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Table of Abbreviations

ADEME	Agence de l'environnement et de la maîtrise de l'énergie
AI	Artificial Intelligence
CED	Cumulative Energy Demand
CPU	Central Processing Unit
EPI	European Processor Initiative
GHG	Greenhouse Gas
GWP	Global Warming Potential
ICT	Information and Communication Technologies
IoT	Internet of Things
HD	High Definition
JRC	Joint Research Centre
LAN	Local Area Network
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
PEF	Product Environmental Footprint
PCR	Product Category Rules
PoS	Proof of Stake
PoW	Proof of Work
ToR	Terms of Reference
WAN	Wide-Area Network

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Executive Summary

This is the final report of the study "Assessment of the energy footprint of digital actions and services". The study aims to increase transparency about the energy consumption of the ICT (Information and Communication Technologies) sector, and to evidence the behavioural factors best suited to influence and to reduce its adverse impacts. Specifically, the scope of the study is to shed light on the too-often forgotten energy impact of ICT by providing a comprehensive overview of existing published estimates relating to the energy consumption of day-to-day digital actions and services, establishing simple and accurate estimates of the energy consumption for a limited number of these actions and services (ten in total), and creating communication materials for the purpose of disseminating these results via various communication channels. In doing so, this study gathers and provides evidence to help the European Commission identify mechanisms to address and mitigate the issue of ever-increasing energy consumption of the ICT sector, while achieving the RePowerEU Plan's and European Green Deal's objectives.

To achieve these objectives, the study relied on a step-by-step approach. First, a literature review of published estimates relating to the energy consumption of day-to-day digital actions and services was carried out to increase the knowledge around the topic and facilitate the activities in the subsequent steps. The review did not only provide a mapping of existing energy consumption estimates on each digital behaviour, but also looked into the methodologies used to generate these estimates and estimated their quality, relevance and reliability. In addition, a separate literature review was conducted on technological uncertainties and disruptive technologies that could influence the energy consumption of the ten considered digital behaviours and of the ICT sector in the future.

Second, a detailed quantification of the energy consumption of the ten digital behaviours was performed using a Life Cycle Assessment (LCA) approch. The study was performed following the ISO 14040:2006 and ISO 14044:2006 standards for LCA methodology, with the development of a Life Cycle Inventory (LCI) model for each behaviour, and an estimate of the energy savings of recommended best practices for an average user. The categories of equipment covered in the LCA are the user environment (Tier 1), the network (Tier 2), and the data centres (Tier 3). The calculated energy consumption values were compared with the estimates from the literature, and options to minimize the energy consumption and the environmental impacts of the ten digital behaviours were analysed.

In parallel, a total of ten visuals, one for each considered digital behaviour, were developed for the purpose of disseminating the findings of the present study via various communication channels. These visuals were created to share key takeaway messages with the general public, in order to increase awareness on the energy consumption associated with each digital behaviour and on the best practices to save energy. Finally, the limitations of the study were highlighted and recommendations drafted with the aim of increasing data transparency and standardisation.

The detailed literature review of published estimates on the energy consumption of digital actions and services revealed that **not all of the ten considered behaviours had been studied comprehensively**. While actions such as video streaming, video gaming, video conferencing, music streaming, and storing data in the cloud have attracted particular attention, especially since the start of the COVID-19 pandemic, other actions have been somewhat neglected. This can be partly explained by the lack of available data and the relatively small individual impacts related to actions such as writing and sending an email, or downloading a file to a PC, while other actions started to spark interest only in recent years, for example social networking and switching off the Wi-Fi router. We also found that **there is a gap in the literature for a transparent and comprehensive assessment of the impacts of disruptive technologies on the energy consumption of ICT**, including the roll out of 5G and its rebound effects.

When looking at the methodologies used to produce estimates on the energy consumption of different digital behaviours, **LCA emerged as the most comprehensive, accurate, and widely used approach, despite being time-consuming and data intensive**. While extremely common and recognised especially for carbon footprint and energy consumption assessments in ICT, LCA continues to suffer from variability in its application, which partially limits the comparability of results. Some practitioners argue that other methodologies such as modelling and direct measurement can also represent effective alternatives. Regardless of the methodology chosen, it is important to be mindful that **the estimates found from the literature can only be compared to a certain extent due to the adoption of different assumptions and system boundaries** across the analyses.

Notwithstanding this limited comparability, the analysis of the literature and the life cycle assessment performed in this study confirmed that **the energy consumption of day-to-day digital actions and services is significant, and energy savings can be achieved when more sustainable behaviours are adopted by average users**. Digital technologies are playing an increasing role in driving economic growth and creating a more connected society, and digitalisation is offering many opportunities to support the achievement of environmental goals by, for example, supporting teleworking, remote learning and healthcare. Yet, the sector itself is also a source of greenhouse gas (GHG) emissions and is accounting for an increasing share of global electricity consumption, expected to rise to 13% by 2030[1]. While **the energy impacts of digital behaviours** might seem negligible when taken individually (i.e. when applied to an individual action and an individual user), these **become considerable when these behaviours are performed repeatedly over time by each member of the entire cohort of users**, especially since the rise of remote work and virtual communication made online services essential. In the context of the recent energy crisis and launch of RePowerEU, **it therefore becomes important to raise users' awareness about the impact of their individual digital behaviours and to encourage the adoption of more sustainable digital habits**.

In addition to the best practices identified from the literature review, the quantitative assessment carried out in this study pointed out **the most effective levers to minimize the energy consumption and the environmental impacts of day-to-day digital actions and services**. The device used is often responsible for the majority of the energy consumption, for example when streaming videos, playing videogames, or video conferencing, and the size of the screen obviously plays a key role, so **using smaller devices** (e.g. smartphone, tablet, laptop) can lead to notable energy savings. **Lowering the video quality** is also an effective way to reduce the amount of energy used when streaming videos. When possible, it is always recommended to **connect to a fixed network** (e.g. fixed internet connection at home or via Wi-Fi) as this consumes less than mobile networks. Then, we identified a list of **behaviour-specific recommendations** including, for example, limiting the time spent on social media or playing videogames, avoiding to watch videos only to listen to the music, cleaning regularly the data stored in the cloud, repairing the phone when possible instead of replacing it with a new one, and switching off the Wi-Fi router when not needed for extended periods of time (e.g. when leaving for holidays).

Finally, it is worth mentioning that **adopting more sustainable habits when writing and sending an email and downloading a file to a PC can lead to significant energy savings when applied to a European or global scale**, despite their low energy consumption and environmental impact if taken individually compared to other digital behaviours. Some **examples of recommended energy saving practices** for these digital actions include limiting the size of the files attached to emails, unsubscribing from irrelevant newsletters, and downloading files only when necessary.

[1] Freitag et al (2021). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations https://www.sciencedirect.com/science/article/pii/S2666389921001884

The table below summarises the **estimated energy consumption and environmental impact**, expressed in terms of Global Warming Potential (GWP), **of the ten day-day digital actions and services** analysed in this study together with the **identified list of recommended best practices to save energy**. These estimates were produced assuming behaviour-specific average European device mixes as well as an average European network consisting of mobile and fixed network to perform the digital behaviours. The same European network mix has been assumed for all behaviours.

Digital behaviours	Average energy consumption of the action (and GWP) in the EU	Recommended best practices to save energy
1h of video streaming	0.051 kWh (56 gCO_2eq)	Use smaller devices Use fixed networks Decrease video resolution
1h of video gaming	0.051 kWh (60 gCO_2eq)	Use smaller devices Use fixed networks Reduce the number of hours playing video games
1h of video conferencing	0.128 kWh (135 gCO_2eq)	Use fixed networks Limit the number of participants Reduce the time of the meetings
1h of music streaming	0.048 kWh (58 gCO_2eq)	Use smaller devices Use fixed networks Try not to watch videos only for the music
1h of social networking	0.024 kWh (42 gCO_2eq)	Use fixed networks Use social networks with more static content (less videos) Reduce the daily usage of social networks
Write and send an email	0.009 kWh (5 gCO_2eq)	Limit the number of recipients Limit the size of the attached files Unsubscribe from irrelevant newsletters
Download a file (1 GB) to a PC	0.004 kWh (2 gCO_2eq)	Use fixed networks Download a file only if necessary
Store data (1 GB) in the cloud for 1 year	0.147 kWh (98 gCO_2eq)	Clean regularly your data stored in the cloud Turn off the automatic syncing of photo uploads
Prolong the lifespan of a phone	8.7 $kgCO_2eq$ per year[2]	Repair your phone instead of replacing it Consider extending the lifetime of your phone before purchasing a new one.

[2] Avoided GHG emissions per year.

Switch off the Wi-Fi router (for 2 weeks)	3.77 kWh (2.2 $kgCO_2eq$)[3]	Switch-off the Wi-Fi router while on holidays/away from home

[3] Energy savings and avoided GHG emissions.

1. Introduction

1.1. Overview of this study

This document represents the Draft final report of the project ‘‘Assessment of the energy footprint of digital actions and services’’. The project, running from November 2022 to May 2023, was commissioned by the European Commission (DG ENER) and performed by a consortium consisting of Ramboll Management Consulting and Resilio (hereafter referred to as the Consultant).

In the context of increasing digitalisation of all areas of society (e.g. households, private companies, public administrations and infrastructures), the ICT sector is responsible for ever growing energy consumption and GHG emission levels. Despite remarkable energy efficiency gains, the energy consumption of the ICT sector has grown to the point of becoming nowadays significant, as the need for digital tools, internet traffic, and the number of connected devices increase.

However, a certain degree of uncertainty on the estimates for the energy consumption and carbon footprint of ICT systems persists due a lack of publicly available data behind existing figures and estimates. It is also well documented that published estimates[4], in particular reports by companies on their ICT-related energy consumption, tend to somewhat underestimate the actual level of energy consumption attributable to their ICT systems.

Overall, several elements point towards the fact that the energy consumption of the ICT sector is significant and will likely continue to grow. For instance, Mobile data traffic is projected to continue growing quickly, quadrupling by 2027[5]. In Denmark, data centre energy use is projected to triple by 2025[6]. Yet, the exact magnitude of this expected growth is difficult to project, as many demand- and supply-side factors will influence this trend. The demand for ICT services will be shaped by the uptake of new solutions, technologies, and business models, such as artificial intelligence, edge computing, cryptocurrency mining and IoT (Internet of Things) technologies. In addition, while the chips[7] and EPI[8] initiatives show steady energy efficiency improvements of the ICT, major breakthrough technologies such as quantum computing, 5G and fiber rollout could contribute to decreasing the energy consumption of currently very energy-intensive applications.

It therefore becomes paramount to identify mechanisms to address the issue of ever-increasing energy consumption of the ICT sector. Behavioural changes of consumers using digital tools could, in particular, complement already well-advanced energy efficiency measures. These changes of behaviour could be encouraged by increasing the awareness of consumers on the energy consumption levels associated with their day-to-day digital actions (e.g., streaming a movie, sending emails, playing videogames, etc.), promoting more frugal behaviours and adressing potential rebound effects as well.

With the aim of better understanding the energy consumption levels associated with the ICT sector, this study reviewed existing estimates relating to the energy consumption of day-to-day digital actions and services, and provided a set of accurate and simple estimates on

[4] Freitag et al. (2020). The climate impact of ICT: A review of estimates, trends and regulations Lancaster University. Available from: https://arxiv.org/ftp/arxiv/papers/2102/2102.02622.pdf

[5] International Energy Agency (2022). Data Centres and Data Transmission Networks, https://www.iea.org/reports/data-centres-and-data-transmission-networks

[6] ibid

[7] European Commission (2022). European Chips Act https://digital-strategy.ec.europa.eu/en/policies/european-chips-act

[8] EuroHP(2022). The European Processor Initiative (EPI)https://eurohpc-ju.europa.eu/participate/our-projects/european-processor-initiative-epi_en

the energy consumption of a number of day-to-day digital behaviours for the purpose of disseminating these results via various communication channels.

1.2. Objectives of the study

In line with the Terms of Reference (ToR), this study yielded consensual and science-based figures on the energy consumption of ICT technologies and prepared communication materials to enhance consumers' awareness of the energy and climate impacts of their digital behaviours.

The ultimate goal was to contribute to raising consumers' awareness of the energy consumption of their daily digital actions. Hence, the present study had the following specific objectives:

- Establish a comprehensive overview of studies and published estimates relating to the energy consumption of day-to-day digital actions and services, along with as assessment of the different methodologies used and their respective quality, relevance and reliability, also bringing forward looking elements;
- Provide a set of simple estimates of the energy consumption of a number of day-to-day digital behaviours;
- Create the necessary materials to disseminate these results via various communication channels.

More specifically, the study focused on a list of 10 digital behaviours, for which estimates were produced and communication materials were developed. The 10 digital behaviours were shortlisted in agreement with the European Commission, based on their relevance and on the Consultant's recommendations related to data availability and communicability potential.

