Study Mission report on Energy Aware service Delivery and Consumption

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Foreword

DVB is an industry-led consortium of broadcasters, manufacturers, network operators, software developers, regulators and others from around the world committed to designing open, interoperable technical specifications for the global delivery of digital media and broadcast services. DVB specifications cover all aspects of digital television from transmission through interfacing, conditional access and interactivity for digital video, audio and data. DVB dominates the digital broadcasting environment with thousands of broadcast services around the world using DVB specifications. There are hundreds of manufacturers offering DVB-compliant equipment. To date, there are over 1 billion DVB receivers shipped worldwide.

Executive summary

For many years, the impact of information and communication technologies on the environment went relatively unnoticed. But the effects are consequential and gaining attention. DVB started a study mission on Energy-Aware service Delivery and Consumption (EADC) in September 2022 to address this topic. The objectives were to review and analyse how all relevant energy-related aspects can be taken into consideration in DVB systems. The group then identified the potential need for new or revised specifications.

The Study Mission produced this report giving an overview of what is done in the ecosystem, thanks to contributions from DVB Member delegates, exchanges with external entities or answers to a survey launched to seek more inputs from the industry. This allowed to generate a list of all ideas that could help to improve energy efficiency when using DVB technologies. This is only the beginning of the consideration of sustainability issues in the ecosystem, but it is now difficult to find a company or a SDO that is not actively engaged on this subject.

In the conclusion, it is recommended that DVB considers energy efficiency when developing new Commercial Requirements through a light touch process, using guidance and suggestions supported by reasoned argument. Proposed next steps could be to begin by taking into consideration the four identified use cases:

1. Common energy consumption measurement
2. Energy consumption exposure
3. Energy consumption as a criterion for video source or quality selection
4. Modernisation or introduction of more energy efficient technologies

Some use cases could be taken into consideration directly by existing working groups, for example in DVB-I, DVB-DASH or DVB-AVC, and other use cases will probably require the creation of a new working group, working specifically on energy efficiency as these use cases will imply transversal work between different groups - like CM-SEG for example.

In addition to these guiding principles, guidelines / whitepapers could help to support the sustainability strategies of DVB Members.

Introduction

It is widely recognised that global warming has an increasingly detrimental effect on our planet. It is reported by the United Nations [1] that the situation is sufficiently dire that urgent action is required to reduce our impact. One of the ways that this can be achieved is by looking for ways to reduce the energy footprint of everything we do. Everyone and every organisation potentially have a role to play.

Digital is not immaterial. It is made up of around 34 billion devices and other IT equipment, millions of kilometres of copper and fibre optic cables connected to 1.1 billion gateways, 10 million antennas, 67 million servers housed in data centres, and around 200 million other network devices. These devices are used by more than 4 billion people (i.e., over 55% of the world's population). According to estimates [2], the digital sector represents 2-4% of global greenhouse gas (GHG) emissions, far behind the transport, housing and food sectors which account for 70% of the total. However, these emissions are expected to grow at a rate of ~6% per year, mainly due to the improvement in the rate of digital access (mainly in Africa) and the increase in the number of devices. The worst of the impacts are mainly linked to device manufacturing (TVs, computer screens etc.), accounting for 79% in France, followed by data centers at 16% and networks at 5%, according to a 2022 study by ADEME and Arcep [3]. Nevertheless, this forecast should be carefully correlated with the major players commitments to reach carbon neutrality by 2050, in line with the Paris Agreement.

The urgency of climate change is pushing various standards organisations into considering their role in sustainability issues, and DVB has put itself on a similar path through the creation of a study mission on energy aware service delivery and consumption.

Contents

1. Scope

The objectives of the DVB Study Mission on Energy-aware service delivery and consumption are to review and analyze how all relevant energy-related aspects can be taken into consideration in DVB systems. A further objective is to identify the potential need for new or revised specifications to allow energy-efficient options during service delivery and consumption in delivery networks and home networks, including the impact of DVB specifications on IRDs and AV output systems.

The present document provides on overview of the work done by other groups and SDOs, summarizes feedbacks received from the industry and provide commercial use-cases, consider what is feasible today, and identify any gaps for future work.

2. References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, DVB cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[1] https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/

[2] https://joinup.ec.europa.eu/collection/rolling-plan-ict-standardisation/ict-environmental-impact-rp2023

[3] https://www.arcep.fr/uploads/tx_gspublication/etude-numerique-environnement-ademe-arcep-note-synthese_janv2022.pdf

[4] https://www.gsma.com/betterfuture/esg-metrics-for-mobile

[5] https://jac-initiative.com

[6] https://www.gsma.com/betterfuture/resources/strategy-paper-for-circular-economy-mobile-devices

3. Definitions and conventions

3.1. Terms

For the purposes of the present document, the following terms apply:

Carbon footprint	The CO_2 emissions associated with the life cycle of a product, process, or service. An organisation's carbon footprint involves the direct and indirect CO_2 emissions that it causes (see Scopes 1, 2 and 3 below).
Carbon offsetting	The compensation for carbon dioxide emissions arising from industrial or other human activity, by participating in schemes designed to make equivalent reductions of carbon dioxide in the atmosphere. See also Section 4.11.3.
CO_2e	Carbon dioxide equivalent. For any quantity and type of greenhouse gas, CO_2e signifies the amount of carbon dioxide which would have the equivalent global warming impact.
Digital Terrestrial Television	A technology for terrestrial television by which television stations broadcast digital content via radio waves to televisions in consumers' residences.

Eco-design	Eco-design considers environmental aspects at all stages of the product development process, striving for products which make the lowest possible environmental impact throughout the product life cycle.
Energy footprint	The energy associated with the life cycle of a product, process, or service.
Greenhouse Gas Protocol	A standard setting organization for measuring and managing emissions.
Life Cycle Analysis	A methodology for assessing the environmental impact associated with all stages of a product, process, or service.
Managed IPTV	A television service offered to viewers via a dedicated internet-based network.
Net Zero	Net zero means cutting greenhouse gas emissions to as close to zero as possible, with any remaining emissions re-absorbed from the atmosphere, by oceans and forests for instance (from: https://www.un.org/en/climatechange/net-zero-coalition).
Over-the-top media service	A media service offered to viewers directly via the internet.
Scope 1	Emissions from sources that an organization controls directly.
Scope 2	Indirect emissions from the production of purchased energy.
Scope 3	Other indirect emissions that occur in the value chain of an organization.
Streaming	A method of transmitting or receiving content over a computer network as a steady, continuous flow. This allows playback to start while the rest of the data is still being received.

3.2. Abbreviations

For the purposes of the present document, the following abbreviations apply:

3GPP	3rd Generation Partnership Project
ADSL	Asymmetric Digital Subscriber Line
ATSC	Advanced Television Systems Committee
CDN	Content Delivery Network
CMAF	Common Media Application Format
CO_2e	Carbon Dioxide Equivalent
CO_2	Carbon Dioxide
CPU	Central Processing Unit
CSRD	Corporate Sustainability Reporting Directive
CPE	Customer-Premises Equipment, Customer-Provided Equipment
DASH	Dynamic Adaptive Streaming over HTTP
DTT	Digital Terrestrial Television
DVB	Digital Video Broadcasting
DVB CM	DVB Commercial Module
DVB CM-SEG	DVB Commercial Module - Security Expert Group

DSL	Digital Subscriber Line
EEI	Energy Efficiency Index
EFRAG	European Financial Reporting Advisory Group
EMF	Electromagnetic Field
ESG	Environment, Social, and Governance
ESRS	European Sustainability Reporting Standards
ETSI	European Telecommunications Standards Institute
EVC	Essential Video Coding
FTTx	Fiber tot he (x), where (x) is variable, for example FTTN (Fiber to the node), FTTH (Fiber to the home), FTTP (Fiber to the premises)
GHG	Greenhouse Gas (Emissions)
GSMA	Global System for Mobile Communications Association
HDR	High Dynamic Range
HEVC	High Efficiency Video Coding
HTTP	HyperText Transfer Protocol
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IPR	Intellectual Property Rights
IPTV	Internet Protocol Television
ISO	International Organization for Standardization
ITU	International Telecommunications Union
JAC	Joint Audit Cooperation
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
MPEG	Moving Picture Experts Group
NFRD	Non-Financial Reporting Directive
OLED	Organic Light-Emitting Diode
OTT	Over-The-Top (streaming)
PVR	Personal(ized) Video Recorder
RAN	Radio Access Network
SDO	Standards Development Organizations
SDR	Standard Dynamic Range
SG	Study Group
STB	Set-Top Box

SVOD	Subscription-Based Video on Demand
UNFCCC	United Nations Framework Convention on Climate Change
VOD	Video on Demand
VVC	Versatile Video Coding
WP	Working Party

4. Work of other groups and SDOs

4.1. 3GPP

In 3GPP, energy efficiency has been studied in SA, SA5 and RAN. SA have studied system requirements and principles and provided an Energy Efficiency Control Framework. SA5 has specified concepts, use cases, requirements and solutions for energy efficiency assessment and optimization for energy saving, as well as Energy Efficiency (EE) KPIs. RAN EE study has concentrated on the definition of network energy consumption models, evaluation methodology and KPIs, also studied and identified techniques on the gNodeB (the 5G base station) and UE (User equipment) sides to improve network energy savings in terms of both Base Station transmission and reception.

