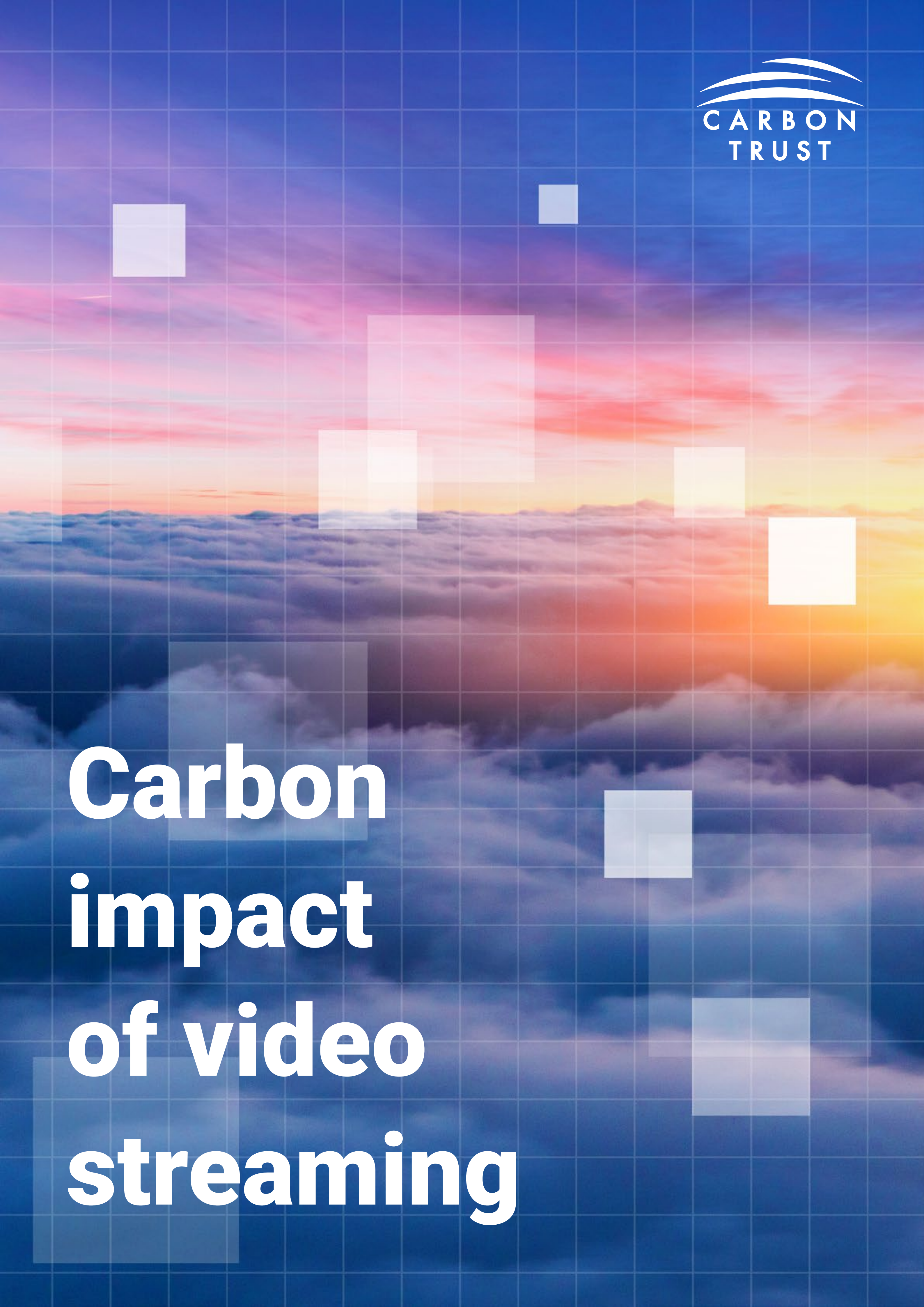

CARBON TRUST

Carbon impact of video streaming

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Date

June 2021

CARBON TRUST

DIMPACT
Insight to action on digital carbon impacts

About the Carbon Trust

Established in 2001, the Carbon Trust works with businesses, governments and institutions around the world, helping them contribute to, and benefit from, a more sustainable future through carbon reduction, resource efficiency strategies, and commercialising low carbon businesses, systems and technologies.

The Carbon Trust:

- works with corporates and governments, helping them to align their strategies with climate science and meet the goals of the Paris Agreement;
- provides expert advice and assurance, giving investors and financial institutions the confidence that green finance will have genuinely green outcomes; and
- supports the development of low carbon technologies and solutions, building the foundations for the energy system of the future.

Headquartered in London, the Carbon Trust has a global team of over 200 staff, representing over 30 nationalities, based across five continents.

About DIMPACT

DIMPACT is a collaborative project, convened by Carnstone, with world-class researchers from the University of Bristol and thirteen of the world's most innovative media companies. DIMPACT participating companies are: BBC, BT, Cambridge University Press, Channel 4, dentsu international, Informa, ITV, Nordic Entertainment Group, Netflix, Pearson, RELX, Schibsted, and Sky. DIMPACT developed originally out of the Responsible Media Forum in 2015, with a group of companies that wanted to better understand the GHG emissions of their digital media products and services. DIMPACT was formed in 2019, and started working with the University of Bristol Department of Computer Science to develop a tool that provides assessment modules for the GHG emissions of digital publishing, advertising services, business intelligence, and video streaming.

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Contents

Executive summary

This white paper is about the carbon impact of watching one hour of video streaming

(specifically in reference to on demand streaming, not live streaming). It looks at this from a life cycle perspective, and presents the results in terms of carbon emissions for one hour of video streaming. It considers the energy use of the different components that are involved in the distribution and viewing of video content: data centres and content delivery networks (used for encoding and storage); internet network transmission; home routers; end-user viewing devices (e.g. TVs, laptops, tablets, smartphones); and TV peripherals (e.g. set-top boxes), where relevant.

The boundary scope includes only the operational electricity use of the different components

not the content creation nor the embodied emissions of the equipment. The carbon emissions from the electricity use are all calculated based on national electricity grid average emission factors, so do not recognise where data centres and network operators directly use renewable electricity.

This white paper explains the details of the assumptions and methods used and discusses the challenges and uncertainties involved in estimating the carbon impact of video streaming.

The aim is to contribute to the understanding of the topic, so that future decisions can be based on an informed understanding of the issue, with an insight of the methods, uncertainties and variability that can affect the estimates.

Two methodologies are presented, with the key difference between the methods being how the network electricity is allocated to video streaming.

The first is the conventional approach, which is well established and has been used in most previous studies, and follows an average allocation methodology, where the internet network electricity is allocated using an average energy per data volume metric [kWh/GB]. This white paper also presents a power model approach, which uses a marginal allocation methodology, where a baseload power is allocated per user, and a marginal energy component is allocated related to the data volume used. The power model approach recognises that the dynamic relation of energy to data volume in a network is very flat – i.e. there is a high fixed power baseload which does not vary in relation to the data volume, with only a small increase in power consumption in response to the data consumption. The power model approach uses research published in September 2020; before then there was not sufficient information published for the power model allocation approach to be applied widely. **While the power model approach more closely represents the instantaneous use of energy in the network, the conventional approach represents the average energy use and therefore is generally used for reporting and accounting purposes.**

The following analogy of a bus network is helpful in illustrating the differences between the two allocation approaches. The energy (i.e. fuel) used by the buses in the network is fairly fixed, with only a marginal increase relative to the number of passengers. The power model approach will allocate a fixed amount of energy per user, plus a marginal amount per kilometre travelled. The conventional approach will allocate an average amount of energy per passenger-km, (which would be derived from the total annual fuel consumption, and the total annual passenger-km travelled). The power model approach reflects the immediate impact of whether you use the bus or not, while the conventional approach reflects the average impact of using a bus (as it considers the total annual operational emissions of the bus network) and is useful for average accounting purposes.

It should be noted that neither of the allocation methods reflects the peak data usage, and this is one of the drivers of the longer-term total network energy consumption.

As with most carbon footprint assessments there is inherent variability and uncertainty in the estimation of the carbon impact of video streaming,

which gives rise to a range of results. (Variability refers to variations due to factors such as time or place, while uncertainty refers to the degree of precision of measurements.)

The variability is due to temporal, geographical and technological factors.

The biggest variability relates to the country-specific electricity grid emission factor – for example, in Europe Germany's grid emission factor is approximately 30 times that of Sweden, which translates directly to a 30 times difference in the overall carbon footprint. The second most significant factor affecting the variability in the carbon footprint is the viewing device used – the footprint (related specifically to the energy of the viewing device) of watching on a 50-inch TV is roughly 4.5 times that of watching on a laptop, and roughly 90 times that of watching on a smart phone. The year that an estimation relates to is also significant, as improvements in technology mean that the energy intensity of equipment is continually decreasing, and separately the electricity emission factors are decreasing as the electricity grids decarbonise through the utilisation of greater proportions of renewables. Also, network energy intensity factors will vary by operator and by country, due to factors such as age of network equipment, topology of the network, population density, and even climatic factors such as ambient temperature and humidity.

The European average footprint is estimated to be approximately

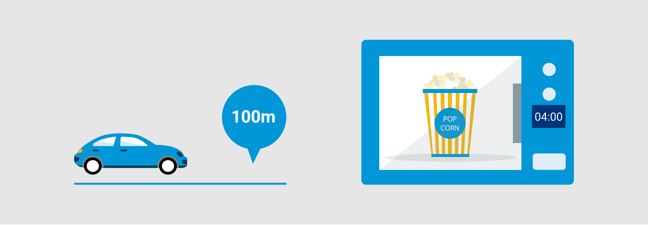
55 gCO_2e

per hour of video streaming

The most significant effect of the uncertainty is related to the internet network component of the footprint.

The uncertainty in the network energy arises from the differences in allocation method, and from the fact that there is a limited number of publicly available data points for the energy intensity of networks.

At the individual level, the carbon footprint of viewing one hour of video streaming is very small compared to other everyday activities



The European average footprint estimated in this white paper is approximately 55gCO_2e per hour of video streaming for the conventional allocation approach. (This estimate uses a European average grid emission factor, a representative mix of viewing devices, and network energy intensity figures for 2020.) For comparison, the emissions from microwaving a bag of popcorn for four minutes is about 16gCO_2e (also using a European average grid emission factor), while driving 100 metres in an average petrol car emits around 22gCO_2e. These footprint figures for video streaming are comparable with some other recent estimates. However, there are also some previous studies with much higher estimates, the main reason for the difference being that those studies used older network energy intensity figures which are significantly higher than figures relevant to 2020.

The analysis in this white paper also shows that the viewing device is typically responsible for the largest part of the carbon footprint.

Using the power model approach, which reflects the instantaneous (or marginal) changes in energy, demonstrates that changes in bitrate (due to different resolutions and other settings) result in only a very small change in the carbon footprint.

This is because the internet transmission and the home router use much the same energy whatever the data volumes are, and the viewing devices energy consumption also only changes by small amounts depending on the viewing resolution.

Understanding the longer-term impacts of video streaming is more complicated.

The total network energy is primarily driven by the total peak demand for data. However, as networks are continually upgraded with newer network equipment that is more energy efficient, the greater data volumes can be handled with less energy consumption. What is driving the peak demand? Is it demand for services, and which services – those that use higher data volumes, or those that require faster response times (lower latency)? Or are the technology improvements that enable higher bandwidths driving new applications and services that can take advantage of these improvements?

In this white paper we also note that actions and trends in the ICT sector are driving down the carbon intensity of ICT services including video streaming.

The large data centre cloud providers are increasingly purchasing renewable electricity, many with 100% renewable targets, with some already at 100%. Similarly, a number of major telecoms network operators have 100% renewable targets, and an increasing number are setting approved 1.5°C compatible science-based targets. The end-user viewing devices are also becoming more energy efficient due to a mix of technology advances, regulation and standards (e.g. around standby power and maximum power thresholds).

This may be further helped through the trend of using smaller devices such as tablets and laptops for viewing rather than TVs, although it is not clear; a) how much this is purely substitution of a device rather than additional viewing; and b) to what extent communal viewing of larger screens offsets the additional energy requirements. However, there is a trend for TVs to have larger screen sizes, and therefore potentially higher energy consumption (albeit as noted above, technology is improving the energy efficiency of televisions and other devices, and screen sizes cannot continue to increase in size indefinitely), together with an overall increase in number of viewing hours.

This white paper aims to improve the understanding of the carbon footprint of video streaming and its complexity, variability and uncertainty.

It should be seen as a work-in-progress, as there are many opportunities for further research to improve understanding in this area. A key area to investigate further is different allocation methods, as it is critically important that the method is appropriate for the questions being asked and the decisions taken. Related to this is the need for understanding the key drivers around increased demand for data, in particular peak data demand. To understand these issues also requires availability of more detailed information from network operators on energy and data. As the carbon intensity of electricity reduces (and operators use 100% renewable electricity), then the embodied emissions of equipment and devices will become more significant, therefore this should be the next area to assess in more detail. Other areas that would benefit from more research and more data are: the allocation of the home router energy and information on devices and applications using the home router; and information on the mix and use of viewing devices.

What is clear is that a strong understanding of the impact and context of video streaming is vital to inform future decisions affecting the use of video streaming and the use of ICT in general. Analysis of Cisco forecasts show that, in 2020, long-form video streaming (i.e. with an average viewing time of greater than five minutes) accounted for about 45% of total internet traffic. Depending on how trends in video streaming change in the future, the associated internet traffic could have impacts on the total energy demand of the internet.

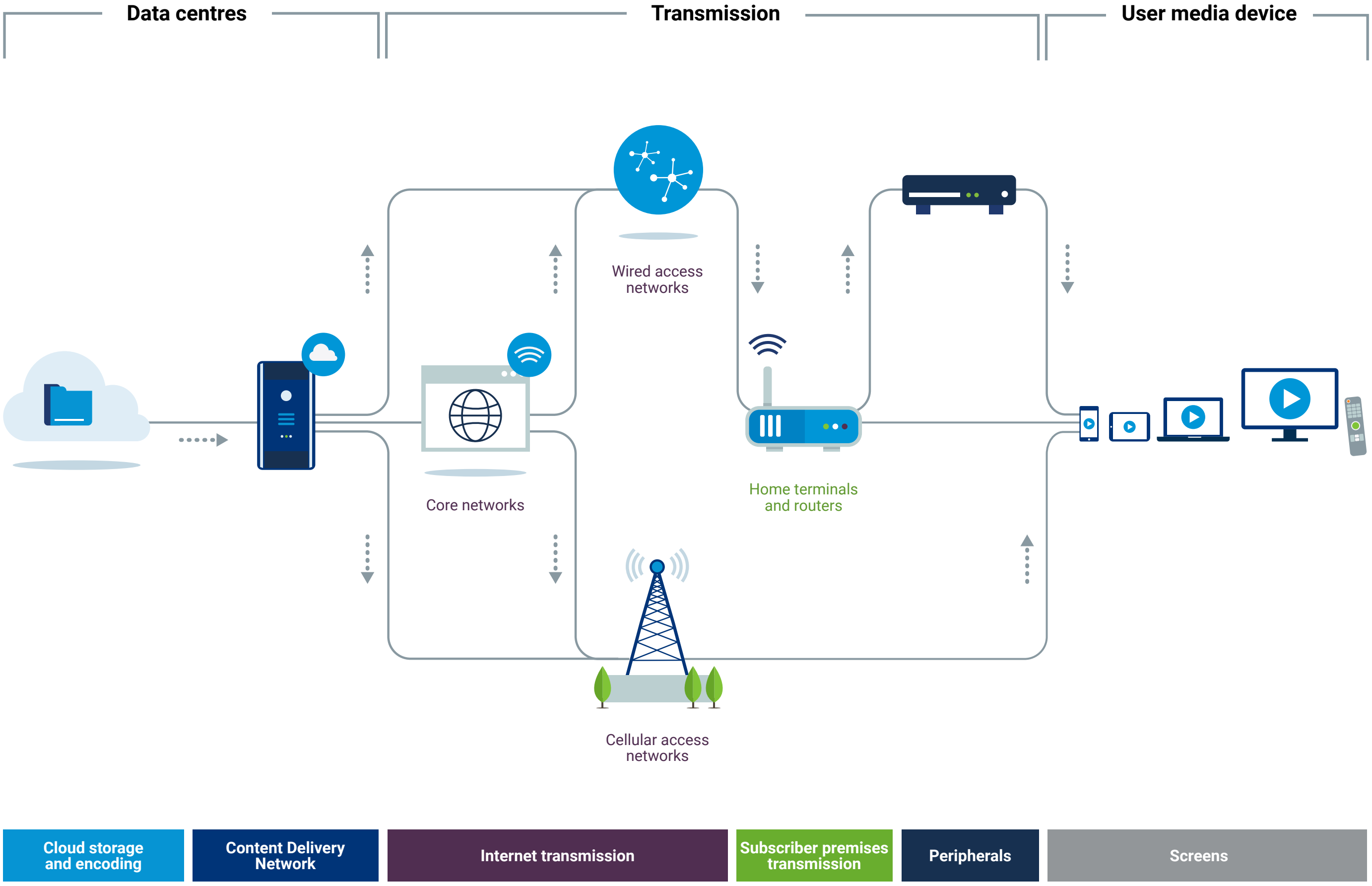
1. Introduction

1.1. Purpose of the white paper

The purpose of this white paper is to contribute further to develop knowledge around the measurement of the energy and carbon impact of on demand video streaming (VoD). The white paper presents the current magnitude for the electricity consumption and operational carbon emissions of video streaming. Subsequently, the white paper outlines current policy trends, both on governmental and company levels. The white paper discusses the complexities of video streaming and moreover the complexities of measuring its carbon footprint.

To provide a proper understanding of this complexity, the white paper explores the different components involved in video streaming (as shown in the diagram below) from a life-cycle perspective: Data Centres (for originating and encoding of video content), Content Delivery Network (CDN - for temporary storage and delivery), Internet Network Transmission, Home Terminals and Routers, Home Peripherals (e.g. set-top-boxes), and End-User devices (screens). To estimate the video streaming carbon footprint, this paper outlines where in the life-cycle the emissions take place and what magnitudes they have.

Figure 1. Process map showing boundary scope of video streaming



The scope included is that related to the distribution and viewing of video streaming, as shown in Figure 1. Content creation is not included. The emissions relate to the operational electrical energy use of the different components, and do not include the embodied emissions of the equipment. The carbon emissions from the electricity use are all calculated based on national electricity grid average emission factors, so do not recognise where data centres and network operators directly use renewable electricity.

This white paper has been developed to provide an explanation of the calculations behind the numbers for the emissions of video streaming, and explain what factors and assumptions are used, and how these affect the calculated numbers. The white paper presents two different methods for allocation of energy to video streaming services, discusses why this is important, and why allocating internet network energy purely on a data volume basis, can give misleading results, if not properly understood.

The two methodologies presented in this white paper are:

1.

The conventional approach

The conventional approach uses an average allocation methodology, where the internet network electricity is allocated using an average energy per data volume metric [kWh/GB].

2.

The power model approach

The power model approach uses a marginal allocation methodology, where network baseload power is allocated per user/subscriber, and a marginal network energy component is allocated related to the data volume used.

The two approaches also use different allocations for the home router energy. The conventional approach uses an average allocation related to the data volume, while the power model approach allocates router energy considering number of users, number of connected devices per user, and also allocates the energy used by the router when it is in an idle state.

The conventional approach is the well-established approach that represents the average energy use and therefore is very suitable for reporting and accounting purposes. The power model approach more closely represents the instantaneous use of energy in the network, and is therefore useful for understanding the short-term marginal change of energy consumption in response to changes in viewing patterns.

For a more detailed description of the conventional approach methodology please see the Methodology section, for a presentation of the impacts see the Results, and for a description of the power model approach and further comment on the impact and its implications, see the Discussion section.

The methodologies for calculating the emissions impact of video streaming presented in this white paper are based on the approaches used in models developed by DIMPACT and Netflix. The Carbon Trust was approached by DIMPACT to review both models and to interview the companies using them.

DIMPACT, a collaborative project convened by Carnstone, with researchers from the University of Bristol and 13 global entertainment and media companies, has over the last years developed an online tool for reporting emissions. DIMPACT's online tool is designed for the DIMPACT member companies to use with their specific data to estimate the carbon emissions of the value chain of their digital media services, excluding content creation. It is used primarily for organisational reporting (for example, reporting of Scope 3 emissions), but also to support the identification of opportunities for designing lower carbon services. The tool provides modules for a variety of digital services including video streaming.

Independently, Netflix developed a model in partnership with Engie Impact and with the advice of an international panel of academic experts, to estimate the emissions impact of an hour's worth of video streaming from a life-cycle perspective.

Both models use the conventional approach with similar methodology and assumptions, and the results (when expressed as emissions for an hour of video streaming) show close alignment. The Netflix model additionally has an option to use the power model approach, which was developed based on published research on network power models (Malmodin 2020b) and with further input from academic experts.

The Carbon Trust has critically reviewed the structure and assumptions in both models, and where possible we have cross checked some of the key inputs and assumptions against other data. In this white paper, we also discuss the merits and disadvantages of different assumptions and approaches.

This white paper then considers current and future policy related to both the environmental impact of streaming and of the ICT sector in general, in the context of these estimates. A comprehensive set of legislative and non-legislative initiatives are in place to work towards climate neutrality in Europe by 2050. For the ICT sector specifically, the European Commission sets out a digital strategy. The main focus of this analysis will be on European Union Policy and specific relevant national policies that are currently in place or in a development stage. On a European level the main focus will be the European Green Deal. For the purpose of this paper, the focus will be on policy relating to environmental reporting and climate action for the streaming and ICT sector. The white paper also discusses industry-led initiatives, focusing on existing initiatives being undertaken by the sector itself to either measure, report or reduce carbon emissions associated with video streaming.

Given the developing nature of research and methodology for the measurement of the emissions of video streaming, this paper highlights opportunities for further research into improving the methods and criteria for evaluating video streaming emissions.

1.2. Contextual background

There is growing awareness and concern expressed in the media over the carbon and energy impact of the ICT sector, including on the impact of video streaming.

A variety of different estimates of the carbon impact of video streaming have been published (See Table 1). This table illustrates the variability of recently published estimates. Companies and academics have been working to better understand the impact of video streaming and to improve the estimates of the carbon impact.

Table 1. Estimates of the carbon impact of video streaming

Estimate	Year relates to	Reference	Carbon intensity [g CO_2e / streamed hour]
Purdue University estimate	2020	Obringer, 2021	440
IEA global estimate **(Revised estimate, December 2020)**	2019	IEA, 2020c	36
IEA global estimate **(Original estimate, February 2020)**	2019	IEA, 2020c	82
BITKOM: global estimate for 2018 | 720p | 65" TV	2018	Bitkom, 2020	130
BITKOM: global estimate for 2018 | 4K | 65" TV	2018	Bitkom, 2020	610
BITKOM: global estimate for 2018 | 720p | Smartphone | Fixed networks	2018	Bitkom, 2020	30
Shift Project updated global estimate	2018	The Shift Project, 2020	394
Shift Project global estimate (from AFP interview)	2018	The Shift Project, 2019b France24, 2019	3,200
BBC iPlayer estimate	2016	BBC, 2020	98
LBNL/NU estimate for the U.S.	2011	Shehabi, 2014	360
BBC estimate for the UK for 2011 | STB + TV | SD (480p)	2011	BBC, 2011	76

There are a number of factors that can have a significant impact on the results and explain some of the variability in the results. One is the fact that ICT technology is continually being updated and improving in energy efficiency, thus the year to which the results relate is significant, and using outdated energy intensity (and hence carbon intensity) figures will over-estimate the result. The second factor is related to the method of allocating the energy (and hence emissions) of shared resources (such as the internet transmission). A third significant factor is that the carbon intensity of electricity (i.e. the electricity grid emission factors) vary significantly from country to country, and also have been reducing over time due to decarbonisation of the electricity supply.

The COVID-19 pandemic highlighted society's reliance on ICT, and particularly the internet infrastructure. Data traffic increased due to demands from home working, home education, and home entertainment. This increased awareness of the impact of ICT in general, including video streaming. Interestingly, although there was a significant increase in data traffic, this did not have a similar impact in terms of energy use. Telecom network operators reported only marginal (less than 1%) increases in energy consumption, despite increases in data traffic of up to 50% (GSMA, 2020).

This effect has also been reflected for the whole of 2020. Telefonica reported a 45% increase in data traffic in 2020, due to COVID-19, yet reported a slight decline in enterprise energy use (noting that the networks account for ~90% of their enterprise energy use) (Telefonica, 2020). Similarly, Cogent, a large operator of fibre-optic backbone networks, reported a 38% increase in data traffic for 2020, however, its overall network energy use decreased (Cogent, 2020a; 2020b). Such up-to-date reporting by network operators refutes the assumption that energy use is directly proportional to data volumes, and demonstrates that increased data traffic does not automatically result in more network energy use. This relationship is even more significant in a year where the effects of COVID-19 has resulted in large surges in data traffic, due to homeworking.

2. Background – global energy and carbon impact of the E&M and ICT sectors

2.1. Video streaming as part of the Entertainment and Media sector

Video streaming is an entertainment service delivered over the internet. As such, it is heavily dependent on elements of the ICT sector. To understand the emissions of streaming it is helpful to realise how video entertainment (and the media industry in general) has been digitising.

ICT has become an intrinsic part of everyday work and social life, with constant connection, instantaneous media and social media. Multiple economic sectors rely on ICT, with ICT providing a horizontal layer that cuts across a vast number of industries.

The development of video entertainment has been rapid. Video store rentals were replaced with DVD postal delivery, which in turn has been replaced by online streaming. Like other sectors, the Entertainment and Media (E&M) sector has gradually shifted towards digitalisation and dematerialisation of its services. Video streaming is reliant on the ICT and E&M sectors to deliver content into the home, and within the ICT system there are multiple touch points. **The key ones being:**

The originating and encoding of video content is performed in **Data Centres**

Video content is stored on edge servers close to the end-user for better quality streaming using **Content Delivery Networks (CDN)**

The **transmission** of video from the data centres to the CDN to the home occurs over the telecommunications networks comprising the internet

The home is connected to the internet using **home terminals and routers**

Some video services use home **peripherals** (e.g. set-top boxes) to enable selection of the services

And finally, watching the video uses an end-user device such as a **laptop, tablet, smartphone, or TV**.

All of these stages consume electricity and hence generate related carbon emissions. This therefore requires an understanding of the wider context of ICT and E&M.

2.2. Defining ICT and E&M sector and boundary

The remainder of this section looks at the global carbon footprint of ICT and E&M, including historic and future trends. We start with some definitions.

The Information and Communication Technology (ICT) sector is defined by the OECD as "a combination of manufacturing and services industries that capture, transmit and display data and information electronically"[1].

For reporting of GHG emissions this usually relates to the emissions of these three components:

- **data centres that store and process data,**
- **telecommunications networks (including both mobile and fixed) that transmit data, and**
- **end-user devices that further process and display data.**

Defining the boundary of the ICT and E&M sectors is of critical importance when estimating the sector's carbon emissions, recognising the points of cross-sector overlap and convergence.

Assessments of the global emissions impact of the ICT and E&M sectors typically use quite specific boundary definitions of what equipment is included in ICT vs what is included in E&M. These are purely for the purposes of estimating the global emissions impact, and may not completely align with more general perceptions of the ICT and E&M sectors.

Thus, looking at the global emissions impact, we follow the boundary definitions from Malmodin & Lundén, (Malmodin, 2018a).

ICT emissions boundary

The Information and Communication Technology (ICT) sector is broadly categorised as IT services and telecommunications networks, and is categorised by three sub-components: data centres that store and process data, networks (including both mobile and fixed) that transmit data and end-user devices (excluding devices included in the E&M boundary).

E&M emissions boundary

'The Entertainment and Media (E&M) sector comprises all electronic equipment utilised for media and entertainment purposes, including: TVs, cameras, and other E&M consumer electronics, as well as physical paper media and printing.