The 10 digital behaviours considered in the study are:

- One hour of video streaming
- One hour of video gaming
- One hour of video conferencing
- One hour of music streaming
- One hour of social networking
- Write and send an email
- Download a file to a PC
- Store data in the cloud for N year(s)
- Prolong the lifespan of a phone
- Switch off the Wi-Fi router

Based on the findings for each digital behaviour, communication materials were developed for the purpose of disseminating these results via various communication channels.

1.3. Overview of this report

This report is organised into the following chapters:

- **Chapter 1.** *Introduction*
- **Chapter 2**. *Methodological approach*
- **Chapter 3.** *Overview of estimates on the energy consumption of day-to-day digital actions and services*
- **Chapter 4.** *Quantified estimates of the energy consumption of day-to-day digital behaviours*
- **Chapter 5.** *Best practices to save energy, limitations and recommendations*
- **Appendices.**
- **References.**

2. Methodological approach

This chapter presents a summary of the methodology adopted for the analysis in line with the objectives mentioned above.

The first step of the work was to carry out a literature review of published estimates relating to the energy consumption of day-to-day digital actions and services, to increase the knowledge around the topic, facilitate the activities in the subsequent steps and present the findings in a coherent and well-organised manner.

The second step involved the detailed quantification of the energy consumption of the ten day-to-day digital behaviours and of the energy savings of recommended best practices for an average user. A LCA was carried out to measure the energy consumption of the digital behaviours, with the development of a LCI model for each behaviour.

Finally, a number of visuals to be used for the purpose of disseminating the findings of this present study were developed with the assistance of a team of graphic designers in Ramboll. These visuals were created to communicate to the general public key takeaway messages to increase the knowledge on the energy consumption associated with each digital behaviour and on the best practices to save energy.

2.1. Literature review of existing published estimates relating to the energy consumption of day-to-day digital actions and services

A literature review was performed on the ten digital behaviours listed in the introduction. This exercise had the following three objectives:

- Identify the relevant sources and establish a preliminary mapping of available information (on estimates and methodologies);
- Extract and map the relevant estimates found in the literature;
- Provide an overview of the methodologies used to generate the estimates.

The focus of this literature review was mainly on academic papers, articles, white papers, governments reports and studies, reports from key players of the ICT industry, and medias. Grey literature was used to understand the broader context in which the behaviours analysed evolve and the echo of certain publications. Given that estimates on energy consumption change over time and can become obsolete, the review prioritised literature published since 1 January 2020. The list of reviewed sources was updated along the study.

A list of key words was defined for each of the ten digital behaviours to collect and shortlist relevant sources. The complete list of the keywords used is displayed in the table below. This list includes keywords related to each behaviour which are normally used in the literature, as well as the names of some key applications and providers of these digital services.

Table 1 List of keywords used in the literature search

General key words common to all ten digital behaviours	
Energy consumption, kWh, environmental impact, usage phase, carbon footprint, reducing energy consumption, reducing environmental impact, ICT use, footprint[9], digital behaviour, devices, power consumption	
Key words specific for each digital behaviour	
One hour of video streaming	*Video streaming, Netflix, Youtube, Prime Video, watching a movie, watching a video, streaming platforms, streaming a video*
One hour of video gaming	*Video gaming, console, video game, PC gaming, game play, Xbox, PS4, online gaming, cloud gaming*
One hour of video conferencing	*Video conferencing, video call, Microsoft teams, Zoom, facetime, video versus audio calling, remote working and energy consumption*
One hour of music streaming	*Music streaming, listening to music, playing music on your phone, spotify, apple music, digital music*
One hour of social networking	*Facebook, Tik Tok, reddit, youtube, scrolling, social media, posting a photo on social media, taking a selfie on social media, sending a message on social media, scrolling, social networking*
Write and send an email	*Sending an email, receiving an email, outlook, gmail, yahoo, sending a email with a file, sending an email with a pdf, sending a short, email with attachement, email with attached file*
Download a file to a PC	*Download a file to PC/from a phone/from the cloud/from an email*
Store data in the cloud for N year(s)	*Storing data, cloud, document on the cloud, keeping data online for one year*
Prolong the lifespan of a phone	*Extend the lifespan of a phone, impact of a phone, circular economy, obsolescence and phones, keeping a phone for longer, reducing the*

	environmental impact of a phone, reducing the environmental impact of a smartphone
Switch off the Wi-FI router	*Switch off Wi-Fi router, Wi-Fi box, internet box, reducing the impact of a Wi-Fi, switching off the Wi-Fi at night/on the weekend/on holidays*

Classification of the documents

The documents found were categorised into a database created in Excel. Key information collection for each document included:

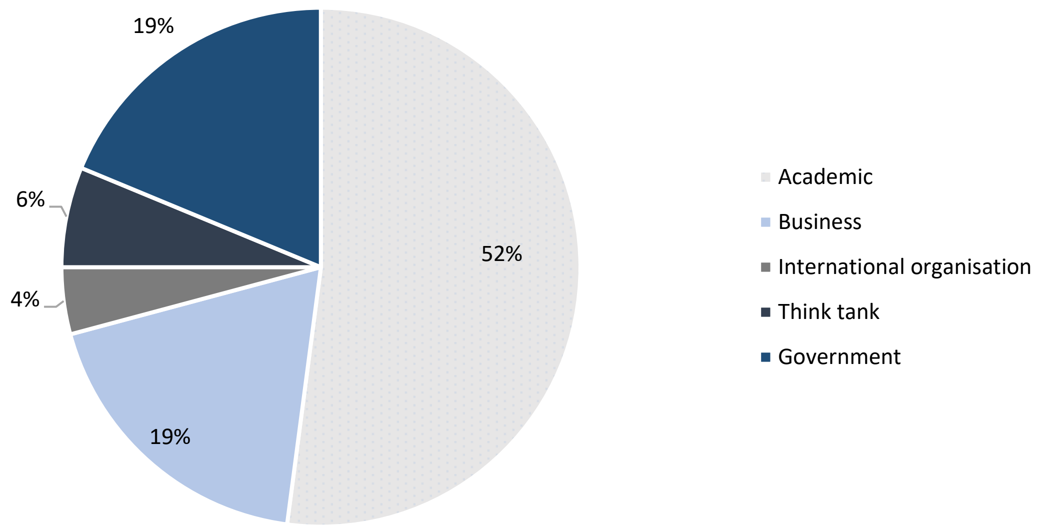
- General information on each document with Title, Author, Year, Organisation, digital behaviour covered;
- Key takeaway messages, with a summary of the paper and any good practice suggested;
- Information on estimates, with the value provided and any other relevant information on the assumptions made for the estimation;
- Methodological information, including the type of methodology used, the performance of an additional third-party review, the system boundary of the analysis, the scope of the study, and the data quality.

Regarding the gathered methodological information, it is important to notice that only publicly available information was collected. Indeed, the lack of information on particular methodologies made it challenging to assess the accuracy of estimates as well as compare them. For instance, several documents included in this literature review did not explicitly define their methodology, providing very little information on the system boundaries or the precise scope of the study.

Composition of the literature review on the ten digital behaviours

The resulting body of reviewed literature consisted of a total of 84 documents in total (including grey literature and papers on the overall ICT sector), in particular 61 of these papers were used to collect estimates on energy consumption. See Appendix 1. As displayed in Figure 1 below, the documents collected in this literature review are mostly from academia, businesses and governments. Papers falling under the category 'government' include papers from government agencies, EU institutions or national ministries. Some of these were commissioned by external organisations (consultancies, for instance).

Figure 1 Overview of the type of sources in the literature review

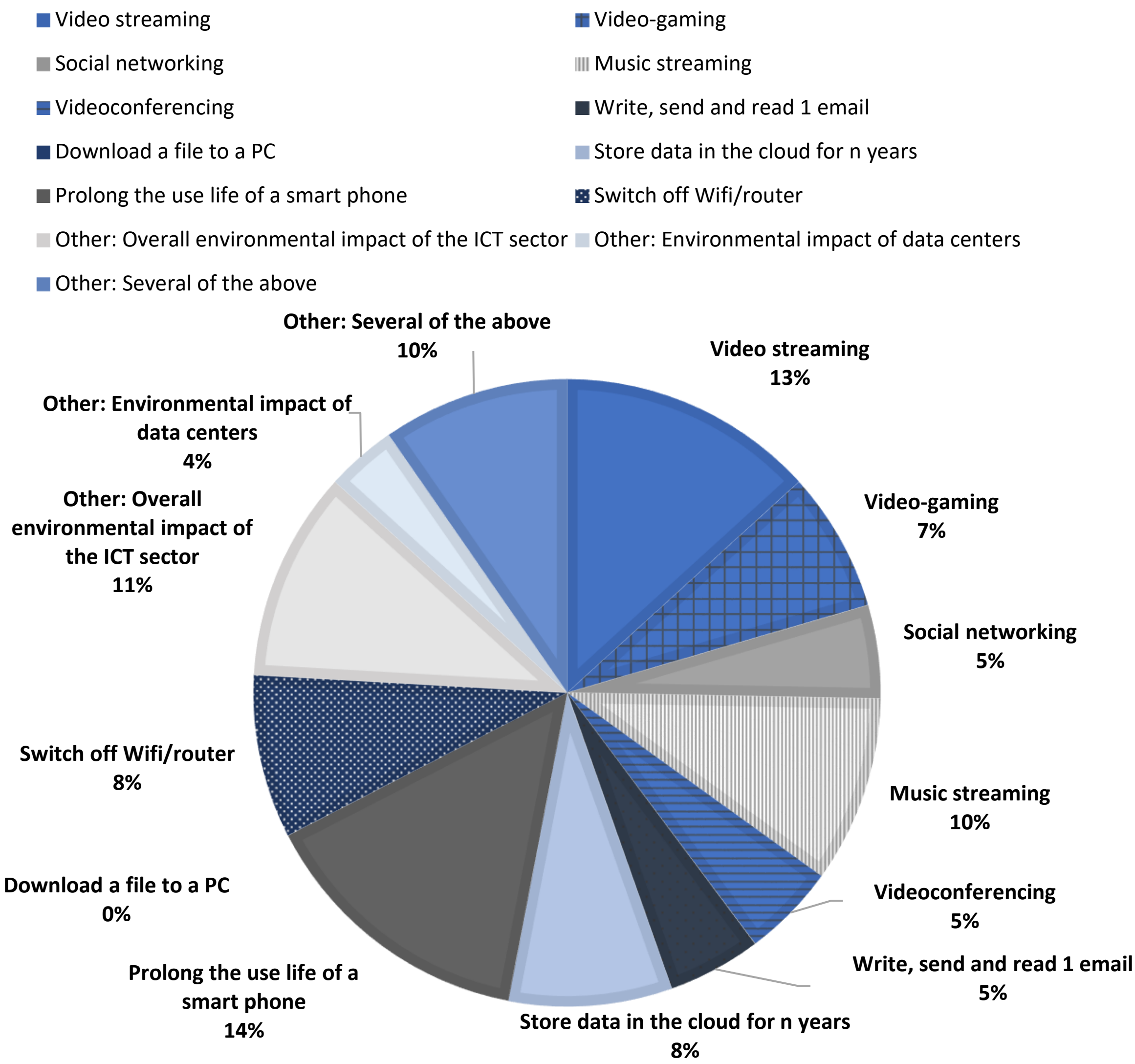


When considering the digital behaviours covered in the analysis, the review identified more literature focusing on video streaming, video gaming, prolonging the use life of a phone, as well as on the overall impact of the ICT sector, as displayed in Figure 2 below. While the documents classified in the latter category do not include estimates relevant to any of the specific digital behaviours, they provide useful information on the broader context, as they present current and future trends in the ICT sector. Overall, it was observed that most digital behaviours have been extensively analysed in the literature. Yet, these were generally more studied from a carbon footprint perspective rather than an energy consumption angle.

For some digital behaviours, there was however a clear lack of scientific literature which made it challenging to collect relevant estimates. For instance, while it was stated numerous times in the grey literature that switching off the home Wi-Fi connection, can reduce a household's energy consumption, all papers actually referred to a unique study published by ADEME (*Agence de l'environnement et de la maîtrise de l'énergie*). In another case, the literature analysing the impacts of downloading a file was very scarce, while scholars seemed to have given more attention to the act of storing data for a certain number of years.

Regarding the identified energy consumption estimates, it was challenging to collect relevant consumption numbers on an hourly basis since numerous papers focused on annual energy consumption averages, or looked at the global energy consumption associated with a certain digital behaviour. In some cases, without additional information on the assumptions used, it proved to be impossible to extract relevant numbers from the documents. For instance, in the case of videogaming, estimates on the yearly energy consumpion of a gamer were provided, yet, authors did not specify the assumed number of hours a gamer plays in a year.