Summary of existing 3GPP energy efficiency standards:

- SA (Service and System Aspects)
    - TR 21.866: Study on Energy Efficiency Aspects of 3GPP Standards - Identifies and studies the key issues and the potential solutions in defining Energy Efficiency Key Performance Indicators and the Energy Efficiency optimization operations in existing and future 3GPP networks.
- SA5 (Management, Orchestration and Charging)
    - TS28.310: Management and orchestration; Energy efficiency of 5G - Specifies concepts, use cases, requirements and solutions for the energy efficiency assessment and optimization for energy saving of 5G networks.
    - TS28.552: Management and orchestration; 5G performance measurements - Specifies the performance measurements for 5G networks including network slicing. Performance measurements for NG-RAN are defined in this document, and some L2 measurement definitions are inherited from TS 38.314. The performance measurements for 5GC are all defined in this document. Related KPIs associated with those measurements are defined in TS 28.554.
    - TS28.554: Management and orchestration; 5G end to end Key Performance Indicators (KPI) - Specifies end-to-end Key Performance Indicators (KPIs) for the 5G network and network slicing.
    - TS28.622: Telecommunication management; Generic Network Resource Model (NRM) Integration Reference Point (IRP); Information Service (IS) - Specifies the Generic network resource information that can be communicated for telecommunication network management purposes, including management data about energy efficiency.
    - TR28.813: Management and orchestration; Study on new aspects of Energy Efficiency (EE) for 5G. - Investigates the opportunities for defining new Energy Efficiency (EE) KPIs and new Energy Saving (ES) solutions.
- RAN1 (Radio Layer 1 - Physical Layer)
    - TR 38.864: Study on network energy savings for NR - Investigates network energy consumption modelling, techniques for network energy saving, evaluation of gains and impact.

4.2. Carbon Trust

The Carbon Trust is a consultancy founded by the UK government in 2001. Its mission is to accelerate the move to a decarbonised future and in this capacity, they support organisations globally in their efforts to move toward Net Zero. In the realm of streaming, they have worked with the DIMPACT group to produce a white paper entitled ‘Carbon impact of video streaming’ (June 2021, https://www.carbontrust.com/news-and-insights/news/updated-calculation-released-on-the-carbon-impact-of-online-video-streaming).

The paper studies the carbon impact of 1 hour of video streaming, notably on-demand streaming (as opposed to live streaming). Video streaming involves many components, which include data centres, content delivery networks (CDNs), internet network transmission, home routers, end-user viewing devices, and TV peripherals such as set-top boxes. It excludes the energy required to produce content, as well as the embodied emissions (those associated with producing the equipment used in the above components). Further, to map electricity use to carbon emissions, national electricity grid averages are used, thereby ignoring the use of renewable electricity which is currently frequently used.

The paper presents two methodologies for allocating network electricity to video streaming to arrive at a figure for how much energy is used during an hour of video streaming. The conventional method assumes that the energy used for transmission of content is linear in the amount of data. This gives rise to the concept of *network intensity*, which is measured in kWh/GB. This method is often used for accounting and reporting purposes, as it represents the average energy use.

The second method measures power rather than energy (noting that energy equals power times duration), and in this case a baseload power is defined per user, along with a marginal power component that is linear in the data volume transmitted. The baseload power is typically large relative to the marginal component. This method is suitable for assessing the instantaneous energy use in a network.

It is noted that neither method is suitable for assessing peak data usage, which is one of the elements that determines longer-term total energy consumption. With the introduction of new network equipment, less energy is consumed, and greater data volumes can be handled. The Carbon Trust paper asks what is driving this peak demand – whether it be demand for services that require higher data volumes or lower latency. Or is it the introduction of higher bandwidths itself that is driving new services that make use of this bandwidth?

Further, the estimation of the energy consumption and carbon footprint of video streaming is inherently subject to significant uncertainty and variation, leading to significant variability in the measurements. These are due to temporal, geographical and technological factors. The biggest source of variability is due to the electricity grid emission factor, i.e., the number that relates the production of energy to the production of CO_2. The second most significant source of variability stems from the viewing device used --- larger screens (televisions, for example) use many times more power than smaller screens such as those found in mobile phones. Uncertainty further arises due to the lack of available data. A final source of uncertainty comes from the estimates of the network intensity, which additionally tend to fall over time with the introduction of new equipment.

The main points made in this white paper are as follows:

- The main conclusions in this white paper are based on a standard power model, whereby internet transmission energy is assumed to be linear with respect to the amount of data transferred.
- An alternative power model is also explored, whereby the linear model is augmented with an offset. This model accounts for the fact that many devices use energy whether in use or not.
- In Europe in 2020, on average an hour of video streaming incurs a carbon footprint of 55 g CO_2e.
- For large televisions, the viewing device is typically responsible for more than 50% of the overall carbon footprint.
- Smaller displays use much less energy than large displays. Watching on a 50 inch display has a carbon footprint about 4.5 times that of watching on a laptop, and 90 times that of watching on a smart phone. When a streamed video is watched on a smartphone, the network consumes a relatively large proportion of the total required energy.
- Displays are becoming more efficient over time due to a combination of technology advances, regulation and standards.
- User devices drive the impact of video streaming (displays, laptops, set-top boxes, home routers, etc.), in Europe representing around 89% of emissions impact per hour of video streaming.
- Changes in video quality, notably viewing resolutions and settings affecting the bitrate have a relatively small impact on carbon emissions. This pertains to the marginal gain in the power model, and for wireless networks. In mobile networks the gain is proportionally higher.

4.3. Carnstone

Carnstone is a consultancy firm who has produced the LoCaT report documented elsewhere in this study mission report. They are also the conveners of the DIMPACT group. Relatively recently, they have produced a report in association with Ofcom (the United Kingdom's communications regulator) entitled "Carbon emissions of streaming and digital terrestrial television", as reviewed in this section. It uses data from the UK only, but follows the attributional life cycle analysis (LCA) approach used in other studies (notably BBC White Paper 372 and the LoCaT study). The two functional units considered are the energy consumption per device hour (measured in Wh/h) and the total annual energy consumption attributed to all device hours of DTT and OTT in the UK. Likewise, the study reports greenhouse gas emissions. A diagram of DTT and OTT components studied in this white paper is given in Figure 1.

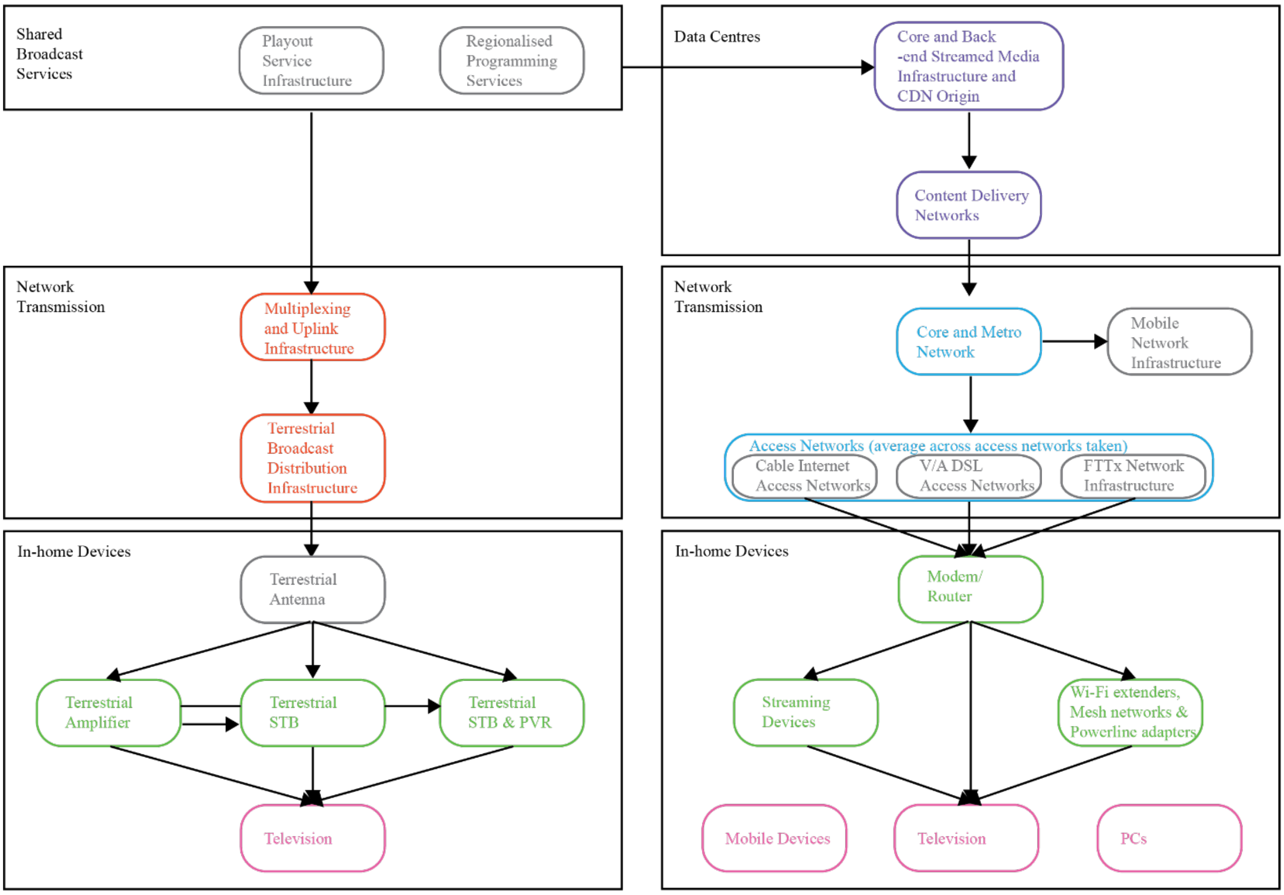


Figure 1. DTT and OTT components considered in the Carnstone study. Energy usage of grey components are out of scope. DTT components are shown on the left, while OTT components are shown on the right.

