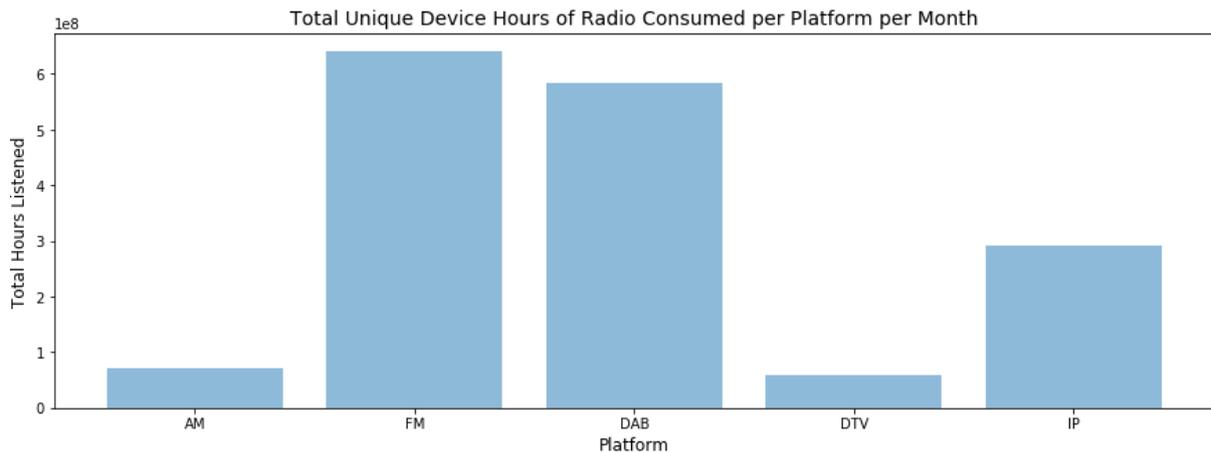
Of all IP consumer devices, desktops and monitors represented the highest share of energy in 2018 at 9.2 GWh, followed by Internet radio sets at 9.1 GWh and smart speakers at 8.1 GWh. For all radio sets and smart speakers, the mean energy resulting from device standby power was considerably higher than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



**Figure 4:** 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

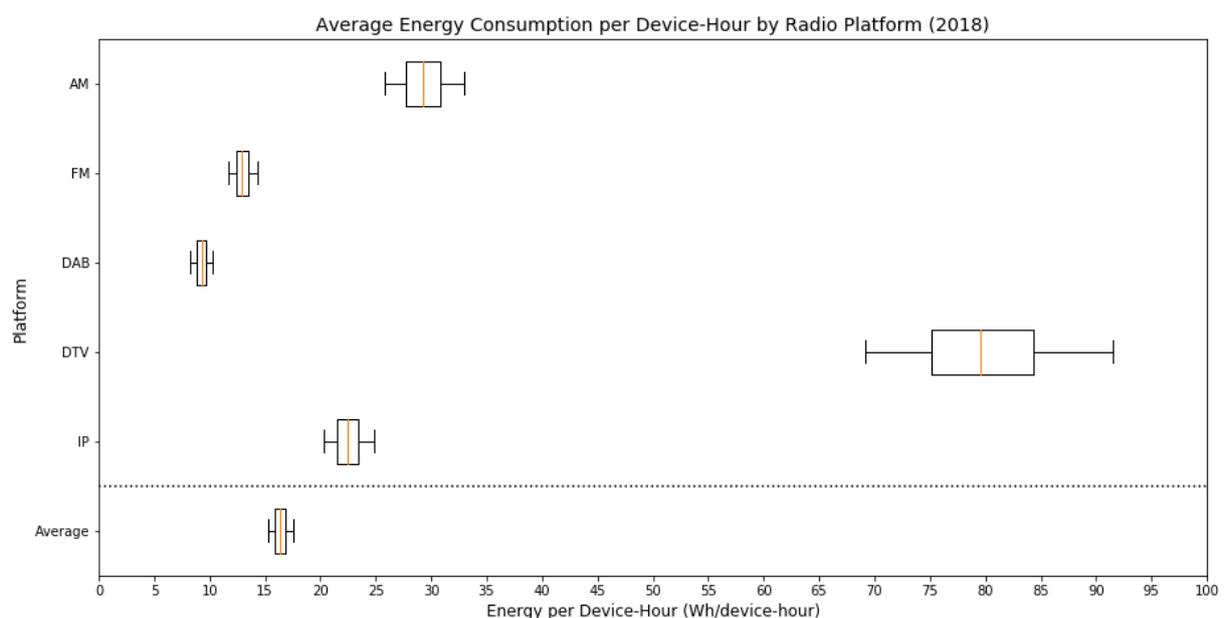
due to the vastly higher on power compared to standby. Furthermore, only a small proportion of TV and STB standby energy was attributed to radio services.