Figure 2 Overview of the different digital behaviours covered in the literature review



2.2. Literature review on technological uncertainties

A separate literature review was conducted on technological uncertainties and disruptive technologies that could influence the energy consumption of the considered ten digital behaviours and of the ICT sector in the future. This section of the literature review had the following goals:

- Understand how technologies like edge computing, IoT, Blockchain, and AI are going to impact the energy consumption of the ICT sector;
- Assess how the roll out of 5G[10] is expected to impact the overall energy consumption of the ICT sector, and how it compares to previous technologies (2G, 3G, 4G)[11];

[10] 5G is the fifth-generation technology standard for broadband cellular networks.

[11] In general, these acronyms refer to the different generations of technology standards employed for cellular networks.

- Acknowledge and estimate the rebound effects[12] associated with these new technologies.

Given that the landscape of disruptive technologies is constantly evolving, studies published after 1 January 2020 were prioritised. The complete list of the keywords used to search for relevant documentation is provided in the table below.

Table 2 List of keywords used in the literature search on technological uncertainties and disruptive technologies

General key words on technological uncertainties and disruptive technologies	
Energy consumption, kWh, environmental impact, ICT, disruptive technologies, emerging technology, new technlogies, energy efficiency trends of the ICT sector, new technologies, change energy consumption, carbon footprint	
Key words for specific technologies	
5G	*Energy efficiency, energy impact, 5G, 4G, 3G, 2G*
Edge computing	*Green computing, green IT, sustainable computing, power-aware algorithms, edge computing*
Artificial intelligence	*Ai, Artificial intelligence, Machine learning, Deep learning, chatGPT*
IoT	*IoT (Internet of Things), Smart devices, Connected devices, Smart grids,*
Blockchain	*Blockchain, Energy consumption, Energy efficiency,Cryptocurrency mining, Proof of work (PoW), Proof of stake (PoS)*

The documents selected were classified in an Excel database. This database gathered information related to the title, date of publishment, type of author, link to the document, and provided a summary of the key messages.

The resulting body of papers consisted of a total of 44 documents. Papers originated from a balanced mix of scientific, academic and grey literature. There was a significant amount of literature on the 5G topic. It was more challenging to find information on the energy consumption impacts related to other technological trends. Indeed, existing literature on these other technological trends focuse more heavily on their enabling effect to reduce energy consumption in other industries, rather than in the ICT sector per se.

The full list of papers identified can be found in the Appendix.

[12] The rebound effect refers to the reduction in expected gains from new technologies that increase the efficiency of resource use, because of behavioural or other systemic responses.

2.3. Quantification of the energy consumption of several day-to-day digital behaviours

2.3.1. General definition of LCA

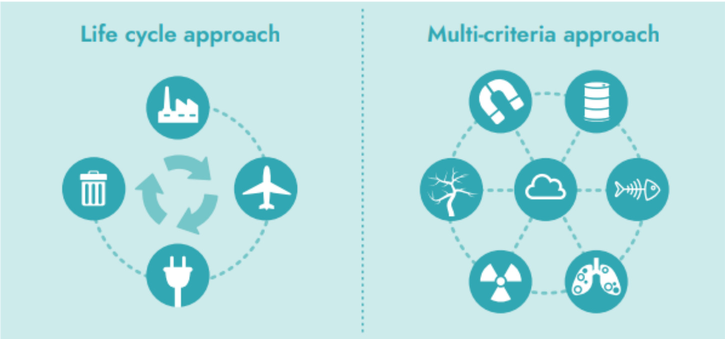
In order to perform the quantification of the energy consumption of several day-to-day digital behaviours, we have decided to follow Life Cycle Assessment standards.

Life Cycle Assessment is a method to evaluate the environmental impact of a service or a product. It follows the **ISO 14040:2006**[13] and **ISO 14044:2006**[14] standards for LCA methodology, which provide a systematic framework for conducting and reporting LCA studies under several concepts. It differentiates from other environmental accouting methods such as carbon footprint or others for two main reasons:

First, a LCA is a **multicriteria** approach. The results of the study will be communicated not only using energy indicators, but also with **other environmental indicators** such as global warming potential or the depletion of abiotic resources to give a broader undestanding of the impact.

The second reason is the scope of the impact. The study accounts for a "**cradle-to-gate**" approach, which means that the **entire life cycle** of the product was considered, from the extraction of raw materials to the manufacturing and distribution of the product.

Figure 3 The life cycle and multi-criteria approach



Several key concepts are unique of a LCA and will be described for each of the behaviours:

Quantity: all indicators are described quantitatively.

Function: this study is defined with a function (aim of the study,public targeted, etc).

Attribution or consequence: it defines if the LCA can be modeled to a product or a system in the economy. It includes indirects effects related to a system.

2.3.2. The four stages of a LCA

Following the ISO 14040:2006 standards, a LCA study consists of 4 stages:

- Goal and scope definition
- Life Cycle inventory analysis
- Life Cycle impact assessment

[13] "ISO 14040:2006(Es), Gestión Ambiental — Análisis Del Ciclo de Vida — Principios y Marco de Referencia," accessed April 6, 2023, https://www.iso.org/obp/ui#iso:std:iso:14040:ed-2:v1:es.

[14] "ISO 14044:2006(En), Environmental Management — Life Cycle Assessment — Requirements and Guidelines," accessed April 6, 2023, https://www.iso.org/obp/ui/#iso:std:iso:14044:ed-1:v1:en.

- Interpretation of the life cycle results

Goal and scope definition

Phase of the Life Cycle Assessment involving the definition of the study's objective,the purpose of the study and the decision process for which it will provide support in environmental decision making.

Life Cycle inventory analysis

Phase of the Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a prodct through its life cycle.

Within this phase, the following steps are taken in order to ensure the quality of the results.

Data collection: collection of data and calculation procedures of the system under study.

Elementary flow inventory: material or energy entering the system being studied that has been drawn from the environment without previous human transformation, or material or energy leaving the system being studied that is released into the environment without subsequent human transformation.

Allocation and assignment rules: partitioning the input or output flows of a process or a product system between the product system under study and one more other product systems.

Data quality evaluation: characteristics of the data that relate to the ability to satisfy stated requirments

Life Cycle impact assessment

Phase of the life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a prodcut system throughout the life cycle of the product.

Selection, classification and characterisation: the primary goal of this stage is to assess the environmental implications of potential impacts by utilizing the inventory data. This involves identifying specific impact categories, such as climate change, associating the relevant inventory data with these categories using impact category indicators, and subsequently applying a characterisation factor. The findings obtained from this phase are then used in the interpretation stage.

Weighting and Normalisation: The indicators numerical results can be arranged, standardized, categorized, and weighted, based on the preferences of the evaluator. While this approach simplifies comprehension, there is no widely agreed-upon scientific consensus on the optimal method for conducting such evaluations.

Interpretation of the life cycle results

Phase of the life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Sensitivity and Uncertainty Analysis: to establish the potential variations in outcomes, sensitivity and uncertainty analyses are essential as the model is based on some data obtained from the literature, indicating its reliance on secondary sources which could introduce uncertainty.

Table 3 Summary of the methodology to estimate the electricity consumption of digital behaviours

Focus on electricity consumption
The electricity consumption was calculated using a **hybrid approach**, which combined both **process-based** and **input-output-based methods**. The process-based method was used to calculate the **electricity consumption associated with the realisation of the behaviour**, while the input-output-based method was used to estimate the electricity consumption associated with the upstream processes for the fabrication of end-user devices and supporting infrastructure (network, and data centers), such as the production of raw materials. In order to calculate the electricity consumption for each process, we used **secondary data** collected from the literature, databases and internal studies. Mostly, this secondary data consisted in statistics of consumption patterns at the EU level. We also used secondary data from **industry databases** and **academic literature** to attribute an electricity consumption for each equipment. (ex: annual average electricity consumption of an average gaming laptop). To account for the environmental impacts of the electricity consumption, we used life cycle impact assessment (LCIA) methods. **LCIA methods were used to estimate the potential environmental impacts associated with the production and use of electricity**, such as global warming potential, acidification, and eutrophication. Overall, the methodology adopted for the LCA described was **robust and transparent**, and it allowed us to accurately estimate the environmental impacts associated with the electricity consumption of the behaviours analysed.

The general methdodology provided above is the framework used for all Life Cycle Assessments. We will now go througth the specific methodology used in this study. The following statements cover all the digital behaviours modeled in the study. Case to case functional units, boundaries and allocations will be covered directly in chapter 4.

2.3.3. Goal and Scope Definition

Goal of the study

The goal of this study is to **provide estimates on the energy consumption of digital behaviours** at the EU-27 level. Subsequent goals are associated with the study:

- Identify the significant steps that can be taken to reduce the energy consumption associated with such behaviours.
- Provide objective communication regarding the environmental and energy-related impacts of these behaviours.

Framework

This work is intended to comply with the ISO 14040:2006 and 14044:2006 standards. Wherever possible and relevant to our context, the methodological choice will also refer to complementary standards such as:

ITU L1410[15] - Methodology for environmental life cycle assessments of information and communication technology goods, networks and services

PEF Guidelines[16] and PEFCR (Product Environmental Footprint Category Rules Guidance) relative to IT equipment[17] and to PEFCR (Product Environmental Footprint Category Rules Guidance) relate to Internet Service Provision[18]

Intended audience

This study was commissiond by DG ENER of the EU Commission. The audience targeted is mainly:

- European citizens
- Policy-makers

The results are not intended to be used in comparative assertions for disclosure to the public.

Validity of the results

The outcomes are exclusively applicable to the circumstances specified by the assumptions outlined in this report. Any alterations to these conditions may alter the conclusions. As a result, LCA practitioners cannot guarantee the applicability or dependability of these findings for third-party use or for purposes other than those stated in this report.

2.3.4. Scope of the study

Within the framework of our study, the objective is to provide the latest knowledge (2022-2023) about the energy consumption and environmental impacts of day-to-day digital behaviours using the LCA method described above, within the scope of the European Union. Only the direct impacts will be taken into account. Indirect impacts, positive and negative (such as direct or indirect rebound effects, substitution, structural changes), are not taken into account.

Product system to be studied -Technological Boundaries

This study deals with digital behaviours. The scope of the digital behaviours covered are described with categories of equipment also called “tiers”:

Tier 1 - End-user Devices: This classification pertains to end-user devices, including computers, screens and other IT equipments used on a daily basis.

Tier 2 - Network: This grouping encompasses network infrastructures that enable data exchange between end-users' devices and data centres. The network consists of fixed, mobile, and core components, and encompasses end-user routers.

Tier 3 - Data centres: This classification comprises equipment that is relevant to hosting and data processing, such as switches, firewalls, routers, and storage devices.

[15] “L.1410 : Methodology for Environmental Life Cycle Assessments of Information and Communication Technology Goods, Networks and Services,” accessed April 7, 2023, https://www.itu.int/rec/T-REC-L.1410/en.

[16] “PEFCR_guidance_v6.3-2.Pdf,” accessed April 7, 2023, https://eplca.jrc.ec.europa.eu/permalink/PEFCR_guidance_v6.3-2.pdf.

[17] “PEFCR_guidance_v6.3-2.Pdf.”

[18] “General principles for the environmental labelling of consumer products,” La librairie ADEME, accessed April 7, 2023, https://librairie.ademe.fr/produire-autrement/6103-general-principles-for-the-environmental-labelling-of-consumer-products.html.

Figure 4 Three Tiers Illustration

Product system to be studied -Temporal Boundaries

This study covers digital behaviours in Europe in 2023. Consequently, the selected data is as representative as possible of 2023, except for European data until 2019 that also included UK. If data is missing, it has been replaced and extrapolated as much as possible with data no older than 2015.

Product system to be studied - Geographical boundaries

The geographical scope considered in this study covers IT equipment located in the European Union and UK (27 states members and UK).

Function and functional unit

Every digital behaviour has its funciton and functional unit. We will cover this topic for each digital behaviour.

System Boundaries

The **life cycle stages** considered in the LCA study include:

- Raw material extraction, transportation of raw materials to the manufacturing facility, manufacturing of the product, packaging of the product,
- Transportation of the product to the retailer,
- Use of product by the consumer (in this case the electricity consumption of the behaviour)
- End-of-life disposal.

Inclusion: the elements modeling the study are covered under three “tiers”. The list of types of equipments covered by the study is presented in Table 4:

Table 4 System Boundaries Inclusion elements

Tier 1 – User environment
End-user equipment (latpop, smartphone, desktop,…)
Audio device (Connected speaker)
Tier 2 – Network
IT equipment involved in mobile (2G, 3G, 4G, 5G) and fixed networks (FTTX, ADSL)
Non-IT equipment involved in mobile (2G, 3G, 4G, 5G) and fixed networks (FTTX, ADSL)

Tier 3 – Data centres
IT equipment (computing, storage, network)
Non-IT equipment involved in the infrastructure (cooling systems, generators, UPS, batteries, etc.)

Exclusion: several flows have not been included in this study. Below are listed flows not included for all the 10 behaviours.

- TV/radio networks, due to the lack of information regarding the constituent equipment Enterprise networks, due to the lack of information regarding the constituent equipment
- PSTN (Public Switched Telephone Network), due to the lack of information regarding the constituent equipment
- Some consumer electronics like media players, cameras, GPS, due to the lack of information

Any further excluded flows that are specific to the behaviours will be itemized in the relevant sections within chapter 4.