Excluded from the study are several aspects of video transmission, including:

- the production of content;
- the embodied and end-of-life emissions (i.e. only the use phase of a product's life cycle is considered);
- enabling effects of television viewing (the opportunities of a service to avoid energy use elsewhere – for example streaming a video may stop someone to drive to a shop to buy a DVD);
- procurement of renewable energy;
- mobile network transmission.

Given that this study focusses on TV-like content, any other video (for example Youtube, DVDs, games consoles) were excluded as well.

The number of device hours for DTT viewing in the UK was estimated to be 27,674 million hours (per year). For OTT the number of viewing hours is estimated at 19,594 million hours (per year). This translates to 4.7 device hours per day for DTT and 2.3 device hours per day for OTT. For OTT viewing, 75% occurred on a television, whereas the rest was on other types of devices.

The energy consumption for DTT is estimated at 9.1 Wh/h excluding the viewing device, and 54 Wh/h for OTT. When the viewing device is included, the energy consumption becomes 76 Wh/h for DTT and 113 Wh/h for OTT.

DTT energy consumption can be broken down into 2.6 Wh/h for datacenters, 3.1 Wh/h for customer premises equipment (CPE), 3.5 Wh/h for peripherals and 67 Wh/h for viewing devices.

OTT energy consumption is broken down into 12 Wh/h for network transmission, 21 Wh/h for CPE, 21 Wh/h for peripherals and 58 Wh/h for viewing devices.

The total annual energy consumption in the UK is 252 GWh for DTT and 1064 GWh for OTT when viewing devices are excluded. When viewing devices are taken into account, DTT costs 2109 GWh per year (27,674 million device hours) and OTT takes 2208 GWh per year (19,594 million device hours).

The results presented in this study are in line with other studies, including the LoCaT and BBC studies, Uncertainty remains in the estimation of OTT energy requirements, as the network intensity metric (the energy needed to transmit a unit of data) is a global figure based on academic studies.

4.4. Greenhouse Gas Protocol

The Greenhouse Gas Protocol has defined standards for reporting emissions associated with the activities of companies. Notably, these include Scope 1, 2 and 3 reporting:

- **Scope 1.** These are the direct emissions from resources owned and controlled by the reporting company.
- **Scope 2.** These are indirect emissions related to the purchase of energy, steam, heat, and cooling.
- **Scope 3.** These are indirect emissions – not included in Scope 2 – that occur in the reporting company's value chain, both upstream and downstream.

While Scope 1 and 2 emissions are relatively straightforward to measure, Scope 3 emissions are much more difficult to assess. The Greenhouse Gas Protocol separates Scope 3 emissions into 15 separate categories, spread over upstream and downstream activities. The upstream categories are (1) purchased goods & services, (2) capital goods, (3) fuel & energy related (not in Scope 1 or 2), (4) upstream transportation & distribution, (5) waste from operators, (6) business travel, (7) employee commuting, (8) upstream leased assets. The downstream categories are (9) downstream transportation & distribution, (10) processing of sold products, (11) use of sold products, (12) end-of-life treatment of sold products, (13) downstream leased assets, (14) franchises, and (15) investments.

For media companies, category 11, use of sold products, is relevant. The category description is "End use of goods and services sold by the reporting company in the reporting year". At a minimum this includes:

> "*The direct use-phase emissions of sold products over their expected lifetime (i.e., the scope 1 and scope 2 emissions of end users that occur from the use of: products that directly consume energy (fuels or electricity) during use; fuels and feedstocks; and GHGs and products that contain or form GHGs that are emitted during use).* ***Optional****: The indirect use-phase emissions of sold products over their expected lifetime (i.e., emissions from the use of products that indirectly consume energy (fuels or electricity) during use)*"

4.5. DIMPACT

DIMPACT is an initiative of several media and technology companies to understand the environmental impact of digital media and entertainment. At the heart of DIMPACT are Carnstone and the University of Bristol. The aim is to help participants in the initiative achieve the following goals:

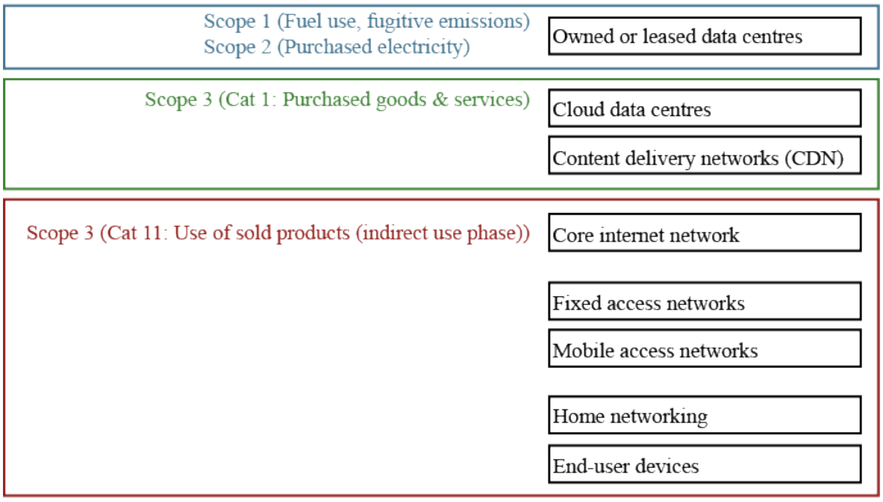
- Estimate GHG emissions associated with digital media and entertainment products. DIMPACT has developed a methodology for achieving this goal, as described below.
- Respond to the data needs of customers, policy makers and other stakeholders. Media companies are increasingly being asked about their environmental footprint, but data is either scarce, inaccurate, or changing over time. In addition, DIMPACT's modelling may help with enhanced Scope 3 (indirect emissions) reporting.
- Disseminate information.
- Promote transparency and collaboration to enable rapid decarbonisation.

DIMPACT has developed a methodology for measuring emissions incurred along the transmission chain, and they make available a web-based tool for participants to evaluate their product-level emissions.

There are currently two reports available on their website dimpact.org, one describing their methodology, and one presenting a literature review.

In terms of Scope 3 reporting, DIMPACT considers categories 1 (Purchased goods and services) and 11 (Use of products sold) of relevance. Most DIMPACT participants do not sell the devices that are used to view their content. This means that the emissions caused by end user devices (televisions set-top boxes, home networking equipment) are considered Scope 3 indirect use-phase emissions. Reporting these emissions are currently considered optional by the Greenhouse Gas Protocol, as well as by the Science-Based Targets Initiative.

The DIMPACT scope therefore goes beyond the minimum requirements in terms of accounting and target setting. A typical media company's processes are mapped to Scopes 1, 2 and 3 as follows:



Modelling of energy consumption in transmission systems can be performed for at least two different reasons, one being reporting, and the other being causal modelling to understand how a change in the system would lead to a change in energy consumption. The DIMPACT methodology uses an attributional life-cycle assessment method to attribute the energy spent to the different processes involved. This approach is effective for reporting, but it cannot be used for optimizing a system's energetic performance. DIMPACT is currently considering how a causal assessment methodology may be implemented.

Further, due to the rapid evolution of the digital sector, there remain open questions around energy and carbon emission trends. Due to the complexity of the industry and lack of predictive models, DIMPACT argues that it is difficult to know the impact of specific actions applied to any part of the industry. To improve this situation, DIMPACT offers several policy principles:

1. Expand access to shared and recent data
    a. Enable standardised data sharing across the digital sector
    b. Use recent data (less than 1-2 years old) to inform future decisions
2. Use appropriate modelling for decision making
    a. Additional research on demand-response (peak vs. off-peak internet use)
    b. Modelling of changes to the digital sector's energy use
3. Create energy efficiency incentives
    a. Promote energy-efficient devices and infrastructure
    b. Incentivise efficient device and infrastructure use
4. Prioritise broad availability of low carbon and renewable energy
    a. Investments in low-carbon and renewable energy infrastructure
    b. Enable low-cost renewable energy for at-home usage.

4.6. ETSI

In ETSI, existing specifications cover several aspects of energy efficiency, which include energy efficiency metrics and measurement methods for mobile core equipment, metrics and methods to measure energy performance of Mobile Radio Access Networks, measurement and monitoring of power, energy and environmental parameters for ICT equipment in telecommunications.

<u>Summary of existing ETSI energy efficiency standards:</u>

- TC EE (Technical Committee Environmental Engineering)
    - ETSI ES 203 228: "Environmental Engineering (EE); Assessment of mobile network energy efficiency" - Defines the topology and level of analysis to assess the energy efficiency of mobile networks (excluding terminal).
    - ETSI ES 202 336-1: "Environmental Engineering (EE); Monitoring and Control Interface for Infrastructure Equipment (Power, Cooling and Building Environment Systems used in Telecommunication Networks) Part 1: Generic Interface" - Defines monitoring and control of Infrastructure Environment i.e. power, cooling and building environment systems for telecommunication centres and access network locations.

- ETSI ES 202 336-12: "Environmental Engineering (EE); Monitoring and control interface for infrastructure equipment (power, cooling and building environment systems used in telecommunication networks); Part 12: ICT equipment power, energy and environmental parameters monitoring information model" - Defines measurement and monitoring of power, energy and environmental parameters for ICT equipment in telecommunications or datacenter or customer premises.

4.7. European Non-Financial Reporting Requirements

Currently, the European Union has defined reporting requirements around sustainability in the Non-Financial Reporting Directive (NFRD), which was adopted in 2014. This directive covers around 11.000 large European companies that are required to report on various non-financial aspects of their operation, including environmental issues.