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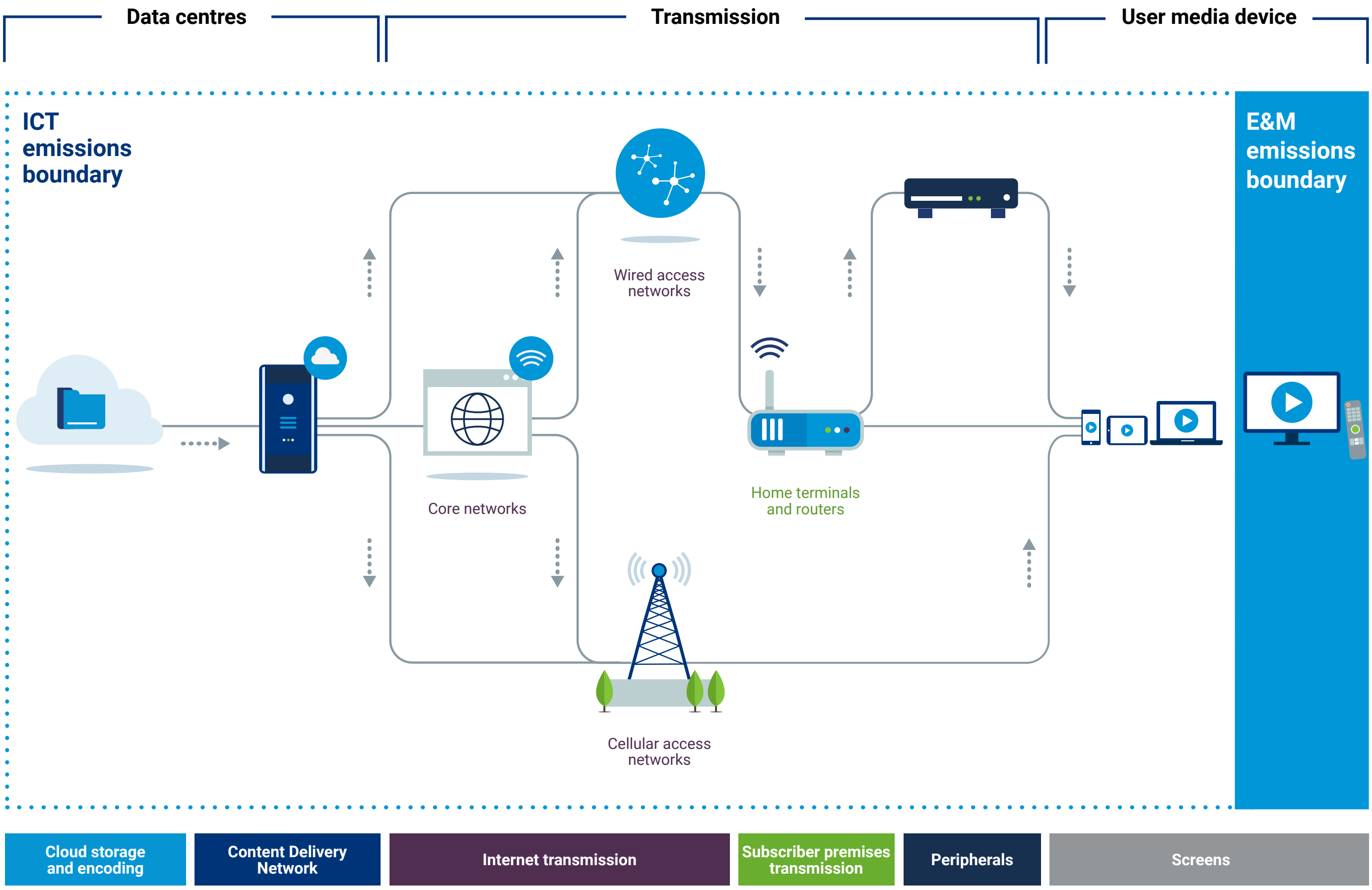
[1] http://www.oecd.org/digital/ieconomy/2771153.pdf

Using the Malmodin & Lundén definition, the following Figure 2 relates the components of video streaming to the ICT and E&M emissions boundaries.

Figure 2. Process map showing ICT and E&M boundaries



2.3. The ICT sector's carbon footprint – variations in estimates

There is inherent complexity and uncertainty when calculating the footprint of ICT. As a result, estimating the carbon emissions of ICT has, historically, proven quite challenging. Previous estimations of ICT's carbon and energy footprint vary substantially. This variation between footprint estimations results from differences in the scope, methodology and boundary definition for the ICT sector, that ranges substantially between previous studies (Freitag et al., 2020).

Firstly, defining the boundary of the ICT sector can impact the results of calculation. The ICT sector, unlike other more finite sectors is more difficult to define in terms of its boundary. The ICT sector actually consists of a variety of very different sub-sectors (e.g. ICT equipment manufacturing, component manufacturing, data centre operations, telecommunication network operations, software, IT services). Whereas, for example, global steel production has a well-defined boundary with a finite number of manufacturing operations/plants and value chain that covers its supply. Additionally, many steel companies report their emissions data, via the World Steel Association, enabling more accurate determination of the steel industry's total footprint. This level of transparency has not yet been achieved within the ICT sector.

Therefore, defining ICT's sector boundary is potentially more complex than other industries. The internet refers to a global integrated network of networks connecting millions of different users and devices, that are each capable of sending, receiving and processing data all of the time. Thus, it is harder to agree on a universal definition of its boundary. As such, previous studies may use differing definitions. Important considerations include the scope of technologies used for the calculation, such as the inclusion of TVs or types of IoT devices. Also, the inclusion of embodied emissions of ICT hardware and equipment is another key consideration. Studies vary depending on their allocation of these full lifecycle emissions. Namely, whether their estimation accounts for end-of-life emissions as well as upstream production and material extraction emissions (Freitag et al., 2020). The carbon footprint of ICT services is also dependent on the electricity mix, that varies between different countries. Thus, whether the calculation accounts for renewable energy portion of electricity used will significantly affect the estimation.

Secondly, as a result of the ICT sector's complexity, the methods and assumptions used for carbon footprint calculations differ between studies. Some adopt a top-down approach of global ICT energy estimates. This approach relies on the extrapolation of historic estimates of carbon intensity and estimating future trends from model projections. Alternatively, systematic bottom-up approaches have been applied, using real-world data to estimate the footprint of each ICT sector component such as global data centre servers (Masanet, 2020a) or network operator emissions (Malmodin & Lundén, 2018a; Malmodin 2020a). These tend to produce more robust estimations as they are based on detailed data points that can be scaled-up to provide a global figure.

In addition, some studies are actually scenario analyses – modelling what the impact for energy and emissions would be, based on differing growth assumptions. Then, these scenarios are often oversimplified and reported in the media to the public as either concrete projections or as facts, when they were simply answering a series of "what if" scenario questions.

Some studies have produced erroneous estimates by relying on previously published estimates of the ICT sector emissions (that may themselves be five to 10 years old), then extrapolating them to the current date using historical growth projections (which may also be five to 10 years old). Because the technology changes so rapidly it is not reliable to simply use extrapolations from historic data. The more robust estimates recalculate the emissions by using the latest available industry data: for data centres using industry data on the number of servers and server energy consumption; for telecoms networks using actual reported emissions from network operators; and for end-user devices using industry data on numbers of devices sold and the energy consumption of different device categories.

An additional complexity is that the emissions intensity of electricity generation varies over time and by location, and these variations are big enough to matter (more than an order of magnitude in some cases). It is therefore difficult to compare independent estimates of ICT emissions directly without supporting information on the *energy* intensity of ICT technology and the *emissions* intensity of electricity generation.

2.4. Current and historical carbon footprint of ICT

2.4.1 Innovation enables greater energy efficiency

The pace of ICT technological innovation has enabled continued improvements in processing power and greater energy efficiency across the sector's entire value-chain. It is widely acknowledged that energy efficiency of ICT and computing equipment has historically doubled every one to three years (Kamiya, 2020; Koomey et al., 2011a, Koomey and Naffziger, 2016), and similarly energy efficiency of networks has historically doubled approximately every two years (Aslan et al., 2018), see box below. This sustained efficiency has helped to stabilise ICT's carbon footprint, even as the sector has continued to expand.

Moore's Law and Koomey's Law

In 1965, Gordon Moore observed that computer microprocessors doubled in transistor density every year (modified to every two years in 1975), increasing the number of transistors per unit area and thus improving performance. Subsequent analysis identified a related trend, a doubling of efficiency roughly every 1.6 years for computing hardware running at full output (Koomey et al., 2011a), a trend that is often known as Koomey's Law. Subsequent analysis showed that efficiency improvements for computers at peak output slowed after 2000 for reasons associated with semiconductor physics but continued to double every 2.6 years (Koomey and Naffziger, 2016). These continual improvements in microprocessor chip design, manufacturing, and software drove energy efficiency improvements that have to some extent offset rising demands for computing and data services.

Aslan's rule

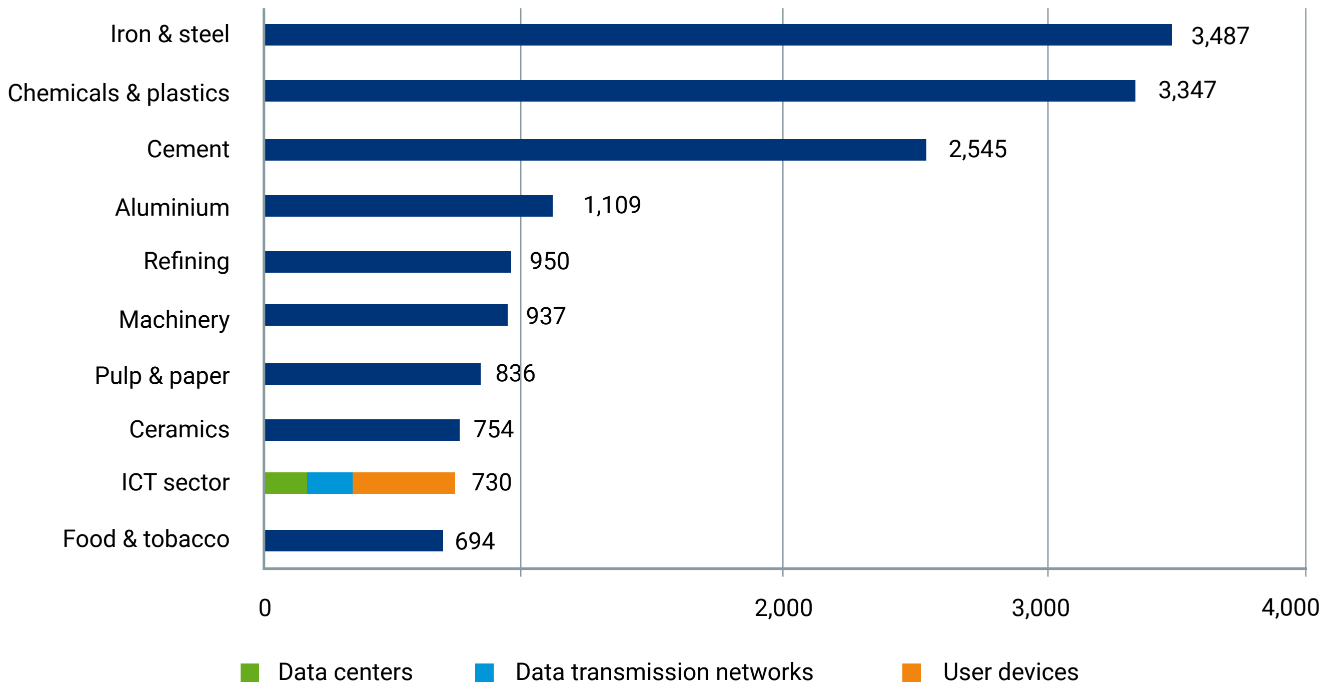
Similarly, analysis of estimates for the average electricity intensity of fixed-line internet transmission networks for data transfers from 2000 to 2015 concluded that electricity intensity (in kWh/GB) decreased by half approximately every two years over that time period (Aslan et al., 2018).

2.5. ICT's carbon footprint in 2020

The ITU Telecommunication Standardization Sector (ITU-T) in its recommendation L.1470 estimated the ICT sector's carbon footprint for 2015 at 740 $MtCO_2e$, including embodied emissions. This equates to approximately 1.3% of global greenhouse gas (GHG) emissions (ITU, 2020). This is almost five times smaller than the global footprint of the iron and steel sector, and smaller than many other large industries (see Figure 3).

Within this footprint, end-user devices account for the greatest portion of emissions (401 $MtCO_2e$), followed by networks (198 $MtCO_2e$) and data centres (141 $MtCO_2e$). The breakdown of ICT's carbon footprint by the sector's different components is shown in Figure 4.

Figure 3. Global greenhouse gas emissions ($MtCO_2e$) by industry, 2014

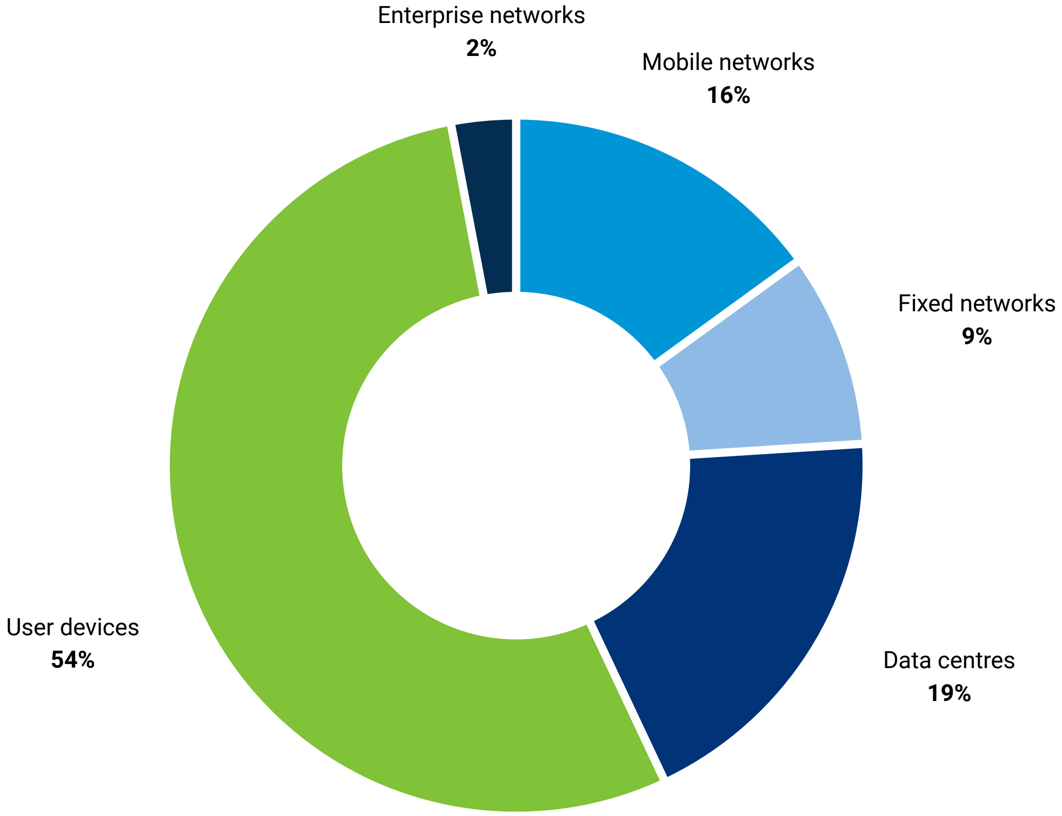


(ITIF, 2020)

The ITU-T L.1470 recommendation suggests that the sector's 2020 carbon footprint would remain at a similar level to the 2015 value, based on the available data in 2019 and using the same bottom-up methodology as in Malmodin (2018a).

This finding supports the view that efficiency improvements and reductions in emissions intensity of electricity continue to effectively stabilise the emissions of the sector even as computing service demands rise.

Figure 4. Carbon footprint of ICT (2015)



(Adapted from ITU-T L.1470)

2.5.1 Historical carbon footprint of ICT

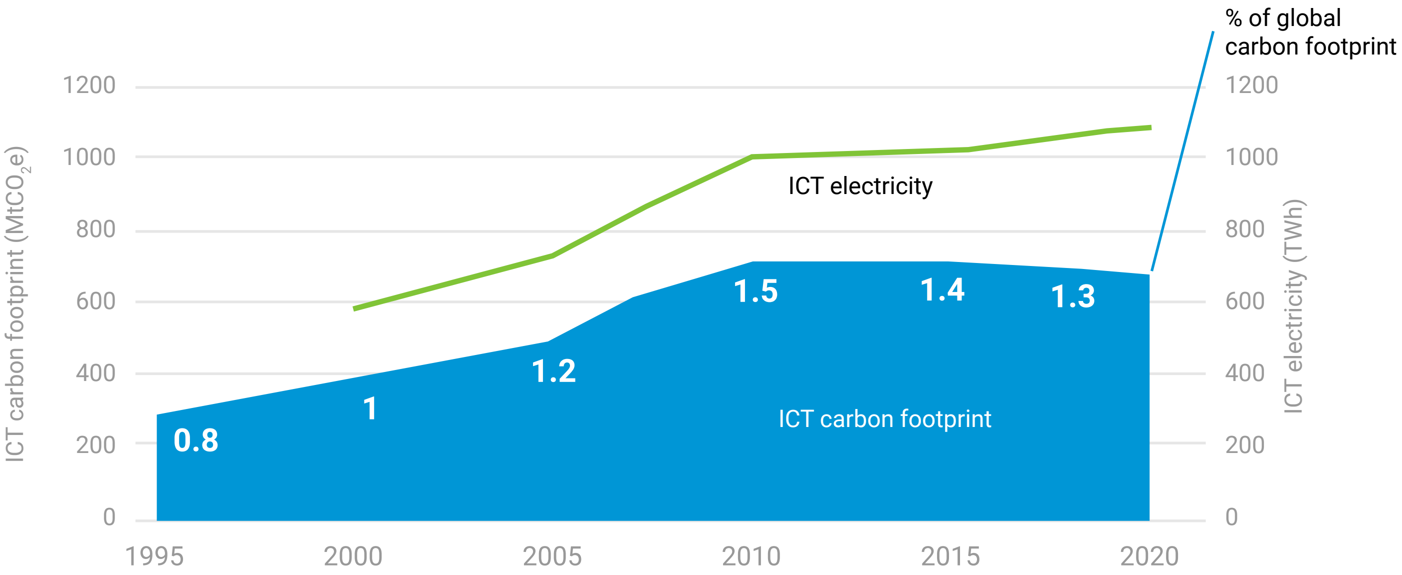
The carbon emissions of the ICT sector increased from the early 1990s to 2010 (GeSI, 2008; Malmodin et al., 2013; Malmodin, 2018a). However, this emissions trend has largely plateaued, remaining relatively stable over the last decade, despite network data volumes continuing to grow year on year. Malmodin (2020a) shows that the ICT emissions curve has flattened and actually dropped from 1.5% to 1.3% of global carbon emissions over the past decade (Figure 5), while the absolute emissions of ICT have fallen slightly from a peak of 730 $MtCO_2e$ in 2015 to 710 $MtCO_2e$ in 2018, and to about 690 $MtCO_2e$ in 2020.

Some other studies have overestimated the global GHG footprint of the ICT sector, particularly when projecting into the future. This is often due to a combination of using historical data and projecting that forward using assumed growth figures. For example, Andrae & Edler (2015) modelled three different scenarios of ICT energy using projections for IP data traffic growth and energy efficiency improvement trends, with different parameters for each scenario. This showed significant variance between the scenarios and sensitivity to the parameters, but all the scenarios assumed an exponential increase in energy consumptions, using effectively fixed compound annual growth rates (CAGRs).

In subsequent years, Andrae updated this modelling with new parameters, reflecting changes in technology (Andrae 2017; 2019; and 2020). Each time the new parameters resulted in at least 50% lower projected energy consumption than the previous modelling. This demonstrates the difficulty of making predictions for ICT energy and GHG emissions, and the dangers of relying on old estimates and applying growth rates based on historical trends. The Shift Project (2019a) used assumptions based on Andrae & Edler (2015) resulting in an over estimation of the global GHG footprint of the ICT sector. Belkhir & Elmeligi (2018) based assumptions on older studies and extrapolated these forwards at fixed growth rates to determine a current value, and then extrapolated these further forwards at the same rate well into the future. For example, the estimates for data centre emissions assumed a fixed 12% per annum growth rate extrapolated to 2040.

An extreme example of this is Huber & Mills (1999) study, which claimed that 'half of the electric grid will be powering the digital-internet economy within the next decade'. Clearly, 20 years later that is not the case.

Figure 5. Historical carbon footprint of ICT sector

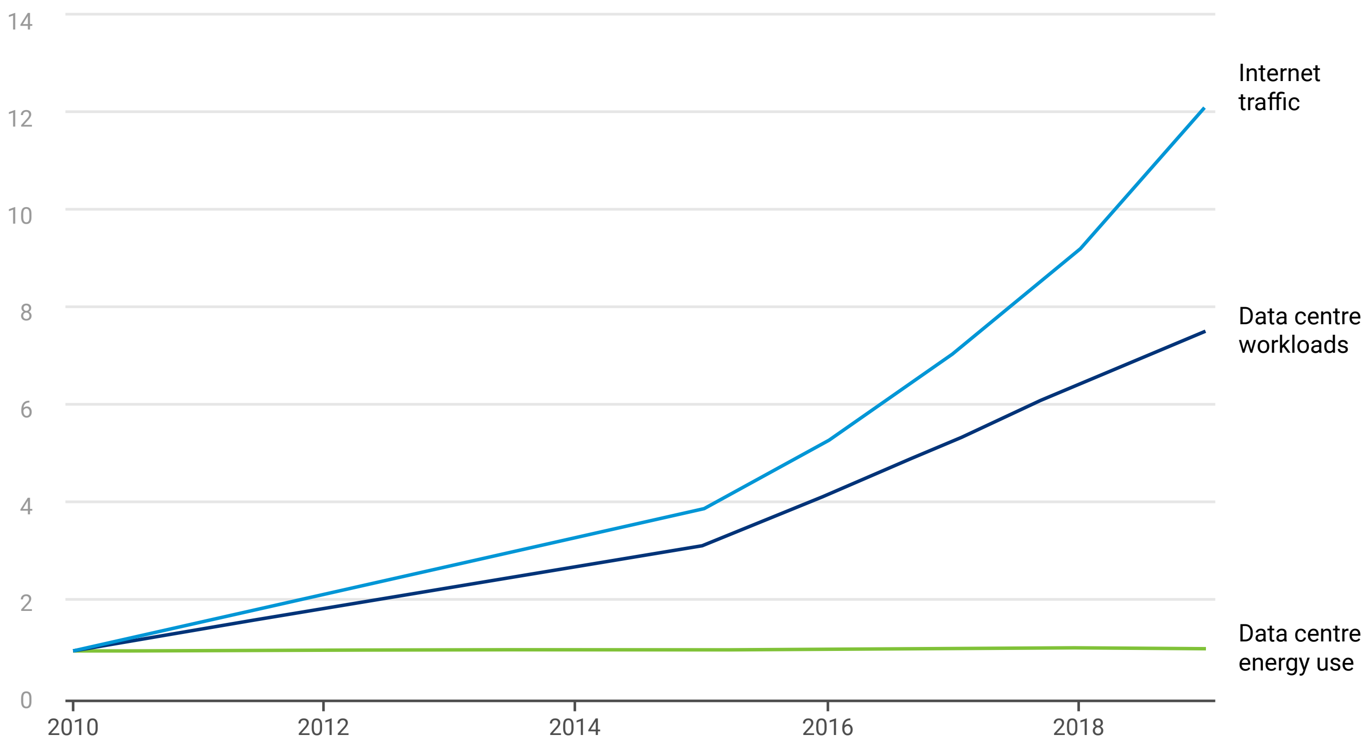


Source: (Malmodin, 2020a)

There is significant evidence that energy and GHG emissions are not directly linked to data traffic growth. This comes both from academic studies (such as Malmodin, 2020b; Kamiya, 2020; Masanet, 2020; Stobbe et al., 2015; Stobbe et al., 2021), and from annual and sustainability reports of various telecommunication network operators showing year-on-year decreases in network energy intensity (e.g. Cogent, Telefónica, Vodafone).

Overall, it is clear that internet data traffic along with data centre demands have grown steadily in the past decade. However, this growth has not resulted in a proportional growth in the energy consumption of ICT (Malmodin, 2020a; Kamiya, 2020). This decoupling of energy from data volumes is illustrated by Figure 6 below.

Figure 6. Global trends in internet data traffic, data centre workloads and energy use (2010-2019)



Source: (IEA, 2020a)
IEA analysis based on: Cisco, 2015; Cisco, 2018b; Cisco, 2019b; Masanet et al., 2020a

(All Figures indexed to 1 for 2010)

2.6. Current and historical emissions of ICT sector components

The current and historical emissions are now considered in more detail by the sub-sectors within the ICT sector's boundary. As mentioned above, these are: data centres, networks, end-user devices and E&M.

2.6.1 Data centres

Data centres act as centralised hubs for processing and storing data used for all internet activities or services, including video streaming but also corporate and government databases, weather forecasting, banking, websites used for commerce and information. This centralised processing ensures greater efficiency and better distribution of information. The growth of internet connectivity and data traffic volumes through data centres has driven up their workloads, that continue to rise year-on-year (Kamiya, 2020).

Data Centre processing and energy

Data centre workloads and energy use have risen in the past decade, however, there is some uncertainty around the magnitude of this trend and the total operational carbon footprint of data centres today. These differences in estimates are dependent on the choice of methodology and boundary for calculations. Masanet et al. (2020a) estimates that since 2010, global data centre energy use has only increased by 6% since 2010 to 205TWh in 2018. Where, this small rise in energy use occurred despite large expansions of data centre workloads and compute instances growing by 550%. The study followed a bottom-up approach to estimate global server energy use including traditional, cloud and hyperscale centres within its scope, but excluded non-CPU computing, such as cryptocurrency data mining, in its reporting. Malmodin (2020) estimated the total electricity use of data centres at 208TWh in 2018, or 0.9% of final global electricity demand, equating to approximately 0.2% of global carbon footprint. These studies along with the ITU all estimate similar values for the energy consumption of data centres, ranged between 200 – 208TWh over the past three years.

Conversely, Hintemann (2018) estimated that global data centre energy consumption increased by a third between 2010 to 2015, reaching 287TWh in 2015. This trend accelerated further in the subsequent two years, estimated at 350TWh by 2017. This report identified the growing role of Bitcoin data mining in driving up higher energy demands on global data processing. However, it is not clear whether this was included within the scope of these calculations (Hintemann, 2018; Hintemann and Hinterholzer, 2019).

One of the reasons for the differences in estimates between Hintermann and Masanet is the assumptions on the rate that more energy efficient hyperscale and cloud computing has replaced less efficient traditional data centres. This may well vary regionally, and would be addressed by more reliable data sources for different data centre types and performance (see conclusions in Masanet 2020b).

Rising demand beyond 2020

There is common agreement that data traffic demands on data centres are projected to continue, particularly for cloud data centre traffic, with Cisco projecting that this could reach 95% of total data centre traffic by 2021, which would represent a 3.3-fold growth of cloud traffic (Cisco Global Cloud Index, 2018a).

The question is how will these increased data and compute workloads translate into data centre energy consumption in the future. There is significant uncertainty around this. One of the key factors is by how much and how quickly cloud data centres are replacing traditional less energy efficient on-premises data centres.

This uncertainty is illustrated by two recent reports for the EU Commission. A report for DG Energy on the impact of ICT (EU Commission, 2020a) estimated data centre electricity consumption of the EU27 member states at 40TWh in 2020, rising to 43TWh by 2025. While a report for DG Connect on cloud computing technologies (EU Commission, 2020b) expects energy consumption of data centres in the EU28 to increase from 77TWh in 2018 to 93TWh in 2025.

These differences in data centre energy use projections vary due to both boundary definitions and the inherent uncertainty of predicting future emissions and the impacts of emerging technologies. Specifically, studies vary in their assessment of energy efficiency trends and to what extent they will continue to negate the environmental impacts of growing data workloads.

Energy efficiency of data centres

As mentioned previously, innovation in ICT has enabled more data to be processed and transmitted with the same amount of energy across the entire value-chain of ICT (servers, data centres and network equipment). Specifically, for data centres, the consolidation and virtualisation of data centre workloads into the cloud has enabled significant efficiency gains (Masanet, 2020a). Additional efficiency gains have been achieved through trends in end-user devices, such as shifting from desktops to use more energy efficient laptops, tablets and smartphones (Malmodin & Lundén, 2018a), or through changes in screen display technologies that have enabled significant reductions in power consumption. These improvements in ICT hardware efficiency have therefore compensated for the growth of network data volumes and the increased number of connected devices (Malmodin, 2016; Malmodin 2020a).

Some studies suggest data centre efficiency improvements are beginning to slow, as PUE (Power Usage Effectiveness) has plateaued since 2013 (survey by the Uptime Institute, 2019). However, these findings were based on an unweighted average of surveyed data centres, therefore relying on the scope of the survey, and not recognising the larger impact that hyperscale data centres will have compared to a small-scale data centre. Also, PUE performance only measures facility energy use, so does not account for server efficiency. This can be more accurately measured by monitoring the total energy use of data centres (Uptime Institute, 2019). Conversely, industry experts suggest that the growth in energy demand that has historically been compensated by efficiency improvements, might continue to hold in the future for data centres (Kamiya, 2020; Masanet, 2020a; Shehabi, 2018; Koomey, 2011b). Masanet (2020a) indicates there may be capacity for further technological and infrastructural efficiency improvements of data centres, that have previously enabled the growth of internet services with only a relatively small increase in associated energy consumption. In tandem, data centres could continue to enhance server efficiencies (through virtualisation and use of advanced cooling systems) and further shift towards more efficient cloud computing.

Additionally, a general shift from inefficient, smaller-scale data centres to hyperscale and cloud centres has enabled greater efficiency of scale, utilising the most advanced cooling and power saving technology to reduce their PUE and infrastructure footprint (Royal Society, 2020; Masanet, 2020a). Infrastructure energy savings could continue in the future, if hyperscale data centres continue to replace smaller scale data centres. This trend is suggested to continue, as the number of hyperscale data centres were projected to nearly double from 2016-2021, to account for 53% of global servers by 2021 (EU Commission, 2020a; Cisco, 2018a). However, this shift in data centre infrastructure to hyperscale may be approaching its limit in the next decade, so the added efficiency gains may not continue indefinitely.

Conversely, other studies suggest that energy efficiency trends for data centres have slowed and may not hold beyond 2020 (Royal Society, 2020). Waldrop (2016) suggests that Moore's law could be impeded by the technical/physical limitations of transistor technology. However, Malmodin & Lundén (2018a) associates this deceleration of efficiency with a time lag between research findings of, and the impacts of, efficiency gains on data consumption. Meanwhile, other studies suggest this efficiency balancing act could become displaced by electricity consumption (Lange, Pohl, and Santarius, 2020; Bordage, 2019).