Cut-off rules: No known flows were neglected. In addition, no flows have been neglected that would have been known to have a significant impact on the environmental indicators.

Allocation procedures

No general allocation has been made for this study. Specific allocations (temporal, data) have been performed for the devices to estimate the percentage of impact associated to the behaviour. This section is detailed in Appendix 3. Note that allocations in background datasets are not modified, these allocations are documented in the background data (Ecoinvent, NegaOctet).

LCIA methodology and types of impacts

Selection, classification and characterisation of the impacts: This phase aims to assess the importance of potential environmental impacts using the results of the inventory. This process involves the selection of impact categories, and the association of inventory data with impact categories (e.g. climate change) and with impact category indicators through characterisation factors. This phase provides information for the interpretation phase. In our context, we will base our analysis on the indicators proposed by the European Commission in the framework of the Product Environmental Footprint (PEF) project developed by the Commission's Joint Reseach Centre (JRC), using PEF 3.0[19]. The table of indicators is listed in Table 5.

Table 5 PEF 3.0 indicators

EF Impact Category	EF Impact Assessment Model	EF Impact Category indicators	Source
Climate Change	Bern model - Global Warming Potentials (GWP) over a 100 year time horizon.	kg CO2 equivalent	Intergovernmental Panel on Climate Change, 2013

[19] The PEF 3.0 does not cover energy. Therefore, we have chosen to report on additional indicators such as Cumulative Energy Demand (that covers energy from renewable and non-renewable sources)

Ozone Depletion	EDIP model based on the ODPs of the World Meteorological Organization (WMO) over an infinite time horizon.	kg CFC-11 equivalent	WMO, 1999
Ecotoxicity for aquatic fresh water	USEtox model	CTUe (Comparative Toxic Unit for ecosystems)	Rosenbaum et al., 2008
Human Toxicity - cancer effects	USEtox model	CTUh (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008
Human Toxicity - non-cancer effects	USEtox model	CTUh (Comparative Toxic Unit for humans)	Rosenbaum et al., 2008
Particulate Matter/Respiratory Inorganics	RiskPoll model	kg PM2.5 equivalent	Humbert, 2009
Ionising Radiation - human health effects	Human Health effect model	kg U25 equivalent (to air)	Dreicer et al., 1995
Photochemical Ozone Formation	LOTOS-EUROS model	kg NMVOC equivalent	Van Zelm et al., 2008 as applied in ReCiPe
Acidification	AcCumulative Exceedance model	mol H+ eq	Seppala et al.,2006; Posch et al., 2008
Eutrophication - terrestrial	AcCumulative Exceedance model	mol N eq	Seppalä et al.,2006; Posch et al., 2008
Eutrophication - aquatic	EUTREND model	fresh water: kg P equivalent marine: kg N equivalent	Struijs et al., 2009 as implemented in ReCiPe
Resource Depletion - water	Swiss Ecoscarcity model	m² water use related to local scarcity of water	Frischknecht et al., 2008
Resource Depletion - mineral, fossil	CML2002 model	kg antimony (Sb) equivalent	van Oers et al., 2002
Land Transformation	Soil Organic Matter (SOM) model	Kg (deficit)	Milà i Canals et al., 2007

Normalisation & Weighting: LCA investigations frequently minimize the number of indicators to enhance the clarity of results. In our analysis, we used a restricted group of indicators derived from the analysis of the environmental impact of ICT in Europe[20]. The list can be found in Table 6.

Table 6 Chosen environmental indicators from PEF 3.0

Impact category	Model	Unit	LCIA method level of recommendation
Climate change	IPCC 2013, GWP 100	kg CO2 eq	I
Particulate matter	Fantke et al., 2016	disease incidence	I
Acidification	Posch et al., 2008	mol H+ eq	II
Ionising radiation, human health	Frischknecht et al., 2000	kBq U235 eq	II
Photochemical ozone formation, human health	Van Zelm et al., 2008, as applied in ReCiPe, 2008	kg NMVOC eq	II
Resource use, fossils	ADP for energy carriers, based on van Oers et al. 2002 as implemented in CML, V. 4.8 (2016)	MJ	III
Resource use, minerals and metals	ADP for mineral and metal resources, based on van Oers et al. 2002 as implemented in CML, V. 4.8 (2016)	kg Sb eq	III
Ecotoxicity, freshwater	USEtox (Rosenbaum et al., 2008)	CTUe	III/Interim

[20] Greens Efa, "Digital Technologies in Europe: An Environmental Life Cycle Approach," *Greens/EFA* (blog), December 6, 2021, https://www.greens-efa.eu/opinions/digital-technologies-in-europe/.

Furthermore, we suggest supplementing this set with two additional indicators that are more easily comprehensible, namely material input per service (MIPS) and primary energy. While these indicators cannot be normalized and weighted, they offer supplementary insights into the environmental effects (see Table 7).

Table 7 Additional indicators

Impact category	Model	Unit	LCIA method level of recommendation
Material input per services	MIPS, Schmidt-Bleek, 1994 and Ritthoff et al., 2002	Kg	N/A
Primary energy	Cumulative Energy Demand	MJ	N/A[21]

The results will also be communicated in planetary boundaries.

The Planetary Boundaries concept provides a science-based global normalisation reference of the risk that human actions will substantially alter the Earth system (Steffen et al., 2015).[22]

In other words, "*planetary boundaries is a concept that enables to compare environmental impacts to the planetary limits, which is a framework helping to estimate in what extend the human activities respect or exceed the safe operating space for humanity*"[23].

In order to do so we use two parameters: the planetary boundaries[24] (annual impact that the planet can sustain) and the World population. As of January 2023 the earth's population was of 7,942 million humans[25]. These values for the planet boundaries are found in Table 8 and Table 9.

Table 8 Planetary Boundaries

Impact category	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Land use	Ecotoxicity freshwater	Water use	Resource use, fossils	Resource use, minerals and metals
Unit	mol N eq	kg P eq	kg eq	kg soil loss	CTUe	m² water eq	MJ	kg Sb eq
Planetary boundaries	6.13E+12	5.81E+09	2.01E+11	1.27E+13	1.31E+14	1.82E+14	2.24E+14	2.19E+08 9
Planetary Boundaries per capita	7,72E+02	7,32E-01	2,53E+01	1,60E+03	1,65E+04	2,29E+04	2,82E+04	2,76E-02
Planetary Boundaties	2,11E+00	2,00E-03	6,93E-02	4,38E+00	4,52E+01	6,27E+01	7,72E+01	7,55E-05

[21] Roland Hischier et al., "Implementation of Life Cycle Impact Assessment Methods," n.d. ; see from page 46

[22] Joint Research Centre (European Commission) et al., *Consumption and Consumer Footprint: Methodology and Results : Indicators and Assessment of the Environmental Impact of European Consumption* (LU: Publications Office of the European Union, 2019), https://data.europa.eu/doi/10.2760/98570.

[23] Efa, "Digital Technologies in Europe."

[24] Joint Research Centre (European Commission) et al., *Consumption and Consumer Footprint*.

[25] US Census Bureau, "U.S. Population Estimated at 334,233,854 on Jan. 1, 2023," Census.gov, accessed May 1, 2023, https://www.census.gov/library/stories/2022/12/happy-new-year-2023.html.

per capita per day								

To be able to compare the environmental impact of the behaviours, we will use the "planetary boundaries per capita per day". In other words, it's the daily limit we shouldn't exceed for the safe operating space for humanity. This equivalence is not often used in LCA but will provide a comprehensive read on the impacts of the behaviours.

Table 9 Planetary Boundaries

Impact category	Climate change	Ozone depletion	Human toxicity, non-cancer	Human toxicity, cancer	Particulate matter	Ionizing radiation	Photochemical ozone formation	Acidification
Unit	kg CO2 eq	kg CFC-11 eq	CTUh	CTUh	Disease incidence	kBq U-235 eq	kg NMVOC eq	mol H' eq
Planetary boundaries	6.81E+12	5.39E+08	4.10E+06	9.62E+05	5.16E+05	5.27E+14	4.07E+11	1.00E+12
Planetary Boundaries per capita	8,57E+02	6,79E-02	5,16E-04	1,21E-04	6,50E-05	6,64E+04	5,12E+01	1,26E+02
Planetary Boundaties per capita per day	2,35E+00	1,86E-04	1,41E-06	3,32E-07	1,78E-07	1,82E+02	1,40E-01	3,45E-01

Types and sources of data

An LCA calculation requires two different types of information:

Data related to physical characteristics: The diversity of the resources covered enabled both a broad and accurate coverage of the environmental impacts of digital technologies and infrastructures, covering one of these sectors: ICT (transversal), ICT (equipment), digital practices, components, media/entertainment, EEE, ICT (data centres), ICT (networks), IoT. These bibliographic resources were the ground of our work for carrying out the LCA and the case studies.

Data related to the life cycle impacts: the data used in the LCA study was obtained from a variety of sources, including the **NegaOctet Database**[26], the **Ecoinvent Database**[27], and the ***Digital technologies in Europe: an environmental life cycle approach* study**[28]. The NegaOctet Database is a comprehensive inventory of energy and digital hardware flows, which includes data on digital equipment and electricity generation and transmission. The Ecoinvent Database is a widely used life cycle inventory database that provides data on the environmental impacts of various processes, products, and services. Finally, the *Digital technologies in Europe: an environmental life cycle approach* study is a research project that assessed the environmental impacts of various digital technologies, including data centers and cloud computing. The study provided valuable insights into the energy consumption and carbon emissions associated with these technologies, which were used in the LCA study to estimate the environmental impacts of the electricity consumption associated with the digital behaviours.

[26] "NegaOctet : une base pour construire le Nutri-Score du numérique," Green IT, December 2, 2021, https://www.greenit.fr/2021/12/02/negaoctet-une-base-pour-construire-le-nutri-score-du-numerique/.

[27] "Home - Ecoinvent," April 5, 2023, https://ecoinvent.org/.

[28] Efa, "Digital Technologies in Europe."

End of life specifications

Within the framework of the NegaOctet project, whether it is for production offcuts or for taking into account end-of-life treatments, the method used is the stocks.The stock method consists of defining a boundary between two life cycles, using a (real or fictitious) stock. The stock method focuses on the product only. No data is required outside the product system being evaluated. Everything before the stock is allocated to the cycle that generated the waste.

Data quality requirements

The rules for data collection in this study aim to meet the system's objectives and limitations, as described below.

- **Technological representativeness:** no proxys have been used to model the technology. Technologies modeled are based on those same technologies.This means that a desktop was modeled with the LCA of a desktop and not with the LCA of a laptop or another equipment.
- **Geographical representativeness:** The data relates to the digital services equipment located in the European Union + UK (27 Member States plus UK). In case of missing data, an explanation of the assumptions made is provided.
- **Time-related representativeness:** This study covers digital behaviours in Europe in 2023. Consequently, the selected data is as representative as possible of 2023. Except for European data until 2019 which also included UK. If data is missing, it has been replaced and extrapolated as much as possible with data no older than 2015.
- **Completeness:** The study includes all identified flows, unless stated otherwise. No-known flows were neglected. In addition, no flows have been neglected that would have been known to have a significant impact on the environmental indicators
- **Parameter uncertainty:** Where possible, data was cross-checked with additional sources. When necessary, comments have been added to high-uncertainty data that could impact the results, the messages and the recommendations of the study.

The EF methodology[29] has its own scale to assess the quality of the data used for LCA purposes.

A scale from 1 to 5 (1 for the best data quality, 5 corresponds to a rough estimate) is used to estimate the quality of the data.

In our case the quality of our data is either calculated and verified (quality rating 1); Measured/calculated/literature and plausibility checked by reviewer (quality rating 2); Measured/calculated/literature and plausibility not checked by reviewer OR Qualified estimate based on calculations plausibility checked by reviewer (quality rating 3).

Representativeness: when calculating the share of terminals used for a behaviour in Europe, some sources date from 2019 or before. As technology trends and habits evolve rapidly; the share of terminals used for a given behaviour in 2023 might be different from the one in 2019; which would impact the results.

[29] European Commission. Joint Research Centre., *Guide for EF Compliant Data Sets.* (LU: Publications Office, 2020), https://data.europa.eu/doi/10.2760/537292.

LCA modelling tool

The assessment of the overall energy consumption of day-to-day digital behaviours has been performed by compiling all the equipment data in an Excel tool.

Critical Review considerations

The critical review allows to communicate the results of the LCA to the general public with transparency under the guidelines of the ISO 14040: 2006 and ISO 14044: 2006 norms.

The critical review of the study was conducted to validate the methodology, assumptions and procedures used to conduct the study. It was carried out by:

- Naeem Adibi, Managing Director and LCA expert, WeLOOP
- Alexandre Charpentier Poncelet, Project Manager, WeLOOP

The critical review report is available on request from the authors of the study.