This directive, however, is going to be replaced by a new directive entitled Corporate Sustainability Reporting Directive (CSRD), which will require around 50.000 European companies to report their impact on the environment, including Scope 1, 2 and 3 emissions. The associated European Sustainability Reporting Standards (ESRS) are developed by EFRAG. The CSRD will be phased in between 2024 and 2028.

4.8. Green Metadata Standard (Green MPEG)

The MPEG green metadata standard (ISO/IEC 23001-11:2023; also known as Green MPEG), contains several components which aim to help reduce the power consumption of transmission and display systems. They all involve the transmission of metadata, which the receiver can use to optimise its power consumption. Currently, the standard has five components, which are briefly described in the following sections. They target mainly streaming and peer-to-peer conferencing applications. The standard is applicable to a variety of codecs, including HEVC and VVC.

4.8.1. Complexity Metrics for Decoder Power Reduction

This component is based on the observation that a processor (CPU) can be directed to run faster or slower dependent on its workload. This works by adjusting its clock frequency. The idea here is a video decoding process will require a certain number of operations to decode a frame. A powerful processor would be able to do this in less time than the time the frame will be displayed. In such a case, the clock speed of the processor can be reduced such that the decoding takes just under the display time of a frame. A lower clock speed means less power consumption.

To know, however, how many operations are needed for the decoding step, some estimate of the decoding process is required. This depends on how the frame was encoded, and this is therefore information that is typically known during encoding of the frame. The encoder can therefore supply, through metadata, sufficient information for the decoder to adjust its clock speed so that the frame is decoded just in time prior to display.

The encoder can estimate frame complexity through “bit stream features” such as the number and size of blocks, the number of intra predictions, the number of nonzero coefficients, etc. To this end the encoder will count the number of times a given feature occurs. The set of frequencies of occurrence is then transmitted as metadata. The decoder receiving this metadata can then estimate the complexity by weighting each frequency of occurrence by the feature-specific complexity, before summing over all features. The resulting complexity is then used to drive the processor’s speed through a process called dynamic voltage and frequency scaling.

4.8.2. Interactive Signalling for Remote Decoder-Power Reduction

A second component allows the receiver of the video stream to make requests to the sender to set certain encoding parameters in such a way as to optimise the decoding process as supported by the receiver. This component is intended to be used in real-time encoding scenarios (for example video conferencing). In this case, three types of encoding parameter can be requested: a change in decoder operations, enabling/disabling certain coding tools, and setting certain video parameters. The amount of energy reduction that can be saved depends on the processor on which the decoding is performed, as well as on the specific decoder implementation.

4.8.3. Display Power Reduction using Display Adaptation

The third component addresses the power consumption of the display itself. This is achieved by reducing the luminance in each frame, either by scaling or by clipping. Currently the metadata is designed to inform televisions with backlit displays, to drive a process known as backlight scaling. The latter is a method of reducing the amount of light emitted by the backlight, while increasing the transparency of each pixel to compensate as much as possible. Large reductions in backlight luminance cannot be fully compensated by changing pixel transparency, and may therefore lead to a loss of quality.

4.8.4. Energy Efficient Media Selection

Certain streaming methods, such as MPEG-DASH, make available the same content in a variety of different quality settings. This is normally intended to adapt the bitrate to the available bandwidth. However, this mechanism can be used to request a content that enables (display) power savings.

4.8.5. Metrics for Quality Recovery after Low-Power Encoding

Finally, there is provision for the transmission of quality metrics. These metrics can be used to enhance the visual quality of content on the display side, after transmission, using a low-power encoding.

4.8.6. Future Developments

Currently scheduled for inclusion into the standard is support for EVC in complexity metric signalling. Support for OLED displays is also forthcoming. There is also work ongoing around the reduction of display energy in the context of streaming applications, which involves transmitting maps as metadata which can be used to reduce individual pixel values by amounts that incur less display energy while controlling visual quality.

4.9. Greening of Streaming

Greening of Streaming is a User Group. They have no intent to create IPR or standards. They do hope to produce recommendations and best practices, but these will not be Standards.

Concerned with the energetic impact of streaming, *Greening of Streaming* describes itself as follows:

> *Greening of Streaming is an organisation with international reach, created to address growing concerns about the energy impact of the streaming sector. We provide a forum for the Global Internet Streaming industry to develop better engineering and to foster collaboration through the supply chain as we create a great experience for the consumer without wasting energy. The world has become increasingly reliant on streaming services for business, entertainment and social interactions. For streaming to continue to change the world for the better, it needs to focus on best practices around energy consumption. Greening of Streaming is a members association that brings the industry together to help create joined up thinking around end to end energy efficiency in the technical supply chain underpinning streaming services. We are working to provide better real-world data to understand energy use relating to streaming, and then to engineer better and to develop and share best practice through the industry community.*

The activities of Greening of Streaming are organised into nine work packages, as follows:

1. Lexicon
2. Outreach
3. Best Practice
4. Events and Energy Measurement
5. Audio Streaming
6. Compression / Decompression
7. KPI and Capacity Planning
8. Enterprise Streaming
9. Academia and Industry Group Liaison

In terms of energy measurements on transmission systems, they find, like others, that the baseload incurred by servers relates to capacity rather than throughput.

A key aspect of the organisation's proposal is that power use should be a key performance indicator along with performance and price. They explore the question as to what would be a 'good enough' default service level in real-world scenarios. They introduced the concept of a 'gold button' scenario, whereby a default streaming profile would be energy-optimised, rather than quality optimised without consideration for energy use.

4.10. GSMA (Global System for Mobile communications Alliance)

Telcos are responsible for 1.6% of total global CO2 emissions and are therefore stepping up initiatives to limit their environmental impact. The GSMA mobile operator alliance has been working on climate issues since COP21, which was held in Paris in 2015. It started by encouraging each operator to set targets to reduce carbon emissions, and then reported a combined goal of achieving Net Zero Carbon emissions by 2050.

To reduce greenhouse gas emissions effectively, it's essential to know how to measure them and share measurement methods. All operators agree on measuring the carbon footprint of direct emissions (coming from operator itself, such as network efficiency). Each operator is free to implement their own modelling standards, but joint actions are carried out, such as standardizing 5G's default sleep mode. In addition, a common methodology is under discussion within the GSMA to measure all indirect CO2 emissions throughout the value chain, upstream by suppliers and downstream by customers.

In the same vein, the GSMA also defines common KPIs (key performance indicators) in terms of ESG (environment, social, and governance) [4]. These indicators make it easier to report and consolidate operators' results on important issues such as digital inclusion, recycling, waste reduction, and working conditions. This is complementary to the JAC's approach (Joint Audit Co-operation for CSR [5]), an association of 25 fixed and mobile operators which, since 2010, has been auditing device and equipment manufacturers on the basis of ESG criteria.

The circular economy is also a key subject for the telecoms industry because the greatest environmental impact comes from mobile device and network equipment manufacturing. Driven in part by market expectations, a new model is emerging around eco-design. The aim is to design more sustainable products that incorporate recycled materials, extend the product lifecycle, improve waste sorting and recycling, promote responsible equipment consumption, and raise awareness among consumers. In November 2022, the GSMA published a white paper offering further device recommendations to operators [6].

4.11. ITU-R SG 6 (broadcasting)

ITU-R Study Group 6, entitled *Broadcasting Service*, is concerned with radiocommunication broadcasting, which includes vision, sound, multimedia and data services. It is principally intended for delivery to the general public. The study group has three working parties (WPs) that deal with terrestrial broadcasting delivery (WP 6A), broadcast service assembly and access (WP 6B), and programme production and quality assessment (WP 6C) respectively. The following subsections outline the activities.

4.11.1. ITU-R Question 147/6

In May 2022, ITU-R has approved question 147/6, entitled *Energy Aware Broadcasting Systems*. This document brings into the remit of ITU-R Study Group 6 the following questions which it directs to be studied:

- What direct impact do the technologies and features used for broadcasting have on energy consumption?
- What indirect impact does the use of external services used for broadcasting have on overall energy consumption?
- What metrics should be used to quantify and report both the direct and indirect impact on energy consumption?
- How can broadcasting be made more energy efficient in order to contribute to the pertinent United Nations' Sustainable Development Goals?

This document forms the basis for emerging and ongoing work on energy-aware broadcast systems. It has led to the creation of a rapporteur group on energy-aware broadcasting, which is discussed in the following subsection.

4.11.2. ITU-R WP 6C RG-EAB rapporteur group on energy-aware broadcasting

Within Working Party 6C on programme production and quality assessment, a rapporteur group on energy-aware broadcasting has been established to coordinate activities in this area. This has so far led to an opinion document and a webinar.

4.11.3. ITU-R Opinion 104: Advice for sustainability strategies incorporating carbon offsetting policies

Carbon Offsetting projects are often considered for the purpose of cancelling out carbon dioxide emissions. Such projects are investment-based. Organisations use them to move toward a net-zero position, often by a given date. However, the role of carbon offsetting is often misunderstood. A sustainable strategy would be to reduce emissions as much as possible *before* considering carbon offsetting. It should therefore not be the first (and only) step in a net-zero strategy, but it should only be considered to offset processes for which emissions cannot be reduced further.

The broadcasting, entertainment and media related industries contribute to climate change through the use of large quantities of power, including for the production of content, and its transmission and final consumption. These industries should be encouraged to reduce the demand for power, source power from non-carbon producing technologies, and deploy energy-efficient options available locally first, and only consider carbon offsetting once all other ways to reduce the carbon footprint have been exhausted.

To this end, ITU-R has produced the following opinion:

> ITU Radiocommunication Study Group 6 (…) is of the opinion that broadcasters and broadcasting related organizations world-wide should have robust sustainability strategies in place[1] that move towards net zero and encourage the implementation of robust energy efficiency schemes that reduce energy consumption *before* considering carbon offsetting protocols as a last resort.