It is also important to consider software's potential for increasing the rate of efficiency improvements. Only considering hardware improvements gives an incomplete picture. Although technology may be approaching the physical limits of transistor density, software can provide additional energy efficiency improvements that will compensate for the hardware energy use to some degree (Leiserson et al., 2020).

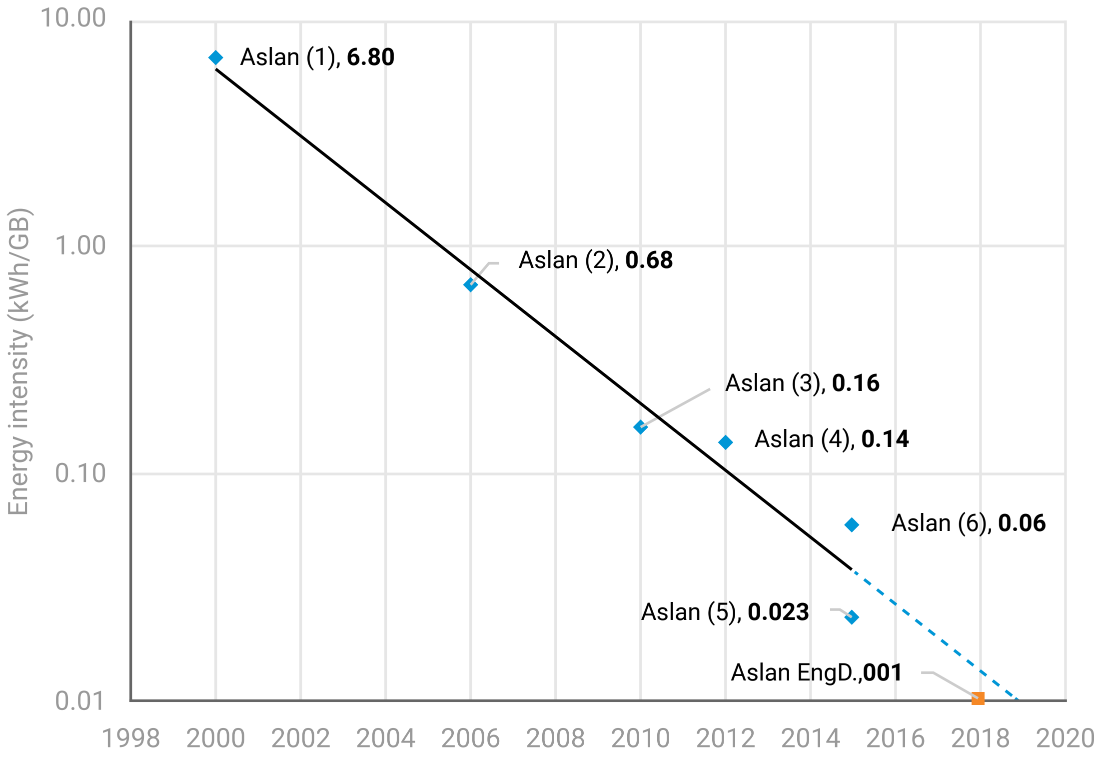
Other studies also suggest that the trends in improving energy efficiency for data centres could continue, Malmodin (2020a) claiming 'data is a function of technology (efficiency)'. Specifically, identifying opportunities for further efficiency gains through mobile networks expansion shift to 5G (Malmodin, 2020a) as well as the capacity for further technological and infrastructural efficiency improvements of data centres (Masanet, 2020b). Clearly, the magnitude and longevity of these energy efficiency trends remain uncertain and any projections should be understood carefully in the light of their assumptions.

2.6.2 Network data traffic and energy

Again, there is common agreement that network data transmission is growing rapidly. Malmodin (2020a) estimated that internet data traffic grew by a factor of 12 in the past decade. While, Cisco (2019b) projected a three-fold increase in total IP traffic between 2017 and 2022, or annual growth rate of 26%, with the total annual traffic surpassing 3 Zetabytes by 2020. Despite the significant growth in network data traffic, the energy consumption associated with networks transmission has only slightly increased in the last five years, (with some network operators holding energy consumption at a constant level), and emissions falling due to increased use of renewable electricity (both as average grid emissions intensities fall, and as network operators purchase increasing amounts of renewables through PPAs and renewable tariffs).

Major network operators regularly publish their energy and emissions data in their annual and sustainability reports, which provides evidence for this trend. (For example, AT&T, BT, Cogent, Sprint, Telefónica, T-Mobile, Vodafone – see Figure 8 and Figure 9). The electricity intensity of data transmission, defined as the energy consumption per data volume (kWh/GB) is continuing to fall year-on-year due to changes in technology. Aslan et al. (2018) projected that the electricity intensity of data transmission halved approximately every two years from 2000 to 2015 across ICT-mature countries (see Figure 7). This is in agreement with Malmodin & Lundén (2018a) that energy intensity can be decoupled from data growth, because of the technological improvements of ICT equipment and the subsequent energy efficiency gains.

Figure 7. Fixed network energy intensity (LOG scale)



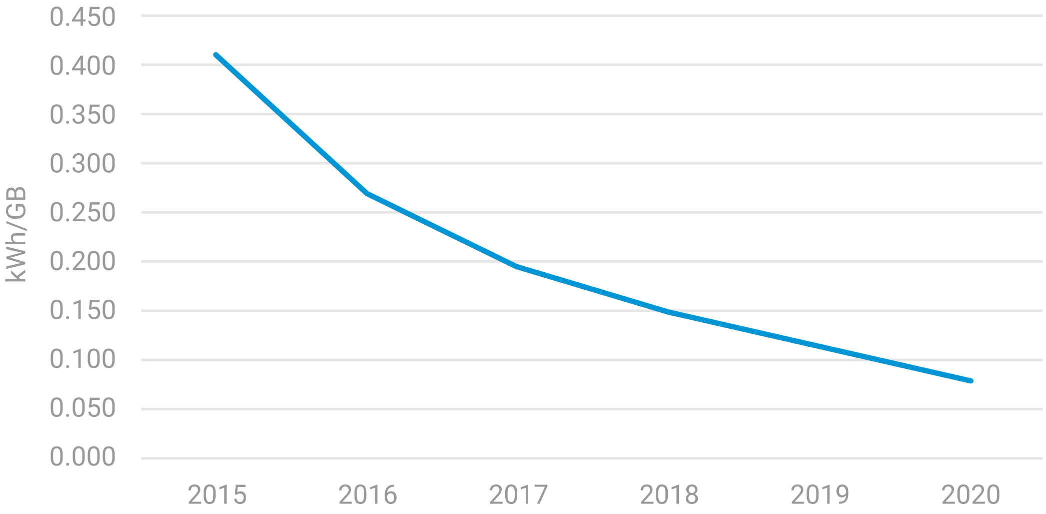
Reproduced from: Aslan et al., 2018; Aslan, 2020.

Note: Data points 'Aslan (1-6)' are from Aslan et al. (2018); data point 'Aslan EngD.' is from Aslan (2020).

Solid line shows the regression for data points 'Aslan (1-6)' for years 2000 to 2015.

Dashed line shows extrapolation of the regression line to 2019.

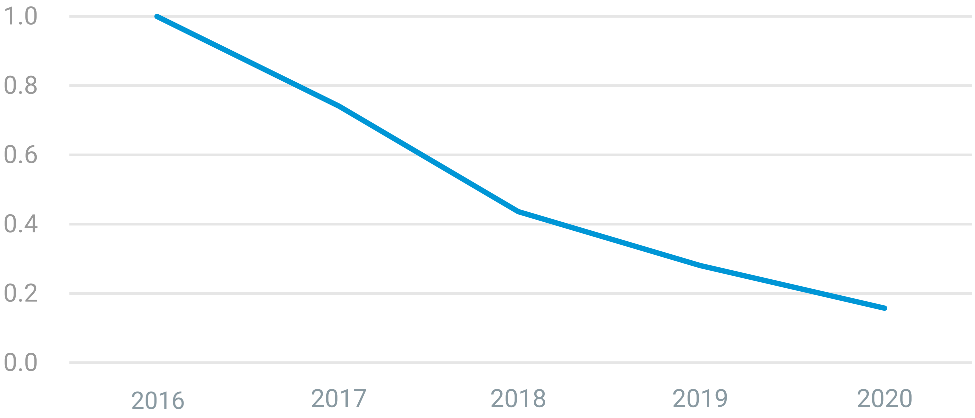
Figure 8. Telefónica energy intensity kWh/GB



Source: data points from Telefónica (2019); Telefónica (2020)

Note: Telefónica is a mobile network operator, and the energy intensity is expected to be higher relative to fixed-line networks. This chart is presented to show the trend in decreasing energy intensity.

Figure 9. Cogent network electricity intensity index by traffic (indexed to 2016)



Source: data points from Cogent (2020b)

Note: Cogent report this information indexed relative to 2016.

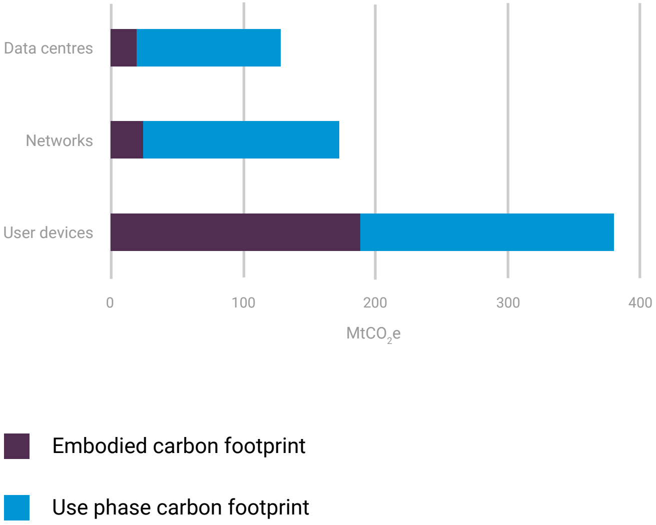
2.6.3 End-user devices

User devices make up the largest portion of carbon emissions of ICT. The emissions of end-user devices making up just over 50% of ICT's overall footprint (shown by Figure 10 below) with the largest portion coming from PCs and laptops (Malmodin 2020a). Malmodin (2018a) suggested that the emissions contribution of user devices decreased between 2010-2015. This is due to technology efficiency trends in user devices, and the trend to use smaller devices (e.g. from PCs and laptops to tablets and smartphones).

Changes in types of user devices:

There is an increasing shift in ICT user device preferences from larger PCs and laptops to mobile devices, supported by apps. This shift has accelerated due to the technological advances in mobile technology, enabling smaller devices to support versatile functions and to maintain higher bitrate speeds to stream video with a higher quality. This has also led to energy efficiency improvements as desktops are replaced by laptops, and laptops are replaced by less energy intensive mobile and tablet devices. This technology shift is expected to continue, with wifi and mobile devices expected to constitute 70% of total IP traffic by 2022, up from around 50% in 2019 (Cisco, 2019b).

Figure 10. Breakdown of ICT sector emissions by component



Reproduced from: Malmodin (2020a)

2.6.4 Entertainment and Media (E&M)

We discuss here the global carbon footprint of E&M, using the narrow emissions boundary definition given earlier (E&M comprises all electronic equipment utilised for media and entertainment purposes, including: TVs, cameras, and other E&M consumer electronics, as well as physical paper media and printing). These emissions are estimated at 640MtCO$_2$e globally for 2015 (Malmodin, 2018a), with the majority of these due to the emissions of TVs.

These E&M emissions have, historically, followed similar energy trends to those of ICT, driven largely by increasing energy efficiency of TVs. Previous studies suggested that in Sweden, by 2010, both ICT and E&M emissions had peaked and remained independent/decoupled from rising data traffic volumes, that continued beyond this point (Malmodin & Lundén, 2016). Malmodin & Lundén's (2018a) follow-up study estimated that the global electricity consumption of E&M had decreased to 585TWh by 2015, falling by 30% from 2010 levels (Figure 11).

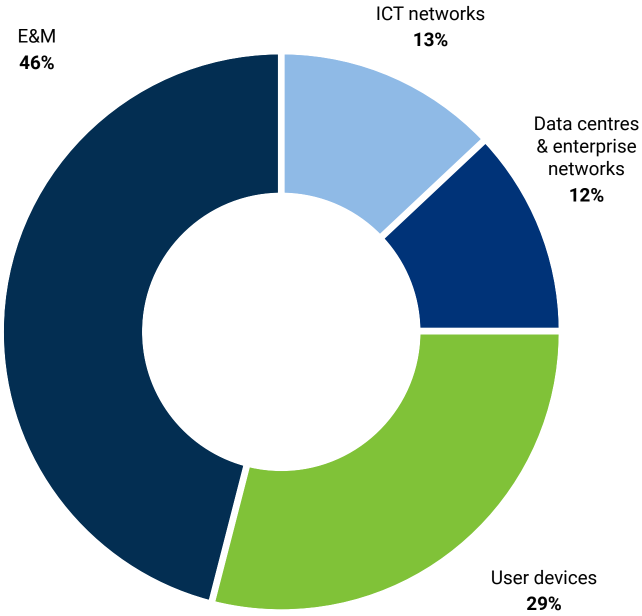
E&M's carbon footprint reductions have been enabled through energy efficiency improvements in hardware and also through a shift towards digitised media, away from paper media production and other physical media such as discs, tapes, and hard drives. In particular, energy efficiency gains have been achieved through improvements in device display technology. Specifically, television displays consume less energy per surface area, so are more energy efficient, offsetting the continued growth of average TV panel sizes. This shift to more efficient devices has resulted in decreased energy use of households, as indicated by the Fraunhofer Institute study of energy use for consumer devices in US homes (Singh et al., 2019).

However, the future total energy use for TVs is likely to level off, and may increase with increasing number of TVs per household and increasing screen size. The future trends may vary significantly by country, with different trends emerging between Europe and the USA.

While the operational electricity energy use of paper media devices (printers, faxes, photocopiers etc) halved between 2010-2015, as a result of reduced paper use in offices and fewer devices required for normal operations (Malmodin & Lundén, 2018a).

There have been no comprehensive global studies of the carbon footprint of other aspects of the E&M sector, thus the narrow definition used above for defining the global emissions of E&M, which excludes cinemas, theatres, and other arenas or physical site events (e.g., sports), and content creation such as film and TV production. Although there exist initiatives for the carbon footprinting of individual events, and of film production, most notably that of Albert.[2]

Figure 11. Carbon footprint of ICT (including E&M sector) (2015)



(Adapted from Malmodin & Lundén, 2018a)

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[2] https://wearealbert.org/production-handbook/production-tools/

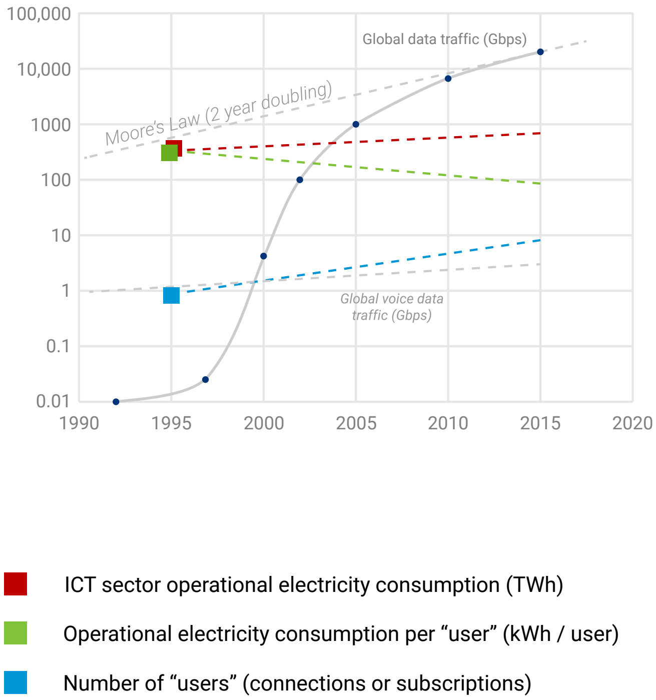
2.7. Growth of global data consumption

The expansion of global internet networks, connected devices and user consumption has led to a steady growth of data volumes. This trend has been apparent since the early 1990s. Between 1990–2000, global data traffic rose exponentially, slowing slightly between 2010–2020, showing a 12-fold increase in data. It is projected to continue growth but at a lower rate, estimated between a factor of five to 10 over the next decade (Malmodin, 2020a).

This has fuelled concerns that global ICT emissions and energy use is following a similar trend. However, as mentioned previously, increased data usage does not correlate directly with increased energy use of the ICT sector (as shown by Figure 12 below).

Overall trends in data traffic are projected to continue increasing: total IP traffic (Figure 13) and mobile data traffic (Figure 14).

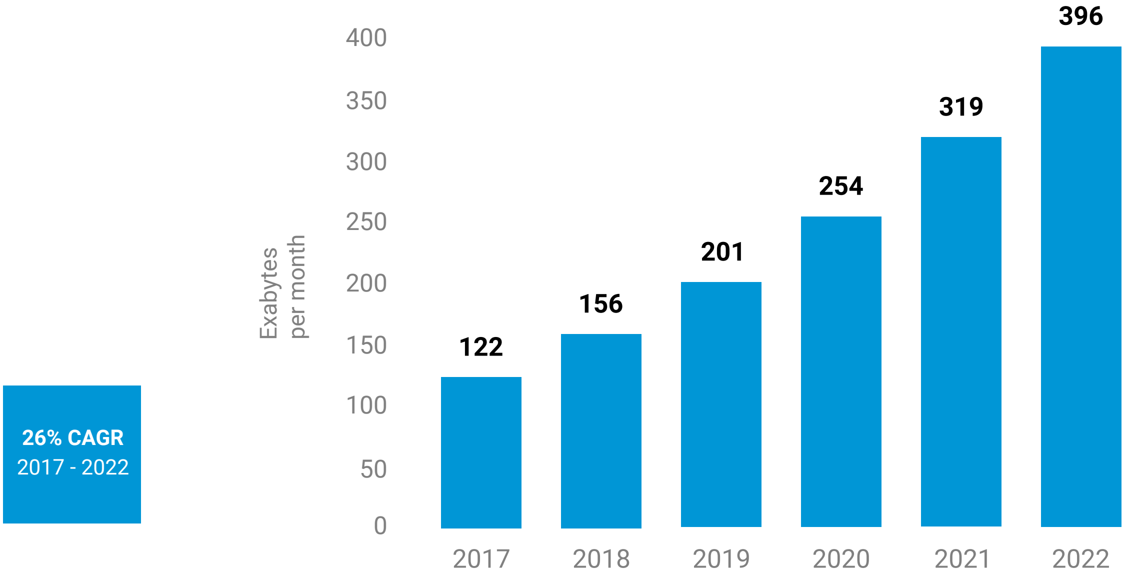
Figure 12. Total data traffic 1990 - 2015



1995 - 2015
3 x energy
10 x users
1,000,000 x data traffic
(10,000 x with also voice data)

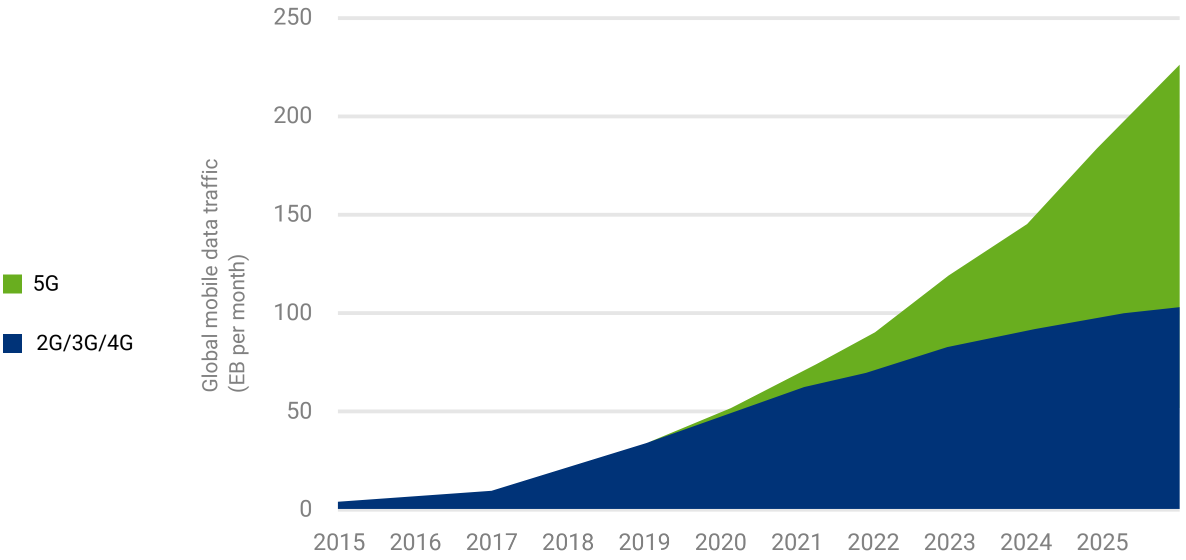
Source: Malmodin & Lundén (2018a)

Figure 13. Cisco VNI Global IP traffic forecast (2017 – 2022)



Source: Cisco (2019b)

Figure 14. Global mobile data traffic projections (2020 – 2026)



Reproduced from: Ericsson (2020)

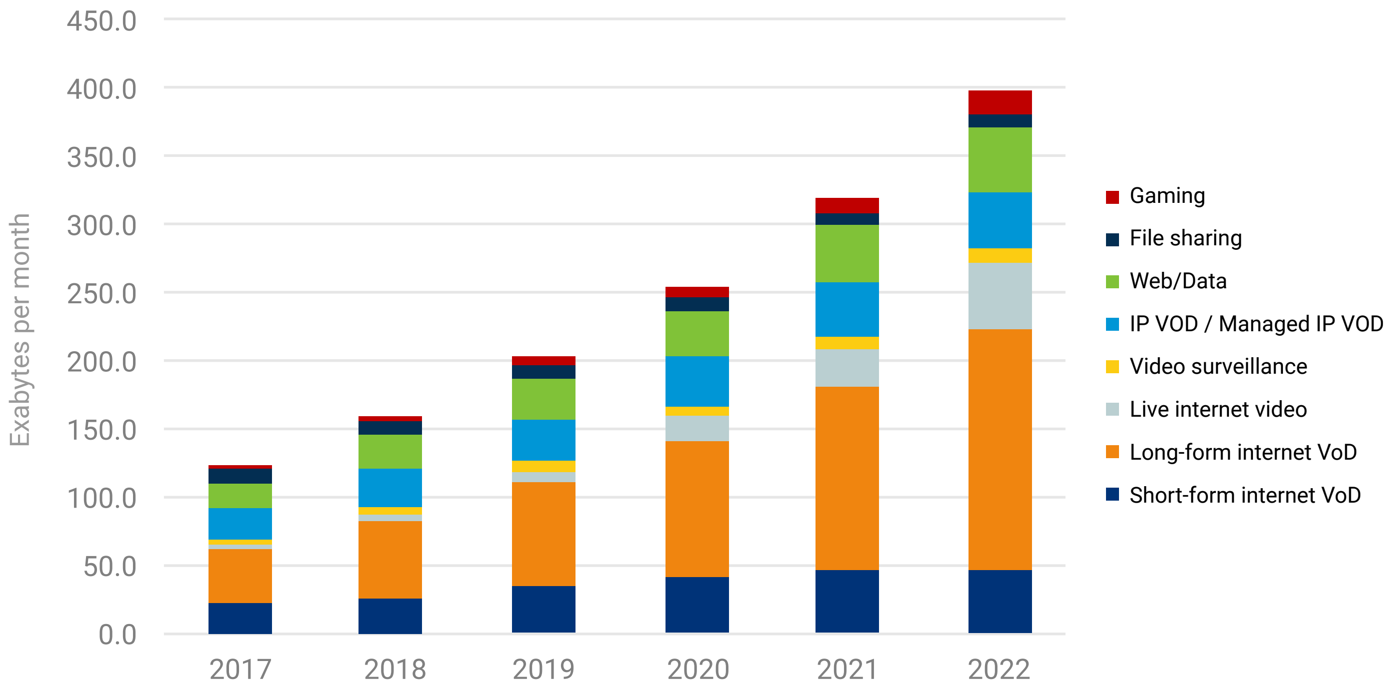
Increase in video streaming

Along with a shift in device preference, there has been a shift in the nature of device data usage and activity. In particular, the demand for video streaming, gaming and telecommunications is growing substantially. Cisco regularly publishes its VNI forecasts of total IP data traffic projections, with the latest analysis published for the five-year period 2017-2022 (Cisco, 2018c; Cisco, 2019b). Cisco defines Internet Traffic as 'all IP traffic that crosses an internet backbone', and total IP traffic includes Internet Traffic plus Managed IP Traffic, which is defined as 'corporate IP WAN traffic and IP transport of TV and VoD'. The breakdown of global IP traffic is shown in Figure 15, and the compound annual growth rates for the separate data types is shown in Table 2. (Note, Cisco uses the criteria for "long-form video" as 'video sites whose average viewing time is longer than five minutes').

It can be seen from Table 2 that long-form internet video-on-demand has a CAGR of 33% for 2017-2022, and in 2020 was forecast at about 40% of total IP traffic, or about 45% of total internet traffic. While for total video traffic, Cisco forecasts that global IP video traffic will be 82% of all IP traffic in 2022, up from 75% in 2017, at a CAGR of 29% for 2017-2022 (Cisco, 2019b).

Note that these Cisco forecasts are from analysis carried out in 2018, so are not considering any impact of increased video streaming or internet traffic from COVID.

Figure 15. Global IP data traffic by type



Source: Carbon Trust analysis of Cisco VNI Global IP Traffic Forecast, 2017–2022 (Cisco 2018c)

Table 2. Compound annual growth rates (CAGR) for IP Traffic data types (2017-2022)

Data type	CAGR (2017-2022)
Short-form internet VoD	20%
Long-form internet VoD	33%
Live internet Video	75%
Video surveillance	45%
IP VOD / Managed IP VOD	12%
Web/Data	20%
File sharing	-2%
Gaming	55%
TOTAL	**26%**

Source: Carbon Trust analysis of Cisco VNI Global IP Traffic Forecast, 2017–2022 (Cisco 2018c; and Cisco 2019b)

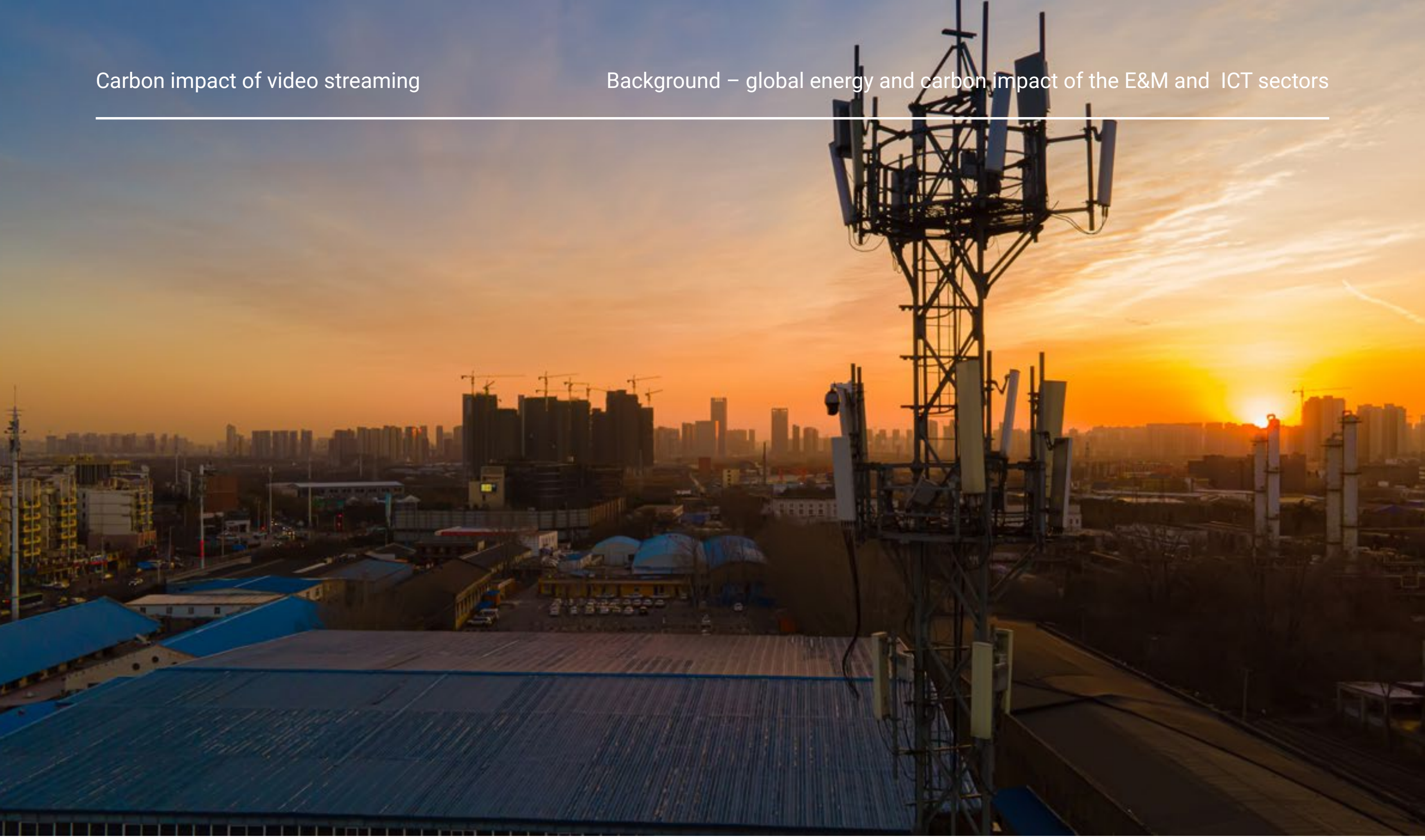
Note: some figures have been rounded.