2.3.5. Treatment of missing data

For cases **where data is missing** or selecting between different sources is challenging (after evaluating their relevance), a generic approach is used where the worst-case scenario is attributed, which penalizes the results. As an example, for a given dektop model, if two environmental factors exits and are both as acceptable, we will use the one with the greater impact.

2.3.6. Lifespan of the equipment

Regarding **lifespan**, there is currently no universally agreed definition. The interpretation and understanding of this concept vary among different stakeholders such as manufacturers, users, and end-of-life treatment operators. For this particular study, all lifespan values for the different equipments came from the **Digital technologies in Europe**[30] study.

2.4. Development of communication materials to disseminate these results via various communication channels

The preparation of the communication materials involved three main steps:

- Definition and agreement on the approach to the campaign together with the European Commission, defining the ambition and key principles behind the initiative;
- Definition of the targets and messages to convey following the completion of the literature review and of the quantification;
- Development of the communication materials.

To design a series of visuals to disseminate these results via various communication channels, key takeaway messages were developed to cover all the analysed digital behaviours. These short messages aimed at driving the attention of the general public towards the energy consumption associated with their day-to-day digital actions and, in a

[30] Efa, “Digital Technologies in Europe.”

nutshell, summarise the most prominent findings emerging from the analysis of the literature and quantification of the energy consumption estimates.

In some cases, the messages put the significant energy impacts of the digital behaviours into perspective by comparing them with other energy consuming actions or technologies which are easy to relate to (e.g., making a coffee with an espresso machine, using a dishwasher, etc.). In other cases, best practices to save energy were described together with their associated benefits. Since the campaign aimed at driving digital users to limit their energy consumption, communication materials focused on energy consumption levels (rather than CO_2 equivalent levels).

In agreement with the Commission, the visuals were designed to disseminate the results fo this study via various communication channles, in particular on social media, targeting both a young and adult audience already familiar with the ICT sector and potentially interested in energy savings and energy policies. The visual were developed by a team of graphic designers in Ramboll in full compliance with the corporate visual identity of the European Commission by applying the graphic rules set out in the European Commission's Visual Identity Manual[31], including its logo.

[31] The manual is available here: https://commission.europa.eu/resources-partners/european-commission-visual-identity_en

3. Overview of estimates on the energy consumption of day-to-day digital actions and services

In this chapter, we present the findings of the analysis of the published estimates relating to the energy consumption of day-to-day digital actions and services. These findings are based on the review of the existing scientific literature, but also of the reports and studies published by companies and government bodies. The review focused mostly on estimates for the EU as a whole and, in some cases, on estimates for certain Member States. There was, for instance, particular emphasis on France, thanks to the work of organisations like Ademe, GreenIT, Arcep and the Shift Project.

As introduced in the previous sections, the analysis focused on a list of ten digital behaviours which cover some of the most common digital actions of a typical user. Besides looking into the associated energy consumpion estimates, the review also produced an argumentative overview of the methodologies used to establish these estimates, including considerations on their quality, relevance and reliability.

3.1. Background and context on the ICT sector

Digital technologies are playing an increasing role in driving economic growth and creating a more connected society. Digitalisation describes the growing number and volume of applications of information and communications technologies across the economy. Some of these digitalisation trends are genuinely astounding: 90% of the data in the world today was created in just the past two years, and there are now more mobile phone subscriptions worldwide than there are people. People and devices are also becoming connected in ever-increasing numbers. More than 3.5 billion people, or nearly half the global population, now use the internet, up from only 500 million in 2001. In 2020, 91 percent of households across the EU27 had access to the internet[32]. Yet, only 70% of households can benefit from very high capacity fixed network connectivity with the potential of offering gigabit speeds[33]. Financial markets, investment trends and digital disruption in other sectors also signal the pervasiveness of digitalisation and the more significant interactions between the digital and energy worlds. Digitalisation offers many opportunities to support the achievement of environmental goals, for example, by supporting teleworking, remote learning and healthcare (which reduce reliance on polluting transportation modes), as well as by enabling energy efficiency and smart building technologies for instance.

However, the sector itself is also a source of greenhouse gas emissions and requires the utilisation of materials, which may also have negative environmental impacts. The ICT sector accounts for approximately 7% of global electricity consumption[34], and it is forecasted to rise to 13% by 2030[35,36].

[32] Statista (2021) Share of households in selected European countries with internet access from 2017 to 2020 https://www.statista.com/statistics/185663/internet-usage-at-home-european-countries/

[33] DESI (2022) https://digital-strategy.ec.europa.eu/en/policies/desi#:~:text=The%20Digital%20Economy%20and%20Society%20Index%20%28DESI%29%20summarises,Economy%20and%20Society%20Index%20%28DESI%29%20reports%20since%202014.

[34] European Commission (2022). EU action plan on digitalising the energy system https://ec.europa.eu/commission/presscorner/detail/en/QANDA_22_6229

[35] Freitag et al (2021). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations https://www.sciencedirect.com/science/article/pii/S2666389921001884

[36] Ibid.

Interestingly, there is typically less evidence about the energy consumption of the ICT sector, with a degree of uncertainty regarding existing estimates[37] due to the rapid pace of development in the sector. Depending on the studies, it is generally argued that the ICT sector represents between 3 and 6% of all energy consumed globally in 2020[38,39,40]. The World Bank estimates the relatative GHG emissions of the ICT sector in accordance with the following breakdown:

- Consumer devices (e.g., TVs, computers, smartphones): 49-80%
- Data centres: 15-29%
- Connectivity networks (mobile, fixed): 12-24%

For instance, data centers, which are used to store and process vast amounts of digital information, consume large amounts of energy to power servers, cooling systems, and other infrastructure required to keep the equipment running. To be precise, global data centre electricity use in 2021 was 220-320 TWh, or around 0.9-1.3% of global final electricity demand[41]. This energy demand is predicted to rise by only 3% (despite much higher increases in demand for data traffic and storage) thanks to ongoing efficiency improvements.

In the past decade, the ICT sector has steadily implemented measures to reduce its energy consumption. For example, many companies have invested in energy-efficient hardware and optimised their data centres to reduce energy usage. The sector has also actively encouraged individuals to adopt more sustainable digital habits by promoting energy-efficient devices. Efforts to raise awareness about the impact of individual digital behaviours and their energy consumption must be intensified across the industry.

As stated above, at least half if not a large majority of GHG emissions come directly from users' devices. According to the International Energy Agency (IEA), when it comes to the carbon footprint, 30% is coming from embodied emissions and 70% from use phase emissions[42]. Such estimates suggest that raising awareness about sustainable digital behaviours is indeed relevant to build an energy efficient economy.[43]

In the context of a global energy crisis and the recent launch of RePowerEU[44], every sector of the economy must take an active role in reducing our collective energy consumption. For this reason, shedding light on the too-often-forgotten impact of the ICT sector is essential.

[37] Energy Consumption of ICT (2022). Energy Consumption of ICT https://researchbriefings.files.parliament.uk/documents/POST-PN-0677/POST-PN-0677.pdf

[38] Ibid.

[39] Freitag and Berners-Lee (2020) The climate impact of ICT: A review of estimates, trends and regulations. Lancaster University https://arxiv.org/ftp/arxiv/papers/2102/2102.02622.pdf

[40] European Commission (2022). Factsheet - An EU Action Plan to digitalise the energy system https://ec.europa.eu/commission/presscorner/detail/en/fs_22_6230

[41] International Energy Agency (2022). Data Centres and Data Transmission Networks https://www.iea.org/reports/data-centres-and-data-transmission-networks

[42] Freitag et al. (2022). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations https://www.sciencedirect.com/science/article/pii/S2666389921001884

[43] In addition, these behaviours can also have an impact on the energy spent in the manufacturing phase. Such is the case when users prolong the life of their smartphones or other devices by delaying their replacement.

[44] https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

3.2. Methodologies used to establish energy consumption estimates

3.2.1. Major methodologies identified in the literature review

Researchers have developed various methodologies to estimate the energy consumption of the ten digital behaviours presented earlier in this report. Such methodologies are the object of fierce debates among academia and specialised institutions. These debates focus primarily on questioning the accuracy and reliability of these methodologies. On the one hand, some argue that specific methods, such as Life Cycle Assessment, provide a more comprehensive and accurate energy consumption estimate. In contrast, others argue that more straightforward and less resource-intensive methodologies, such as modelling or direct measurement, can be just as effective. In this context, it is crucial to understand the strengths and weaknesses of the widespread methodologies used to estimate the energy consumption of digital behaviours. The principal methods collected throughout the literature review are presented below.

Life Cycle Assessment

First, LCA is a widely used methodology across industries, including the ICT sector, to assess the environmental impacts of products and services. It appears to be the most widespread methodology for estimating the energy consumption of digital behaviours. Such methodology is based on a systematic and quantitative approach that assesses the environmental impacts of a product or service over its whole life cycle[45]. While the level of detail may vary from one LCA to another, it usually considers all the energy and material inputs and outputs associated with the product or service analysed, including production, transport, use, and disposal of devices. Typically, for a digital behaviour such as watching a video online, a LCA would include data such as the energy consumption of the device used to watch the video, the energy used to transmit the video data over the internet, and the energy required to store and process the video data for instance.

In this regard, LCA is considered a robust methodology because it provides a comprehensive and systematic approach to assessing the energy consumption in the ICT sector. Additionally, this LCA follows ISO standards (ISO 14040:2006, ISO 14044:2006) which are believed to make LCAs even more reliable. It ensues that the LCA follows a clear framework[46]. The standards outline the principles, requirements, and guidelines for conducting LCA studies, including the definition of the scope and boundaries of the study, the selection of data sources, the calculation of environmental impacts, and the interpretation of results.

It is important to note that while LCA are extremely common in the ICT sector, in general, they are applied to environmental footprint assessments[47] more often than to energy consumption assessments[48].

[45] European Environmental Agency (2020) life cycle assessment https://www.eea.europa.eu/help/glossary/eea-glossary/life-cycle-assessment

[46] European Commission (2018). European Platform on LCA | EPLCA https://eplca.jrc.ec.europa.eu/lifecycleassessment.html

[47] Carbon footprint assessment is the process of measuring the total amount of GHG emitted by an individual, organization, or product over its entire life cycle, with the aim of identifying sources of GHG emissions, setting reduction targets, and making informed decisions to reduce environmental impact.

[48] Energy consumption assessment involves analysing the amount of energy used by an individual, organization, or product, and evaluating the efficiency of energy use. It aims to identify opportunities to reduce energy use, increase efficiency, and decrease energy costs, and inform policy decisions related to energy efficiency.

In addition; this LCA is very much inspired from the PEF metholodology developed by the JRC and the EU Commission. This methodology is partly followed for the purposes of the Life Cycle Assessment. This will allow the Commission to confortably use this study as it is in line with the standards in the market.

Strengths

- Comprehensive approach that usually considers all stages of product or service life cycle[49]
- Allows to compare different products or services to determine which is more energy efficient (e.g., it can compare different types of consoles or different social media)
- Can identify environmental hotspots and areas for improvement.

Weaknesses

- Requires detailed data on the energy and material inputs and outputs of each life cycle stage, which may not always be available
- Can be time-consuming and expensive
- LCA continues to suffer from variation in practice, making it difficult to compare[50].

Modelling

Second, modelling was found to be a common methodology to compute the energy consumption of digital behaviours. Modelling involves creating a mathematical or computer-based model to estimate the energy consumption of a digital behaviour. This methodology requires the creation of a simplified representation of the digital behaviour being under consideration. The model may include equations that describe the energy consumption of different components of the digital behaviour, such as the device, network infrastructure, or data centres[51]. For example, a model may calculate the energy consumed by a device based on its power consumption rate and the time spent watching the video. The model may also include assumptions about user behaviour, such as the average time people spend watching videos online, or the devices they use to stream videos.

The robustness of this methodology highly depends on the quality of the data used and whether the assumptions are realistic.

[49] FibreNet (2019). Life Cycle Assessment: Benefits and limitations http://fibrenet.eu/index.php?id=blog-post-eleven

[50] Curran (2014). Strengths and Limitations of Life Cycle Assessment https://www.researchgate.net/publication/281212698_Strengths_and_Limitations_of_Life_Cycle_Assessment

[51] International Energy Agency (2018). Statistics report Energy end-use data collection methodologies and the emerging role of digital technologies https://iea.blob.core.windows.net/assets/34e2659e-809c-4299-bb51-c0343257af08/Energy_end-use_data_collection_methodologies_and_the_emerging_role_of_digital_technologies.pdf

Strengths

- Can estimate energy consumption quickly and inexpensively[52]
- Can easily vary input parameters to test different scenarios
- Can incorporate different assumptions about user behaviour and technology

Weaknesses

- Depends on the accuracy of the model, input parameters ans assumptions
- May not capture all relevant factors that impact energy consumption
- Model outputs may not be easily interpretable[53].