4.11.4. Webinar on energy aware broadcasting

ITU-R Working Party 6C has held a webinar, a recording of which is available online at the following address: https://www.itu.int/en/ITU-R/seminars/Pages/Webinar-on-Energy-Aware-Broadcasting.aspx . Three speakers presented various aspects of energy use in broadcasting:

- Roser Canela Mas (Bafta) presented *albert*, an organisation that helps the film and TV world calculate the emission of CO_2 of content productions. It also includes a certification mechanism.
- Jens Malmodin (Ericsson) presented his latest research on measuring the energy and carbon footprints of broadcasting and streaming.
- Birgit Gabriel (ARTE) presented the efforts ARTE, a German-French broadcaster, has gone through to reduce their energy use.

Based on this webinar, ITU-R has produced a report which is currently published and available as ITU-R Report BT.2521, 'Practical examples of actions to realize energy aware broadcasting'.

4.12. ITU-T Study Group 5 (environment and circular economy)

The full name of ITU-T Study Group 5 is "Electromagnetic fields (EMF), environment, climate action, sustainable digitalization, and circular economy". It is concerned with the development of standards on the environmental aspects of ICT and digital technologies, as well as protection of the environment. This includes electromagnetic phenomena and climate change. This study group develops international standards, guidelines, technical papers and assessment frameworks that support the sustainable use and deployment of ICT and digital technologies, and to evaluate their environmental impact. Particularly relevant for DVB is the L-series of documents, which deal with "environment and ICTs, climate change, e-waste, energy efficiency, construction, installation and protection of cables and other elements of outside plant". Within this series, the documents in the range L.1300 to L.1399 are of interest, as they are on energy efficiency, smart energy and green datacentres. Some specific documents worthy of note are (this is a non-exhaustive list – the reader is encouraged to visit https://www.itu.int/ITU-T/recommendations/index_sg.aspx?sg=05):

- L.1300: Best practices for green datacentres
- L.1302: Assessment of energy efficiency on infrastructure in data centres and telecom centres
- L.1310: Energy efficiency metrics and measurement methods for telecommunication equipment
- L.1315: Standardization terms and trends in energy efficiency
- L.1325: Green ICT solutions for telecom network facilities
- L.1332: Total network infrastructure energy efficiency metrics
- L.1333: Carbon data intensity for network energy performance monitoring

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1 The Paris Agreement encourages nations to move to net zero as soon as possible.

- L.1340: Informative values on the energy efficiency of telecommunication equipment
- L.1350: Energy efficiency metrics of a base station site
- L.1351: Energy efficiency measurement methodology for base station sites
- L.1360: Energy control for the software-defined networking architecture
- L.1361: Measurement method for energy efficiency of network functions virtualization
- L.1362: Interface for power management in network function virtualization environments – Green abstraction Layer version 2

The document range L.1400 to L.1499 is about assessment methodologies of ICTs and CO_2 trajectories. Example documents are:

- L.1400: Overview and general principles of methodologies for assessing the environmental impact of information and communication technologies
- L.1420: Methodology for energy consumption and greenhouse gas emissions impact assessment of information and communication technologies in organizations
- L.1450: Methodologies for the assessment of the environmental impact of the information and communication technology sector
- L.1470: Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement
- L.1471: Guidance and criteria for information and communication technology organizations on setting Net Zero targets and strategies

4.13. LoCaT Study

The Low Carbon TV Delivery project (LoCaT) is a collaborative initiative from several European organisations active in TV and Broadcast (Association Technique des Editeurs de la TNT (ATET), Broadcast Networks Europe (BNE), the ORS Group, Quadrille and Salto). It has commissioned Carnstone, a management consultancy firm specialized in sustainability and corporate responsibility, to study greenhouse gas emissions associated with different TV delivery methods. These methods include digital terrestrial television (DTT), managed IPTV, and streaming and on-demand viewing delivered via the internet (over-the-top (OTT) services). The study focusses on data available for Europe. As this work is about the delivery of content via fixed line networks, viewing devices are not included in the analysis, although other home user devices such as set-top boxes are included as they form part of the delivery infrastructure. The production of content was also excluded.

4.13.1. Infrastructure for Tested Delivery Methods

The LoCaT study has assessed the carbon footprints of DTT, OTT and managed IPTV services. The infrastructure considered for DTT broadcasting is shown in Figure 2. As can be seen, terrestrial broadcast infrastructure and in-home devices are included, whereas shared broadcast services are not considered. In-home viewing device are considered out-of-scope as well. The home caching device is considered in some future scenarios only.

The assumed OTT delivery structure is shown in Figure 3. Here, datacentres are included as is the internet infrastructure. Note that the average is taken over the different types of access networks. The television as well as any mobile devices/infrastructure are excluded.

Finally, the IPTV infrastructure is shown in Figure 4. Here, multi-cast servers and datacentres are included, as well as the internet infrastructure. Once again, the average is taken over the different types of access networks. Among the in-home devices, the television is excluded.

4.13.2. LoCaT study: observations and comments

The study has focussed on emissions generated in several European countries. The countries were selected based on availability of data, and on variability between countries (prevalent delivery methods, topography, population, viewing behaviour, geographical region, size), ensuring that the data and modelling is appropriate for different scenarios.

While the study did not consider the energy consumed by televisions, it did only consider viewing hour incurred on television sets, notably excluding viewing that occurred on smartphones, tablet and PCs. It also excluded any viewing that takes place using mobile networks, focussing instead on fixed line networks.

The energy consumption per device viewing hour in Europe is estimated to be 14 Wh for DTT, 109 Wh for OTT and 153 Wh for IPTV. If this content were watched on a 56 W television (the example given by LoCaT), then this energy consumption becomes 70 Wh for DTT, 165 Wh for OTT and 208 Wh for IPTV. There are, however, significant differences between the countries examined. This is due to differences in viewership (lower DTT penetration, for example, means higher overall energy consumption), the use of peripherals (PVRs and STBs) and the data volumes realised for OTT and IPTV. As a consequence, the energy consumption varies by country as shown in Table 1.

Table 1. Energy consumption per device hour in Wh, excluding television sets

Country	DTT	OTT	Managed IPTV
UK	18	72	94
France	8	76	111
Austria	54	129	176
Sweden	31	109	134
Europe (All)	14	109	153

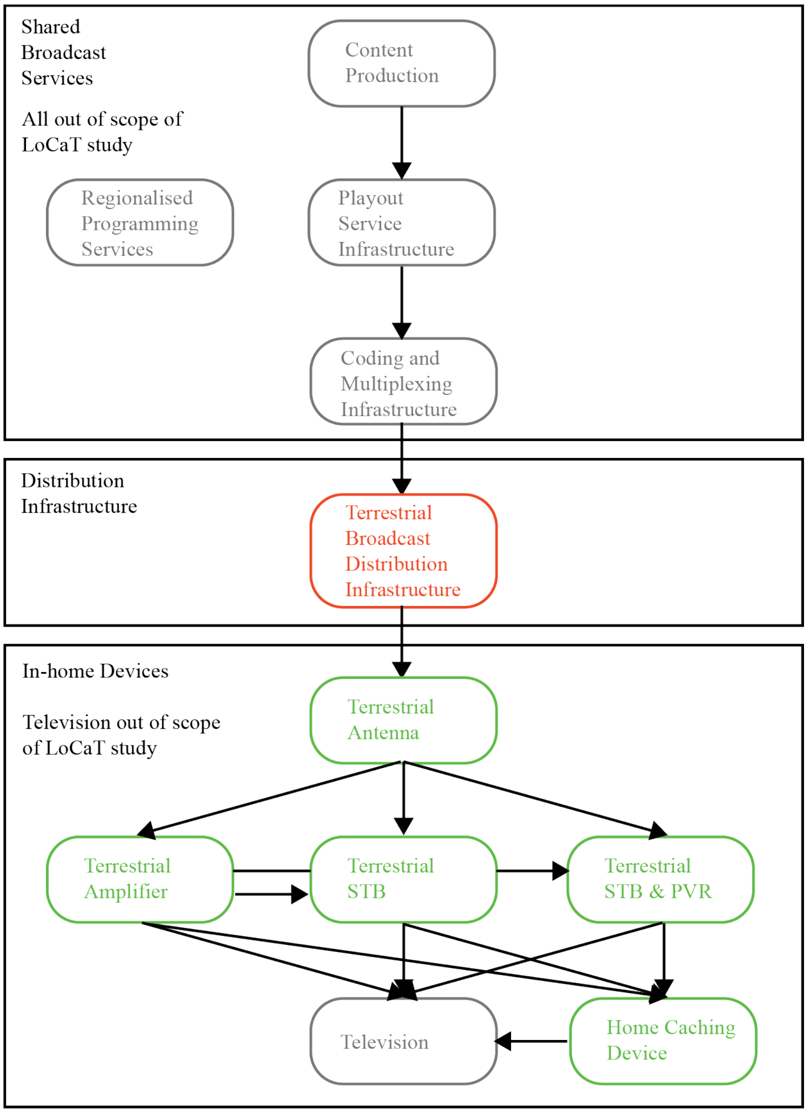


Figure 2. DTT infrastructure considered in LoCaT study. Grey boxes are considered out-of-scope.