As shown in Figure 5, 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 5:** Mean number of unique listening hours for BBC radio in 2018 per platform per month

However, increased listenership did not account for all variation in mean energy per platform. This is demonstrated in Figure 6, 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 9 times more than DAB), followed by AM at 29.3 Wh/device-hour and IP at 22.5 Wh/device-hour.



**Figure 6:** Estimated energy per device-hour to prepare, distribute and consume BBC radio in 2018 per platform

## 4.2. Sensitivity Analysis: Baseline

As shown in Table 1, 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 2. 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 2:** 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
<b>Baseline</b>	325	7.7	30.8	20.1	17.1	24.3
<b>On Power (+50%)</b>	345	7.6	31.5	21.6	16.1	23.2
<b>On Power (-50%)</b>	303	7.9	29.9	18.3	18.3	25.5
<b>Standby Power (+50%)</b>	380	7.4	33.6	21.8	14.6	22.6
<b>Standby Power (-50%)</b>	268	8.2	27.0	17.3	20.7	26.7

Table 2 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 Section 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 Section 4.4.

#### 4.3.1. Scenario 0: Business As Usual

Figure 7 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.

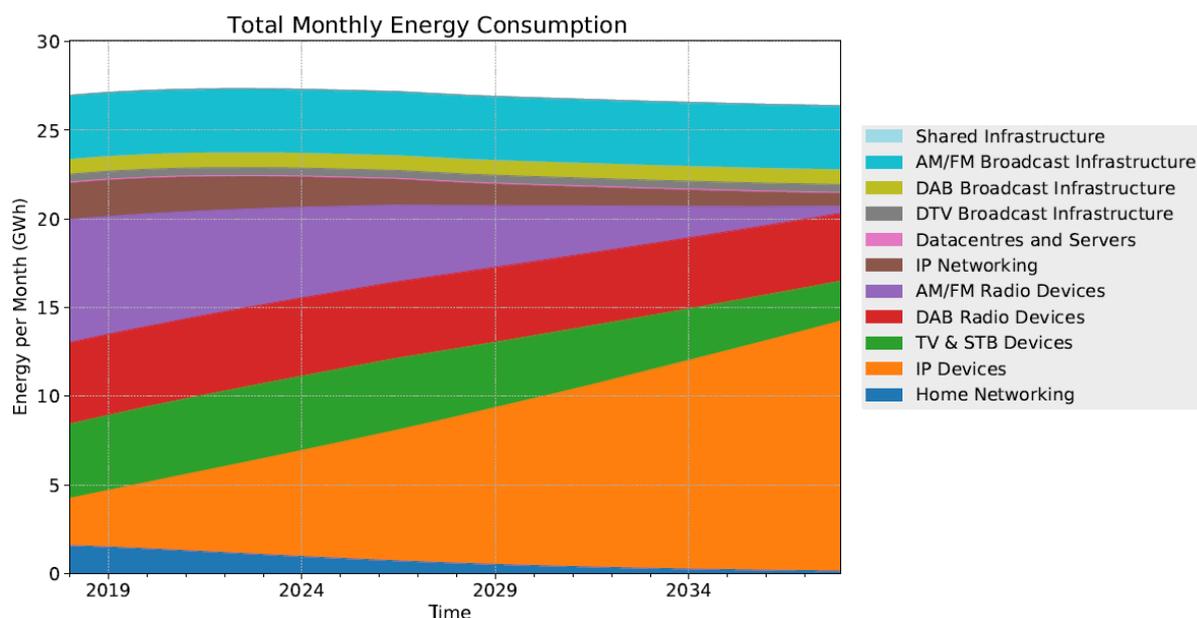


Figure 7: Estimated energy per month to prepare, distribute and consume BBC radio from 2018 to 2037 under BAU

#### 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 Figure 8. 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.