Direct measurement

Third, a common methodology identified in the literature is the direct measurement of energy consumption. This methodology requires to perform a physical measurment of the energy consumption of a device or service, most of the times, during its use phase. In the context of energy consumption of digital behaviours such as watching a video online, direct measurement requires using a power meter or another energy monitoring device to measure the actual energy consumption of the device or devices used to access the video[54]. The power meter would be connected between the device and the power source and record the energy consumption in real time.

This methodology is generally considered a robust methodology, but it may have limitations in accurately measuring energy use for certain activities: it requires measuring actual energy use in real-world conditions, which can provide accurate and reliable data; yet, it can be challenging to accurately measure energy use for some types of digital behaviours, such as online gaming, where the energy consumption can vary depending on the specific device used. To address these limitations, some researchers have used combinations of direct measurement and modeling or simulation to develop more comprehensive assessments of energy use.

Strengths

- Provides an accurate and direct measurement of energy consumption during the use phase of a device or service
- Allows for detailed analysis of energy consumption at a specific moment in time, which can be useful in identifying areas for energy efficiency improvements

Can be used to verify or validate estimates generated following other methodologies

Weaknesses

- Does not always account for the energy consumed during the production and disposal phases of the device or service
- The results are only representative for specific conditions (specific time and place); they do not take into account the fluctuations over time and space.

[52]Ibid.

[53]Ibid.

[54] Green Software Foundation (2021). HOW TO MEASURE THE ENERGY CONSUMPTION OF YOUR FRONTEND APPLICATION https://greensoftware.foundation/articles/how-to-measure-the-energy-consumption-of-your-frontend-application

- Results may not be representative of the energy consumption of the average user, as user behaviours can vary significantly.

Bottom-up approach

A few scholars used a bottom-up approach methodology. This methodology involves estimating the energy consumption of individual components of a digital device or system and then adding them up to get an estimate of the overall energy consumption. This approach is based on analysing the energy consumption of individual components, such as the CPU, memory, storage devices, network interfaces, and other peripherals, and then summing up their energy consumption to get an estimate of the total energy consumed. Indeed, the bottom-up approach for estimating the energy consumption of digital behaviours is similar to a LCA methodology in that both approaches involve a detailed analysis of individual components and their associated energy consumption. However, there are some key differences between the two methodologies. These are the following:

- The LCA methodology evaluates the entire life cycle of a product or process, while the bottom-up approach usually focuses on specific components or processes.
- LCA methodology considers upstream and downstream impacts, including impacts associated with transportation and energy use, while the bottom-up approach may not consider upstream or downstream impacts or may only consider a limited set of impacts.
- LCA methodology may use a standardized framework and methodology, as defined by ISO standards, while the bottom-up approach does not have a standardized framework.
- While LCA provides a comprehensive view of environmental impacts, it can be time-consuming and data-intensive, while the bottom-up approach may be more efficient but may not provide a comprehensive view of overall environmental impacts.

An advantage of the bottom-up approach is that, similarly to a LCA, it can provide a detailed understanding of the energy use associated with different digital activities. This can be useful for identifying opportunities for energy savings and efficiency improvements. However, like other methodologies, its quality depends highly on the type of data used.

Strengths

- Provides a detailed breakdown of the energy consumption of individual components, allowing for a more accurate estimate of energy consumption
- It can be applied to a wide range of digital devices and systems, from personal computers to data centers
- It can identify which components are the most energy-intensive, allowing for targeted energy efficiency improvements

Weaknesses

- Accurate data may not be available for all components, which can lead to inaccurate estimates of energy consumption
- The bottom-up approach may not account for variations in energy consumption due to differences in user behaviour or device settings.

It has to be noted that the bottom-up approach can require '**refining existing estimates**'. While this is not a methodology per se, this means that researchers use the work of previous studies as a starting point and refine them based on new data or improved modelling techniques. Theoretically, this allows for the creation of more accurate estimates over time. For example, a new study may use more recent data on the energy efficiency of devices or strive to correct errors made in previous studies, which allow creating more reliable estimates.

3.2.2. Explaining the variations in estimates

When looking at the methodologies used to produce estimates about the energy consumption of different digital behaviours, it is important to consider how the different components of a methodology can impact the value generated.

First, the energy estimates generated by each method rely on certain **assumptions and data inputs**. If these assumptions or inputs are different across studies, it can lead to differences in the estimated energy consumption. For example, if an analysis assumes that the users of video games mostly play on phones and PC, while another considers consoles as well, the numbers will automatically vary significantly.

The scope and boundaries of the study can also impact the energy estimates. For example, some studies may only consider the energy consumption of a single device or activity, while others may consider the entire life cycle of a product or service. Differences in scope and boundaries can lead to significant differences in the estimated energy consumption.

Differences in time and location can also impact energy estimates. For example, the energy mix, carbon-intensity and efficiency of the electricity grid can vary across countries or regions, as well as over timeleading to differences in energy consumption estimates. Additionally, changes in energy prices or consumer behaviour can impact energy consumption over time.

Furthermore, the **quality or source of the data** used can significantly impact the estimates produced. Indeed, using secondary data, generated data, publicly available data, or a mix of the three can impact the final numbers. And in the same line of thought, access to data can constitute a significant barrier to conducting energy consumption studies. Some issues, like the energy consumption of downloading a document to a PC, can be complicated to analyse due to limited data availability or lack thereof.

Regardless of the methodology chosen, when interpreting the available evidence, as argued by Freitag and Berners-Lee[55], it is important to be mindful of the following issues:

- the age of the data;
- potential limited ability to access and analyse the data;
- the potential for conflict of interest, particularly when researchers are affiliated with ICT companies that do not make data and analysis freely available;
- differences in approaches and lack of consensus regarding the scope of analysis concerning what precisely constitutes the ICT industry.

Considering the points listed above, the estimates found in the literature can only be compared to a limited extent, that is when the assumptions and the system boundaries of the analysis are compatible. Yet, they can serve as a basis for understanding the extent to which our day-to-day digital behaviours determine our energy consumption levels.

[55] Freitag and Berners-Lee (2020). The climate impact of ICT: A review of estimates, trends and regulations https://arxiv.org/ftp/arxiv/papers/2102/2102.02622.pdf

3.3. Energy consumption estimates of digital actions and services

3.3.1. One hour of video streaming

Video streaming is certainly one of the digital behaviour that has attracted the most attention. It has become a even more trending topic since the start of the COVID19 pandemic and the need for self-isolation[56]. And indeed, rightfully so. According to Ericsson[57], 69% of mobile connections were related to video streaming in 2021, and one-third of this percentage comes from Netflix and Youtube alone[58]. According to Cisco's annual report[59], video streaming services escalated almost 25% per year globally, which makes video streaming a concern for future energy consumption of the ICT sector.

Although it may be argued that reducing the energy consumption associated with video streaming of one individual user has a modest impact[60], significant energy savings can be achieved when applied to a European or global scale.

Interestingly, the debate around the current energy consumption of video streaming is particularly polarized[61].In 2020, the IEA[62] argued that generally, in recent available figures in the literature, flawed assumptions exaggerate the electricity consumption of data centres and data transmission. This contributes to overestimating the overall energy comsumption associated with video streaming. It particularly criticises assumptions made by the Shift Project[63], arguing it inflates the energy intensity of data transmission networks by around 50-fold. For the IEA, these result from using high and outdated energy-use assumptions for various access modes, as well as from calculation mistakes. According to the IEA, the errors also come from a stated assumption of 3Mbps apparently being converted in error to 3 megabytes per second, MBps, with each byte equivalent to eight bits. While the later mistake was considered in the reviewed estimate published in 2020, only some of the errors in the calculation have been addressed. Hence, the IEA strived to update the numbers provided by the Shift Project by making time-based intensity values. Likewise, for the Greenspector[64] it is clear that the Shift Project study overestimates grid consumption.

As for Makonin et al. (2020)[65] who used modelling to estimate the energy consumption of video streaming, what is needed on the subject is a reasonable model that considers all

[56] Makonin et al. (2022). Calculating the Carbon Footprint of Streaming Media: Beyond the Myth of Efficiency https://computingwithinlimits.org/2022/papers/limits22-final-Makonin.pdf

[57] Ericsson (2022). Mobility Reports https://www.ericsson.com/en/reports-and-papers/mobility-report/reports

[58] Sandvine (2019). White Paper Video and Television Piracy https://www.sandvine.com/hubfs/Sandvine_Redesign_2019/Downloads/Whitepapers/Sandvine_WP_Video%20TV%20Piracy%20Ecosystem%20Impact%2020190625.pdf

[59] Cisco (2021). Networking, C.V. Cisco Global Cloud Index: White Paper. Available online: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns1175/Cloud_Index_White_Paper.html

[60] International Energy Agency (2020). Author George Kamiya, The carbon footprint of streaming video: fact-checking the headlines https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines

[61] The Shift Project (2019). LEAN ICTTOWARDS DIGITAL SOBRIETY https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf

[62] International Energy Agency (2020). Author George Kamiya, The carbon footprint of streaming video: fact-checking the headlines https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines

[63] The Shift Project (2019). LEAN ICTTOWARDS DIGITAL SOBRIETY https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf

[64] Greenspector (2020). The Impact of playing a Canal + video study https://greenspector.com/en/impact-playing-canal-video/#resultats

[65] Makonin et al. (2022). Calculating the Carbon Footprint of Streaming Media: Beyond the Myth of Efficiency https://computingwithinlimits.org/2022/papers/limits22-final-Makonin.pdf

previous models published in the literature. According to the authors, the existing models are either too high-level or incomplete and partial. With this in mind, they have proposed a holistic end-to-end model that balances high-level considerations with an improved level of details.

Yet, it is essential to note that while these studies indicate the energy consumption associated with streaming, their main focus remains carbon footprint, which may impact the overall design of the methodology.

A point to remember when thinking of video streaming is that according to most scholars looking into the subject[66], the viewing device is typically the source of the most significant energy consumption. Indeed **the energy consumption of watching a video varies significantly depending on the device used.** This is primarily due to their varying display sizes, screen technologies, and processing power. In general, larger display sizes require more energy to operate, so televisions typically consume the most energy when watching a video[67]. However, the type of display technology used (e.g. smartphone vs TV) can also significantly impact energy consumption. Overall, for watching videos, televisions are typically the most energy-consuming devices, while smartphones and tablets are the most energy-efficient. Additionally, focusing on different service providers can have an impact on the estimates created. For instance, some studies focusing on Netflix[68] and Canal+[69] found different results. For Makonin et al (2020) watching Netflix for an hour consumes between 0.783 and 0.983 kWh, while the Greenspector (2020) found that watching one hour of Canal+ consumes 0.214 kWh. Yet, Emeji (2015) found that one hour of watching Neflix consumes between 0.115 kWh and 0.289 kWh considering higher and lower data quality. The gap in energy consumption between different streaming services can therefore be subject to debate.

The literature also emphasised that lowering the video quality is an effective leverage to decrease the energy consumption of video streaming. For Ejenbi et al, (2015)[70], from high to low resolution, there is a possible difference of 88.8 GWh a year globally, enough to power over 20,000 homes in the UK or 100,000 homes in India. The study demonstrates that making simple adjustments to video quality settings on Netflix can lead to significant energy savings of up to 34%, based on the measurements conducted. By analysing the impacts of these settings on both the energy consumption of client systems and the network, they estimate that global energy savings of over 100 GWh per year are possible if users make informed choices in their video streaming habits. They conclude that providing energy usage information to digital video users can empower them to make more energy-efficient choices in their video settings, leading to reduced electricity costs and carbon emissions.