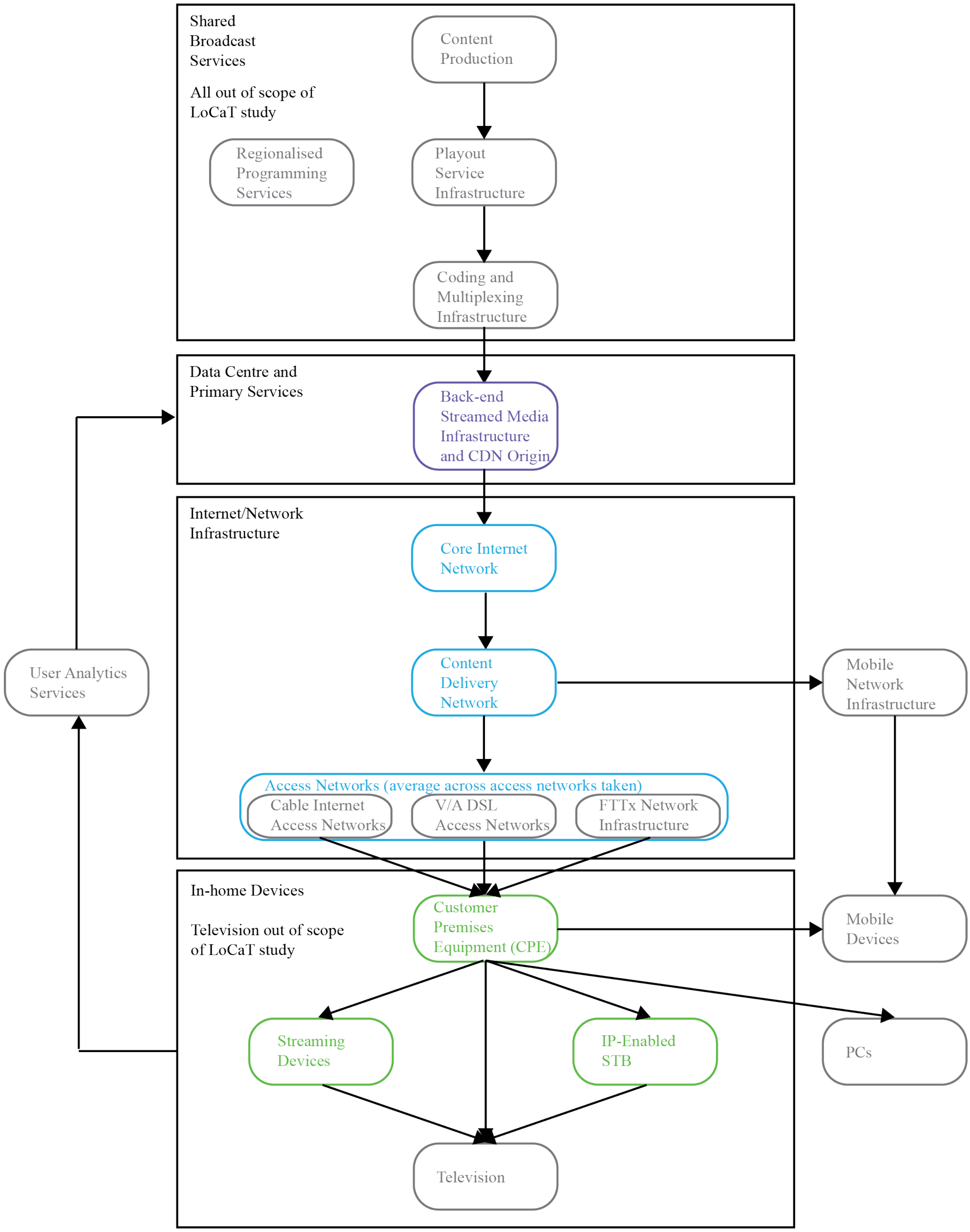


Figure 3. OTT delivery infrastructure as considered by the LoCaT study. Grey boxes are deemed out-of-scope for this study.

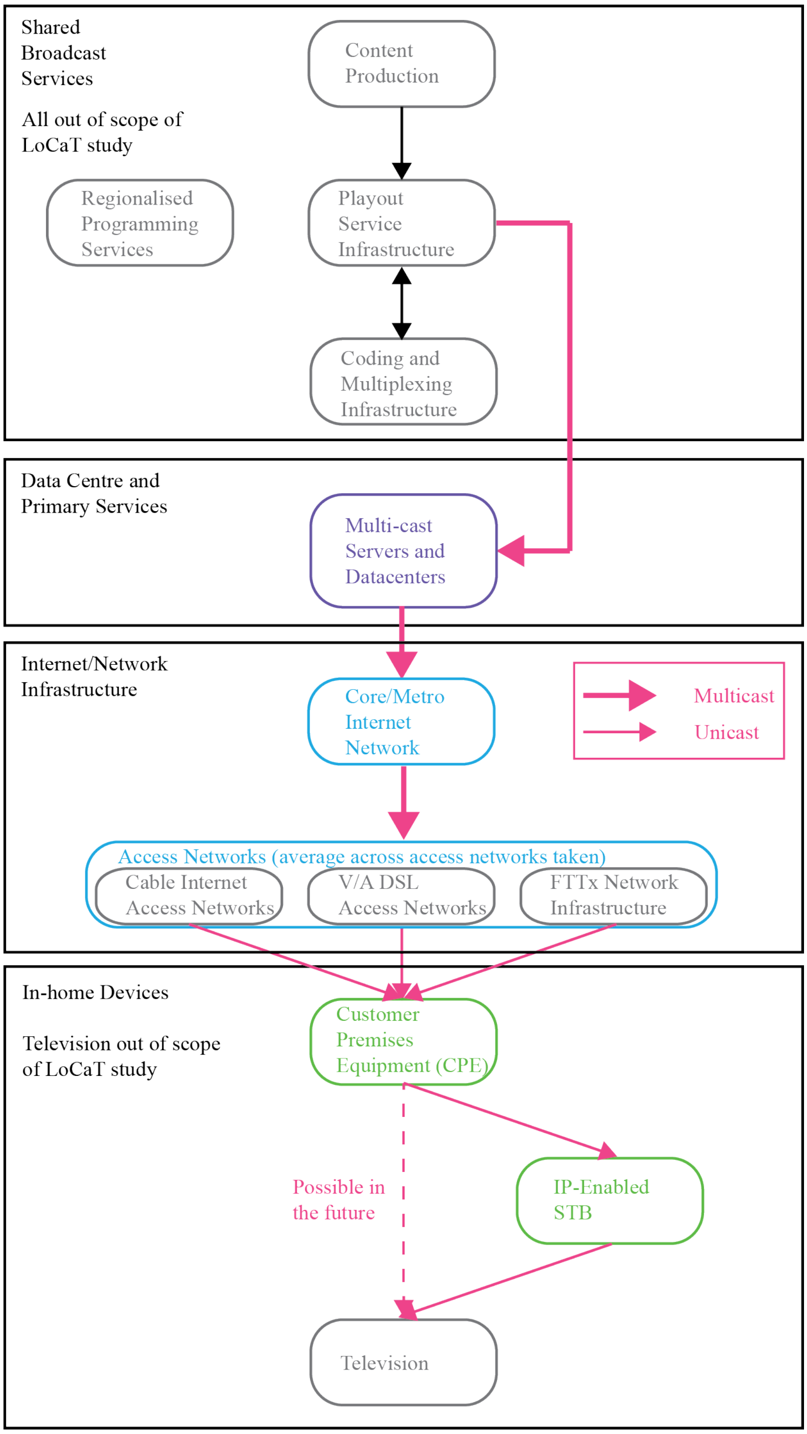


Figure 4. The network infrastructure assumed for IPTV delivery by the LoCaT study. Grey boxes are out-of-scope of their study.

For DTT, the different components involved incur the following cost in terms of energy per device hour: broadcast infrastructure 7.6 Wh, terrestrial aerial amplifier 2.9 Wh, and terrestrial STB 3.3 Wh,

For OTT, the split per component is as follows: cloud plus CDN 1.5 Wh, core network 7.3 Wh, access network plus CPE 80 Wh, peripherals 20.4 Wh.

Finally, for managed IPTV, the split per component is as follows: cloud plus CDN 1.3 Wh, core network 0.0 Wh, access network plus CPE 125.7 Wh, peripherals 25.7 Wh.

4.13.3. Main Outcomes

The main points made in the LoCaT study are as follows:

- OTT streaming and managed IPTV incur higher energy consumption relative to DTT delivery. For an hour of viewing on a single device, the European averages were 14 Wh for DTT, 109 Wh for OTT and 153 Wh for managed IPTV.
- The majority of energy used when watching television is incurred by user devices, independent of delivery method. For DTT delivery, often a passive aerial is connected directly to the television, leading to the smallest energy footprint for end user devices implicated in content delivery, relative to IPTV and OTT services.
- Linear viewing is in decline, but still makes up the largest proportion of viewing (95% in 2015; 90% in 2019). Linear viewing consumes less energy, and assuming that the decline in linear viewing is compensated by non-linear viewing, this means that the total energy consumed for content delivery is going up.
- Linear viewing via IPTV uses multicast technology, which reduces data transmission in the core network. Its associated energy efficiency, however, does not compensate for the energy consumed by IPTV set-top boxes. This is why IPTV viewing is more energy intensive than DTT viewing.
- The complexity of the systems under study, combined with the lack of primary data, brings significant uncertainty. This means that extrapolating energy consumption into the future is especially difficult.

The report speculates that non-IP delivery methods may help in driving down peak demand of IP-based delivery methods, noting that peak demand has a strong impact on overall energy consumption.