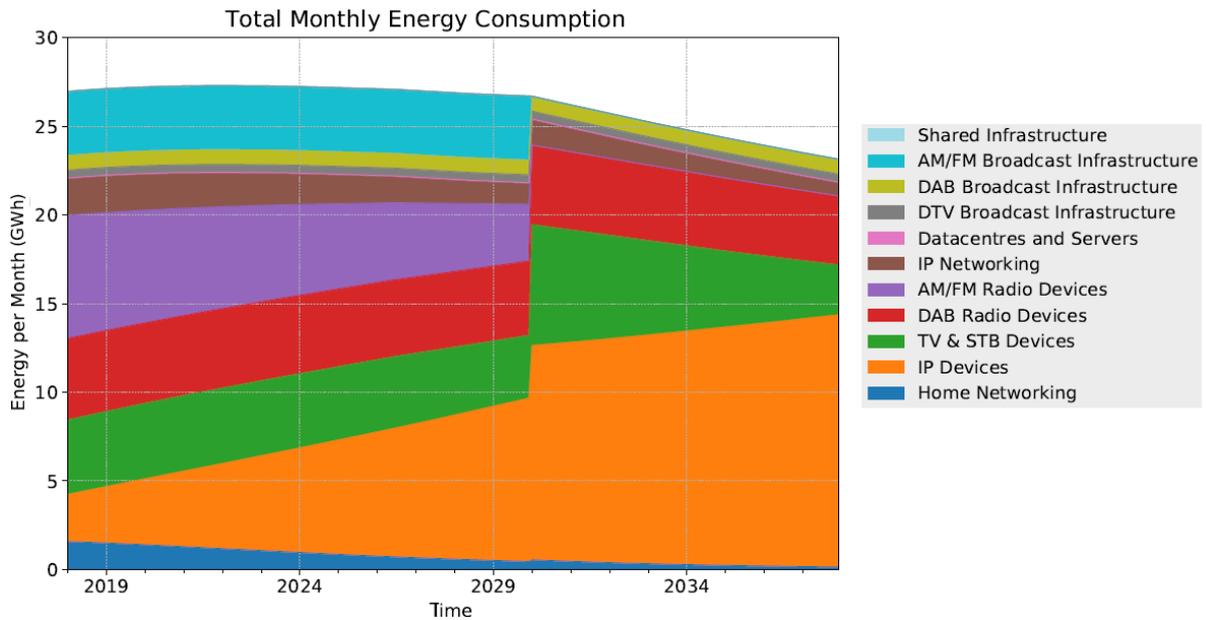


Figure 8: Estimated energy per month to prepare, distribute and consume BBC radio from 2018 to 2037 for Scenario 1

### 4.3.3. Scenario 2: DAB/IP Only

Figure 9 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.