Other estimates of the proportion of traffic that is due to video streaming may use slightly different definitions compared to the Cisco analysis. Sandvine reports that in 2020 all video streaming accounted for over 65% of all cellular network traffic by volume and 58% of total internet traffic (Sandvine, 2020a; Sandvine, 2020b).

Concern over increasing video streaming has generated a lot of media attention, incorrectly asserting that increased data traffic trends for video streaming are causing an increase in the ICT sector's carbon footprint.

Internet access & IoT trends

The ICT sector has undergone huge expansion since the early 1990s, increasing its application across many sectors and industries. This shift to digitalisation has brought huge benefits to society such as universal access of information, ease of communication, efficiency of process as well as enabling emissions savings across other sectors. As such, global internet accessibility and user connectivity has grown. This trend is projected to continue, with 66% of the global population expected to have access to the internet, and 70% will have mobile connectivity by 2023. Additionally, the global average connected devices per person could reach 3.6 by 2023, up from 2.4 in 2018 (Cisco, 2020). While the application of the Internet of Things (IoT)/M2M connections is projected to reach 4.4 billion by 2023 (representing a four-fold annual increase from 2018) (Cisco, 2020) and grow exponentially to 2026 at a CAGR of 23% for cellular IoT connections (Ericsson, 2020). Additionally, the growth of connected IoT devices such as smart meters or video surveillance are projected to account for over half of all connected devices by 2023 (Cisco, 2020). These trends will inevitably place greater energy and data demands on the ICT sector. However, studies suggest that IoT devices use very small amounts of energy, thus the addition of extra connection points and devices would only marginally increase the overall carbon footprint of the ICT and E&M sectors by 2020 (Malmodin & Lundén, 2018a) and by 2025 (Das & Mao, 2020).



2.8. Future trends in ICT carbon emissions footprint

Forecasting future ICT emissions is fraught with uncertainty. Emissions projection estimates rely on the extrapolation of figures from past trends, using historical ICT data. However, the speed of ICT technological advancement and gains in energy efficiency usually outpace these estimates, rendering assumptions outdated. As mentioned previously, Andrae & Edler (2015) paper's projected worst case scenario has had to be revised in Andrae et al. (2017), Andrae (2019), and in Andrae (2020) in order to account for this ever-changing environment. Therefore, the accuracy of ICT future emissions projections is the subject of uncertainty and scrutiny.

It is difficult to project far into the future of the ICT sector, due to the rapid nature of technology advancements and improvements in energy efficiency. There is debate about whether this trend will continue to hold. Some studies suggest that computing efficiencies may reach their technological limits (Waldrop, 2016), however, to date, this has yet to be proven. While, other studies posit that energy efficiency trends will eventually peak, and beyond this point, the energy impacts of increasing data traffic and connected devices will no longer be negated by increased energy efficiency.

Emerging trends in ICT, beyond 2020, add to the uncertainty of forecasting future emissions. These trends include machine learning, blockchain and cryptocurrencies, IoT and 5G mobile networks (IEA, 2020a). The wider impacts of these trends on energy demand are unclear. They will contribute substantially to data centre workloads and internet data traffic but also present opportunities for technology efficiency gains. For example, energy improvements are predicted for future mobile networks, as more efficient 4G networks begin to dominate the market. This trend could accelerate further by 2025, as 5G networks emerge (Cisco, 2020), with leading operators suggesting 5G could be between ten to 20-fold more energy efficient per byte than 4G (Huawei, 2019). Whether energy efficiency improvements will outpace increases in data traffic is unclear – a number of mobile network operators expect that the roll out of 5G will increase their total energy consumption.

Even if there are overall increases in energy consumption, the total emissions of the ICT sector are likely to fall significantly, as larger numbers of network and data centre operators move to using 100% renewable electricity, and the national electricity grids continue to decarbonise.

To relate this back to the subject of this white paper – video streaming has touchpoints with ICT along the video delivery process, and is therefore dependent on ICT. However, video streaming is only one of the services that relies on the ICT infrastructure, and has different demands and trends from other rapidly developing areas such as IoT and automation.

3. Methodology and approach

This section provides a summary of the methodological approach used to estimate the carbon emissions impact of video streaming. An overview of this approach, referred to as the conventional approach within this paper, is discussed including the characteristics of the conventional approach, the boundary used to define the footprint and a brief explanation of allocation and its role in this estimation technique. Following this overview, the key parameters used in this estimation approach and a high-level explanation of their derivation is provided.

3.1. Overview of the conventional approach

Characteristics

- Utilises average transmission network energy intensity estimates derived from academic literature
- Relies on an allocation approach to attribute the energy consumption of a shared network to the services that use the network
- Transmission network energy consumption is allocated to streaming based on data volume transmitted for one hour of streaming
- Data centre and user media devices energy consumption is allocated based on viewing duration

Intended use

- Organisational foot-printing for video streaming service providers
- Network/system level carbon footprint estimation

Strengths

✓ Well understood and accepted by the industry

✓ Accounts for all energy consumption across the network when scaled to network level

✓ Straightforward accounting and allocation approach

Limitations

X Representative of a particular network and period of time

X Sensitive to characteristics of the transmission network considered for estimation. These network characteristics include network equipment efficiency, quantity of network users and data traffic

X Unsuitable for estimation of the marginal carbon impact due to a change in level of service, such as a change in video quality

The conventional approach may be described as an average energy intensity approach, as it utilises average transmission network energy intensity[3] to estimate the network energy consumption attributable to video streaming. Furthermore, as the transmission network is an interconnected system of network users and services, the energy consumed by the network is shared among the various users and services that access the network. In order to divide the network energy consumption among the various users and services, an allocation approach is employed. In this case, the transmission network energy consumption is allocated based on the volume of data transmitted across the network by the video streaming service, hence the utilisation of transmission network energy intensity. An implication of this is that energy consumption of idle network equipment is allocated based on the internet service's transmitted data volume, with higher bitrate services like video streaming receiving a larger share of idle energy. Other allocation approaches are conceivable, such as network energy allocation based on share of peak network traffic or based on duration of use, but allocation based on data volume is the typical focus in academic studies and therefore the most widely understood.

As the energy intensity is derived at the network level, the conventional approach is widely accepted as an appropriate estimation methodology for organisational foot-printing for organisations that provide internet services, such as video streaming providers, and if employed across an entire transmission network, would account for all of the energy consumed. This approach is also appropriate to use for a network or system level estimation of video streaming's carbon footprint. For this study, the conventional approach has been adapted to estimate the carbon impact for one hour of video streaming.

There are sensitivities and limitations to the conventional approach, which should be understood as well. The conventional approach is representative of a particular network and period of time. For this study, the parameters used are characteristic of mature transmission networks in 2020 such as those found in Western and Northern Europe. As networks are continually evolving, the parameters used in this approach should be updated to reflect the characteristics of the network during the period of time being evaluated. Transmission network energy intensities in particular are quickly outdated, as discussed in the preceding sections of this paper. Additionally, while the conventional approach is suitable for organisational foot-printing purposes, it is unsuitable for estimation and analysis to assess the marginal carbon impact due to a change in level of service, such as comparing the carbon emissions of streaming in different resolutions. This is primarily due to the conventional approach's reliance on average transmission intensities, which do not reflect the dynamics of network transmission equipment as network load changes.

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[3] Transmission network energy intensity relates the network energy consumed to a metric, in this case the data volume transmitted through the network. The unit of measure for transmission network energy intensity is kWh/GB, where kWh represents the energy consumed by the transmission network and GB represents the data transmitted over the network, in gigabytes. Transmission network energy intensity estimates are generally derived and published through academic literature using a top-down evaluation of energy consumption of a transmission network and the volume of data that is transmitted across the network over a specified period of time.

3.2. Approach boundary

The conventional approach draws its boundary around the component stages of the video streaming process: data centres, transmission and end-user devices, as shown in Figure 16 below. The lifecycle boundary for this approach includes only the in-use electricity consumption of each video streaming process component and excludes the embodied carbon and end-of-life emissions of data centres, network equipment and end-user devices.

These component stages are discussed in further detail below and assumptions related to each component are presented in Table 3.

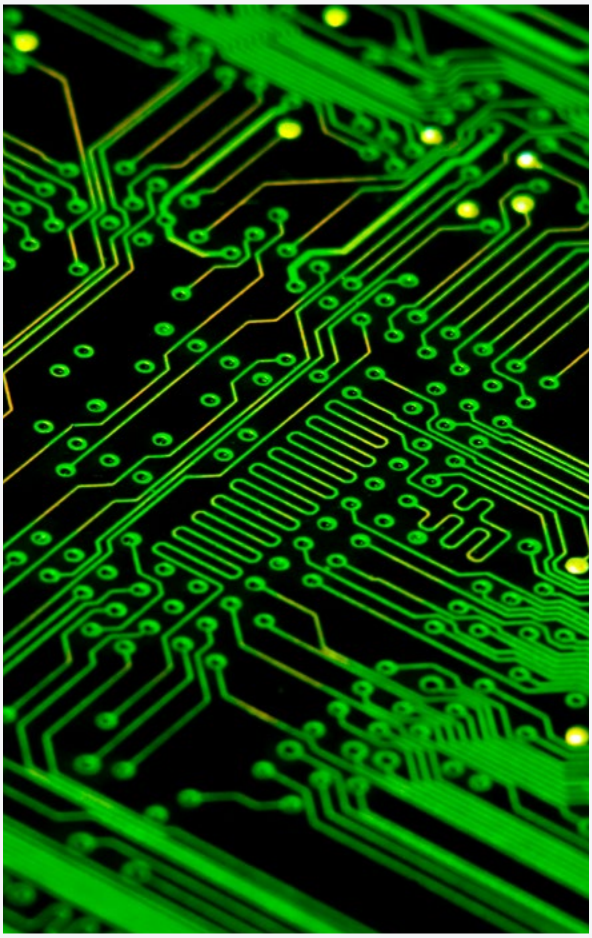
3.3. Data centres

The data centres process component encapsulates both the cloud storage and encoding services and content delivery networks (CDN). In simplistic terms, data centres are where the video data are stored and retrieved when a user streams video over the network. CDNs serve a particular region by storing more proximate copies of the original video data which helps to reduce congestion on the network and improve transmission times. Within the conventional approach methodology, the energy consumption related to data centres is estimated with an energy intensity per viewing hour of 1.3Wh/hour, which is derived from a selection of DIMPACT members based on measured data in 2020. The energy consumption related to data centres is estimated as shown in equation (1).

(1)

$$ED_C = ID_C \times D$$

Where ED_C is the data centre energy consumption, ID_C is the energy intensity of data centres and D is the duration of video streaming, in this case one hour.



Parameter definitions

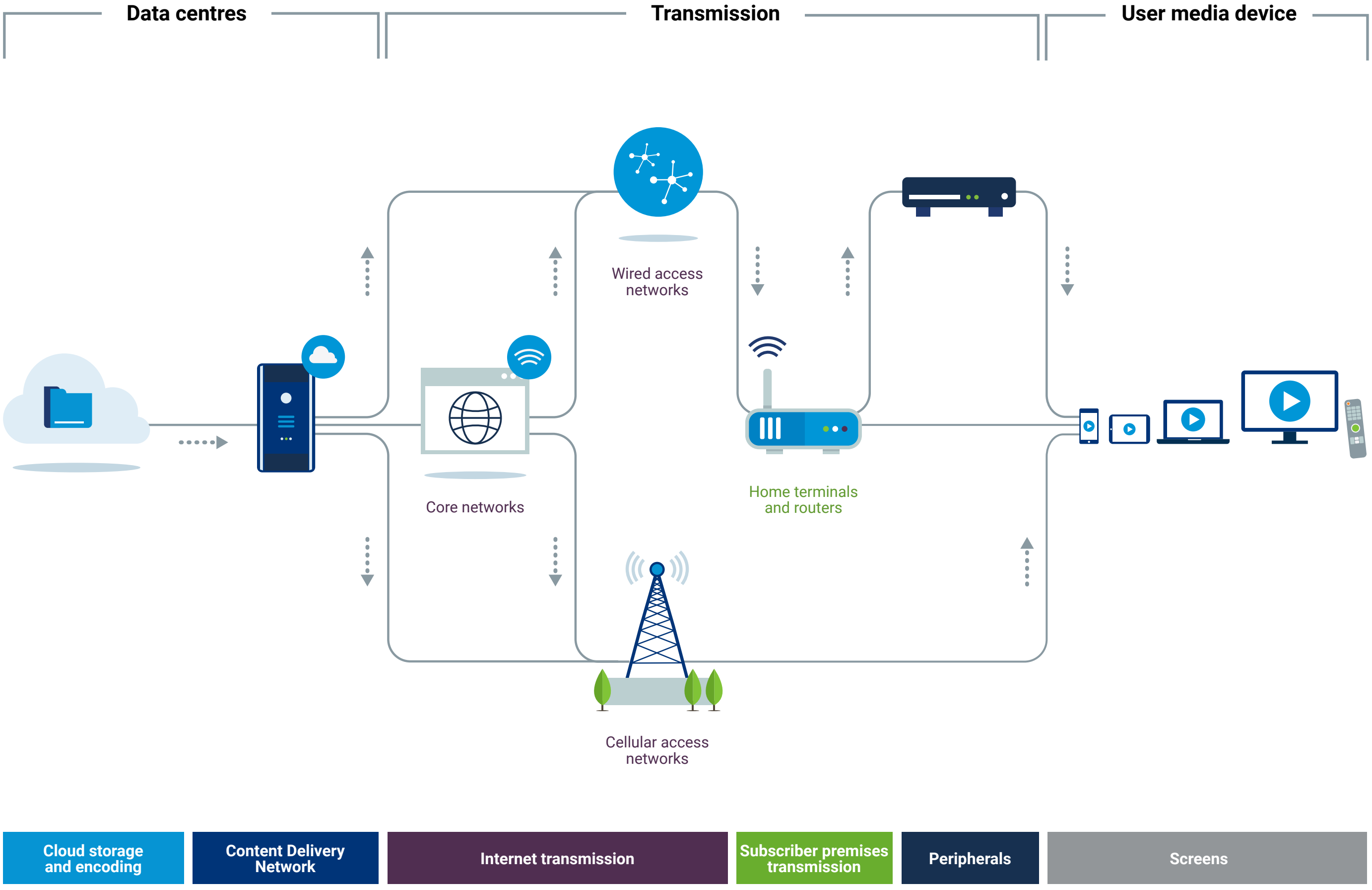
Global parameters	E_V = energy consumption of the video streaming process C_V = carbon emissions of the video streaming process $EF_{g,n}$ = electrical grid emission factor for region, n D = duration of video streaming R = data transmission rate
Data Centres & Content Delivery Network	E_{DC} = data centre energy consumption I_{DC} = energy intensity of data centres
Transmission – Network (Core & Access)	E_{FN} = fixed network energy consumption I_{FN} = energy intensity of fixed network transmission $P_{FN,i}$ = proportion of viewing time over fixed network at data transmission rate Ri relative to the entire streaming service E_{MN} = mobile network energy consumption I_{MN} = energy intensity of mobile network transmission $P_{MN,i}$ = proportion of viewing time over mobile network at data transmission rate R_i relative to the entire streaming service
Transmission - Home router	E_{HR} = home router energy consumption I_{HR} = energy intensity of home router transmission
End-User devices	E_{VD} = viewing device energy consumption W_s = average power consumption of screens W_p = average power consumption of peripherals $P_{s,i}$ = proportion of viewing time at $W_{s,i}$ relative to the entire streaming service $P_{p,i}$ = proportion of viewing time at $W_{p,i}$ relative to the entire streaming service

3.4. Transmission network

The next component of the video streaming process is the transmission network, which includes energy consumption over both fixed and mobile networks, which can be further broken down into core network transmission, access network transmission and subscriber premises equipment (e.g. home wifi routers).

For the conventional approach, transmission network energy intensities are derived from academic literature for fixed and mobile networks. These estimates include both the core and access network elements in an aggregated figure.

Figure 16. Video streaming process map indicating the components that make up the video streaming process. The associated energy intensities of the transmission network elements are included



Energy allocated based on total viewing hours

Core and access networks

Fixed network energy = 0.0065 kWh/GB

Mobile network energy = 0.1 kWh/GB

Home routers

0.025 kWh/GB
(only applies to fixed networks)

Energy allocated for one hour of streaming

Conventional approach

Table 3. Conventional approach assumptions by streaming process component

Streaming component	Conventional approach assumptions
Data centres & Content Delivery Network	Energy intensity, I_{DC} (2020) = 1.3Wh/hr Derived from a selection of DIMPACT members, based on measured data in 2020
Transmission – Network (Core & Access)	Fixed network • Energy intensity, I_{FN} (2020) = 0.0065kWh/GB • Derived from Aslan et. al, 2018 using the regression analysis presented in the paper Mobile network • Energy intensity, I_{MN} (2020) = 0.1kWh/GB • Sourced from Pihkola et. al, 2018
Transmission - Home router	• Energy intensity, I_{HR} (2019) = 0.025kWh/GB • Based on 10W home router (only used with fixed networks) and average household fixed network data consumption derived from Ofcom figures • Only applicable to fixed network viewing
Data transmission rates	Fixed network • Standard definition (SD): 2.22Mbps (1GB/hr) • Full high definition (FHD or HD): 6.67Mbps (3GB/hr) • Ultra-high definition (UHD or 4K): 15.56Mbps (7GB/hr) Mobile network • Save data setting: 0.37Mbps (0.17GB/hr) • Automatic data setting: 0.56Mbps (0.25GB/hr) • Maximum data setting: 6.67Mbps (3GB/hr) These figures are derived from published Netflix figures on data usage (Netflix, 2021)
End-user devices	• Reasonable estimates of average power (W) for specific devices, see Appendix for details • The standby time of end-user devices was not included in this analysis

The fixed network energy intensity used in the conventional approach is 0.0065kWh/GB, which is representative of fixed network energy intensity in 2020. This figure is derived through academic literature (Aslan et. al, 2018), where transmission network energy intensities were evaluated and consolidated from a number of academic studies to generate estimated fixed network energy intensity from 2000 to 2015. A regression analysis was performed and this regression was used to extrapolate fixed network energy intensity to 2020, resulting in the figure used in the conventional approach. The energy consumption from fixed network transmission is represented below by equation (2) for a single viewing scenario and by equation (3) for a streaming service with a mix of bit rates.

(2)

$$E_{FN} = I_{FN} \times D \times R$$

(3)

$$E_{FN} = I_{FN} \times D \times \sum_{i=1}^{n} R_i \times P_{FN,i}$$

Where E_{FN} is the fixed network energy consumption, I_{FN} is the energy intensity of fixed network transmission, R is the data transmission rate and $P_{FN,i}$ is the proportion of viewing time over fixed network at data transmission rate R_i relative to the entire streaming service.

The mobile network energy intensity used in the conventional approach is 0.1kWh/GB and is representative of mobile network energy intensity in Finland in 2020. This figure is sourced from academic literature (Pihkola et al., 2018), where mobile network energy intensity was estimated using publicly reported energy consumption figures from mobile network operators and data traffic figures from the Finnish Communications Regulatory Agency (FICORA). A regression analysis was then performed to estimate the mobile network energy intensity in 2020. The energy consumption from mobile network transmission is represented below by equation (4) for a single viewing scenario and by equation (5) for a streaming service with a mix of bit rates.

(4)

$$E_{MN} = I_{MN} \times D \times R$$

(5)

$$E_{MN} = I_{MN} \times D \times \sum_{i=1}^{n} R_i \times P_{MN,i}$$

Where E_{MN} is the mobile network energy consumption, I_{MN} is the energy intensity of mobile network transmission and $P_{MN,i}$ is the proportion of viewing time over mobile network at data transmission rate R_i relative to the entire streaming service.

The remaining element of the transmission network is the subscriber premises equipment, which is represented by home routers in the conventional approach and only applies to video streaming over fixed network. The home router energy intensity used in the conventional approach is 0.025kWh/GB which is derived based on the annual energy consumption of a 10W home router and fixed network data consumption per capita figures relating to 2019 and published by Ofcom in 2020 (Ofcom, 2020a). The energy consumption of home routers is represented below by equation (6) for a single viewing scenario and by equation (7) for a streaming service with a mix of bitrates.

(6)

$$E_{HR} = I_{HR} \times D \times R$$

(7)

$$E_{HR} = I_{HR} \times D \times \sum_{i=1}^{n} R_i \times P_{FN,i}$$

Where E_{HR} is the home router energy consumption and I_{HR} is the energy intensity of home router transmission.

3.5. End-user devices

The final component of the video streaming process included in the conventional approach is end-user devices, which includes screens (e.g. TVs, laptops, smartphones) and peripherals (e.g. set-top boxes and gaming consoles). A selection of end-user devices was researched and a reasonable estimate of average hourly energy consumption was associated with each device, see Appendix for detailed information. The energy consumption of user devices is represented below by equation (8) for a single viewing scenario and by equation (9) for a streaming service with a mix of devices.

(8)

$$E_{VD} = \left(W_s + W_p\right) \times D$$

(9)

$$E_{VD} = \left(\sum_{i=1}^{n} W_{s,i} \times P_{s,i} + \sum_{i=1}^{n} W_{p,i} \times P_{p,i}\right) \times D$$

Where E_{VD} is the viewing device energy consumption, W_s is the average power consumption of screens, W_p is the average power consumption of peripherals, $P_{s,i}$ is the proportion of viewing time at $W_{s,i}$ relative to the entire streaming service and $P_{p,i}$ is the proportion of viewing time at $W_{p,i}$ relative to the entire streaming service.

In total, the energy consumption of video streaming using the conventional approach is the sum of the energy consumption of the video streaming process components, as shown in equation (10) below and the emissions are estimated by applying an emission factor for grid electricity, as shown in equation (11).

Where E_V is the energy consumption of the video streaming process, C_V is the carbon emissions of the video streaming process and $EF_{g,n}$ is the electrical grid emission factor for region, n.

(10)

$$E_V = E_{DC} + E_{FN} + E_{MN} + E_{HR} + E_{VD}$$

(11)

$$C_{V,n} = E_V \times EF_{g,n}$$

The conventional approach as described above is used to estimate the energy and emissions of video streaming and the analysis is presented in the Results section. A representative mix of devices was developed which defines the proportions in the preceding equations and facilitates the estimation of video streaming's carbon impact at the system level. The device mix defines the proportion of viewing time for each combination of network type, data transmission rate, screen and peripheral and can be found in the Appendix.

4. Results summary

This section presents the results of the assessment of the carbon impact per hour of video streaming in Europe in 2020 alongside analysis illustrating the main drivers of video streaming's carbon impact. Europe was selected as the primary region of analysis as the modelling parameters used are representative of developed networks in Western and Northern Europe. To present the analysis in this section, including the quantity of carbon emitted per hour of video streaming in Europe, the conventional approach is used.

In summary, this section highlights the following key insights from the analysis performed for this white paper:

- **The amount of carbon emitted per hour of video streaming in Europe is small**
- **The electrical grid's carbon intensity has a critical effect on the carbon impact of video streaming**
- **Emissions from user devices are an important consideration in the video streaming process**

4.1. The amount of carbon emitted and energy consumed per hour of video streaming in Europe is small

The European average carbon emissions per hour of video streaming for the year 2020 has been estimated to be 56gCO$_2$e/hour video streaming using the conventional approach, as shown in Figure 17.

This average figure reflects the European average grid intensity (2020 IEA grid factors, grid year 2018 (IEA, 2020b)), an assumed representative mix of end-user devices (see Appendix), and the modelled average bitrate (6.40Mbps or 2.88GB/hour) based on the representative device mix. The equivalent energy consumption is a European average of 188Wh per hour of video streaming using the conventional approach (Figure 18).

Figure 17. Estimated emissions from one hour of video streaming (European average in 2020)

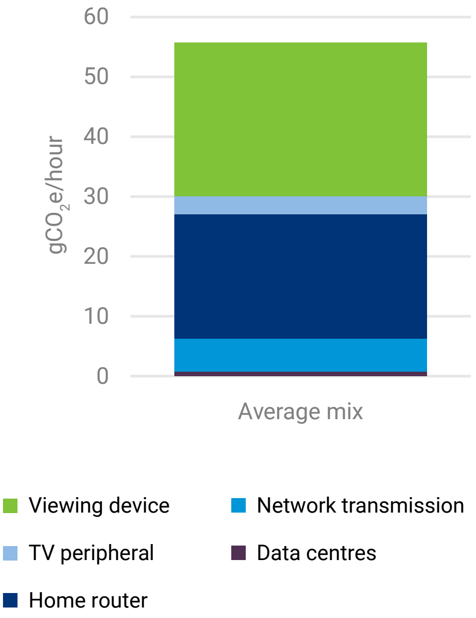
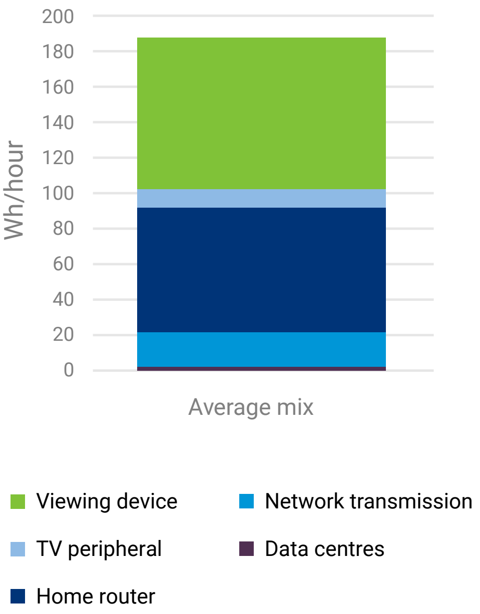


Figure 18. Estimated energy consumption from one hour of video streaming (European average in 2020)



The breakdown of emissions and energy per hour of streaming from the results above yields the following: Data centres (including hosting, encoding and CDNs), account for less than 1gCO_2e/hour and approximately 1Wh/hour, representing roughly 1% of total emissions and energy. Network transmission (core and access) accounts for 6gCO_2e/hour and 20Wh/hour (10% of total emissions and energy). Home routers account for 21gCO_2e/hour and 71Wh/hour (38% of total emissions and energy). Finally, end-user devices account for 28gCO_2e/hour (25gCO_2e/hour from viewing devices and 3gCO_2e/hour from peripherals) and 96Wh/hour (86Wh/hour from viewing devices and 10Wh/hour from peripherals), which makes up the remaining 51% of the emissions and energy from video streaming.

These results show that the emissions and energy consumption from one hour of video streaming are small. However, it should be noted that these figures must be used with care, and are not designed to be used as representative figures for any given scenario.

These figures are derived using the conventional approach, with its associated intended uses and limitations as described in the Methodology section. As the internet operates as a network, its energy consumption is inherently shared between a wide range of services and end-users. Therefore, to arrive at a figure quantifying the impact of one hour of streaming, energy consumption of the network must be ‘allocated’ to video streaming using some allocation approach. The allocation approach is not an exact science, and thus will not be a totally accurate representation of true energy consumption.

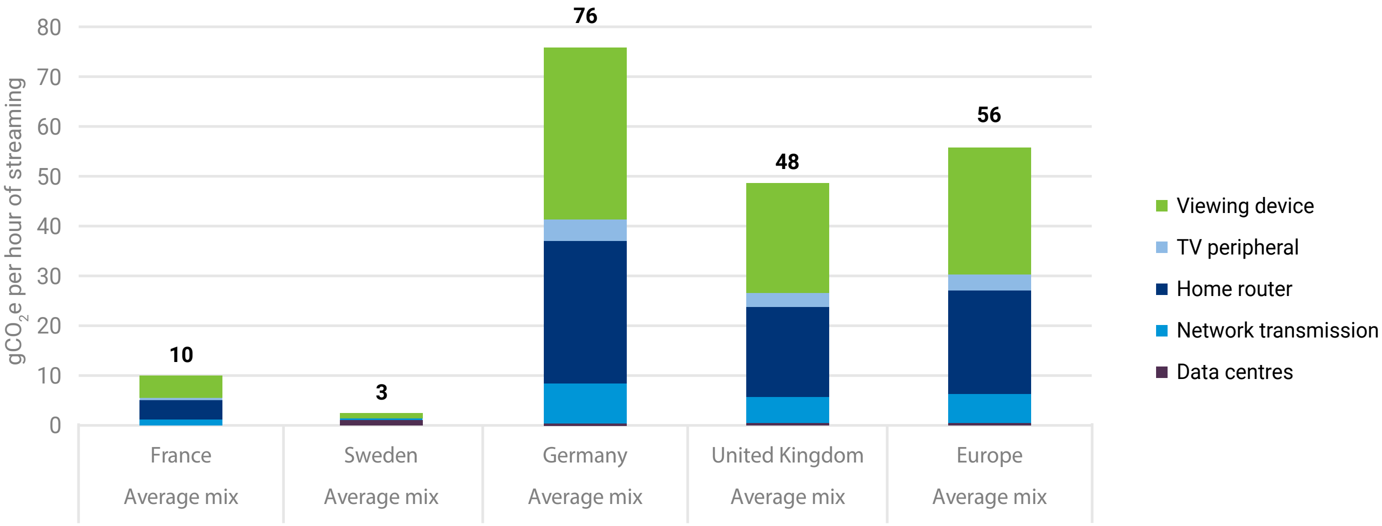
These figures are also based on a specific set of parameters that model a representative scenario in Europe. The parameters used to model the network transmission are characteristic of the most developed and efficient networks, such as those found in the UK and Northern and Western Europe. Finally, the modelling parameters used in these figures, represent a snapshot in time and any projections using these figures should be done so with this understanding and care.