5. Regulators

5.1. European Commission

5.1.1. EU Regulation 2019/2021: Ecodesign requirements for electronic displays

The European Commission has a regulation in force that defines ecodesign requirements for electronic displays. It is based on energy efficiency index limits for power-on mode viewing. The energy efficiency index is defined as:

$$EEI = \frac{P_{\text{measured}} + 1}{(3\ (90 \tanh(0.02 + 0.004(A - 11) + 4)) + 3) + 3}$$

In this equation, the following parameters are used: A is the viewing surface area in dm^2, P_{measured} is the measured power in power-on mode in Watts in the normal configuration, in standard dynamic range (SDR). The limits for power-on mode are as follows:

	$EEI_{\max}$ for electronic displays with up to 2,138,400 pixels (HD resolution)	$EEI_{\max}$ for electronic displays with more than 2,138,400 pixels and less than 8,294,400 pixels (UHD-4K)	$EEI_{\max}$ for electronic displays with more than 8,294,400 pixels (UHD-4K), and for MicroLED displays
1 March 2021	0.90	1.10	n.a.
1 March 2023	0.75	0.90	0.90

A 10% reduction is available for displays implementing automatic brightness control.

Separate power limits apply to electronic displays in power-off mode, standby mode and networked standby mode.

5.1.2. EU Regulation 2019/2013: Energy labelling

The European Commission has created a regulation on energy labelling of electronic displays (Commission Delegated Regulation (EU) 2019/2013), dating from 11 March 2019. It supplements regulation (EU) 2017/1369. This regulation defines 7 energy classes (A to F), which depend on an energy efficiency index. This index is calculated as follows (noting that it is slightly different from the energy efficiency index defined in (EU) 2019/2021):

$$EEI_{\text{label}} = \frac{P_{\text{measured}} + 1}{(3\ (90\tanh(0.025 + 0.0035(A - 11) + 4)) + 3) + corr_{\text{l}}}$$

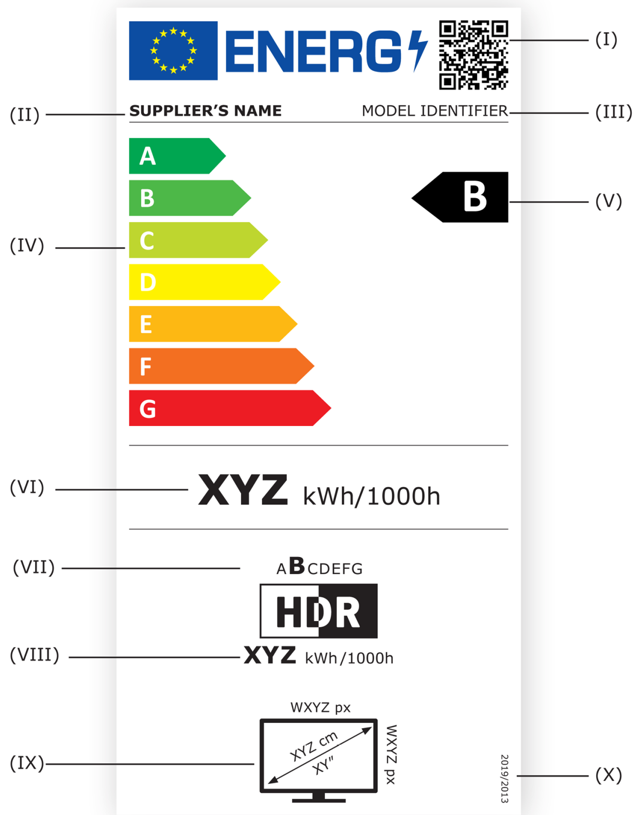
In this equation, the following parameters are used: A is the viewing surface area in dm^2, P_{measured} is the measured power in power-on mode in Watts in the normal configuration. In standard dynamic range mode, the measurements are carried out using standardised test sequences of moving pictures from dynamic broadcast content. In high dynamic range mode, HDR functionality is activated by metadata available in the standardised HDR test sequences. Finally, $corr_{\text{l}}$ is a correction factor which is set to 0 for televisions and monitors (it is non-zero for displays used in digital signage).

The energy classes are defined in terms of the energy efficiency index as follows:

Energy efficiency class	Energy efficiency index
A	$EEI_{\text{label}} < 0.30$
B	$0.30 \leq EEI_{\text{label}} < 0.40$
C	$0.40 \leq EEI_{\text{label}} < 0.50$
D	$0.50 \leq EEI_{\text{label}} < 0.60$
E	$0.60 \leq EEI_{\text{label}} < 0.75$
F	$0.75 \leq EEI_{\text{label}} < 0.90$
G	$0.90 \leq EEI_{\text{label}}$

There is a 10% allowances available for displays that incorporate automatic brightness control (ABC).

The energy label is then defined as follows:



6. Current state of Energy-aware service delivery and consumption

6.1. Survey summary

With the objective of identifying, reviewing, and analysing all relevant energy-related aspects of DVB systems, the DVB Study Mission on Energy-Aware service Delivery and Consumption has surveyed actors in the ecosystem.

The questionnaire allowed actors to describe their sustainability strategies regarding energy use both in delivery networks and in home networks. The summary of the responses below will help CM-SM-EADC to identify the potential work to be done by DVB.

To facilitate their use, the responses have been sorted by perspectives, using the same perspective than 3GPP (Energy Efficiency, Energy Saving and Digital Sobriety) and showing if it is in DVB scope or not. The technologies listed here are the one listed in the responses and not technologies listed by DVB. Before making any recommendation on such technologies, DVB will need evidence to justify their inclusion in specifications, guidelines, or whitepapers.

6.1.1. Not identified as in scope of DVB

Energy efficiency (KPIs and measurements)	- IoT to monitor and analyze energy consumption at city and home scale - Sustainable experts assisting projects in calculating emissions and using the environmental system effectively
Energy Saving (Use cases and solutions to optimize the Energy Efficiency)	- About employees' impact: Reduce employees commuting distances, bike leasing and e-charging stations on the company premises, environmentally friendly travel policy - About office/datacenter impact: Electricity from renewable sources, LED, optimized cooling, carbon capture
Digital Sobriety (Eco-friendly usage, Eco-design)	

6.1.2. Could be implemented by DVB members but not in DVB specifications

Energy efficiency (KPIs and measurements)	- Energy consumption measurement. Today different metrics are used according to data available: chipset manufacturers are using mW, head-end suppliers are using kWh/service, infrastructure provider are using kWh/site, STB providers are using kWh/device and when some providers manage the E2E chain, they can use kW/GB or even CO2/GB. There is no perfect modeling approach today. Assumptions had to be made when data consumption are depending on third parties. And even when there is no third party involved in the delivery chain, average is used, and traffic/audience are not considered.
Energy Saving (Use cases and solutions to optimize the Energy Efficiency)	- Modernization and withdrawal of least efficient network equipment (e.g. 2G, 3G, ADSL for network operators or DVB-T for broadcasters) - Use circular economy on devices but also on other components like network equipment. - Use 100% reusable materials in devices - Reduce power consumption of equipment (chipsets, servers, devices, …) every year for similar feature set - Promotion of environmental criteria in procurement - Save recorded programs in the cloud instead of locally. That way, there is no longer a need for a hard disk in set-top boxes.

Digital Sobriety (Eco-friendly usage, Eco-design)	- Don't use peripheral devices like STB when the media format is natively supported by the rendering device - Eco-design approach on hardware : o Fast introduction to the market of latest HW platforms (CPUs) to benefit of better electricity footprint o Long-lasting products - Eco-design approach on software : o Longevity: when designing new versions of the software, the R&D teams must ensure that they can run on different types of hardware platforms, including older versions that customers may still have. o Reducing energy-waste: the focus is on software optimization, enabling the number of servers and energy consumption to be reduced for the same service (efficiency of the algorithms, improving the overall software architecture of solutions, introduction of new features such as the use of artificial intelligence) - Use by default of a mode combining good quality and low energy consumption in video players (no 8K, limited HDR effects, ...) while keeping the possibility to have a "Gold button" that allows to activate the best possible quality for those who want high visual performance. Or at least allow manual bitrate selection on ABR streams. - Don't use low latency OTT streaming mode on contents without real time constraint - Best practices for end users : o Extend the life of devices (keep devices for longer, bring your equipment back, join the circular economy, …) o Adopt new habits (use Wi-Fi when possible, watch videos in moderation, no auto play, download instead of streaming, use low resolution on small screens…) o Saving energy (On or off but no in between, Use energy saving mode, Use an Eco Filter to make your stories greener…)

6.1.3. Could be implemented in DVB specifications

Energy efficiency (KPIs and measurements)	- Define DVB Energy efficiency KPI by extending only if and where needed existing specifications (ETSI TC EE?) - Real time power measurement reporting addition in existing reporting specifications - Open API used by end-user devices and reporting their power consumption too - Do a comparative evaluation of energy cost toward other specifications
Energy Saving (Use cases and solutions to optimize the Energy Efficiency)	- Extend DVB-I to allow players to select an instance according to its energy efficiency - Endorse best-in-class video compression technologies like VVC that would provide substantial power savings for a given video quality - Signal delivery optimization at various network (SFN boost, Dynamic broadcast gaining free capacity during good weather, …) - ATSC 3.0 datacasting allowed in DVB specifications - Power save modes everywhere it is relevant in the end-to-end chain - MPEG Green metadata (ISO/IEC 23001-11)
Digital Sobriety (Eco-friendly usage, Eco-design)	- Guidelines for an energy efficient usage in DVB specifications: o Use multicast/broadcast on large audience events o Use only one OTT format (multiplication of chunk formats is costly)

7. Use cases

7.1. Common energy consumption measurement

7.1.1. Description

From a regulator perspective:

- I want to have a nationally or internationally recognized reporting framework on energy consumption allowing to accurately compare energy efficiency of services or DVB technologies against each other and themselves over time.