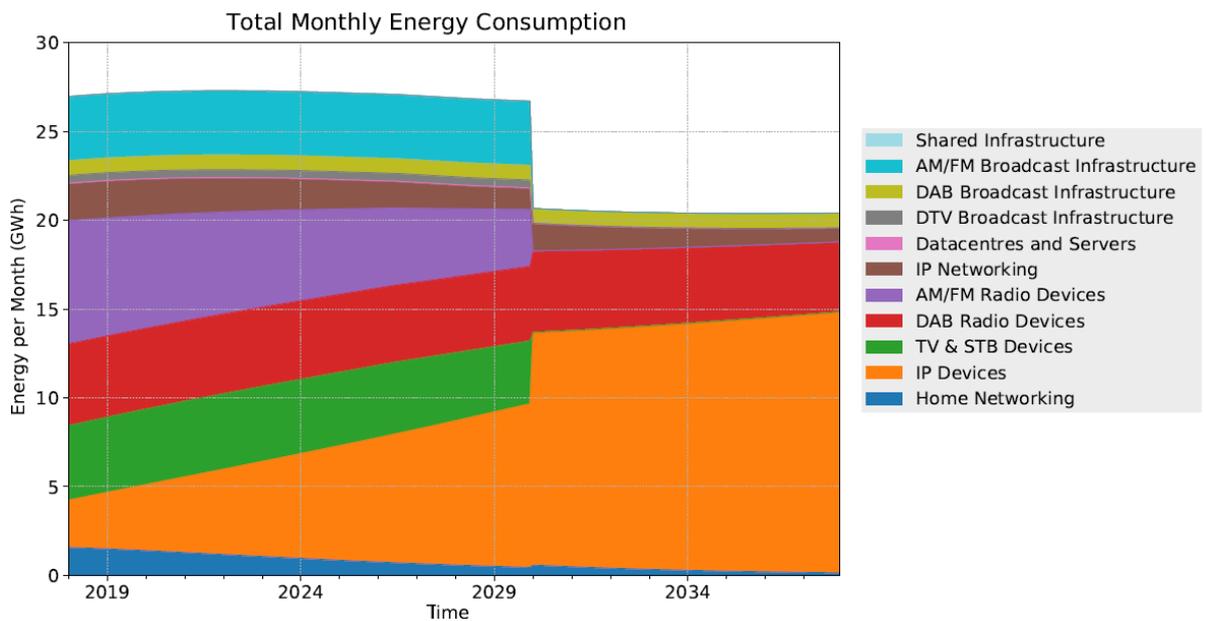


Figure 9: Estimated energy per month to prepare, distribute and consume BBC radio from 2018 to 2037 for Scenario 2

#### 4.3.4. Scenario 3: IP Only

Figure 10 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 1726 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.

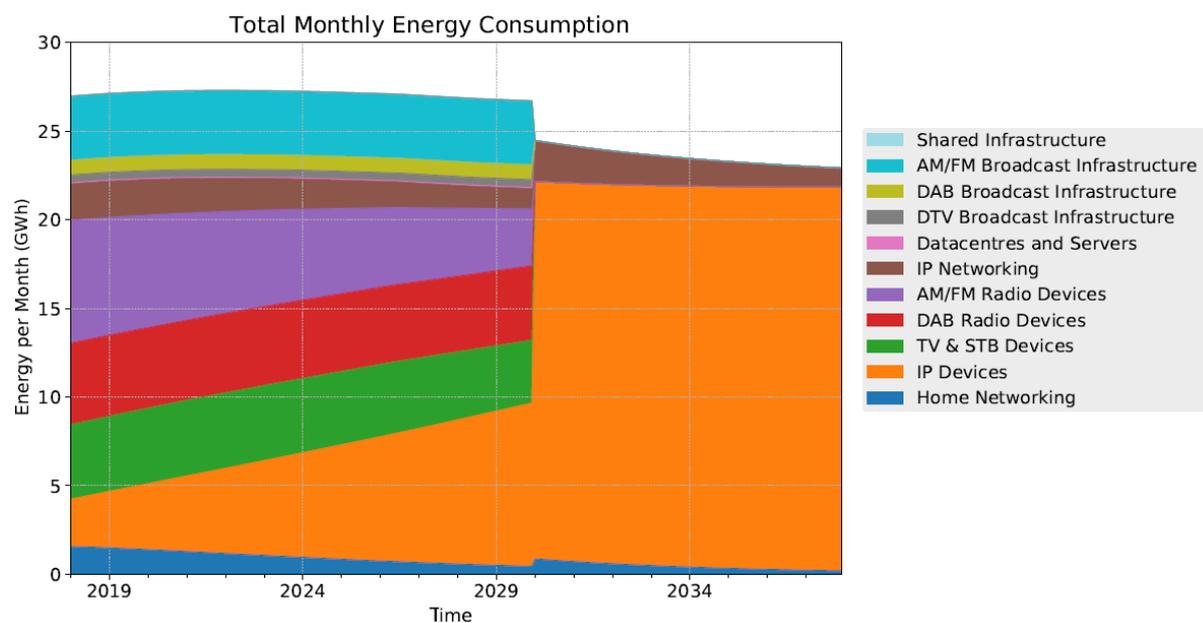


Figure 10: Estimated energy per month to prepare, distribute and consume BBC radio from 2018 to 2037 for Scenario 3

#### 4.3.5. Summary

Figure 11 shows the mean energy saving for Scenarios 1-3 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.