4.2. The local electrical grid's carbon intensity has a critical effect on the carbon impact of video streaming

The geographical location of video streaming consumption has a critical influence on the calculated carbon impact of an hour of video streaming. The carbon impact of an hour of video streaming shows considerable variability from country to country, due to the calculation of video streaming emissions using country-specific electrical grid emission factors. This is illustrated clearly in Figure 19, where emissions per hour of streaming estimated using the conventional approach with a representative mix of end-user devices in France, Sweden, Germany and the United Kingdom are presented alongside the European average.

Of the countries included in this analysis, the highest figure is in Germany with 76gCO_2e/hour and lowest figure is in Sweden with 3gCO_2e/hour. In comparison, the European average carbon impact of video streaming is estimated as 56gCO_2e/hour. This group of countries has been chosen to compare with the European average, as they fit the network characteristics represented by the conventional approach in this paper, and represent a range of grid intensities in Europe, whilst also having large populations.

Figure 19. Emissions from video streaming by region in 2020



These results demonstrate the critical effect a decarbonised electrical grid has on emissions from video streaming. Energy consumption per hour of streaming is already low as a result of the distributed nature of the transmission network between millions of users and when coupled with an efficient, decarbonised electrical grid, the emissions impact is very low, such as in the case of Sweden and France.

This demonstrates how important it is for governments to continue to drive the decarbonisation of the electricity grids.

A case study for India

Compared to the European average, India represents a country with significantly different characteristics, which may contribute to a much different assessment of the carbon and energy impacts of an hour of video streaming.

- India has a much higher grid intensity emission factor than Europe: ~2.5x European average
- Better access to fast internet speeds through mobile networks as opposed to fixed
- India surpassed 500 million internet connections in 2018, the majority of which are mobile/dongle connections (Techwire Asia, 2020)
- More carbon intensive mobile network, due to greater usage of diesel generators and less clean energy used for network equipment at cell sites (CNBC TV18, 2020)
- India's energy and carbon impact is therefore likely to differ significantly compared to the average European impact, driven by a much more mobile focused average mix of devices, higher grid intensity and likely more energy and emissions intensive mobile network
- Encouragingly, telecommunication companies in India, such as Airtel (Airtel, 2016), are recognising these characteristics and taking action to reduce their reliance on diesel generators and to increase their uptake of renewable energy

Furthermore, this analysis shows little variation in the energy consumption associated with an hour of video streaming from country to country, as the modelling parameters for network transmission are representative of efficient European networks generally and are not granular enough to represent the differences in network transmission efficiencies between European nations. In reality, network related energy consumption is likely to vary depending on geographical location, as the efficiency of equipment in the network will vary. For example, some networks in developed economies will still contain a mix of legacy and newer equipment, but may have generally more efficient equipment compared to less developed economies (Coworker.com, 2019). However, this is not reflected in these modelled results, as network energy consumption is modelled using average network energy intensity.

4.3. User devices drive the impact of video streaming

Table 4. Breakdown of emissions and energy consumption by video streaming process component for Europe in 2020

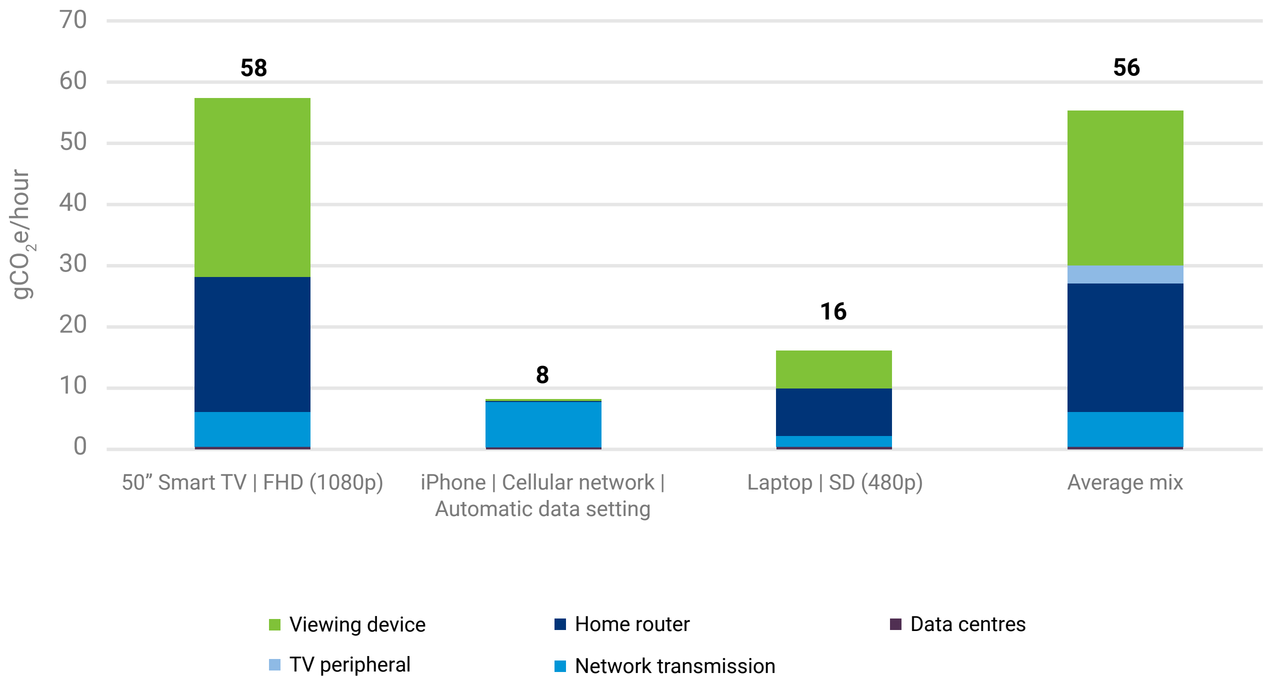
Video streaming component stage	Emissions (gCO_2e/hour streaming)	Energy consumption (Wh/hour streaming)	% of total
Data Centres	<1	1	1%
Transmission Network	6	20	10%
Home Router	21	71	38%
TV Peripheral	3	10	5%
Screens	25	86	46%
Total	56	188	100%

End-user devices, including screens, TVs, laptops, smartphones and peripherals, like set-top boxes, are the largest contributing component to the energy and carbon impact of an hour of video streaming, accounting for 51% of the total European average mix emissions impact using the conventional approach (see Figure 17 and Table 4). With the inclusion of home routers, the devices in the home represent 89% of the total European average mix emissions impact per hour of video streaming.

At the per user level, the carbon emissions associated with data centres and network transmission equipment is small, due to the allocation of the network level energy consumption across a significant population of millions of video streaming users. This results in low emissions and energy use relative to that of end-user devices when assessing the impact of one hour of streaming.

With the exception of video streaming with a smartphone, end-user devices (screens and peripherals) account for a large portion of the carbon and energy-related impact from an hour of video streaming across a range of use cases (Figure 20 and Figure 21).

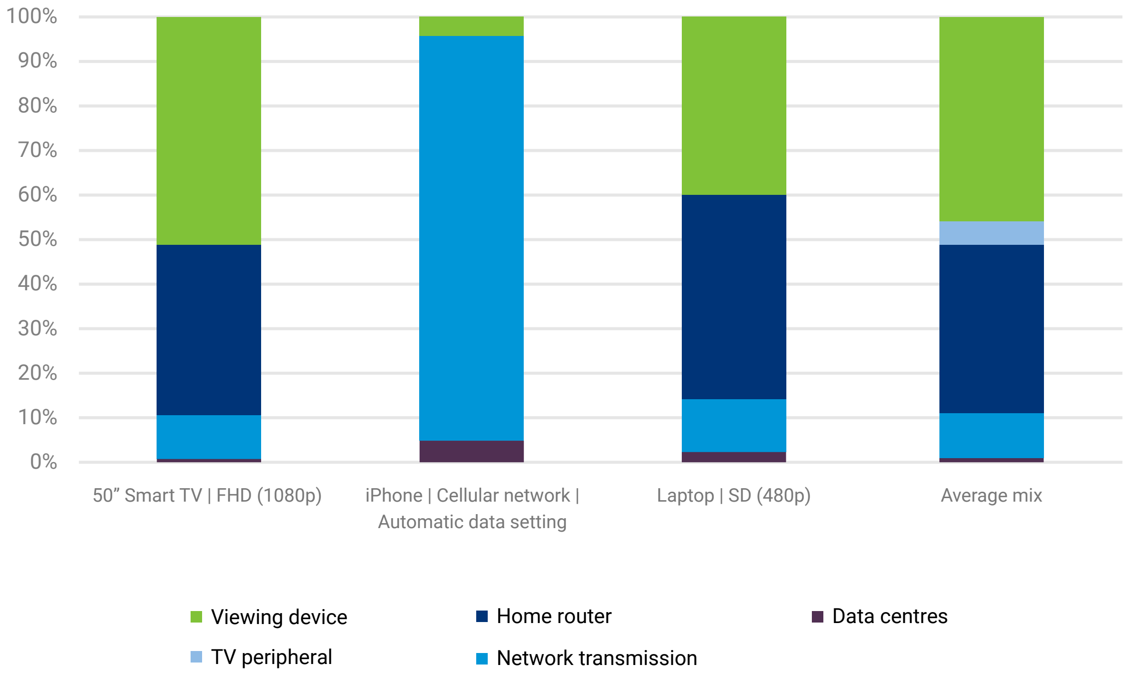
Figure 20. Emissions from video streaming by viewing device (European averages in 2020)



This phenomenon is more prominent in the case of a more power hungry end-user device, such as the 50in smart TV scenario (streaming in FHD over fixed network) presented above, where end-user devices account for 51% of emissions and the home router accounts for an additional 38% of emissions. For the laptop scenario (streaming in SD over fixed network), the home router is largest contributor to total emissions at 45%, followed closely by emissions from the laptop itself at an estimated 40%.

In comparison, device-related emissions when using an iPhone over a mobile network connection account for 4% of total emissions. The average mix scenario broadly reflects the breakdown of emissions of the 50in smart TV scenario, as the average device mix assumes that 70% of viewing occurs on TVs.

Figure 21. Proportion of emissions by streaming process component by viewing device (European averages in 2020)



Notably, content encoding and hosting in data centres and CDNs has a relatively small energy and carbon impact. This is primarily due to the fact that data centres and Content Delivery Networks are highly efficient, particularly as data centres are increasingly trending towards hyperscale capacity, and thus gaining significant efficiency advantages (GlobeNewsWire, 2019).

CDNs enable closer proximity between the end-user and the video content to achieve a reduction in latency and are therefore computationally light, only reading and writing data copied from the core content stack.

5. Discussion

This section will discuss and contextualise the findings of this white paper's analysis. We will introduce emerging research surrounding the modelling of network transmission energy consumption and explore how this new information can be applied to a power model approach that attempts to estimate the short-term marginal effects of a change in viewing patterns related to video quality. There will also be discussion related to the analysis presented in the Results section, uncertainty around the future of video streaming and points for further research.

5.1. Emerging research offers new insight into the short-term marginal effects of changing viewing patterns

Recently, public awareness of the impact of our digital lives has grown and many internet users are interested in understanding the most meaningful actions they can take to reduce their digital carbon footprint. Video streaming has come into focus in this context due to the large volume of data that is transmitted through the network and in turn the estimates of video streaming's carbon impact which typically rely on average network energy intensity figures.

As discussed in the Methodology section, the conventional approach is not well suited to assessing the short-term marginal effect of changing viewing patterns i.e. how changing video quality from SD to HD or HD to 4K affects carbon emissions. This is due to the utilisation of average transmission network energy intensities, which relate network energy consumption to data, and is particularly true for high bitrate applications like video streaming.

Estimation approaches utilising average transmission network energy intensities work well for organisational footprinting and system level estimates, but are not sufficiently granular to reflect the power consumption dynamics of transmission network equipment relative to computational load and network traffic.

Recent work by Jens Malmodin (Malmodin, 2020b) proposes a simple transmission network power model that offers a promising approach to estimating the short-term marginal effects of changing viewing patterns in video streaming quality. A brief overview of this research is presented below and following this overview, the power model approach to estimating the marginal carbon impact of streaming at varying video qualities is presented, which incorporates the simple transmission network power model.

5.2. Malmodin's simple power model provides a closer representation of the dynamics of internet transmission

Malmodin's proposed power model offers a more accurate reflection of the instantaneous and short-term effect of video streaming on network energy consumption. The power model makes use of a baseload and dynamic component power model in accounting for the internet transmission-related energy of networks and more closely represents the always on state of network equipment and energy consumption, compared to a conventional average kWh/GB factor.

In modern network equipment, the power draw is not only a function of computational load or data traffic, but it is also driven by the baseload (or idle power) consumption of the equipment's operation. Network and core computing equipment operates 24/7 at a constant baseline of power consumption when idle, i.e. minimal load/data demand. This constant operation is a requirement of network equipment so that it is ready to listen and respond instantly to incoming signals. When data load increases, as illustrated for mobile radio equipment in Figure 22 (Malmodin, 2020b), the power consumption of the equipment experiences only a marginal increase of up to 30% relative to baseload power consumption. This is because the baseload power consumption is provisioned to cope with peak demand.

Figure 22. Power and data model for a suburban 4G radio unit/base station (Malmodin, 2020b)

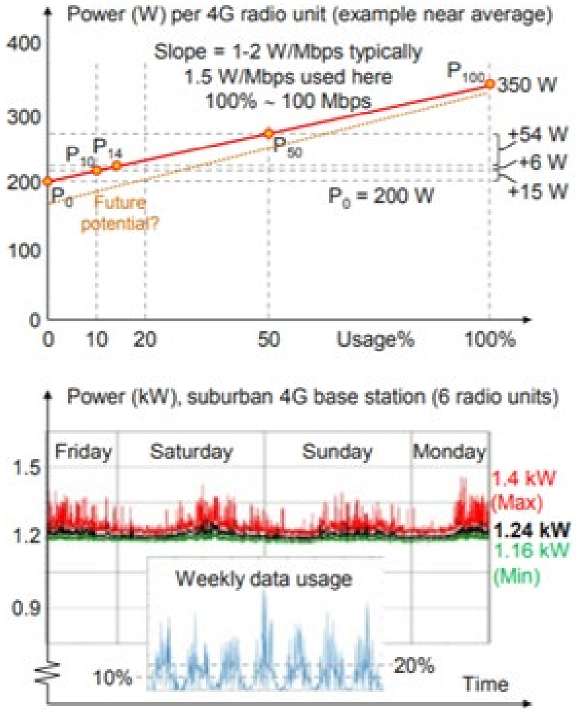
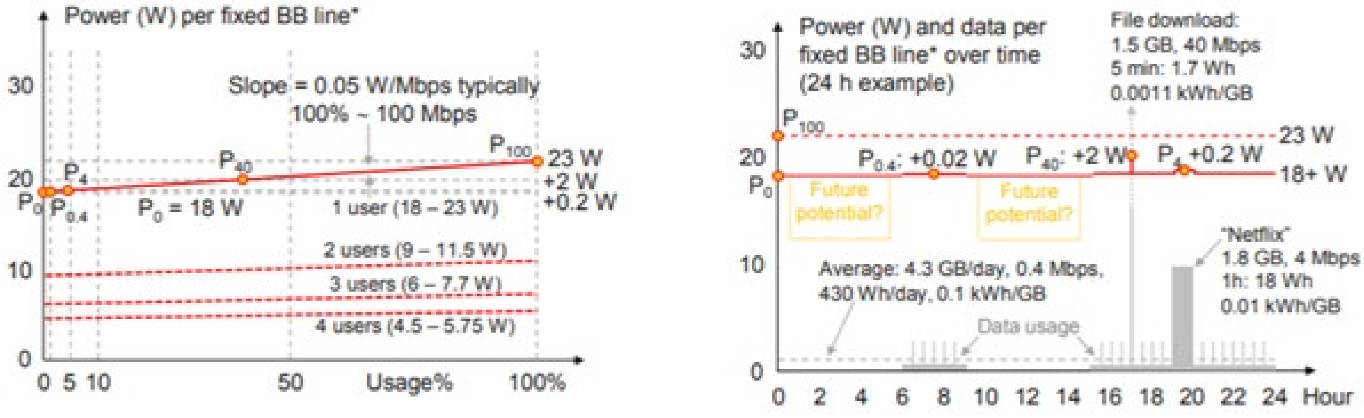


Figure 23 (Malmodin, 2020b) illustrates what this means in a home for a fixed line, where home router power draw is a constant wattage 24/7. Consequently, this illustrates that additional data consumption and usage load applied to network equipment from medium to high bandwidth services like video streaming does not lead to a significant short-term increase in network device energy consumption. Instead, the short-term impact of high bitrate video streaming is only marginal. The higher bitrate required to watch an hour of video streaming in 4K (2160p) compared to Full HD (1080p) requires additional electrical power, but only marginally so relative to baseload power consumption. Using Malmodin's proposed power model allows us to capture this aspect of video streaming energy and emissions impact in a more representative manner. The conventional approach on the other hand is not a suitable tool for this particular application as it does not reflect this behaviour of network computing, instead simplifying the representation of networks to a single average kWh/GB factor derived from energy and data volume figures at the network level.

There are still, however, open questions and uncertainty surrounding the power model approach, including validation that it can scale to the network level and account for 100% of network energy consumption and how best to address allocation of idle energy consumption. This is expanded on later in the Discussion section.

Figure 23. Power/data and power/time models for a fixed BB access line in a household. This includes home router equipment (Malmodin, 2020b)



5.3. Methodology of the power model approach

This section provides a summary of the methodological approach used to estimate the short-term marginal carbon emissions impact of video streaming at varying video qualities. An overview of this approach, referred to as the power model approach within this paper, is discussed including the characteristics of the power model approach, the boundary used to define the footprint and a brief explanation of allocation and its role in this estimation approach.

Following this overview, the key parameters used in this estimation approach and a high-level explanation of their derivation is provided.

5.4. Overview of the power model approach

Characteristics

- Utilises Malmodin's transmission network power model (Malmodin, 2020b)
- Relies on an allocation approach to attribute the energy consumption of a shared network to the services that use the network
- Transmission network energy consumption is allocated to video streaming in two ways: baseload energy is allocated by viewing duration and active devices and dynamic energy is allocated per data
- Energy consumption of data centres and end-user devices is allocated based on viewing duration
- Mobile network power model is representative of 4G networks only

Intended use

- Assessment of the short-term marginal impact of change in video quality

Strengths

✓ Power model provides a closer representation of the dynamics of internet transmission enabling assessment of the marginal impact of varying viewing quality

✓ Data centres and end-user devices are estimated in an analogous manner to the conventional approach

Limitations

X Representative of a particular network and period of time

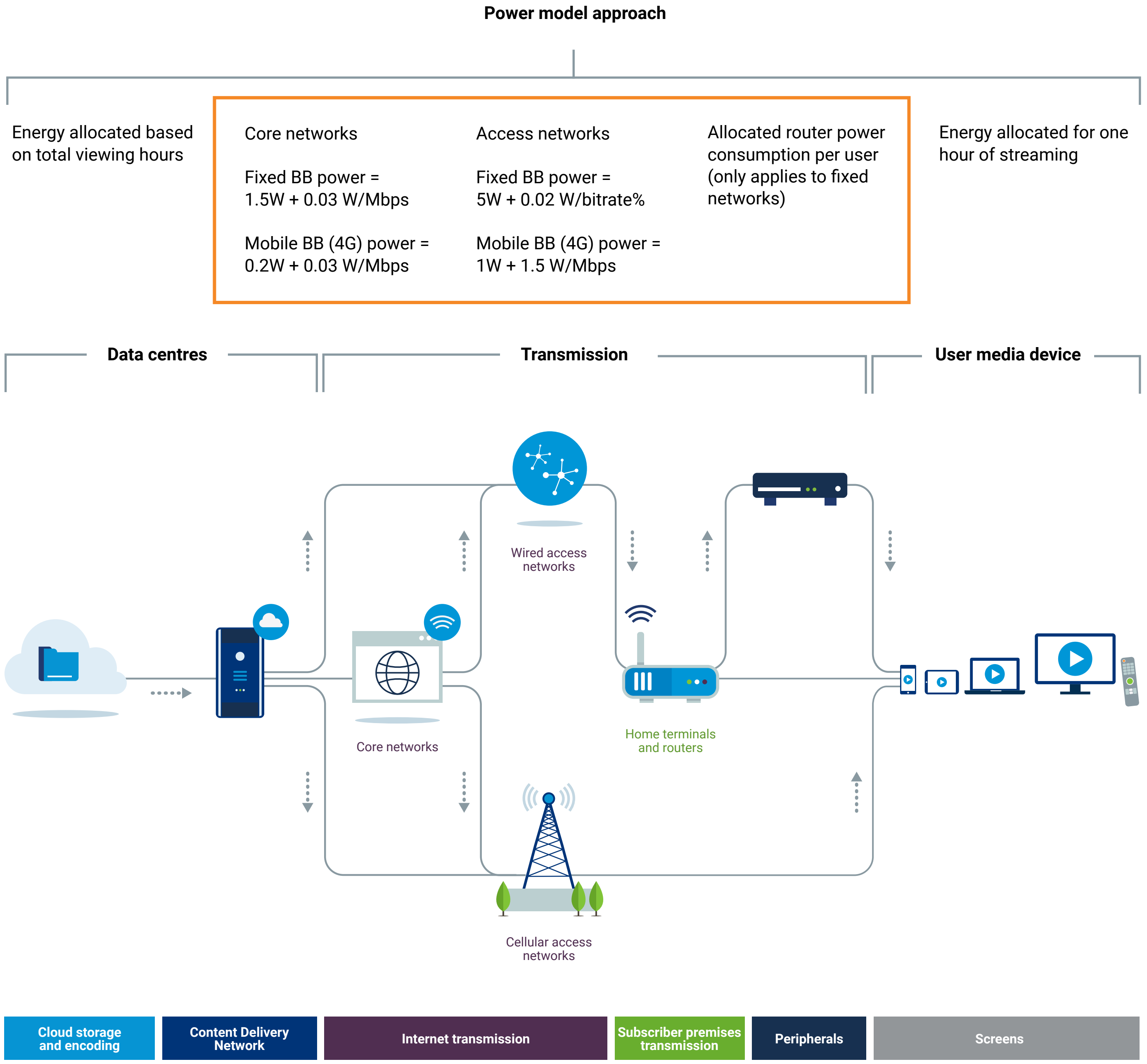
X Sensitive to characteristics of the transmission network considered for estimation. These network characteristics include network equipment efficiency, quantity of network users and data traffic.

X Relatively nascent, with open questions and uncertainty that currently restrict it from being used as an alternative to the conventional approach for organisational foot-printing

The power model approach builds on the foundation of the conventional approach and replaces the average energy intensity approach used for estimating energy and emissions of network transmission with Malmodin's power model. This is represented in Figure 24 below, where the difference from the conventional approach is boxed in orange, alongside the power model parameters that define the fixed and mobile network estimation.

As the data centres and end-user devices components of the power model approach are consistent with the conventional approach, they will not be discussed in this section. For detail on these components, refer to the Methodology section for the conventional approach. The governing parameters and assumptions of the power model approach are detailed in Table 5.

Figure 24. Video streaming process map indicating the components that make up the video streaming process. The associated parameters that define the network transmission model of the power model approach are boxed in orange. The remaining components are consistent with the conventional approach.



This approach may be described as a transmission network power model based approach, as it utilises Malmodin's proposed power model to estimate the transmission network energy attributable to video streaming. Allocation is an important consideration for the power model approach, which allocates transmission network energy differently for the baseload and dynamic components of the power model. This is discussed further in this section when the equations governing the power model are presented.

As this approach utilises Malmodin's recent transmission network power model, it is a relatively nascent approach to estimating the carbon impact of video streaming and has open questions and uncertainty, particularly surrounding validation that the power model can appropriately scale to the network level, and how best to address the allocation of a user's idle network connection. Therefore, in this paper we use the power model approach to assess the short-term marginal impact of a change in video quality, rather than as an alternative to the conventional approach.

5.5. Approach boundary

In an analogous manner to the conventional approach, the power model approach draws its boundary around the component stages of the video streaming process: data centres, transmission and end-user devices, as shown Figure 24. The lifecycle boundary for this approach includes only the in-use electricity consumption of each video streaming process component and excludes the embodied carbon and end-of-life emissions of data centres, network equipment and end-user devices. These component stages are discussed in further detail below and assumptions related to each component and model parameter are presented in Table 5.

5.6. Transmission network

The governing equations of the power model approach's transmission components include multiple elements, but can be split into a fixed network model and a mobile network model, both with distinct core and access network components. Within each of the core and access components is a baseload and dynamic component, where the baseload is fixed and represents the network equipment's idle power consumption, and the dynamic element varies in proportion to bitrate.

This is demonstrated below by equation (12) for the fixed network. The baseload power elements represent the idle power consumption of network equipment per fixed line connection, where a fixed line connection typically serves a single household. As the fixed line connection is a shared service, we allocate the baseload among the users of the connection, which is done per active device. Thus, the fixed line connection is divided by the number of active devices accessing the fixed line, represented by equation (13), which is derived from the quantity of users per fixed line, the quantity of connected devices per user and the average proportion of actively connected devices at any given time. Furthermore, as the baseload of the fixed connection is drawing power continuously, the power model only captures the power drawn while actively video streaming. In practice, there are periods of the day and night where the fixed line connection is not being actively used by any internet service, but is drawing power nonetheless. To account for this idle energy, we use an idle time allocation factor to attribute a portion of the idle connection to video streaming.

Finally, the dynamic power components are estimated, where the dynamic core network power component is proportional to bitrate of the video stream and the dynamic access network power component is proportional to the bitrate % of the video stream. In other words, the bitrate % is the percentage of the fixed line connection's bandwidth that is being utilised by the video stream.

Parameter definitions

Global parameters	D = duration of video streaming R = data transmission rate F = idle time allocation factor Q_A = quantity of active devices per fixed line connection Q_U = quantity of users per fixed line Q_D = quantity of devices per user A = active device factor as a proportion of total devices
Transmission – Fixed Network	E_{FN} = energy consumption over the fixed network $B_{FN,C}$ = baseload fixed core network element per fixed line connection $B_{FN,A}$ = baseload fixed access network element per fixed line connection $V_{FN,C}$ = dynamic fixed core network component $V_{FN,A}$ = dynamic fixed access network component S = bandwidth of the fixed line connection
Transmission – Mobile Network	E_{MN} = energy consumption over the mobile network $B_{MN,C}$ = baseload mobile core network element per subscriber $B_{MN,A}$ = baseload mobile access network element per subscriber $V_{MN,C}$ = dynamic mobile core network dynamic element $V_{MN,A}$ = dynamic mobile access network dynamic element
Transmission - Home router	E_{HR} = energy consumption of the home router B_{HR} = baseload power consumption of the home router

The resulting total power draw is multiplied by the duration of the video stream to estimate energy consumption.

(12)

$$E_{FN}=\left(\left(\frac{B_{FN,C}+B_{FN,A}}{Q_{A}}\right)\times F+\left(V_{FN,C}+\frac{V_{FN,A}}{S}\times 100\right)\times R\right)\times D$$

(13)

$$Q_{A}=Q_{U}\times Q_{D}\times A$$

Where E_{FN} is the energy consumption over the fixed network, $B_{FN,C}$ and $B_{FN,A}$ are the baseload elements per fixed line connection for core and access networks, respectively, Q_A is the quantity of active devices per fixed line connection, F is the idle time allocation factor, $V_{FN,C}$ and $V_{FN,A}$ are the dynamic components for fixed core and access networks, S is the bandwidth of the fixed line connection, R is the data transmission rate and D is the viewing duration. Q_U represents the quantity of users per fixed line, Q_D is the quantity of devices per user and A is the active device factor as a proportion of total devices.

In principle, the mobile network power model follows a similar structure, however, the power model is derived per subscriber, so there is no further allocation to the per user level. Represented by equation 14, the mobile network energy consumption is estimated via baseload power elements for the core and access networks in addition to dynamic power elements of the core and access networks, which are proportional to bitrate. The resulting total power draw is multiplied by the viewing duration to determine energy consumption over the mobile network.

In contrast to the fixed network power model, there is no allocation of idle energy in the mobile network model because mobile network equipment is continuously interacting with connected devices to serve reference and sync data (Malmodin, 2020b). As a result, subscribers may be considered to have a constant active connection to the mobile network.

(14)

$$E_{MN}=\left(B_{MN,C}+B_{MN,A}+\left(V_{MN,C}+W_{MN,A}\right)\times R\right)\times D$$

Where E_{MN} is the energy consumption over the mobile network, $B_{MN,C}$ and $B_{MN,A}$ are the baseload elements per subscriber for core and access networks, respectively, and $V_{MN,C}$ and $V_{MN,A}$ are the dynamic components for mobile core and access networks, respectively.