As a side note, it is important to consider that Netflix has changed its compression algorithm over time to improve the quality of its video streaming while reducing its data usage. The company has made several changes to its encoding process and introduced new video codecs, such as VP9 and AV1[71], which are more efficient than older codecs like H.264. These changes in the compression algorithm have significant implications for the energy used when watching videos on Netflix. By improving the efficiency of video compression,

[66] Carbon Trust (2021). Carbon impact of video streaming https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/carbon-impact-of-video-streaming

[67] International Energy Agency (2020). Author George Kamiya, The carbon footprint of streaming video: fact-checking the headlines https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines

[68] Ejembi (2015). Client-side energy costs of video streaming University of St Andrews https://research-repository.st-andrews.ac.uk/handle/10023/9353?show=full

[69] Greenspector (2020). The Impact of playing a Canal + video study https://greenspector.com/en/impact-playing-canal-video/#resultats

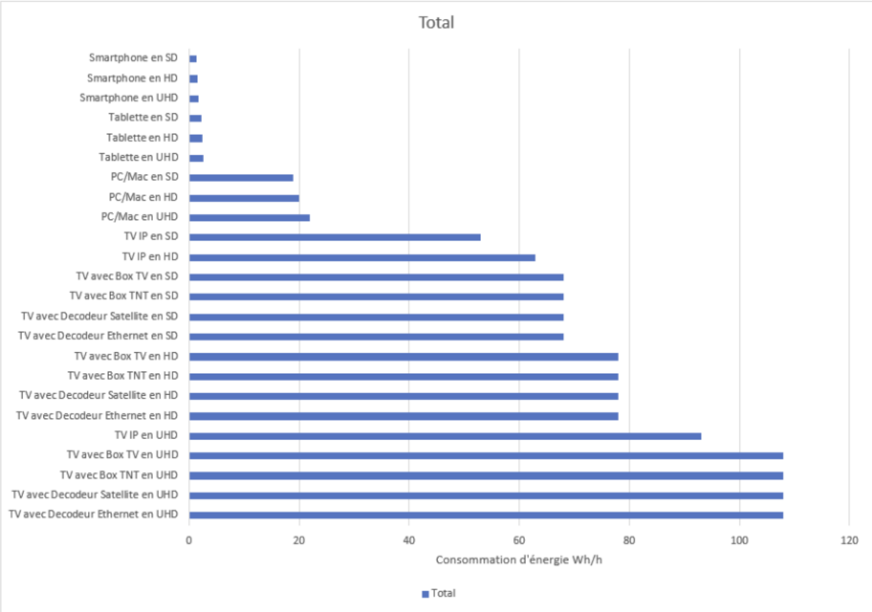
[70] Ejembi (2015). Client-side energy costs of video streaming University of St Andrews https://research-repository.st-andrews.ac.uk/handle/10023/9353?show=full

[71]VdoCipher (2021). Tech Update: Netflix Updates Codecs Use for Efficient Encodinghttps://www.vdocipher.com/blog/tech-update-netflix-updates-codecs-use-efficient-encoding/

Netflix can deliver high-quality video content using less data, which should translate to lower energy consumption for both the company and the end-user.

However, the actual energy consumption can vary significantly depending on the specific device and the type of video being watched. The figure below displays the energy consumption of video streaming according to different scenarios.

Figure 5 Energy consumption of video streaming depending on the device used



Source: https://greenspector.com/en/impact-playing-canal-video/

The estimates on video streaming collected from the literature are displayed in the table below.

Table 10 Estimates for one hour of video streaming

Title	Author	Year	Estimate	Relevant information about the estimate	Method used
The carbon footprint of streaming video: fact-checking the headlines [72]	International Energy Agency	2020	36 gCO_2 0.08 kWh	This paper considers one hour of video streaming on the basis of Netflix using different scenarios, video quality, and devices	Bottom-up approach
Carbon Impact of video Streaming[73]	The Carbon Trust	2021	55 gCO_2eq 0.188 kWh	European average footprint European average energy consumption	Conventional allocation approach[74]
Lean ICT - Towards Digital Sobriety[75]	The Shift Project	2019	5,270 kWh (original) 0.659 kWh (corrected) 3.2 $kgCO_2$	This study has provided corrected estimates, each consider different use scenarios	Hybrid methodology[76]

[72] International Energy Agency (2020). Author George Kamiya, The carbon footprint of streaming video: fact-checking the headlines https://www.iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-headlines

[73] Carbon Trust (2021). Carbon impact of video streaming https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/carbon-impact-of-video-streaming

[74] 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].

[75] The Shift Project (2019) Lean ICT Towards Digital Sobriefty https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf

[76] While the Shift Project's methodology shares some similarities with life cycle assessment (LCA) approaches, it is not a traditional LCA methodology. Rather, it is a hybrid methodology that combines data from various sources and models to estimate the energy and emissions associated with the production, distribution, and use of digital technologies.

The Impact of playing a Canal + video study[77]	Greenspector	2020	0.214 kWh	This number corresponds to the average end-to-end consumption for Canal+ fleet	Not traditional LCA[78] *Calculation methods standardized by ETSI*
Vidéo en ligne : quels impacts environnementaux ?[79]	GreenIt	2019	0.5 to 4.5 kWh	This number considers different device, video quality, and connection scenarios	LCA
Calculating the Carbon Footprint of Streaming Media: Beyond the Myth of Efficiency[80]	Makonin et al	2020	0.783-0.983 kWh	This paper considers video streaming on Netflix	Modelling (holistic end-to-end)
The overlooked environmental footprint of increasing Internet use[81]	Obringer et al	2021	0.036 kWh for standard definition video to 0.450 kWh 22 g (low) to 270 gCO_2 (high)	The study considers standard definition of video streaming versus high-definition video	Bottom-up analysis
Client-side energy costs of video streaming[82]	Ejembi et al.	2015	0.115 kWh to 0.289 kWh	This study considers, low, and high Netflix quality	Direct measurement
Evaluation de l'impact environnemental de la digitalisation des services culturels[83]	ADEME	2022	66 gCO_2eq – 177 gCO_2eq	This estimate is about watching a movie for one hour	Multicriteria LCA *ISO 14044:2006*

3.3.2. One hour of video gaming

Video gaming has become one of the most popular forms of entertainment worldwide. Yet, its growing popularity has also raised concerns about its environmental impact and energy

[77] Greenspector (2020). The Impact of playing a Canal + video study https://greenspector.com/en/impact-playing-canal-video/#resultats

[78] It is considered a non-traditional LCA because it goes beyond the traditional boundaries of a LCA study. While traditional LCAs focus on measuring the environmental impact of a product or service throughout its entire life cycle, the Greenspector study narrows its focus to the energy consumption associated with playing a specific video on a streaming platform.

[79] Greenit (2019) Vidéo en ligne : quels impacts environnementaux ? https://www.greenit.fr/2019/07/22/%ef%bb%bfvideo-en-ligne-quels-impacts-environnementaux/

[80] Makonin et al. (2022). Calculating the Carbon Footprint of Streaming Media: Beyond the Myth of Efficiency https://computingwithinlimits.org/2022/papers/limits22-final-Makonin.pdf

[81] Obringer et al. (2021) The overlooked environmental footprint of increasing Internet use https://pennstate.pure.elsevier.com/en/publications/the-overlooked-environmental-footprint-of-increasing-internet-use

[82] Ejembi (2015). Client-side energy costs of video streaming University of St Andrews https://research-repository.st-andrews.ac.uk/handle/10023/9353?show=full

[83] Ademe (2022). Evaluation de l'impact environnemental de la digitalisation des services culturels https://librairie.ademe.fr/dechets-economie-circulaire/5942-evaluation-de-l-impact-environnemental-de-la-digitalisation-des-services-culturels.html

consumption[84]. As the technology used in video games becomes more advanced, the hardware required to run these games has become more powerful and energy-hungry, leading to increased energy consumption.

This issue has attracted the attention of many stakeholders, with researchers and organisations investigating the environmental impact of video gaming and the potential solutions to reduce its energy consumption. Some studies have pointed out gaming's responsibility for a considerable amount of energy consumption and determined its energy consumption[85, 86]. Other studies have focused on developing more energy-efficient gaming hardware and promoting environmentally-friendly gaming practices[87, 88, 89].

It remains complex to identify the energy consumption of video gaming, specifically if one tries to estimate the energy consumed during one hour of gameplay. Indeed, the energy consumption related to video gaming is highly dependent on several factors. The type of **video game can significantly impact the energy consumption of gaming**. For instance, the energy required to run video games is much higher today than it was when the first games appeared in the 1970s[90]. Games now require a much higher quality of graphics, higher resolution of the connected displays, and the streaming of game content. For instance, games in 3D with advanced physics engines can consume more energy than simpler games like 2D platformers or puzzle games[91]. Mills and Mills (2016)[92] even explained that contemporary games consumed 70 times more than those in the seventies.

On the other hand, the **device used to play video games can also significantly impact energy consumption.** Generally, devices with more powerful processors and graphics cards consume more energy than those with lower-powered hardware[93]. Similarly to video streaming, devices with larger screens require more energy to operate, so gaming on a large monitor or television can consume more energy than gaming on a smaller screen. For example, gaming on a high-end PC can consume significantly more energy than gaming on a low-end laptop or tablet[94].

Other factors that can affect energy consumption in video gaming include the graphics quality of a video game. High-quality graphics require more processing power, which leads

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[84]Mills et al. (2019). Toward Greener Gaming: Estimating National Energy Use and Energy Efficiency Potential> Computer Games Journal https://www.researchgate.net/publication/336909520_Toward_Greener_Gaming_Estimating_National_Energy_Use_and_Energy_Efficiency_Potential

[85] Abraham (2022). The Carbon Footprint of Playing Games, Digital Games After Climate Change https://link.springer.com/chapter/10.1007/978-3-030-91705-0_6

[86] Ibid.

[87]Mills et al (2019). Toward Greener Gaming: Estimating National Energy Use and Energy Efficiency Potential https://eta-publications.lbl.gov/publications/toward-greener-gaming-estimating

[88] Ibid.

[89]Milsls et al (2019). Toward Greener Gaming: Estimating National Energy Use and Energy Efficiency Potential https://www.researchgate.net/publication/336909520_Toward_Greener_Gaming_Estimating_National_Energy_Use_and_Energy_Efficiency_Potential

[90] Copenhagen Centre on Energy Efficiency (2020). Reducing the energy use of video gaming: energy efficiency and gamification https://c2e2.unepccc.org/wp-content/uploads/sites/3/2020/10/reducing-the-energy-use-of-video-gaming-energy-efficiency-and-gamification-en.pdf

[91]Copenhagen Centre on Energy Efficiency (2020). Reducing the energy use of video gaming: energy efficiency and gamification https://c2e2.unepccc.org/wp-content/uploads/sites/3/2020/10/reducing-the-energy-use-of-video-gaming-energy-efficiency-and-gamification-en.pdf

[92] Mills, N., & Mills, E. (2016). Taming the energy use of gaming computers. Energy Efficiency, 9(2), 321–338.

[93] USA Facts (2022). How environmentally friendly are video games? https://usafacts.org/articles/how-environmentally-friendly-are-video-games/

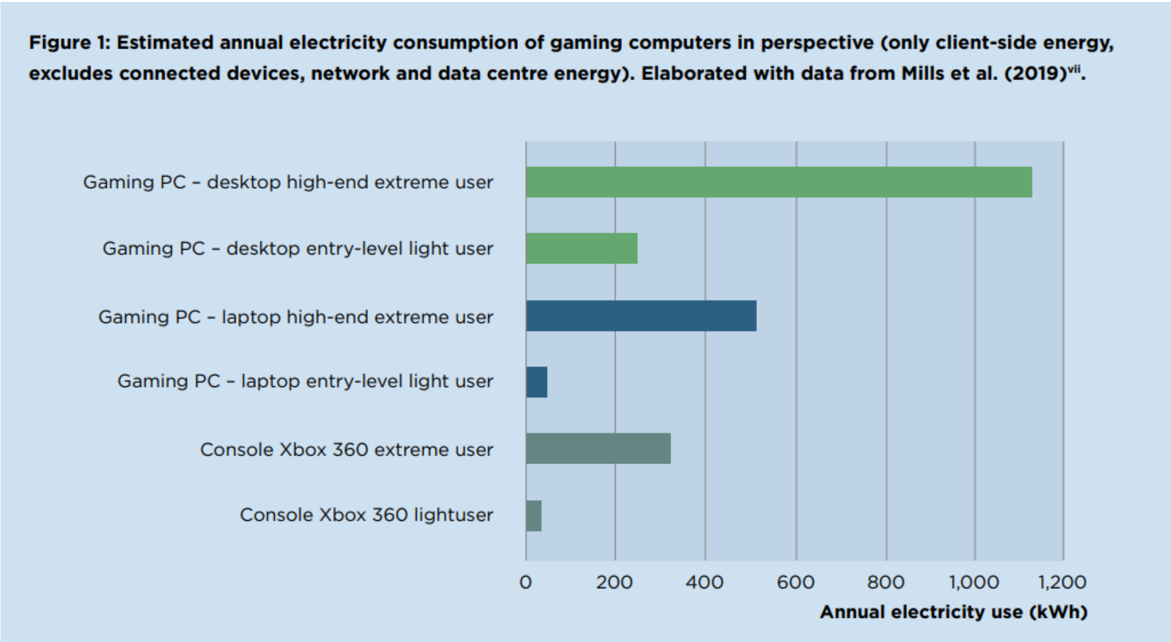
[94] Copenhagen Centre on Energy Efficiency (2020). Reducing the energy use of video gaming: energy efficiency and gamification https://c2e2.unepccc.org/wp-content/uploads/sites/3/2020/10/reducing-the-energy-use-of-video-gaming-energy-efficiency-and-gamification-en.pdf

to increased energy consumption[95]. Video games with lower graphics quality can be run on devices with lower-powered processors, resulting in lower energy consumption.

Additionally, several scholars have modelled, or at least considered, the **intensity of the gameplay, which means the frequency at which users play.** While this does not impact the energy of gameplay for one hour, this is a crucial aspect to consider. Indeed, playing video games for extended periods of time can lead to increased energy consumption. The longer a gaming session lasts, the more energy is required to power the device used to play the game. Hence, games designed to be played for more extended periods, such as open-world games or strategy games, can lead to more extended gaming sessions, resulting in more energy consumption. These differences are shown in Figure 6. This has led many scholars to simply suggest reducing gameplay time.