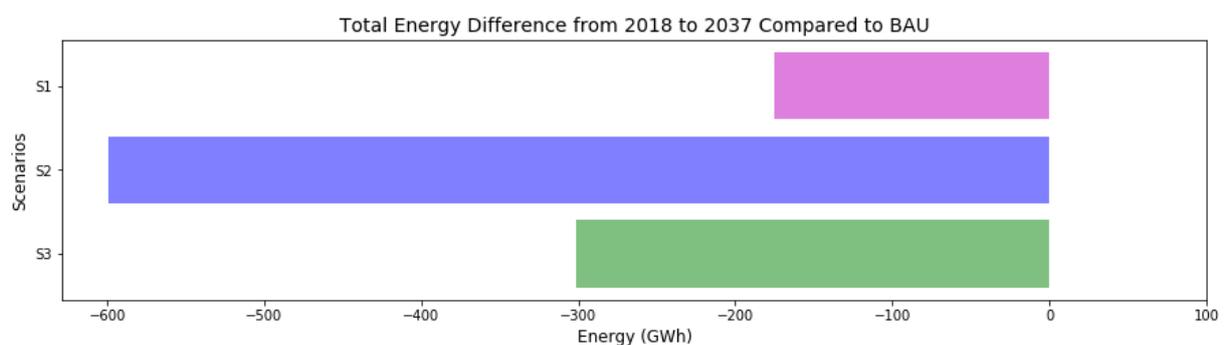


Figure 11: Estimated mean annual energy saving for each scenario compared to BAU from switch-off to 2037

#### 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 1-3). 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 3 presents all three configurations simulated. Configuration A is the original case used in Section 4.3, Configuration B omits the Mediatique projections, and Configuration C does not use location as a sole determinant for device migration.

**Table 3:** 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 12, 13 and 14 present a comparison of energy across Configurations A, B and C for Scenarios 1-3. 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, Figure 12 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.

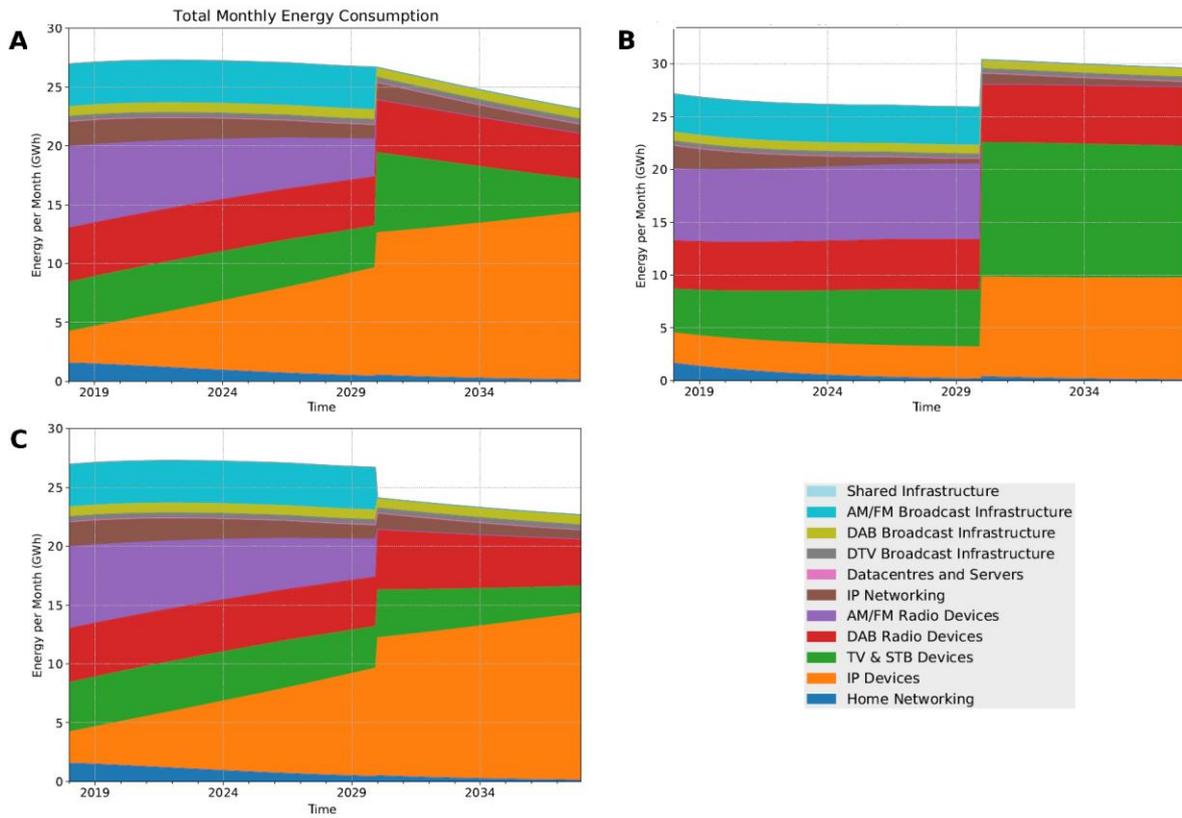


Figure 12: Comparative energy per month of BBC radio from 2018 to 2037 for Configurations A, B and C for Scenario 1