The final component of transmission over a fixed network is the home router, where energy consumption is estimated as shown in equation 15 As home routers are typically always on and draw power at a near constant rate, the energy consumption of the home router is estimated simply using a baseload power consumption, which is divided by the number of active devices accessing the router. In an analogous manner to the core and access baseload elements, an idle time allocation factor is applied and the product is multiplied by viewing duration to determine energy consumption.

(15)

$$E_{HR}=\frac{B_{HR}}{Q_{A}}\times F\times D$$

Where B_{HR} is the baseload power consumption of the home router.

Table 5. Power model approach assumptions by streaming process component

Streaming component	Conventional approach assumptions
Data centres & Content Delivery Network	• Energy intensity, IDC (2020) = 1.3Wh/hr • Derived from a selection of DIMPACT members, based on measured data in 2020.
Transmission – Network (Core & Access)	Fixed network • Baseload elements, $B_{FN,C}$ = 1.5 W/line and $B_{FN,A}$ = 5W/line • Dynamic elements, $V_{FN,C}$ = 0.03W/Mbps and $V_{FN,A}$ = 0.02W/bitrate% • Users per line, Q_U, sourced from Population Reference Bureau (Population Reference Bureau, 2020), see Appendix • Devices per user, Q_D, sourced from Cisco Annual Internet Report (Cisco, 2020), see Appendix • Idle time allocation factor, F = 3 • Active device factor, A assumed to be 0.5 • Fixed line connection bandwidth, S = 75Mbps assumption based on discussion with J. Malmodin and verified with speed test statistics Mobile network (4G) • Baseload elements, $B_{MN,C}$ = 0.2W/subscriber and $B_{MN,A}$ = 1W/subscriber • Dynamic elements, $V_{MN,C}$ = 0.03W/Mbps and $V_{MN,A}$ = 1.5W/Mbps Baseload and dynamic elements for fixed and mobile networks are sourced from Malmodin, 2020b, page 94
Transmission - Home router	• Baseload element, B_{HR} = 10W/line
Data transmission rates	Fixed network • Standard definition (SD): 2.22Mbps (1GB/hr) • Full high definition (FHD or HD): 6.67Mbps (3GB/hr) • Ultra-high definition (UHD or 4K): 15.56Mbps (7GB/hr) Mobile network • Save data setting: 0.37Mbps (0.17GB/hr) • Automatic data setting: 0.56Mbps (0.25GB/hr) • Maximum data setting: 6.67Mbps (3GB/hr) These figures are derived from published Netflix figures on data usage (Netflix, 2021)
End-user devices	• Reasonable estimates of average power (W) for specific devices, see Appendix for details • The standby time of end-user devices was not included in this analysis

5.7. The short-term marginal effect of video streaming quality on carbon emissions

With an understanding of Malmodin's proposed transmission network power model and how it has been applied to develop the power model approach used in this white paper, we estimate the short-term marginal effect of video streaming quality on carbon emissions. In this context, short-term effect refers to the marginal effect on network emissions as it responds to a change in demand, given a fixed network capacity. Over a longer period of time, network infrastructure is updated with new network equipment technologies and additional capacity is added to address medium and long-term changes in network demand, particularly in response to consistently elevated levels of peak demand. This has knock-on effects to total energy consumption of the network. The power model approach and the resulting analysis presented here do not attempt to model these medium and long-term effects, nor do they model the effects on data centres and end-user devices as video quality changes.

To assess the short-term marginal effect of video streaming quality on carbon impact, we used a representative fixed network scenario and a representative mobile network scenario for Europe in 2020. The representative fixed network scenario is modelled with a 50in smart TV, which requires no additional peripherals to connect to the fixed network via a home router, while the representative mobile network scenario is modelled with an iPhone 11.

Figure 25 and Figure 26 demonstrate the marginal impact of bitrate on aggregated core and access transmission emissions over the fixed network and mobile network, respectively. For clarity, the fixed network emissions shown do not include emissions from the home router. Over the fixed network, three video qualities are evaluated: SD, HD and 4K, with bitrates corresponding to 2.22Mbps, 6.67Mbps and 15.56Mbps, respectively. Over the mobile network, Netflix's user mobile data settings are used which have corresponding data usage limits (in GB per hour) which have been translated to an average bitrate in Mbps. These settings are: save data setting, automatic data setting and maximum data setting with bitrates corresponding to 0.37Mbps, 0.56Mbps and 6.67Mbps, respectively.

Figure 25. Marginal impact of bitrate on core and access transmission emissions (fixed network)

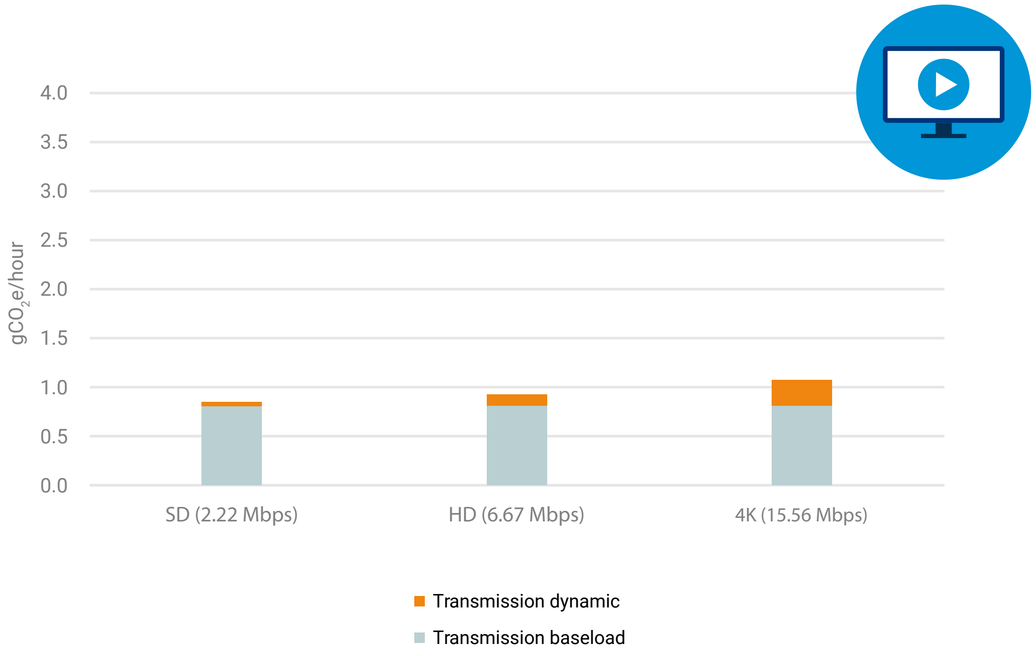
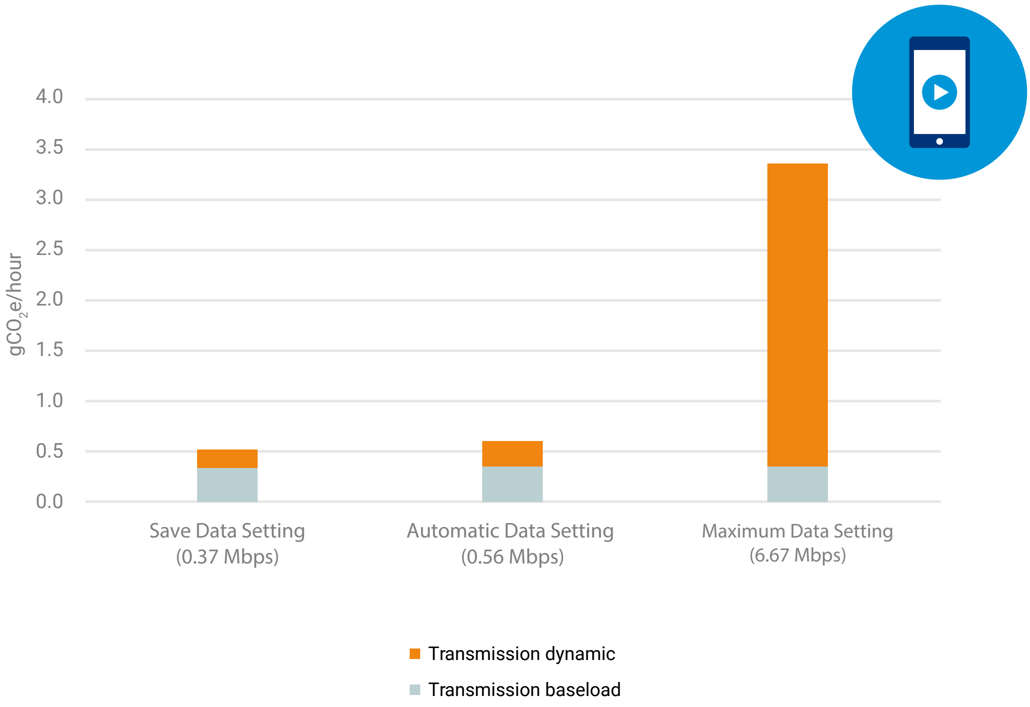


Figure 26. Marginal impact of bitrate on core and access transmission emissions (4G mobile network)



The marginal impact over fixed network as resolution and bitrate increase, is relatively small, where the transmission emissions grow from just under $1gCO_2e$/hour to just over $1gCO_2e$/hour between SD and 4K. This represents an increase of 26% in aggregated core and access transmission emissions from SD up to 4K. The baseload emissions, which remain constant, are estimated as approximately $0.8gCO_2e$/hour and therefore make up the largest proportion of fixed network transmission emissions across the spectrum of video quality assessed here. In essence, this demonstrates the fixed network's low elasticity in relation to data transmission rate.

The mobile network has a different response, demonstrating a higher elasticity in relation to data transmission rate. From the save data setting to the automatic data setting, there is an increase in transmission emissions of 16%, though both settings still result in estimated transmission emissions of less than $1gCO_2e$/hour. Comparing the maximum data setting to the save data setting, transmission emissions increase by 545%, growing to nearly $3.5gCO_2e$/hour. The constant baseload emissions are estimated as less than $0.5gCO_2e$/hour. While the mobile network demonstrates a higher elasticity related to data transmission rate, the transmission emissions are still relatively small even at higher bitrates.

These results are contextualised in Figure 27 and Figure 28, where the transmission emissions are presented alongside the corresponding total emissions from the video streaming process. Again, the low elasticity of the fixed network is demonstrated with total emissions growing only 1% from SD to 4K viewing. Core and access transmission emissions make up approximately 3% of the total video streaming emissions for the fixed network scenario across the three video qualities evaluated and end-user devices make up the majority of total emissions. In comparison, the mobile network transmission emissions drive an increase in total emissions of 7% between the save data and automatic data setting and an increase in total emissions of 231% from the save data to the maximum data setting. The transmission emissions account for 42% of total emissions in the save data setting up to 83% of total emissions when using the maximum data setting.

Figure 27. Marginal impact of bitrate on total emissions (fixed network)

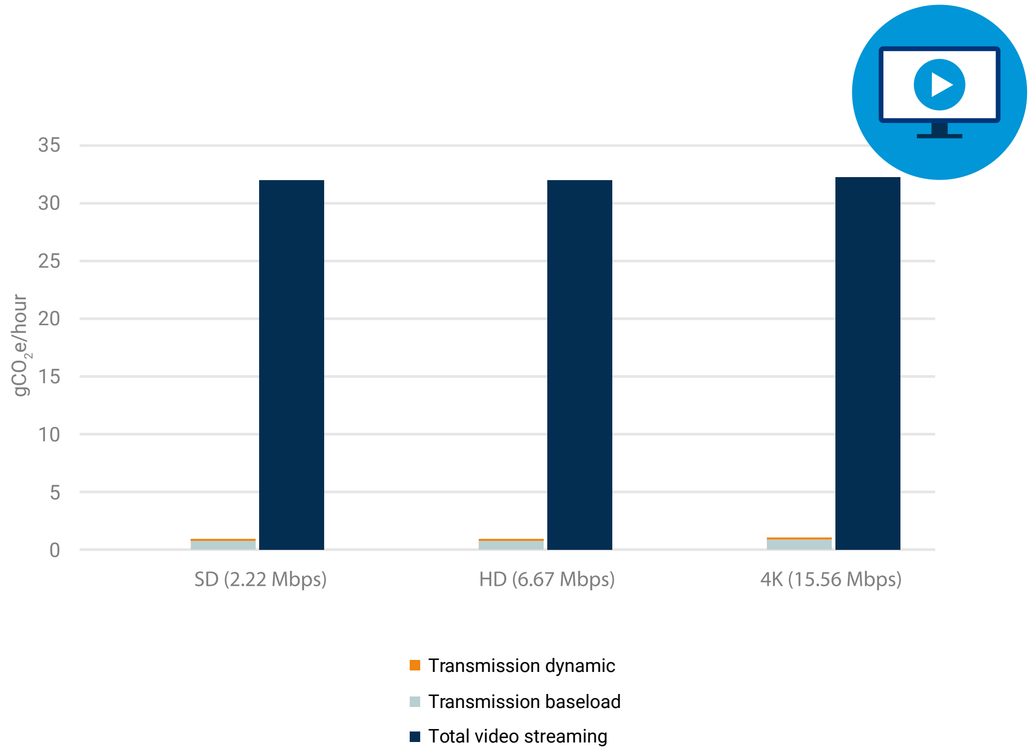
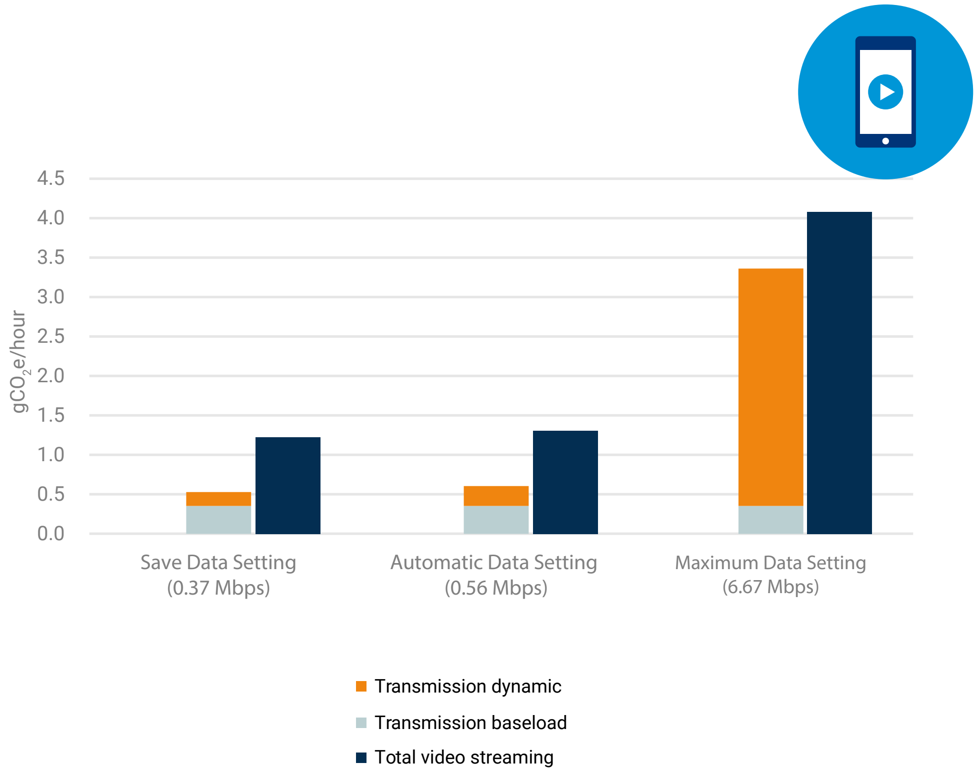
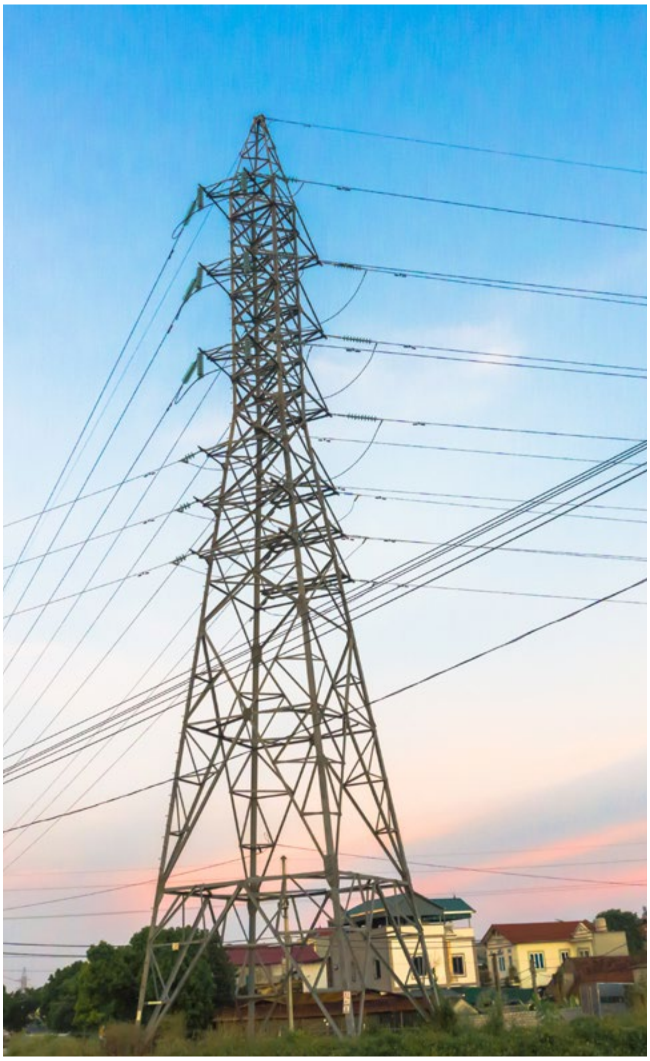


Figure 28. Marginal impact of bitrate on total emissions (4G mobile network)



The key insights derived from this analysis are that the low elasticity of the fixed network in response to bitrate imply that the fixed network transmission emissions are more closely linked to network capacity than they are linked to the short-term response to increased traffic. For the mobile network, increased bitrate has a demonstrable effect on short-term transmission emissions, primarily as a result of the power consumption characteristics of mobile base stations (Malmodin, 2020b). For users, the most effective way to reduce their carbon impact of streaming depends on the network being used. Over a fixed network, using a more energy efficient or smaller viewing device has a far greater impact than changing video quality, particularly as end-user devices dominate the total emissions from streaming over fixed network. In fact, this analysis demonstrates that changing video quality while streaming over a fixed network has a negligible short-term impact. For a typical user streaming over a mobile network with a smartphone, emissions are small even at higher bitrates, estimated at less than 5gCO_2e/hour in this scenario using the power model approach. However, utilising data usage settings that minimise bitrate offers an opportunity to reduce emissions.



5.8. Further validation and refinement of the power model is a logical next step

The power model approach provides an allocation approach that more closely represents the dynamics of internet transmission as it incorporates a power model derived from the study of power consumption profiles of fixed and mobile networks. Furthermore, it partially decouples energy consumption from data volumes through use of the baseload element and we understand that energy consumption in networks is not linearly proportional to data volume, as evidenced by reported energy consumption figures in relation to increased internet traffic during the COVID-19 pandemic (GSMA, 2020).

As the power model approach offers a new methodology for allocating network energy and emissions to internet services, during the course of this study we have performed an initial sense check of the numbers used in the power model to determine their representativeness for a limited number of leading telecommunications network operators (telcos). The total annual transmission network energy for each operator was estimated using the power model, where annual baseload energy consumption was estimated with the quantity of fixed line subscribers and quantity of mobile subscribers for each telco multiplied by the baseload element of the power model and multiplied by hours per year. The annual dynamic energy consumption was estimated using the annual quantity of data transmitted over the network to derive an average annual network bitrate, which was then multiplied by the dynamic element of the power model and multiplied by hours per year.

The resulting annual energy consumption figures for fixed and mobile networks were then compared to the actual total reported energy figures, to test the accuracy of the power model approach. This indicated that using the power models for fixed networks accounted for approximately 60% of the total measured energy expected, while the mobile power models accounted for approximately 70% of the measured energy expected (see Table 6). This initial comparison demonstrates that the power model approach provides a reasonable approximation across a range of network operators when compared against their most recent energy consumption figures for operation of their network (typically these were 2019 figures). While our sense check indicates the power model is a reasonable approximation, the figures in Table 6 below demonstrate that the power model gives a slightly low estimate of network energy consumption. However, as discussed later in the Discussion section, limited availability of detailed and granular network data makes the validation process challenging and to some extent, incomplete.

Table 6. Percentage of network energy estimated by the power model relative to reported network energy consumption of selected telcos

Network type	Telco 1	Telco 2	Telco 3	Telco 4	Telco 5
Mobile	76%	N/A	33%	82%	125%
Fixed	64%	N/A	N/A	N/A	62%
Total	73%	56%	N/A	N/A	63%

Further validation of the power model requires a more detailed understanding of operational energy consumption split by type of network i.e. fixed broadband, 2G mobile network, 3G mobile network, 4G mobile network and 5G mobile network. Furthermore, we must know the number of subscribers and the total data volume transmitted (or ideally a measure of average bitrate) through both fixed and mobile networks, measured using consistent methods. In its current form, the mobile network power model is representative of 4G networks. However, network operators operate a range of generational mobile network technologies from legacy 2G and 3G equipment, to modern 4G and cutting-edge 5G and if network data is published, it is not disaggregated by network technology, and often not even disaggregated between fixed and mobile.

While the power model is representative of the characteristics of efficient European networks, refinement of the power model is logical to represent a broader range of technologies (i.e. 3G and 5G mobile networks) and regions (i.e. India and the United States). Furthermore, network operators themselves may wish to develop their own baseload and dynamic coefficients for use in the power model to specifically represent their unique network characteristics.

There is also a need for refinement of the idle network energy allocation methodology in the power model approach. This refinement is currently limited by a lack of data around key assumptions and consensus on the most appropriate allocation approach. The refinement of these assumptions could be supported through greater data from network and service providers, with access to granular level consumer data (although this would need to respect personal data privacy), as well as by utilising consumer surveys and data that provides insight into the internet services that are driving peak network demand.

The power model approach offers a new perspective on the allocation of network energy and emissions. Considering this new perspective, further discussion, consensus and standardisation of allocation approaches among industry players is a logical next step.

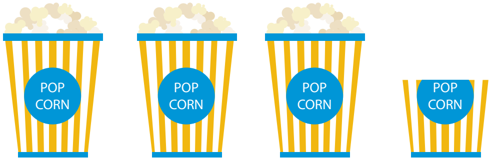
5.9. Video streaming impact contextualised

In order to put the emissions impact of an hour of video streaming into context, some comparative scenarios are presented, comparing the European average impact of an hour of video with day-to-day activities of regular consumers.

An hour of video streaming vs. microwaving a bag of popcorn

The European average emissions of an hour of video streaming using the conventional approach = 56gCO$_2$e.

The average emissions of microwaving a bag of popcorn for four minutes in a typical 800W domestic microwave oven (assuming European average grid intensity) = 16gCO$_2$e.

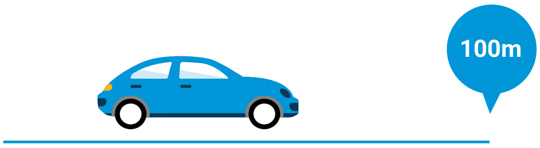


The emissions of an hour of video streaming are roughly 3.5x that of microwaving a bag of popcorn

An hour of video streaming vs. driving 100m

The European average emissions of an hour of video streaming using the conventional approach = 56gCO$_2$e.

The average emissions of driving a distance of 100m = 22gCO$_2$e.



The emissions of an hour of video streaming are approximately 2.5X those of the average emissions of driving a distance of 100m.

Comparing the energy of an hour of video streaming with some household devices

The European average total energy consumption of an hour of video, using the conventional approach, of 188Wh/hour has been compared to the energy (Wh) used by some typical household devices.

Table 7 below represents the use of several domestic appliances in certain use cases, in terms of equivalent minutes of video streaming, e.g. one boil of the kettle = 19 minutes of video streaming.

Table 7. Comparison of the energy of one hour of video streaming with some household devices

Device use case	Power (W)	Energy (Wh)	Equivalent minutes of EU average video streaming (conventional approach)	Source of device power
Home router (1 hour on time)	10	10	3	D+R International, 2020
Electric kettle (2 minute boil)	1800	60	19	Frequencycast, 2021
LED lamp (1 hour on time)	8.5	8.5	3	Eartheasy, 2021
Microwave (4 minutes cooking popcorn)	800	53	17	The Spruce, 2021 (Assumed 600-1200 W)

5.10 For consumers, device selection can reduce environmental impact, but systemic approach to energy efficient devices offers a more meaningful opportunity

The results of the analysis in this white paper indicate that consumer device selection has a much greater impact on video streaming-related emissions than the choice of video streaming quality. This paper acknowledges the potential impact consumer influence can play through their consumption habits. However, when end-user devices are considered in aggregate, there is great systemic opportunity for device manufacturers to drive down energy consumption of viewing devices through a continued focus on energy efficiency improvements. Voluntary agreements have been used in this context to encourage improvements to energy efficiency in small network equipment such as home routers (D+R International, 2020). In Western Europe alone, end-user devices may number in the hundreds of millions, based on an estimated six connected devices per person (Cisco, 2020). Energy efficiency improvements for end-user devices out of the box will translate to energy and emissions reductions for the consumer.

The analysis presented in this paper focuses on the use phase energy consumption and emissions of the video streaming process. Devices also have associated emissions related to the full device lifecycle, from raw materials, to manufacturing and end-of-life. For small devices like smartphones, materials and manufacturing make up the largest proportion of lifecycle emissions, as evidenced by the iPhone 12 (Apple, 2020), where production-related emissions account for 83% of lifecycle emissions. Therefore, design improvements that enable consumers to increase the period of time between device upgrades are an important consideration for reducing environmental impact.

Where consumers want to influence and reduce video streaming impacts, device selection has the greatest potential to enable them to do so. Viewing an hour of video streaming content on smaller mobile devices, such as smartphones, tablets and laptops, will have a significantly smaller carbon and energy impact compared to watching on an energy intensive device such as 50in smart TV. The carbon and energy per hour of video streaming by using smaller devices, is approximately 15%-30% of the emissions from the use of large smart TVs.

In a practical sense, there are simple behavioural changes that can optimise the energy use from video streaming such as using a mobile device (~1W) when watching video while multitasking or by streaming directly from a smart TV (~100W) or with the use of a streaming stick such as Chromecast or Roku (~2W) instead of streaming via video game console (~90W) in conjunction with a TV. Crucially, whether a consumer watches in SD, full HD or 4K, the energy and carbon impacts of an hour of video streaming will only be marginally greater for the higher quality content.

A systemic approach, which includes device manufacturers focusing on continually improving the energy efficiency and extending the lifetime of the devices they produce, offers a more meaningful opportunity for energy and emissions reduction than behavioural change at the consumer-level alone.

5.11 Internet peak capacity drives energy consumption

In order to understand the impact of video streaming consumption, it is important to understand the dynamics of the internet in relation to energy consumption, and the impact of data consumption on energy and emissions at the level of individual infrastructure components and the system level. An appropriate analogy to illustrate this is a bus transport network. The bus network runs 24 hours a day, seven days a week, with buses regularly moving around the network to transport passengers. Even when absent of passengers, the bus consumes fuel to move itself and as passengers get on the bus, the bus will only consume a small amount of additional fuel in order to transport these passengers. At the network level, the biggest factor in total fuel consumption of the network is the capacity of passengers that it can support. As demand for the bus service grows, additional buses, with their own fixed amount of fuel consumption, are added to the routes that comprise the network.

Similarly, the internet is in constant operation, and like the bus network, currently has an almost constant consumption of energy to power its network equipment. As data traffic increases within the capacity of the network, the additional energy required to transmit this data is only marginal compared to the idle energy of the internet transmission network that is constantly operating.