From a service provider perspective:

- I want to be able to measure my energy consumption on my end-to-end delivery chain even if it includes third-party components or user equipment.
- I want my third-party suppliers to use the same reporting framework on energy consumption.
- I want to have a framework on energy consumption per usage instance taking into consideration the audience.
- I want to be able to compare the energy efficiency of my services with the energy efficiency of the services of my competitors.
- I want to inform users on their energy consumption based on a framework used by all industry players.

From a consumer perspective:

- I want to be able to compare energy consumption over different services.

7.1.2. Existing feature partly or fully covering use case functionality

None in DVB. Some work in others SDO could be used as a basis for further work.

7.1.3. Potential New Requirements needed to support the use case

1. It shall be possible to have a common reporting framework on energy consumption allowing to provide metrics from all components of the delivery chain and used by all industry players.

7.2. Energy consumption exposure

7.2.1. Description

From a regulator perspective:

- I want service providers inform users of the environmental impact associated to the use of their services.

From a service provider perspective:

- I want to inform users about the impact on the energy consumption of the device, bitrate, resolution, or delivery mode selected.
- I want to collect energy consumption of each equipment used by my service (from the user device to the video encoder).

From a consumer perspective:

- I want to be informed of the overall energy consumption of my service.
- I want to know which service or which delivery mode is the most energy efficient.

7.2.2. Existing feature partly or fully covering use case functionality

Some APIs allow reporting in DVB specifications but have not been design specifically to report energy consumption.

7.2.3. Potential New Requirements needed to support the use case

1. It shall be possible to have open APIs allowing to report energy consumption of each component in the delivery chain.

7.3. Energy consumption as a criterion for video source or quality selection

7.3.1. Description

From a regulator perspective:

- I want service providers to allow their users to manually select their bitrates/resolutions and provide recommendation according to the devices used.

From a service provider perspective:

- I want an automatic and dynamic selection of the media instance with optimised energy efficiency.
- I want to be able to prevent users to use a particular bitrate/resolution if a different bitrate/resolution allows the users to have the same Quality of Experience using less energy.

From a consumer perspective:

- I want my video player to select automatically and dynamically a media instance according to its energy efficiency.
- I want to be able to select manually a media instance or a bitrate/resolution allowing a reduction in my energy consumption.
- I want to use a media instance or a bitrate/resolution that optimises my energy consumption with a good Quality of Experience by default.

7.3.2. Existing feature partly or fully covering use case functionality

None in DVB. Some work done in Green MPEG could be used as basis for further work.

7.3.3. Potential New Requirements needed to support the use case

1. It shall be possible to indicate energy efficiency of a media instance in DVB-I.
2. It shall be possible to select a video representation in DASH according to its energy efficiency like it is already done according to its bitrate.

7.4. Modernisation or introduction of more energy efficient technologies

7.4.1. Description

From a regulator perspective:

- I want to have the best user experience on services but with the lowest environmental impact possible.

From a service provider perspective:

- I want to use new technologies which allow me to reduce the energy consumption in my DVB system.
- I want to use the same technology across my different delivery modes (e.g., CMAF over OTT and DVB-NIP).
- I want to understand how innovations in DVB specifications can help to improve my energy efficiency.

From a consumer perspective:

- I want to benefit from latest innovations allowing improvements in energy efficiency (e.g. best available video compression).

7.4.2. Existing feature partly or fully covering use case functionality

- Next gen video codecs have already been supported in DVB specifications
- DVB-MABR has already been supported in DVB specifications
- DVB-NIP has already been supported in DVB specifications

7.4.3. Potential New Requirements needed to support the use case

1. Innovations allowing to improve energy efficiency in DVB specifications shall be supported.
2. The introduction of next gen technology offering a better efficiency shall allow to withdraw legacy technologies (noting that there is also an energy impact when devices are replaced).

8. Conclusion

Over the past year, this study mission has undertaken various activities, which have culminated in this report. After defining its terms of reference, the study mission has worked to understand the state of the art in energy aware transmission systems. It has done so by performing a literature survey and by inviting various speakers (from Greening of Streaming, Einbliq.io, and Green MPEG). In addition, the study mission has created a survey on sustainability matters, the results of which are incorporated into the present report.

The literature shows that the ICT industry consumes a measurable percentage of the total energy used globally --- it hovers around 3%. Of this amount, around 70% to 80% goes towards the communication and consumption of video. Different service delivery systems require different quantities of energy, with broadcast TV being the least energy hungry and streaming consuming the most energy per device hour. For each transmission system, in general the amount of energy is not distributed evenly across the transmission chain. Most of the energy is consumed close to and in the viewers' homes. Notably televisions take a significant portion of the total energy consumption, as do (complex) set-top boxes, and Wi-Fi routers. Access networks also require a non-negligible amount of energy. Less energy per device hour is consumed by content distribution networks and data centres --- even if the global amount of energy consumed by such installations is significant.

Most measurements that lie at the core of these conclusions are relatively coarse, and while well-informed assumptions are made, there is a significant margin of error. They often rely on energy intensity metrics (measured in kWh/GB). Thus, today's measurement capabilities allow rough estimates to be made, which are perhaps good enough for reporting purposes. However, they do not provide for a means to optimise a transmission system, as they cannot predict how the total energy consumption of the system will change if one element of it is changed. Furthermore, some of the data sets gathered are in conflict with other data sets and it would be helpful for further work to be done to understand why.

More recently, power models have been proposed which measure power as a constant baseload with a mark-up for throughput. These models show that the baseload in many components of transmission systems is high, while the additional cost of passing data through is relatively modest. In essence, the energy use in transmission systems is more related to the capacity of the system than its actual use. In part this is due to the 'always on' nature of much of the equipment in such systems, combined with the fact that operators specify their requirements based on peak demand rather than on average demand.

Service delivery systems are complex networks involving many actors each with their own priorities and responsibilities. To be able to optimise such networks it may not be sufficient to individually optimise each component. Instead, it may be possible to spend more energy in one place to gain a significant reduction of energy elsewhere. However, without standardisation, this is unlikely to ever happen. This means there is a role for standards organisations to play, and DVB is in a good position to make a solid contribution.

ITU-T study group 5 is centred around sustainability issues, and has produced a wealth of knowledge, for example on greening of datacentres. ITU-R study group 6 has a rapporteur group working on sustainability issues in broadcasting, and it has already produced several documents. The Green Metadata standard is worthy of note, in that it proposes metadata to be carried that allows a receiving decoding process to reduce its energy consumption. It additionally proposes metadata that a display could use to reduce its energy consumption. Both ATSC and SMPTE are in a state of investigation similar to DVB. Existing and new industry fora are also looking at the problem, including for example the Ultra HD Forum, Greening of Streaming and DIMPACT. Coordination between standards bodies on the topic of sustainability is desirable. We can see that other standards bodies are already beginning to be active in this area, however none has so far adopted an integrated or over-arching approach so this is potentially an opportunity for DVB to take a ground breaking step.

The study mission has made a first assessment as to what opportunities exist within DVB to work on energy efficiency issues. To this end, and with the help of the survey that was conducted by the study mission, four use cases have been identified, and these can be mapped to new and existing groups within DVB. This is discussed in more detail in the 'Recommendations' section.

In summary, sustainability is an important topic that requires careful consideration. The study mission that concludes with the production of the present report represents a very good first step. The strong advice to the Commercial Module is to continue this initial work by following the recommendations described in the following section. This would put DVB in an excellent position to help its members and customers move toward net zero, and so contribute toward the mitigation of climate change in a useful manner. However, we recognise that the broadcasting industry continues to find ways to provide consumers with new, innovative products and services. Picture and audio quality have reached new highs thanks to technological advances. Access services are evolving to provide help for those that need it. Hence, in order to secure DVB member support for energy saving measures, it will be important to respect choice by consumers and also further advances by industrial partners through a light touch process, using guidance and suggestions supported by reasoned argument.

9. Recommendations

DVB should consider energy efficiency as a guiding principle when developing new Commercial Requirements.

Proposed next steps could be to begin by taking into consideration the four identified use cases in this report:

1. Common energy consumption measurement
2. Energy consumption exposure
3. Energy consumption as a criterion for video source or quality selection
4. Modernisation or introduction of more energy efficient technologies

Use cases 3 and 4 could be taken into consideration directly by existing working groups as it could be considered for example in DVB-I, DVB-DASH or DVB-AVC.

But use cases 1 and 2 could best be addressed through the creation of a new working group with a remit to focus specifically on energy efficiency as these use cases will imply transversal work between different working groups - like CM-SEG for example. This new working group tasks and scope of work could be:

- Develop a harmonised, over-arching commercial framework for energy efficiency within the scope of DVB and work towards its implementation across DVB commercial groups.
- Develop and propose commercial requirements for new work items that are lacking commercial energy efficiency requirements and/or are inconsistent with the precepts of the harmonised reporting framework.
- Suggest rather than attempt to impose energy efficiency requirements that may conflict with other legitimate commercial requirements. The goal would be to improve energy efficiency in DVB specifications without placing unreasonable restrictions on functionality and ultimate technology choices.
- Monitor and track the work in other SDOs and review compatibility.
- Contribute to the harmonization of the work on this subject across relevant organizations.

In addition to these guiding principles, the survey results show interest for guidelines / whitepapers. This has been indicated by 80% of respondents as a way to support their sustainability strategy. Implementation guidelines providing examples of energy efficient configuration for some DVB technologies could be relevant, and whitepapers providing recommendation on how different DVB specifications can be mixed to offer a better energy efficiency according to the audience or the network conditions of a service.

The key recommendation from the present document therefore is the creation of an Energy Efficiency group, subject to Commercial Module and Steering Group approval, and at least one suitable candidate coming forward to chair and lead the group.

10. History

Version	Date	Milestone
S100	November 2023	First BlueBook publication (Internal document CM2229r2)