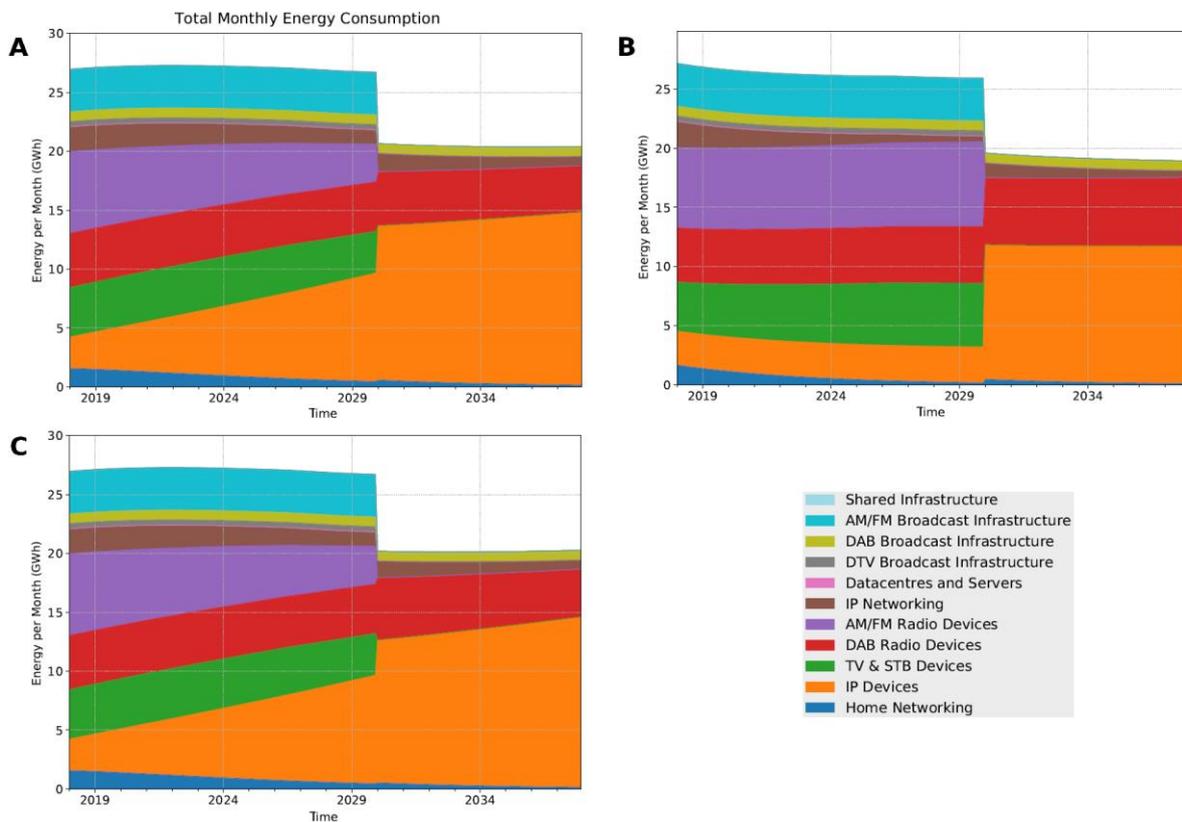
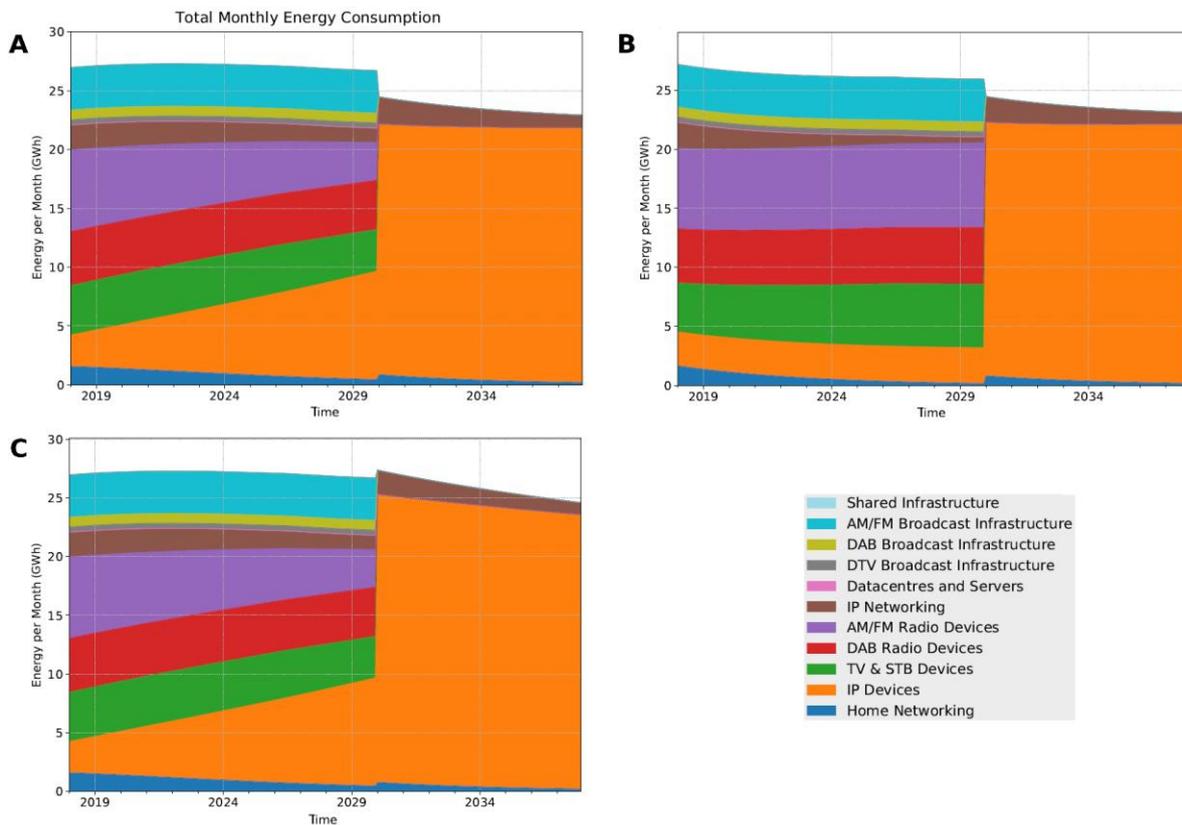