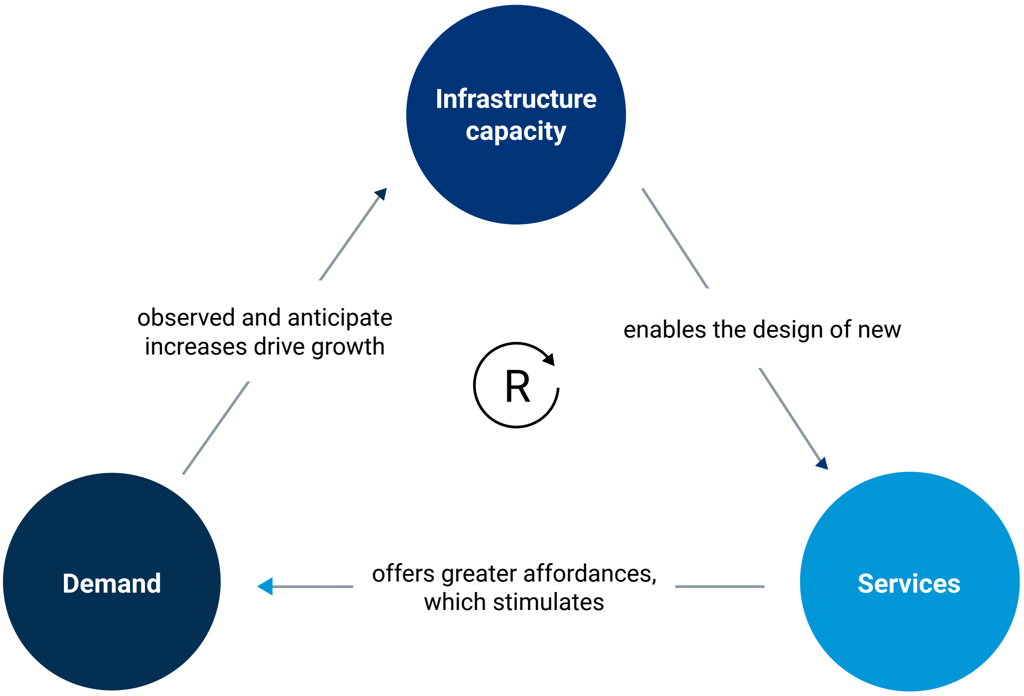
As video streaming and other internet services' demand for the internet's transmission network increases, the capacity of the network must increase to support the additional demand. When the bus is full, capacity is increased, effectively increasing the number of buses in the network. The same occurs when demand for internet transmission nears peak capacity, the capacity is increased by adding to the network. This analogy effectively demonstrates that video streaming's demand for internet transmission capacity has both short-term and medium-term effects, where in the short-term there is only a marginal increase in energy consumption and carbon emissions which does not have a meaningful impact on the system level energy and emissions. In the medium-term, additional network infrastructure is added to support the increased demand which contributes to increased embodied carbon from manufacture of the network equipment and potential for an increase in baseload network energy consumption.

While increased data usage from services like video streaming may not be significantly impacting the total energy and emissions of internet transmission at the system level, it is important to understand what determines the high baseload power consumption in the first place. As illustrated by the bus analogy, peak demand drives the system level energy and emissions. When demand reaches peak capacity, infrastructure expansion is required, resulting in more energy consumption and therefore emissions.

When infrastructure expansion is required, this may be due to the same users making more trips, but also due to new users shifting from other transportation modes or from general population growth. It is however simplistic to assume that the same legacy buses will be added to the same routes to adapt to this demand; instead, larger buses may be procured with higher fuel efficiency or that use alternative cleaner fuel sources, and routing/dispatch may be further optimised. As a result, the bus network's total emissions may increase but not linearly from past trends, and part of the increase is due to shifting carbon from one mode of transportation to another. In a similar manner, network capacity expansion may be required due to the current users streaming more video, from new users who are shifting from traditional forms of TV viewing or from an increase in the number of users with internet connection. Network capacity will expand to meet this additional demand through a combination of means, which may result in an increase in total network energy, but is unlikely to do so linearly.

Internet capacity essentially revolves around a feedback loop of increasing demand which results in additional infrastructure and capacity and therefore energy and emissions. The existence of this increased capacity in turn enables increased demand for the network's services and the cycle continues (Figure 29) (Preist et al., 2016).

Figure 29. Feedback loop of network infrastructure (Preist et al., 2016)



5.12 Consumption of video has progressed in a carbon efficient manner

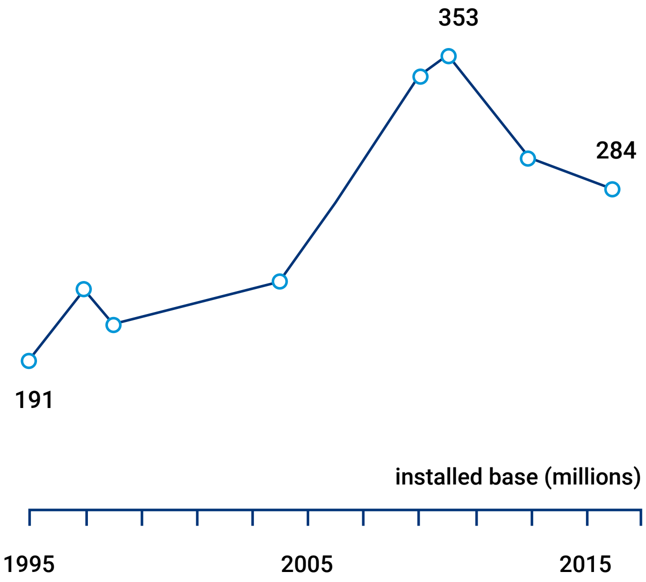
A lot has changed in the last two decades in relation to how we consume visual media content. Until the early-2000s, video rentals at home traditionally required a trip to brick and mortar stores, such as Blockbuster, and renting physical copies of video content, before returning home and watching a movie through a TV and VCR. Around this time, digital video recorders (DVRs) integrated within set-top boxes were introduced to the market and allowed recording of video directly from the TV for on-demand consumption at a later time. By the mid-to-late-2000s video content was increasingly consumed through monthly subscription services offering DVD rentals delivered through the postal system. This model no longer required consumers to travel in order to purchase or rent their video content, and saw the growth in popularity of a monthly-subscription package. Companies such as Netflix and Amazon were responsible for the major growth of this consumption mechanism (West, 2014). By the early 2010s, video consumption had finally shifted towards online streaming services (The Guardian, 2013).

This development of how we consume video content over time has one clear trend, it has become increasingly carbon efficient and dematerialised. From the days of a consumer having to get in their car and drive to a video rental store to access several hours' worth of physical media content at a time, to now being able to stream instantaneously a vast amount of content from within their home, the emissions associated with video consumption have become more efficient. With video streaming, operational emissions are virtually all electric and as we continue to progress towards a future of electrical grids with zero operational emissions through the use of renewable electricity, emissions from video streaming will continue to fall.

5.13 A shift in behaviour may reduce emissions

As previously highlighted, the choice of end-user devices on which video is streamed, can have a large impact on carbon emissions and energy consumption. Therefore, a shift in consumer behaviour, shifting from watching video on large TVs, to smaller mobile devices, may have the potential to reduce video streaming related emissions significantly. Additionally, where consumers switch to renewable electricity tariffs, this will have an even greater impact on the overall carbon impact.

Figure 30. Installed base of TVs in the United States (Urban et al., 2019)



Consumer electronics and its associated trends evolve rapidly, like with the swift development and penetration of smartphones in the global consumer electronics market. A trend seen in the United States, for example, highlights the potential impact that shifting consumer behaviour could make on video streaming emissions. Between 2013 and 2017, the number of installed TVs in the US fell by approximately 5%, a declining trend that has been in motion since 2009 (Urban et al., 2019) (Figure 30). It is not clear if this trend has continued since 2017, and certainly broadcasters in Europe have seen an increase in TV viewing, and a trend for larger screen TVs. In the UK, figures from Ofcom indicate that consumers increasingly prefer mobile and portable devices for accessing the internet (Ofcom, 2020b), where a growing proportion of adults no longer use a computer for going online and instead rely on smaller devices like smartphones and tablets.

A shift in consumer behaviour towards use of smaller devices may represent an opportunity for an increase in the proportion of video streaming content viewed through these smaller more efficient devices, such as smartphones, tablets and laptops. Should consumer behaviour shift away from TV consumption, the energy and carbon savings that could be enabled are potentially significant. The counter argument to this is that the trend towards the use of smaller devices is not directly replacing viewing on TVs, but is in addition to TV viewing, therefore giving rise to an increase in total video streaming consumption.

Furthermore, with the development and roll out of 5G mobile network equipment globally, and the potential this holds for low latency, high-quality connectivity, we may well expect to see a shift towards increased mobile network device consumption of video streaming. 5G has the potential to unlock a significant increase in mobile consumption, being able to provide faster streaming services over mobile networks. However, consumer households are still likely to have a home router, either a fixed line router or a 5G home broadband hub replacing a fixed line router (or possibly both), and therefore savings will not be driven by avoiding home router transmissions related energy use.

5.14 Predicting the future is difficult and has inherent uncertainty

It is inherently difficult to predict what the future may hold for video streaming going forward. Several key aspects of future development should at least be considered when discussing the future of video streaming. These include the uncertainty surrounding future behavioural patterns of consumption, what devices are used to stream video, the effect of 5G, and the difficulty in projecting modelled network energy.

With the rapid nature of end-user device product lifecycles quickly changing due to product innovation, and dynamic consumer behaviour trends, it is hard to say how video streaming habits may change. Here are just a few conceivable scenarios. While the declining trend of televisions in homes demonstrated in the US may continue, we may see more of a shift towards viewing of video streaming on mobile devices. However, there is significant uncertainty surrounding these trends. Unknowns surrounding the future of product development make predicting consumer device use difficult. 5G may play a big role in the future of video streaming, with the roll out of 5G mobile network equipment increasing around the world. As mobile video traffic and mobile devices begin to overtake the growth of other data traffic and fixed devices, internet service providers may attempt to propose new mobile infrastructures and solutions for high performance video streaming services, providing high-quality, high-efficiency streaming (Vo et al., 2017). Should 5G unlock a vast potential of high-quality streaming capability, we may see a heightened shift towards video streaming content viewed on mobile network devices, and smaller more efficient devices, compared to traditional fixed network devices in the home. This may potentially lead to energy and carbon-related savings associated with video streaming. However, a lot remains to be seen in the development of 5G – whether it will achieve the potential capability to deliver high-quality content and whether it may displace some of the use of fixed networks and home routers for video streaming.

From a modelling of video streaming emissions and energy impact perspective, there is also significant difficulty in understanding how the future assessment of internet transmission-related energy per volume of data might change going forward. The modelling of network energy, that has been used in assessing the energy associated with the transmission component of video streaming, is reflective of a specific timeframe. Consequently, the network models must be continually updated going forward, in order to reflect the most recent time period that is being assessed. Simple extrapolations using the figures and approaches in this paper will have a significant amount of uncertainty associated with them, as they will not reflect the network characteristics of future scenarios. However, despite this uncertainty, we can at least expect that networks will only get more energy efficient over time. Historically, the electricity intensity of network data transmission has halved roughly every two years since 2000 (Aslan et al., 2018). As also demonstrated by reporting of energy intensity by network operators – for example, see data reported by Telefónica and Cogent in section 2.6.2 (Figure 8 and Figure 9).

The future may also hold potential rebound effects, resulting from the increased ease of access of low, fixed monthly cost video streaming services. As video streaming has become more accessible and cheaper for consumers, consumers are viewing more and more video streaming content. As video streaming consumption increases in the future there may well be a rebound effect of increased energy use and carbon impact, potentially to the point where efficiency gains in network transmission and end-user devices are outweighed by the increased consumption of streamed video content. This highlights the importance of the continued uptake of renewable electricity to power transmission networks, so that increased network energy consumption does not translate directly to increased emissions.

5.15 Our understanding of network energy and emissions is limited by detailed data availability

What is clear from this research, is that a lack of publicly available data and transparency around energy consumption for all stages of the lifecycle of video streaming is limiting the accuracy and robustness of assessments of video streaming emissions. This is applicable for both the conventional and power model approaches. Should detailed data of network energy consumption at each stage of the network transmission process and network data traffic be easily accessible to studies such as this, it would be invaluable in helping to perform assessments of the environmental impact of video streaming and other internet services. From an accounting and diagnosis perspective, this would also allow for a greater understanding of the accuracy of both approaches currently and enable more progressive thinking on the determination of appropriate allocation approaches.

The current reporting by network providers of their energy data is typically at an aggregate level. Energy or data traffic figures in annual reports are not necessarily consistently defined, and of insufficient granularity to help validate assessments like these. If network providers were to disclose network related energy and data traffic consumption at a more detailed granular level, then the determination of network energy consumption would be enhanced significantly, and future assessments of video streaming emissions would be more easily validated and more accurate. However, it is recognised that most of the major network operators report their carbon emissions in annual reports and CDP submissions, and that telecommunications is one of the leading sectors in committing to science based targets and in use of renewable electricity.

There is also a need for greater data transparency from video streaming service providers, which will inform the assumptions that will have a significant impact on the allocation of energy in transmission of video streaming. Detailed measured data from service providers around customer numbers, and how they interact with their services would greatly enhance the validation of this methodology. Data on the device mix used by consumers and data on streaming activity itself would help improve the accuracy of energy allocation to end-user devices when video streaming. This need for data to be collected and reported is crucial for future ambitions to validate and refine this approach. These assumptions have a significant impact on the energy consumption allocated to video streaming, and thus to be able to improve the estimation of the energy and carbon impact from video streaming requires that data collection and surveying of this kind of data becomes available in the future.

5.16 Areas for further investigation

Certain areas for further research have been identified, which may benefit the future development of video streaming impact assessments and refining the calculations. Firstly, more research could be undertaken to understand peak capacity of the internet, and how this will impact energy and emissions going forward, as peak capacity grows. This is important to understand how future increases in video streaming demand will impact peak capacity of the internet, and how the energy and emissions implications of that will change. As previously mentioned, it is peak demand which ultimately drives the baseline energy consumption of the internet transmission network. More research is needed to understand what is driving the peak capacity demand that in turn drives the provisioned capacity for transmission equipment (and whether advances in technology are simply enabling greater capacity that is then used by new services). Improved understanding of peak network demand will also inform decision making surrounding allocation approaches like those used in the analysis of this paper.

If we are to determine that it is peak demand which is driving the baseline consumption of internet energy, provisioned to meet peak demand, then we must understand who is driving the need for peak demand. Mid to high bitrate services, such as video streaming or streamed gaming, may be the natural first guess at what to point to. Services like these, which often result in significant increases in demand in a single period, may be the drivers of the need for greater power consumption and infrastructure to meet demand. If this were the case, then it raises the question, is the power model approach a fair way to allocate emissions to these services?

The power model approach may effectively be allocating these service providers less emissions based on their marginal impact on internet transmission consumption, whereas in reality, by driving peak demand and therefore baseline power consumption to support this, they should in fact be allocated more emissions related to this. Further research in this area and a better understanding of how network capacity is provisioned, is important to help understand the future trends of capacity and the potential trajectory of emissions and energy consumption from internet transmission.

By understanding who the key players are in decision making around peak capacity we can further understand how to allocate the baseline energy consumption of transmission networks more appropriately, and continue to refine the power model approach. By conducting future research into the drivers and decision makers of peak capacity, we will be able to develop an improved allocation methodology for network energy and emissions, accounting more accurately for the demand-driven baseload of energy consumption in the networks to the key players driving this demand.

Another area where future research should be focused is around the energy per data [kWh/GB] metrics for fixed and mobile networks, and how these may change in the future, and what is an appropriate global average to use in the conventional approach as outlined in this white paper. For instance, the 0.0065kWh/GB figure used in the conventional methodology for fixed network energy allocation may not be a representative global average, but may more likely reflect a lower European average where efficiency in the networks is greater than in less developed areas of the world. Greater research and validation of figures like these is required to enable a conventional approach that is sound enough to provide a high-level total system boundary analysis of video streaming impacts and organisational foot-printing. Further research and investigation should be conducted to build up this database and improve the robustness and validity of such figures used in an average global scenario.

6. Policy developments

6.1. Introduction – Policy developments

This policy section of the white paper follows the main components of the value chain of video streaming, focusing on governmental policy related to data centres, networks and end-user devices both on regional and national level. The geographical scope for this is primarily Europe where there have been significant developments recently, but we acknowledge that further comparison and analysis with other regulatory efforts should be conducted. Subsequently, this section looks at what the industry is currently doing either collectively or at a company level. Similarly, the value chain of video streaming (data centres, networks and end-user devices) will be considered for these industry initiatives. Lastly, there is an assessment of the gaps and opportunities within governmental policy and corporate action.

As mentioned in the introduction, there is an increasing awareness among policy makers that ICT has both the capability to deliver technology to reduce carbon emissions, but it also has its own significant carbon footprint. Therefore, policy makers are concerned both about reducing the direct carbon impact from ICT, and also about encouraging innovation that can enable emission reductions within the sector and in other sectors. Particularly in 2020, this awareness has been reflected in public policy and corporate action on tackling emissions from the sector (including video streaming specifically). With a strong recommendation from the sector that funding for ICT innovation is part of a green recovery, decision makers are looking to improve the conditions for coverage and connectivity by improving the investment environment for ICT. This is illustrated by the examples of explicit inclusion of ICT in the EU Taxonomy and the European Green Deal.

On a European level, concerning the ICT sector and digitalisation, the European Green Deal includes a digital strategy titled ‘Shaping Europe’s Digital Future’, published in February 2020. The European Green Deal is at the core of defining a sustainability framework for Europe and is laying the groundwork for the European Commission’s sustainability roadmap. This comprehensive set of policies is providing a framework to meet the climate targets for 2030 and 2050. Firstly, Europe wants to be the first continent to have no net emissions by 2050. The aim of the digital strategy is to prepare Europe for a new digital age and simultaneously achieve the 2050 climate neutrality targets proposed by the European Commission. The main components within the digital strategy are on Artificial Intelligence, European data strategy, European industrial strategy, High Performance Computing (HPC), Digital Markets Act, Digital Services Act, Cybersecurity, Digital skills and connectivity.

The objectives are formulated under the umbrella of three pillars: (I) Technology that works for people; II) A fair and competitive digital economy, and III) A digital and sustainable society. Underlying this strategy is the objective for Europe to be one of the largest digital players globally.

A ‘digital and sustainable society’ is defined under the strategy as the ICT sector ‘contributing to a sustainable, climate-neutral and resource-efficient economy’. As outlined in the Introduction and Background sections there is uncertainty on the exact contribution of the ICT sector to global energy use and emissions, and this is also affected by what is included within the definition of ICT. The European Commission’s digital strategy claims that the ICT sector accounts for 5-9% of the global electricity use and over 2% of global greenhouse gas emissions (European Commission, DG CONNECT, 2020c). Despite the uncertainty over these numbers, the strategy does clearly acknowledge that technology and innovations from that very same sector could also help reduce global emissions, more than the sector itself emits.

For example, the German government is making strides with presenting an environmental digital agenda with more than 70 measures to make the tech sector more sustainable (German Ministry for Environment, 2020a). The government claims that this digital agenda is the first strategy in Europe that combines digitisation and environmental protection in such a consistent manner. The German environment ministry places the footnote that "If unchecked, digitalisation will become a problem for the climate”, but simultaneously stressing the potential that digitalisation has for containing climate change. Addressing this paradox is at the heart of the many national policies. (ibid.)

In March 2021, the European Commission announced the Green Digital Coalition (European Commission, 2021c). This specifically acknowledges both the emissions of the ICT sector and the potential for reducing emissions in other sectors. It includes a commitment to ‘develop methods and tools to measure the net impact of green digital technologies’, and as of mid-April 2021 had CEOs of 26 companies that had signed the declaration.

The balance between both negative and positive impacts is dependent on improving energy efficiency and circular economy performance of the ICT sector, from data centres to broadband networks to end-user devices.

6.2. Policy developments

6.2.1 Traceability and monitoring frameworks

Currently, consistent data on the energy and carbon emissions from ICT is not available. Many studies are based on academic modelling, rather than bottom-up data reported by ICT companies. Data reported by ICT companies is variable, with some companies providing detailed comprehensive data, while others provide very little data on energy and emissions. Good policy requires good data. To support this, governments and international organisations globally are exploring different measures, on energy efficiency and circular economy.

On a European Union level the objective of proper monitoring can be found, among others, in a public consultation on "Environmental management & performance – sectoral reference document for telecommunications/ICT services". The request for consultation describes that the ICT services sector should 'set out best environmental management practice for all telecommunications and ICT services providers including telecommunication operators, ICT consultancy firms, data processing and hosting companies, software developers and publishers, broadcasters and installers of ICT equipment and sites. Specific environmental performance indicators and benchmarks of excellence for a particular best environmental management practice should also be given whenever possible and meaningful'. (European Commission, 2021d). It should be mentioned that an opportunity for public consultation is not a guarantee for concrete legislation or enactment. However, it does reflect the current awareness regarding the sector and its environmental efforts.

We also see that investing in better measurement is gaining national political traction in some European governments. A recent French legislation document states: 'We need precise, clear, objective data and consensus methodologies on the real impact of digital technology on the environment' (French Senate, 2020). The need for consensus on methodology has been echoed by the industry and having national policy on this will enhance true action. The telecom and environment authority in France had established a roadmap to work together with the industry on improving the methods to better measure the impact on ICT.

In September 2020, the United Kingdom released their 'Sustainable ICT and digital services strategy: targets for 2020-2025' (UK Department of Environment, Food & Rural Affairs, 2020). The strategy quite clearly reveals guidelines for the ICT sector that includes climate targets. The ICT sector should reduce greenhouse gas emissions and work towards net zero targets, using science-based targets. Existing suppliers should work with the government to meet legally binding, or existing/emerging sectoral targets. Similar to the other national and regional strategies, technology and digital innovations are considered essential drivers for sustainable solutions, such as reducing travel, energy transition and reducing waste.

The United Kingdom strategy is also specific on materials traceability for the ICT sector. One of the goals is '100% traceability of ICT at end-of-life (mapping) and 100% compliance and transparency in supply chains'. The goals on the transparency are for the ICT sector to publish an accurate ICT footprint based on the services consumed, of estates and with suppliers, encompassing embodied/embedded carbon. Secondly, for the sector to map and account for all ICT at end-of-life. Thirdly, there is a need for collaboration and setting up a governmental sustainability steering group to increase transparency and subsequently accountability.

6.2.2 Data Centres

Considering the value chain of video streaming, data centres have so far been the most prioritised target of regulatory initiatives. National and regional policy related to the growing number of data centres and the concern over their energy consumption, are well established.

An example of these initiatives on data centres from the Commission is the EU Code of Conduct for Data Centres, first introduced in 2008 (European Commission, 2008). Its aim is to inform and stimulate data centre operators and owners to reduce energy consumption in a cost-effective manner without hampering mission critical functions. The Code of Conduct aims to achieve this by improving understanding of energy demand within the data centre, raising awareness, and recommending energy efficient best practices and targets. The Code of Conduct is a voluntary initiative and partners that are signed up are expected to follow the intent and commitments. It should be noted that the Code of Conduct has been regularly updated since its original development, and has been aligned to EN50600.

There is also an array of other industry sustainability standards and metrics which are increasingly being referenced in policy (which the sector welcomes). For information on Data Centre energy efficiency and other sustainability metrics, and related Data Centre standards see (techUK, 2017a) and (techUK 2017b).

Although still used, the Code of Conduct is now relatively old and until 2020 was only originally a framework. To be more in line with the latest sustainability strategy, the European Commission recently released the ‘2021 Best Practice Guidelines’ (European Commission, 2021a), which is a supplement to the Code of Conduct as an education and reference document to assist data centre operators in identifying and implementing measures to improve energy efficiency. Under best practices concerning associated carbon impacts, there are specific guidelines on ‘Energy Use and Environmental Measurement’, ‘Energy Use and Environmental Collection and Logging’, and ‘Energy Use and Environmental Reporting’. Depending on the level of control of the data centre that an individual organisation has, the general policy is that all actors should ‘Introduce a plan for Environmental Management in accordance with emerging EU guidelines and internationally standardised methodologies’ and ‘Introduce a plan for Energy Management in accordance with emerging EU guidelines and internationally standardised methodologies’.

Also, back in 2008 the United States established the voluntary National Data Center Energy Efficiency Information Program. The program engages numerous industry stakeholders who are developing and deploying a variety of tools and informational resources to assist data centre operators in their efforts to reduce energy consumption in their facilities (US EPA 2008). Since then we have seen other voluntary and self-regulatory initiatives emerge.

An example of the increasing focus on Data Centres by national governments is the proposal of the German Federal Environment Agency to create a register for data centres to monitor future efficiency targets. The agency is therefore preparing a uniform statistical survey of data centres to create a register and to serve as a basis for effective sector coupling. Sector coupling is the idea of interconnecting (integrating) the energy consuming sectors – buildings (heating and cooling), transport, and industry – with the power producing sector. The digital strategy also specifically addresses streaming services providers, encouraging them to operate with data centres with 100% green electricity and to make ‘sensible use’ of waste heat.

In France, both the French government and the senate released recommendations in 2020 on the 'green digital transition'. The senate presented a draft legislation, mentioning limiting the impact of video streaming and improving energy efficiency in data centres. Mentioning the limiting of infinite scrolling, a technique that loads content continuously as the user scrolls down the page. Also, adapting the quality of the downloaded video to the maximum resolution of the terminal. On data centres specifically, the recommendations would require data centres to subscribe to binding multi-year commitments to reduce their environmental impacts (monitored by ARCEP) and by subjecting tax benefits to environmental performance.

6.2.3 Network Transmission

Policy makers and industry have a strong focus on improving the energy efficiency of network technologies. This is reflected by German Environment Minister Schulze, commenting on research into the CO_2 emissions from video streaming commissioned by the German Federal Environment Agency: "To date, the data available on how digital infrastructure affects the climate has been extremely sparse. This is why we are working to bridge the existing gaps in our knowledge with solid research. After all, good policy needs to be based on good data. The most recent findings now show us that it is possible to stream data without negatively impacting the climate if you do it right and choose the right method for data transmission. From an environmental perspective, it would be a good idea to set up more public wifi hotspots, as this is more climate friendly than streaming in mobile networks. The climate benefit of working from home and video conferencing can even increase with the right transmission methods and more efficient data centres. My goal is to capitalise on the German EU Council Presidency to reach a common position on environmentally friendly digitalisation because the best approach would be to set good standards throughout Europe." (German Ministry for Environment, 2020b)

Dirk Messner, President of the Federal Environment Agency, further commented: "This is good news for people who like to watch movies and series. You can use streaming services at home with a fibre optic cable or VDSL without having to feel guilty about the climate. But the volumes of data all around us will grow steadily over the next few years, be it in the form of networked vehicles, home cinema or video conferencing. This is why it is important to find climate friendly transmission channels. Our research shows that we should step up investments in expanding our fibre optic networks. The new 5G transmission technology is also promising in terms of climate change mitigation." (ibid.)

The 'Environment, climate change and circular economy' working group from The International Telecommunications Union, a specialised body from the United Nations, has identified standardisation requirements for the sustainable use and deployment of ICTs and developing international standards. Formulated as the 'ITU-T Recommendations on methodologies and guidelines that assess the environmental impacts of different ICT applications'. These recommendations cover specific ICT related functions, products and services, including, for example: ICT supporting equipment and facilities, installation activities (such as on radio sites), and networks and other services. Additionally, a framework adopted by ITU and its member states is the Connect 2030 Agenda. The purpose of the agenda is to shape the future of the ICT sector by working towards four distinct goals; Growth, Inclusiveness, Sustainability, Innovation and Partnership. Also, the same working group has developed a set of international standards (ITU-T Recommendations) that assess the environmental impacts of 5G systems including the electromagnetic compatibility (EMC) aspects, the electromagnetic fields (EMF) aspects, energy efficiency in 5G systems and their resistibility to lightning and power fault events (ITU, 2019).

6.2.4 End-user viewing devices

As discussed in the Results section, the end-user devices account for the greatest portion of emission in video streaming footprint. Reduction strategies lay within energy efficiency of the end-user devices (Malmodin & Lundén, 2018a), and through changes in screen display technologies that have the possibility to enable substantial reductions in power consumption.

To help EU consumers cut their energy bills and carbon footprint, a new version of the widely-recognised EU energy label was introduced in all shops and online retailers from Monday, 1 March 2021. The new labels will initially apply to four product categories; fridges and freezers, dishwashers, washing machines, and television sets and other external monitors. New labels for light bulbs and lamps with fixed light sources will follow on 1 September 2021, and other products will follow in the coming years. In the USA, the Energy Star program has existed since 1992, managed by the Environmental Protection Agency (EPA), early on it set minimum standards of energy efficiency for computers and servers, and has over time been extended to a wide range of products.

Regulations related to standby mode power settings have been established for many years, for example EU regulation No 642/2009, and IEC 801/2013.

In France, as part of the digital strategy in early 2021, the Ecological Transition Minister Barbara Pompili and the Secretary of State for Digital, Cédric O, presented concrete plans to bring environmental and digital issues together. The plans are outlined under three main pillars: 'develop knowledge of the digital environmental footprint'; 'support a more sober digital environment'; and 'make digital technology a lever for the ecological and solidarity transition'. Thereby also directly addressing the consumer in their digital behaviour. Similar to the German strategy there is a part on addressing the consumer and the fact that they must be empowered and educated to commit to an environmentally conscious use of digital technologies.

Regarding the reuse or recycling of the device itself, the European Union is examining the benefits of 'take-back' schemes for devices. Supporting a take-back scheme should incentivise consumers to return devices that are no longer needed, with the hope of higher levels of recycling.
Also, the 'right to repair' is on the agenda and is receiving more public attention. The 'right to repair' can apply to all consumer goods, but especially introduced to reduce e-waste. In February 2021 the European Parliament voted in favour of the 'right to repair', as part of the Circular Economy Action Plan. Legislation is currently not in place yet, but it sends a strong signal on tackling embodied emissions and e-waste.

6.3. Industry initiatives

As mentioned, the ICT and E&M sectors face various challenges to decarbonise. However, through the power sector and purchases of renewable electricity, ICT is well positioned to keep pace with future targets. In the past, the ICT sector has responded proactively to address its emissions challenge and unlock opportunities for greater energy efficiency across the sector. Leading players within the ICT sector have increased their climate ambition. In the last 10 years, the sector has been taking steps to decarbonise, through accounting and reporting of greenhouse gas emissions, implementing energy efficiency programmes, and incorporating the use of renewables into the energy grid (GSMA, Climate Action Handbook, 2019). This GSMA handbook is ‘designed to be a high level guide to climate change for anyone working in or with the mobile industry. It explains the need for timely and decisive action, how emissions are categorised and the related terminology, before focusing on how the mobile industry is responding and potential next steps'.

The ICT sector is making positive strides to address its energy consumption. ICT companies, specifically data centre operators such as Google, Facebook, Microsoft, Amazon Web Services (AWS), Equinix, along with network operators, continue to increase their share of renewable electricity, through the procurement of Power Purchase Agreements (PPAs). Leading by example, ICT companies have been responsible for over 50% of corporate renewables procurement, globally, in the past five years (Kamiya, 2020; BloombergNEF, 2020; Financial Times, 2021).

Overall, the ICT sector has the means at its disposal to achieve deep decarbonisation, through energy efficiency and use of renewable electricity. However, there is a need for industry-led reporting and increased transparency of ICT companies’ energy and carbon impacts. The following section will outline several industry challenges and opportunities to tackle the associated emissions for video streaming of data centres, networks and end-user devices.

6.3.1 Data centres - Industry

The IEA (2020a) ranked data centres and networks as a sector "on track" to achieve deep decarbonisation. This is supported by both corporate and political players within the sector that are responding to the challenges of climate change, in order to reduce the sector's carbon footprint.

The United Nations specialised agency for ICTs, the ITU, has been working with the industry to minimise the carbon footprint of ICTs, developing international standards (ITU-T Recommendations), for example, in areas as diverse as smart cities, data centres and e-waste management. For data centres specifically, they highlight the exponential growth of data centres worldwide and subsequently the need for data centres to move towards utilising renewable energy sources in their operations. They therefore highlight that investment and research in greening data centres is crucial.

Recently, over 40 organisations announced the creation of the Climate Neutral Data Centre Pact, a set of self-regulatory measures developed with the European Commission to make data centres climate neutral by 2030. The pact was initiated in January 2021 and was described as a 'sector collaboration to ensure data centres are an integral part of the sustainable future of Europe'. In the pact, data centre operators and trade associations agree to make data centres climate neutral by 2030, in line with the European Green deal. The signatories, including Google, Microsoft, OVHCloud, AWS and Atos, commit to various targets for 2025 and 2030 to improve energy efficiency through water conservation, heat recycling and use of renewable energy. The pact is open to companies that own or operate data centres within the EU. Specifically, for energy efficiency, the pact states that the data centres will meet high standards, which will be demonstrated through aggressive power use effectiveness (PUE) targets. Another notable point on energy efficiency is the creation of a new data centre efficiency metric and in line with this, the need to standardise measurement methodologies for future reporting. For 'clean energy' the pact states that the signatory data centres should match their electricity supply through the purchase of renewable energy. Specifically, it targets that data centre electricity demand should be matched by 75% renewable energy or hourly carbon-free energy by 2025 and 100% by 2030 (Climate Neutral Data Centre Pact, 2021).

Large tech companies individually are also setting ambitious pledges to reduce their emissions. In terms of renewable energy use for operations, Google achieved 100% renewables in 2017, Apple in 2018, Facebook set a target to use 100% renewables by end of 2020, and Microsoft and AWS both have 2025 targets.

Google has now announced a target to go much further than matching 100% renewables on an annual basis, and by 2030 will run on carbon-free energy 24/7 everywhere at all times. This will match data centre energy use with renewable production on an hourly basis across the globe. Their strategy in their 24/7 carbon-free future white paper (Google 2020) is very comprehensive, and includes hourly monitoring and controls to shift data centre workloads in time throughout the day and geographically from one data centre to another, in order to synchronise the adaptable workloads with renewables generation through its PPA agreements.

In January 2020, Microsoft set an ambitious goal, pledging to be a carbon negative company by 2030 (significantly including its Scope 3 supply chain emissions), and striving to remove all of the company's historical carbon emissions by 2050, as well as setting up a $1 billion climate innovation fund (Microsoft, 2020). This represents one of the most progressive targets set by any private company to address its carbon footprint (Reuters, 2020).

6.3.2 Networks and transmission - Industry

A collaboration of the ITU, GeSI and the GSMA developed a decarbonisation pathway for the ICT sector, as the basis for setting science-based targets (SBT) guidance for companies within sub-sectors of ICT. This guidance, approved by the Science Based Targets Initiative (SBTi) in February 2020, recommends the first ever science-based pathway established by the industry to cut greenhouse gas emissions in the ICT sector.

Table 8. SBTi guidance for ICT sector companies

Sub-sector	% GHG reduction (2020-2030)
Mobile network operators	45%
Fixed network operators	62%
Data centre operators	53%

The key recommendation of the SBT Guidance is for the ICT sector to decarbonise in alignment with a 1.5°C trajectory (equivalent to approximately a 50% reduction in GGH emissions over the period 2020–2030) and more specifically, to target emissions reductions of 45% for mobile network operators, 62% for fixed network operators and 53% for data centre operators by 2030 (as shown in Table 8) (SBTi, 2020). Some of the measures outlined to help achieve these targets include the continued implementation of energy efficiency plans, switching to renewable/low carbon electricity supply, encouragement of greater carbon consciousness among end-users. As of March 2021, 41 telecommunications companies have either committed to or have set science-based targets, of which 23 companies have set a 1.5°C target (SBTi, 2021). Therefore, signalling a clear direction for the ICT sector to follow a 1.5°C compatible emissions reduction trajectory, and achieve net zero emissions by 2050.

6.3.3 End-user devices – Industry

As discussed in the Results section, the end-user device is responsible for the largest part of the video streaming footprint. To reduce this part of the footprint there are some opportunities through innovations and increased energy efficiency.

Generally, energy efficiency of end-user devices has been improving due to a mix of technology enhancements and power thresholds being set for standby and operation. The historical shift to smaller devices (e.g. PCs to laptops to tablets) has significantly contributed to reductions in total energy consumption from end-user devices. Also, historically, improvements in TV design, shifting from CRT to LCD and then LCD with backlit LED has enabled significant energy savings. For gaming consoles, the industry developed the Voluntary Agreement under the EU Ecodesign Directive for games consoles, to achieve 1TWh of energy savings per year by 2020 across Europe (European Commission, 2015). This voluntary agreement encompasses games consoles manufactured by the three major manufacturers; Sony Interactive Entertainment Inc, Microsoft and Nintendo, accounting for 100% of the market. As such, games consoles must also comply with the regulations set out in IEC 801/2013 for standby and networked standby power consumption, including setting maximum power limits according to each console type sold within the EU and also provide instructions for minimising energy use (Efficient Gaming, 2018).

6.4. Policy developments and observations

There is currently significant activity in the policy arena related to the ICT sector, with much in progress. The European Green Deal is still in development and concrete legislation, that aligns with the framework, will be rolled out throughout 2021. But there is a clearer understanding from policy makers that the ICT sector has the power to reduce the other sectors’ emissions.

There is a clear need to improve reporting, both on collecting consistent and reliable empirical data and streamlining reporting mechanisms. Both the ICT sector and governmental institutions play an important role in this. Currently, policy makers do not have detailed and comprehensive information of the impact of the ICT sector. Both company and government policies could benefit from improved data and streamlining of reporting. Industry agreement is needed on clearer sub-sector boundary definitions, and consistency in measurement of energy efficiency metrics.

Based on a better understanding of the full value chain and the associated emissions, policy should address the components that will have the most material impact along the lifecycle. There is an understanding that end-user devices are responsible for the largest portion of the video streaming emissions, however, concrete policy to reduce these emissions seems limited.

Policy makers should ensure that the digital and energy transition will be as green as possible. Therefore, policy also needs to recognise existing initiatives in the industry, and existing trends in technology. An example of supporting this understanding, is the ITU, the United Nations ICT specialised group, developing a set of methodologies and key performance indicators (KPIs) to assess the environmental impact including measuring carbon footprint, energy performance and efficiency across ICT networks, goods and services. The methodologies and KPIs are developed with the input of the sector itself, and can provide a framework for governmental policy.

7. Conclusions

The key conclusions from the analysis presented in this white paper are:

- **The carbon footprint of viewing video-on-demand streaming is relatively small in comparison to other human activities**
- **The marginal change of energy consumption in response to changes in viewing patterns is small**
- **There is inherent variability and uncertainty in the estimation of the carbon impact of video streaming**

These conclusions are now discussed in a bit more detail to provide some context and explanation.

The carbon footprint of viewing one hour of video streaming is small compared to other potential human activities. The European average footprint estimated in this white paper is approximately 55gCO_2e per hour of video streaming for the conventional allocation approach. (This estimate uses a European average grid emission factor of 0.295gCO_2e/Wh, a representative mix of viewing devices, and network energy intensity figures for 2020). For comparison, the emissions from microwaving a bag of popcorn for four minutes is about 16gCO_2e, boiling a kettle for two minutes is 18gCO_2e (using the same European average grid emission factor), while driving 100 metres in an average petrol car emits around 22gCO_2e (using an average car emission factor of 0.216kgCO_2e/km).

The analysis in this white paper also shows that the viewing device is typically the source of the largest part of the carbon footprint.

The instantaneous (or marginal) changes in energy in response to changes in bitrate (due to different resolutions and other settings) result in only a very small change in the carbon footprint. This is because the energy consumption of most devices and of the network equipment change very little in response to dynamic changes in data volumes, as they have a fairly high constant baseload of energy consumption. This is well illustrated by the power model methodology, which reflects the dynamic power profiles of the network equipment.

As with most carbon footprint assessments there is an inherent variability and uncertainty in the estimation of the carbon impact of video streaming, which gives rise to a range of results. (Variability refers to variations due to factors such as time or place, while uncertainty refers to the degree of precision of measurements). This white paper, and other informed research, should help to reduce the uncertainty in the measurements, and provide a better understanding of the variability.

There are a number of reasons for variability in the results. One of the most significant is the location. The carbon intensity of electricity (measured as the electricity grid emission factor in kgCO_2e/kWh) varies significantly from country to country. For example, Germany's grid emission factor is approximately 30 times that of Sweden. There are also variations by country that can affect the network emissions (such as network technology, topology and ambient temperature), and viewing patterns may vary by country. The type of viewing device has a significant impact on the total carbon footprint – the footprint (related specifically to the energy of the viewing device) of watching on a 50in TV is roughly 4.5 times that of watching on a laptop, and roughly 90 times that of watching on a smart phone. The year that an estimation relates to is also significant, as improvements in technology mean that the energy intensity of equipment is continually decreasing, and separately the electricity emission factors are decreasing as the electricity grids decarbonise through the utilisation of greater proportions of renewables.

Related to the use of renewables, it should be noted that the results in this white paper use the country grid average electricity emission factors, and therefore do not recognise any additional use of renewables by data centre or network operators (or indeed by domestic use of renewable tariffs). This is similar to the GHG Protocol Scope 2 Guidance 'location-based' accounting method for electricity. Whereas the 'market-based' accounting method would recognise use of specific renewable electricity purchases.

This is an important distinction, as an increasing number of both data centre operators and network operators have made significant steps in moving to 100% use of renewable electricity. Following the market-based accounting method would result in a lower overall carbon footprint of video streaming for many countries in Europe.

The most significant source of uncertainty would seem to be related to the network energy component. As the comparison between the two methods shows, the allocation approach has a significant influence on the total footprint, and highlights the need to understand the different approaches and their application when interpreting and using the results. This is discussed further below. Additionally, there are only a limited number of consistently measured, publicly available data points for the energy intensity of networks, which also contributes to the uncertainty in the network energy.

This white paper presents a new method for the carbon foot-printing of video streaming. The power model approach is different from the conventional approach in the way that energy is allocated from the shared components of the network and the home router. It is very common in product carbon foot-printing and in lifecycle analysis to use allocation approaches. Often, there may not be an obvious method to use, rather a variety of approaches that reflect different realities. This white paper is not intended to endorse one method over the other, but to highlight that the two methods are suitable for different purposes and different types of analysis. Both would benefit from further refinement, validation and research. Returning to the analogy of a bus network that has been used through this white paper, the conventional approach reflects an average emission factor per passenger-km, (which would be derived from the total annual bus network fuel consumption, and the total annual passenger-km travelled). Whereas the power model approach reflects the instantaneous marginal change in emissions based on dynamic changes in number of passengers. Therefore, to understand the impact of a decision to take a bus or not, the two approaches will give different answers – the outcome from the conventional approach will be that emissions are reduced by not taking the bus, while the outcome from the power model approach will be that there is only a small marginal reduction in emissions, because the bus is running anyway. However, for a company reporting its annual business travel emissions, it makes sense to use the conventional (average emissions) approach. To extend the analogy a bit further, very different results arise if considering travel by car – then the marginal and average emissions are much more similar to each other, and indeed the marginal emissions of travelling by car would be higher than the average when travelling alone (as the average would assume an average number of passengers greater than one). This reflects the fact that a car is not a highly shared resource, unlike the public transport network or the internet network.

One area for further investigation of the power model approach is how to appropriately allocate the baseload energy. The power model approach in this white paper allocates the energy per user and time of use, however it is difficult to establish what is an appropriate allocation of time – is it connection time, or download time, and how is idle time best allocated? Indeed, other allocation methods can also be considered, such as considering the utility or value of the service being used, or the contribution to peak data demand. However, ultimately using a method that is transparent and practical is also important. The use of the allocation method should also be consistent for other services that use the network, otherwise all of the energy and carbon may not be fully allocated and accounted for. This, then, raises the question of what are the impacts and consequences for other services?

Finally, this white paper has identified areas for further investigation and improved data. In order to improve understanding and measurement, and to inform decision making, more granular methodologies and more granular data is needed. In addition to further work on refining the allocation methodologies discussed above, there is a need for more data in order to provide greater insights than presented in this white paper. Specifically, more detailed and consistent data on network energy and carbon intensity would be helpful to understand the variability in network energy intensity, reduce the uncertainty, provide regular updated figures, and help in validation of the power model coefficients that are used in the power model approach. Ideally, energy intensity figures for different network technologies (e.g. fixed ADSL, fixed fibre, 2G, 3G, 4G, 5G) would be very useful. However, it is recognised that network operators may not wish to publish this level of detail, and anonymised aggregated data could be collated through organisations such as GSMA, ETNO or ITU (similar to the role that the World Steel Association undertakes for the steel industry or the IMO for the shipping industry). Similarly, it would be useful to have more consistent and comprehensive information on data centre energy and emissions (although, as noted in this white paper, the data centre component makes only a small contribution to the overall footprint of video streaming). Greater information on user behaviour, in terms of types of viewing devices, and mix of services and connected devices, would again help to improve the analysis of the footprint of video streaming, and identify any longer term trends. Two other areas for further investigation are better understanding of the factors that drive peak network data demand, and more detailed analysis of the impact of the embodied emissions of devices and equipment on the carbon footprint of video streaming.

8. Questions and Answers

The purpose of this Q and A section is to highlight some of the questions that may be raised from this white paper, and summarise some of the points that are covered in more detail in the white paper.

What is a carbon footprint?

A carbon footprint measures the total greenhouse gas emissions caused directly and indirectly by a person, organisation, service or product. It is measured in tonnes or kg of carbon dioxide equivalent (CO_2e), combining the impact of different greenhouse gases into one figure equivalent to if it were all CO_2, based on their warming potential.

What is the internet?

The internet is the network infrastructure that connects all devices so that they can exchange data. Every device on the internet has an IP address so that each device knows where to send data. The internet is operated by network operators (telecommunications companies and Internet Service Providers – ISPs), and the network operators' networks are connected to other network operators' networks.

Colloquially, the internet can also mean anything that you can do or look up on the internet. So, you could check the weather forecast on the internet. To do this you would connect your device (PC, laptop, or smartphone) over the internet network to a website on a server in a data centre, which would hold a summary of the weather forecast information. The weather forecast is generated in a high-performance computing data centre that is also connected to the internet network. So, colloquially, "the internet" can also include all the data centres that are connected to the internet. When you view a web page on the internet, you are using a web browser on your device (e.g. smart phone, tablet or laptop) to view web pages and content hosted on servers located in data centres, which are connected to you by the internet network.

What is a CDN?

A Content Delivery Network (CDN) acts as a local store (or cache) for digital content on the internet. The CDN content is only updated from the origin server when there is new content or a new version. Particularly for video streaming this is very useful, so when you are watching a video you will be accessing the local version of the video rather than the hosted version at the origin server (which may well be in another country). This gives you a better viewing experience, it reduces latency (the time taken for the data to get to you across the internet from where it is stored), means less waiting and less buffering. CDNs also significantly reduce the total data traffic across the internet, particularly for international traffic, and submarine cable traffic, because they avoid the need to transmit large data volumes from the origin server directly to you every time you watch video streaming.

Many video streaming services use one of the third party CDNs, which will have presence across the globe. Particularly in larger countries, a CDN will have multiple points of presence, located close to the larger population centres. Some video streaming services operate their own CDN. Netflix operates its own CDN, Open Connect, which has a presence in nearly all countries that it operates in.

Allocation – what is it and why is it important?

Measuring the carbon footprint of a product or service over its lifecycle requires calculating the use of energy and other resources that cause greenhouse gas emissions for each of the different lifecycle stages. In many cases a particular product will share use of resources with other products, and so the resources need to be allocated between the different products. For example, a factory may make 12 different products; if you know the total energy used by the factory how do you allocate this to the 12 products? You could allocate it equally based on the total number of products produced, but different products may need very different amounts of energy to manufacture them, and it may be difficult to get accurate information on the energy per product.

For video streaming there are multiple stages where allocation is important, and the different allocation methods can give different results. Allocation approaches for each stage are explained further below, starting with you the viewer, and working back through the lifecycle to where the video content originates.

Lifecycle stages and allocation approaches:

- **TV**
- **Home router**
- **Internet transmission**
- **Data centres and CDNs**

Watching on a TV – when the TV it is switched on, and you are watching a video for an hour, then all of the TV's energy for that hour can be allocated 100% to watching the video. We are assuming that the TV is switched off (or in low power standby mode) when you are not watching, and the standby power is very low, and is therefore excluded from the allocation method used in this white paper. (A more detailed analysis would also consider the average standby energy and allocate it to the different viewing times during the day. As the standby power is small it will have a minimal impact on the overall estimation).

Home router – the home router connects you to the internet and is on 24 hours a day, using energy all the time. The router is being used by various devices and functions throughout the day (e.g. internet browsing, emails, work, video calls, video streaming). The amount of energy used is fairly constant no matter how much data is being downloaded. There are two obvious allocation methods: 1. By data consumed; 2. By time consumed.

The data consumed allocation method assumes an average amount of daily data used, and for one hour of video allocates the energy based on the data used for one hour of video. The conventional method in this white paper uses an average household data usage of 294GB/month, which is about 10GB/day. HD video streaming at a bitrate of 6.67Mbps is equivalent to 3GB for one hour. So, one hour video streaming uses 3/10 of the daily average data (or just under a third). This is then multiplied by the daily energy use of the home router (10W x 24h), which gives about 70Wh for one hour of video streaming. You can see how this allocation method would allocate more than 100% of the energy if you watched four hours of video in one day.

The time consumed allocation method simply assumes that you are using the router for one hour, out of the 24 hours in the day. So, this would allocate 10Wh for one hour of video streaming. The method used in the power model approach in this white paper also allocates idle time-related energy (when no data is being consumed), and also considers that multiple users or devices may be using the router in a household (which varies by country). This results in an allocation of the energy of about 3Wh for one hour of video streaming.

This example serves to illustrate the differences and the importance of allocation approaches. Both approaches are valid and both use reasonable assumptions, it is likely that the power model approach represents an under allocation and the conventional approach an over allocation.

Internet data transmission – the internet consists of hundreds of thousands of network routers that are all connected to each other and manage the transmission of data from the source to your home router. Similar to the home router, these routers are continuously on, using a nearly constant amount of energy all the time, varying only slightly depending on the amount of data traffic. The internet is providing connectivity to multiple devices for multiple purposes, so again there are potentially many different ways that the energy could be allocated.

In this white paper the conventional approach uses an average energy per data traffic value (in kWh/GB), while the power model approach uses a baseload power element (independent of the data traffic), and a dynamic power element (related to the data traffic), which more closely represents how the network energy use actually responds in real time to data traffic volumes. The power model approach therefore allocates a much lower amount of energy for video streaming than the conventional approach does – this is because it assumes that there is effectively an energy cost for being connected to the internet, no matter how much data is being used. This means that other users and services will be allocated a higher amount of energy under the power model approach than the conventional approach.

The conventional approach allocates an average amount of energy based on data usage, whereas the power model approach allocates a marginal amount of energy based on data usage, plus a fixed amount of energy for being connected.

Data centres and CDNs – these host the video content, encode and prepare it for video streaming, and store a local version of the video for streaming to the end-user. Thus, these resources are shared with all the users of the video streaming service. In this white paper, both the conventional and power model approaches use the same method, which is taking the total energy used by the data centres and CDN for video streaming, and dividing by the total hours of video streaming.

How can I reduce my carbon footprint from video streaming?

Well, actually, the carbon footprint of watching an hour of video streaming is not very much. About the same as boiling the kettle to make a cup of tea, or microwaving a bag of popcorn. So, you are not going to save the planet by changing your viewing habits. Probably the most useful thing you can easily do is to switch off your TV when you have finished watching. The energy used by the TV is probably the most carbon intensive aspect of the video streaming lifecycle. A smaller device like a tablet or a smartphone will use much less energy. Of course, the number of people viewing each device will also have an impact – four people watching the same TV together will use about the same amount of device energy as if those four people were watching on separate laptops, but about five times more device energy than the four people each watching on separate tablets. But as the carbon footprint is not very much to start with that should not be the main reason for choice of viewing device. As a consumer, you can influence the carbon footprint by checking that you have chosen an energy efficient TV when you buy a new TV, and the other thing would be to switch to a domestic renewable energy tariff.

The manufacturers of devices and operators of networks and data centres can and do reduce the carbon footprint of their products by manufacturing energy efficient devices, and using renewable energy in their manufacturing, and by using renewable electricity to operate the networks and data centres.

Does HD use double the energy of SD?

The short answer is no. For most of the stages in video streaming, the energy use does not instantaneously vary significantly with the amount of data used. So, there is only a marginal difference in the amount of energy used between streaming in HD (high definition) and SD (standard definition).

However, if the accounting for the energy is done purely on an average energy intensity per data volume (kWh/GB), then it would show that some of the stages use twice the amount of energy in HD as SD, but this does not reflect the immediate energy use. The case is similar for video conferences – regardless of whether you have your video on or not, it has only a marginal impact on the total energy used.

For the internet network stage an analogy would be a bus network. A bus will use almost the same amount of fuel whether there are 20 people or 40 people on the bus (or indeed if there are no people travelling on the bus). There is a fixed amount of energy required simply to provide the service, irrespective of the amount of usage. However, from an accounting perspective the bus emissions may be allocated to give an average per passenger (or per passenger-km) emission factor. This illustrates the important difference between a dynamic (or marginal approach) for allocation, and an average allocation approach. Both are useful for different purposes, with the marginal approach being more relevant for decision making and reflecting short-term actions (e.g. should I catch the bus, or walk or take the car), while the average allocation approach is more relevant for accounting purposes, and longer term decisions (e.g. how many buses are needed for the network).

For a further discussion of this see also the question on allocation, above.

So, what is driving the total energy requirements of the internet network?

This follows on from the previous question, however, this one does not have a simple answer, and would benefit from further research. This question is also covered in the Discussion section of the white paper.

The internet network is designed to manage a peak data traffic load, and as the network is being continually upgraded it is actually built to handle expected future peak demand. The total demand determines the capacity of the network and therefore the energy required to run the network. So, to ensure that there is not congestion the network needs to be able to handle peak demand. The total energy demand will be related to the peak capacity rather than the average demand. This picture is complicated more by the fact that new network equipment will be more energy efficient – i.e. will be able to handle more data traffic for the same amount of energy.

This can be illustrated by returning to our bus analogy. If the bus has a maximum capacity of 50 people, and there are 55 people waiting for the bus – then five people will not be able to get on the bus. With the internet network there is the same difficulty if at peak times the demand on the network is greater than the capacity, this results in congestion, with data packets being "dropped", resulting in either buffering or loss of picture quality if you are watching video streaming. The difference is that for the bus network, it may be possible to put on extra buses at peak times (and have less buses at off-peak times), whereas for the internet network the peak capacity is basically fixed, and cannot be varied on a daily basis – it requires investment in new network equipment and technology to increase it, so from that perspective it is more similar to the road network that the buses run on. The other difference is that technology improvements with networks has meant that network capacity can grow to accommodate annual increases of over 25% in data traffic.

Does watching two hours of video streaming use twice the energy of one hour?

On average yes, however, as discussed above, the internet network uses much the same energy whatever the total data traffic is. So, the main marginal difference between watching two hours and one hour of video streaming is in the energy used by the end-user viewing device (i.e. the TV, laptop or tablet).

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10. Appendix

Appendix 1: Additional modelling parameters

Table 9. Representative device mix for streaming services

Device | Network | Video Quality	Share of Total Devices
Android | Cellular network | Save data setting	1.2%
Android | Fixed network | SD (480p)	1.2%
Android | Cellular network | Automatic data setting	0.9%
Android | Fixed network | FHD (1080p)	0.9%
Android | Cellular network | Maximum data setting	0.1%
Android | Fixed network | 4K (2160p)	0.1%
iPhone | Cellular network | Save data setting	0.5%
iPhone | Fixed network | SD (480p)	0.5%
iPhone | Cellular network | automatic data setting	0.3%
iPhone | Fixed network | FHD (1080p)	0.3%
iPhone | Cellular network | Maximum data setting	<0.1%
iPhone | Fixed network | 4K (2160p)	<0.1%
Computer | Fixed network | FHD (1080p)	11.9%
50” Smart TV | Fixed network | FHD (1080p)	27.0%
50” Smart TV | Fixed network | 4K (2160p)	1.2%
50” TV w/ STB | Fixed network | FHD (1080p)	36.6%
50” TV w/ STB | Fixed network | 4K (2160p)	1.7%
50” TV w/ Gaming Console | Fixed network | FHD (1080p)	3.3%
50” TV w/ Gaming Console | Fixed network | 4K (2160p)	0.2%
Laptop | Fixed network | SD (480p)	6.6%
Laptop | Fixed network | HD (1080p)	5.3%

Assumptions:

- TVs account for 70% of viewing hours (Vox, 2018)
- Share of TVs with peripherals is an estimate, partially based on information available from DIMPACT members. Assumed 40% of TV viewing occurs on smart TVs which require no peripheral, 55% on TVs via set-top box and the remaining 5% on TVs via gaming console.
- Non-TV viewing assumed to be 6% smartphones, 12% desktops and 12% laptops based on Comscore’s The US Total Video Report (Comscore, 2014).
- Android and iPhone share of smartphones estimated based on Statcounter’s Mobile Operating System Marketshare Worldwide (Statcounter, 2021). Android assumed to be 72% and iPhone 28%.
- Simple assumption that 50% of smartphone viewing occurs on fixed networks and 50% on mobile networks.
- Resolution share by viewing hours is adapted from Cisco’s Visual Networking Index estimation of Global UHD IP video traffic for 2021 (Cisco, 2019b). Share of SD viewing hours on TVs is conservatively assumed to be full HD viewing as we only model 50in TVs. Resulting share of viewing resolution on TVs is 96% HD viewing and 4% 4K. Desktop computers assumed to only stream in HD. Assumption that laptops stream in either SD (55% share) or HD (45% share). Smartphones assumed to stream 55% in SD, 40% in HD and 3% in 4K.

Table 10. Estimated power consumption of devices for streaming

Device type	Power Draw (W)	Comment	Source
Android Phone	1	Samsung Galaxy S9, has 11.55Wh battery with up to 16 hours lifetime when watching videos	iFixit for battery Wh, Samsung for battery lifetime
iPhone	1	Assuming ~11Wh battery and 10h of battery life if streaming	Apple, 2021a, Apple, 2021b
Desktop computer	115	Desktop and monitor	Singh et al., 2019
Laptop	22	Portable computer	Singh et al., 2019
Normal TV	100	Conservative estimate for 2020 offering, but reasonable considering older TVs are used to watch Netflix	ENGIE analysis using Best Buy best sellers (Singh et al., 2019)
Smart TV	100	Conservative estimate for 2020 offering but reasonable considering older TVs are used to watch Netflix	ENGIE analysis using Best Buy best sellers (Singh et al., 2019)
Gaming Console	89	Sony PlayStation 4	Mills, 2015, NRDC, 2014 and Singh et. al, 2019
Set Top Box	18	STBs with DVR using reported installed base of all STBs in the US	D+R International, 2020

Table 11. Regional modelling parameters

Region	Average Household Size	Average per Capita Devices and Connections	Electrical Grid Emission Factor Source (Grid Year 2018)
France	2.2	6.1	IEA, 2020b
Germany	2.0	6.4	IEA, 2020b
Sweden	1.9	6.9	IEA, 2020b
United Kingdom	2.3	6.9	IEA, 2020b
Europe	2.3	6.2	IEA, 2020b

Average household size relates to figures for 2019 sourced from Population Reference Bureau 2020 World Population Data Sheet (Population Reference Bureau, 2020), except for Europe which is sourced from Eurostat (Eurostat, 2021).

Average per capita devices and connections relate to 2020 and are interpolated from 2018 and 2023 figures from Cisco Annual Internet Report (Cisco, 2020). Europe is assumed equivalent to Western Europe.

Electrical grid emission factors are sourced from the IEA's 2020 publication of emissions per kWh of electricity for grid year 2018. Europe grid factor is sourced from Memo: Europe (UN) within the IEA dataset.

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