Figure 13: Comparative energy per month of BBC radio from 2018 to 2037 for Configurations A, B and C for Scenario 2

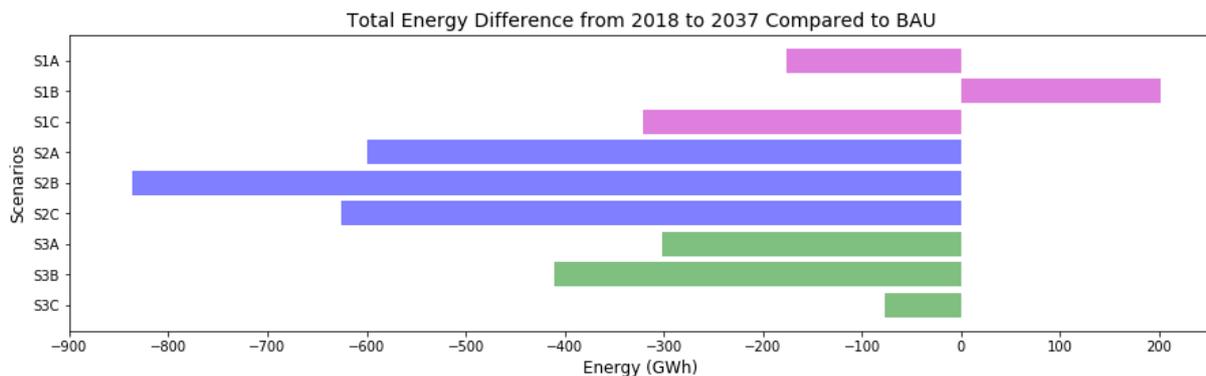


**Figure 12:** Comparative energy per month of BBC radio from 2018 to 2037 for Configurations A, B and C for Scenario 3

For Scenario 2, Figure 13 shows minor differences in energy consumption at switch-off. All configurations led to an energy reduction at 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, Figure 14 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 15 presents the total energy change relative to BAU across configurations and scenarios.



**Figure 13:** Estimated mean annual energy saving for each scenario configuration compared to BAU from switch-off

#### 4.4.2. Listening Hours

Table 4 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 0-3.

**Table 4:** Estimated energy difference across all scenarios if listening hours were to increase or decrease by 50% by 2038

	<b>Change in Total Energy (%)</b>
<b>Listening Hours (+50%)</b>	+7.3 to +9.2
<b>Listening Hours (-50%)</b>	-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 Section 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 5. Ranges represent the changes across Scenarios 0-3.

**Table 5:** Estimated energy difference across all scenarios if on and standby power of radio sets and smart speakers were adjusted by 50%

	<b>Change in Total Energy (%)</b>
<b>On Power (+50%)</b>	+5.9 to +6.7
<b>On Power (-50%)</b>	-6.1 to -5.3
<b>Standby Power (+50%)</b>	+20.7 to +23.1
<b>Standby Power (-50%)</b>	-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 completely switched off when not in use (i.e. the connection between the device and its power supply were removed).

Table 6 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 6:** Estimated energy difference across all scenarios if standby power of devices were set to zero from 2021

	Change in Total Energy (%)		
	Radio Devices & Smart Speakers	Radio Devices Only	Smart Speakers Only
<b>S0: BAU</b>	-36.2	-17.3	-18.9
<b>S1: Digital Only</b>	-36.5	-16.7	-19.8
<b>S2: DAB/IP Only</b>	-39.9	-18.4	-21.5
<b>S3: IP Only</b>	-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 2171 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, we 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<sub>2</sub>e 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<sub>2e</sub>, 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 (Section 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 national 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 national and 41 local, whereas MW covers four national and 31 local; DAB covers seven national and 38 local; and BBC Sounds covers six national and 40 local. Furthermore, satellite and cable broadcast platforms provide seven national and one local (only in London); and DTT provides seven national 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 DTT 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, national 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<sub>2e</sub> 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<sub>2e</sub> 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<sub>2e</sub>. 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<sub>2e</sub>, 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<sub>2e</sub> emissions per year a decade ago, although 74% of this was due to live performances. The remaining 0.14 MtCO<sub>2e</sub> 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 paper, we presented our approach to modelling the energy required to prepare, distribute and consume BBC radio services, both now and under a variety of future scenarios. We adopted the methodology from Schien *et al.* (2020) 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 our baseline results, we estimated the energy use in 2018 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 our 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. The BBC should use its position as a public service broadcaster to influence in these three domains.

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## Appendices

### Appendix A: 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 Appendix 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 Section 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  $23\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$
- **Acoustical environment:** acoustics such that the sound pressure level decreases with distance,  $r$ , from the sound source in accordance with  $1/r \pm 10\%$
- **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  $70\text{ dBA} \pm 10\%$  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  $230\text{ V} \pm 2\%$

Measurements were recorded in the Radio Device Power Use Data Sheet (as in Appendix 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

## Appendix B: Radio Devices

Table 7 presents the devices used to measure on and standby power consumption, as per Appendix A.

**Table 7** Radio devices used to measure power consumption

<b>ID</b>	<b>Radio Device</b>	<b>Year of Manufacture</b>
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

## Appendix C: 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						
<b>Test 1</b>	Temp (°C)		Voltage (V)		Watts (W)	
<b>Test 2</b>	Temp (°C)		Voltage (V)		Watts (W)	
<b>Test 3</b>	Temp (°C)		Voltage (V)		Watts (W)	

STANDBY Mode						
<b>Test 1</b>	Temp (°C)		Voltage (V)		Watts (W)	
<b>Test 2</b>	Temp (°C)		Voltage (V)		Watts (W)	
<b>Test 3</b>	Temp (°C)		Voltage (V)		Watts (W)	

ON Mode						
<b>Test 1</b>	Temp (°C)		Voltage (V)		Watts (W)	
<b>Test 2</b>	Temp (°C)		Voltage (V)		Watts (W)	
<b>Test 3</b>	Temp (°C)		Voltage (V)		Watts (W)	

OTHER COMMENTS						