These findings are important since more than half of the energy used by game consoles is used during game play[96] and it is believed that improving information on energy consumed can directly affect gaming behaviour[97].

Figure 6 Estimated annual electricity of gaming



Source: *https://c2e2.unepccc.org/wp-content/uploads/sites/3/2020/10/reducing-the-energy-use-of-video-gaming-energy-efficiency-and-gamification-en.pdf*

According to the Copenhagen Centre on Energy Efficiency (2020)[98], measuring the energy associated with gaming devices and identifying opportunities for energy savings is challenging. The absence of standardized testing procedures and protocols for energy measurement and performance metrics constitutes an obstacle to the proper monitoring of energy usage for gaming and to clear messaging towards the consumer.

Finally, it is worth mentioning that the literature collected on the topic mostly comes from or focuses on the United States. This is because the country has one of the largest gaming

[95] USA Facts (2022). How environmentally friendly are video games? https://usafacts.org/articles/how-environmentally-friendly-are-video-games/

[96] Urban, B., Roth, K., Singh, M., & Howes, D. (2017). Energy Consumption of Consumer Electronics in U.S. Homes in 2017

[97] Copenhagen Centre on Energy Efficiency (2020). Reducing the energy use of video gaming: energy efficiency and gamification https://c2e2.unepccc.org/wp-content/uploads/sites/3/2020/10/reducing-the-energy-use-of-video-gaming-energy-efficiency-and-gamification-en.pdf

[98] Ibid.

markets in the world. While there have been insightful studies from Europe that have estimated energy consumption or CO_2 emissions associated with video gaming, these studies often consider other digital services as well, and do not specifically focus on the energy consumption of video gaming alone. Considering this, there may be a potential necessity for conducting additional research that exclusively investigates the energy consumption patterns of video gaming in the European context.

The estimates collected in the literature are displayed in the table below.

Table 11 Estimates on one hour of video gaming

Title	Organisation	Date	Estimate	Relevant estimate on the project	Methods
Evaluation de l'impact environnemental de la digitalisation des services culturels[99]	ADEME	2022	84 gCO_2eq to 260 gCO_2eq	One average hour video gaming	Multicriteria LCA *ISO 14044:2006*
The Latest-Generation Video Game Consoles How Much Energy Do They Waste When You're Not Playing?[100]	A study by the Natural Resources Defense Council (NRDC)	2014	from 0.0112 kWh to 0.034 kWh	These estimates compare different consoles, Wii U 34 watts (0.034 kWh) PS4 137 (0.0137 kwh) XBOX one 112 (0.0112 kwh)	Direct measurement
Lean ICT - Towards Digital Sobriety[101]	The Shift Project	2019	0.05 kWh to 0.04 kWh	The estimates show the difference between basic and complex game.	Not a traditional LCA, comprehensive method

[99] Ademe (2022). Evaluation de l'impact environnemental de la digitalisation des services culturels https://librairie.ademe.fr/dechets-economie-circulaire/5942-evaluation-de-l-impact-environnemental-de-la-digitalisation-des-services-culturels.html

[100] NRDC (2014). The Latest-Generation Video Game Consoles: How Much Energy Do They Waste When You're Not Playing? https://www.nrdc.org/bio/pierre-delforge/latest-generation-video-game-consoles-how-much-energy-do-they-waste-when-youre

[101] The Shift Project (2019) Lean ICT Towards Digital Sobriety https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf

Towards Greener Gaming: Estimating National Energy Use and Energy Efficiency Potential[102]	The Computer Games Journal	2019	1,200 kWh	This estimate is the result of 26 systems tested, client-side electricity	Bottom-up modelling approach and an energy efficiency potential analysis
EVALUATION DE L'IMPACT ENVIRONNEMENTAL DU NUMERIQUE EN FRANCE[103]	Arcep/Ademe	2022	0.083 kWh	This number focuses on game play only.	LCA *ISO 14040:2006*
How Much Energy Do Gaming Computers Use? All The Facts[104]	Computer Info bits	2022	0.3 to 0.5 kWh	This estimate refers to energy consumption on PC.	Not provided

3.3.3. One hour of video conferencing

The energy consumption of video conferencing has become an increasingly important topic in recent years. With the rise of remote work and virtual communication, video conferencing has become a staple tool for many businesses and organizations. The literature on this topic has focused on showing the benefits of online meetings versus in-person meetings. Another important proportion of the literature has focused on measuring the energy consumption associated with various types of video conferencing software, as well as identifying strategies for reducing energy usage during virtual meetings. It was found that video conferencing requires much energy to transmit audio and video data over the internet.

Again here, the amount of energy consumed during video conferencing depends on various factors, such as the quality of the audio and video, internet connection speed, and whether or not the camera is being used. When a camera is used during video conferencing, it

[102] Mills et al (2019). Toward Greener Gaming: Estimating National Energy Use and Energy Efficiency Potential https://eta-publications.lbl.gov/publications/toward-greener-gaming-estimating

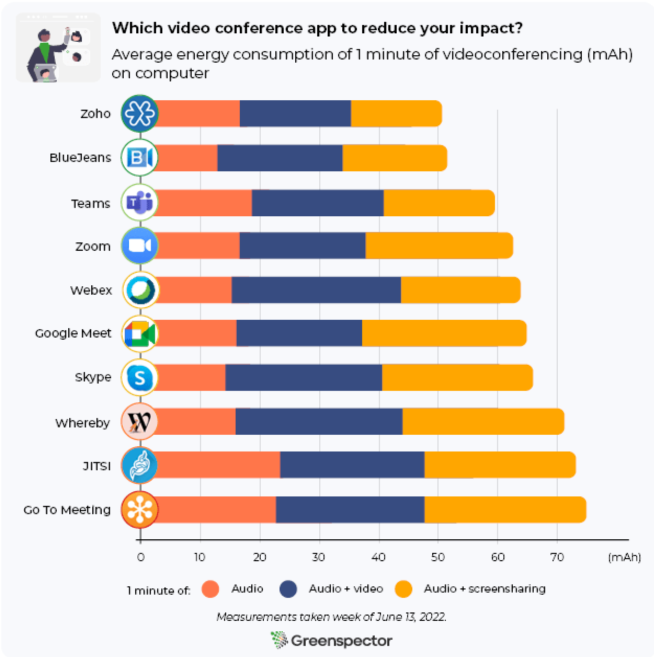
[103] Arcep/Ademe (2022) EVALUATION DE L'IMPACT ENVIRONNEMENTAL DU NUMERIQUE EN France https://www.arcep.fr/uploads/tx_gspublication/etude-numerique-environnement-ademe-arcep-volet01_janv2022.pdf

[104]Computer Info Bits (2022). How much energy do gaming computers use ? all the facts https://computerinfobits.com/how-much-energy-do-gaming-computers-use/#:~:text=A%20gaming%20computer%20requires%20somewhere,than%20a%20laptop's%20power%20usage

requires additional energy to capture and transmit the video data. The camera needs power to operate, and the video data requires more bandwidth to transmit over the internet. This can increase the overall energy consumption of the video conferencing session.

On the other hand, if the camera is turned off during video conferencing, it can significantly reduce the energy consumption of the session[105]. Without the camera, the video data transmission requires less bandwidth, which can result in lower energy consumption. In addition, using audio-only mode for video conferencing can further reduce energy consumption, as it only requires a small amount of bandwidth to transmit audio data.

Figure 7 Energy consumption of videoconferencing apps on PC Source



Source: https://greenspector.com/en/videoconferencing-apps-2022/

Ong et al. (2014)[106] prior to the pandemic, analysed the cost of videoconferencing, including operating costs of the network and videoconferencing equipment, lifecycle assessment of equipment costs, and the time cost of people involved in meetings. They found that videoconferencing takes at most 7% of the energy/carbon of an in-person meeting. This demonstrates that video conferencing, besides consuming energy, could still be considered a greener alternative to in-person meetings. This is because attending an in-person meeting often requires travel, which can consume significant amounts of energy in the form of transportation and accommodation.

Recently, scholars have highlighted a potential rebound effect associated with video conferencing, where the convenience of virtual meetings may lead to an increase in the number of meetings held overall as well as the numbers of participants to meetings, which could potentially offset energy savings achieved through reduced travel. Additionally, the energy consumption associated with video conferencing can still be significant, particularly for large organizations that conduct frequent virtual meetings.

The estimates collected in the literature are displayed in the table below.

[105] The impact of our videoconferencing uses on mobile and PC! 2022 edition - Greenspector

[106] http://www2.eet.unsw.edu.au/~vijay/pubs/jrnl/14comcomVC.pdf

Table 12 Estimates for one hour of video conferencing

Title	Author	Date	Estimate	Relevant information about	Methodology used
Comparison of the energy, carbon and time costs of videoconferencing and in-person meetings[107]	Ong et al.	2014	0.015 kWh	This estimate refers to one hour of streaming using a desktop system.	Modeling
Which video conferencing mobile application to reduce your impact? 2021 Edition[108]	Greenspector	2022	39.42 gCO_2eq	This estimate provides an average for all platforms using 3 scenarios (audio, video, screen sharing).	Direct measurement (Greenspector Test Runner)
The overlooked environmental footprint of increasing Internet use[109]	Obringer et al	2021	0.15 kWh to 1 kWh 90 to 540 gCO_2		Combination of methods, literature review, data analysis, LCA, scenario analysis

3.3.4. One hour of music streaming

The energy consumption of music streaming has also been a topic of interest in recent years. While music streaming may consume less energy than video streaming, it still contributes to the overall energy consumption of the internet. It is estimated to produce annual emissions of 200 million kg of CO_2 in the UK alone[110].

A major study on the impact of music streaming was published by the University of Glasgow in 2019[111]. In the paper, Brennan and Devine found that while the price of music has never been so low, its carbon emissions cost has soared. As for energy consumption, they explain that storing and processing music online uses a tremendous amount of resources and energy. The figure below shows the annual environmental cost of music over time. This is a fascinating paradox since the music has, in appearance, become almost completely dematerialised.

[107] Ong et al (2014) Comparison of the energy, carbon and time costs of videoconferencing and in-person meetings☆ https://www.sciencedirect.com/science/article/abs/pii/S0140366414000620

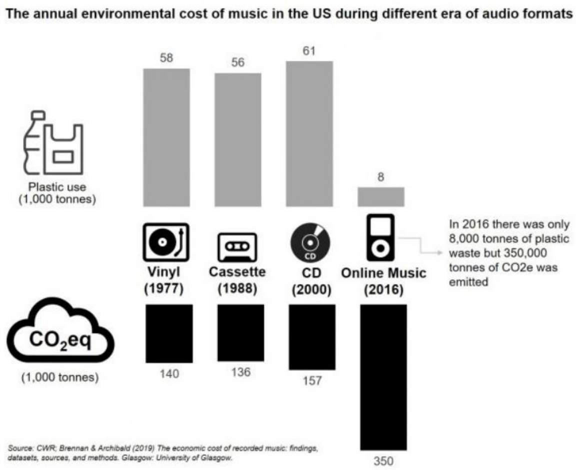
[108] Greenspector (2021) Which video conferencing mobile application to reduce your impact? 2021 Edition https://greenspector.com/en/which-video-conferencing-mobile-application-to-reduce-your-impact-2021/#:~:text=The%20Top%203%20for%20one,last%20app%20in%20this%20ranking.

[109] Obringer et al. (2021) The overlooked environmental footprint of increasing Internet use https://pennstate.pure.elsevier.com/en/publications/the-overlooked-environmental-footprint-of-increasing-internet-use

[110] The Conversation (2019). The environmental impact of music: digital, records, CDs analysed https://theconversation.com/the-environmental-impact-of-music-digital-records-cds-analysed-108942

[111] University of Glasgow (2019). MUSIC CONSUMPTION HAS UNINTENDED ECONOMIC AND ENVIRONMENTAL COSTS https://www.gla.ac.uk/news/archiveofnews/2019/april/headline_643297_en.html

Figure 8 Environmental cost of music across generations



Source: Brennan and Archibald (2019) from https://www.chinawaterrisk.org/resources/analysis-reviews/the-hidden-cost-of-music/

Some suggest that the energy consumption of one hour of music streaming is relatively low, as audio data requires less bandwidth than video data. However, other studies argue that the increasing demand for high-quality audio and the growing popularity of music streaming services drive up energy consumption and are worth addressing. The book *''Decomposed: The Political Ecology of Music"*[112], by Kyle Devine, clearly states that widespread adoption of music streaming services has contributed to the growth of a massive and energy-intensive digital infrastructure that relies on data centres, servers, and networks that consume large amounts of electricity. It is still difficult to collect precise numbers on energy consumption for an hour of music streaming for one user.

Additionally, it does not seem relevant to compare the estimates collected since each study uses different assumptions and scenarios. While some consider the user's device (speaker, headphones, laptop, phone), some focus on compairing different websites (Spotify, Youtube, etc.). This makes it difficult to arrive at a consensus on the actual energy impact of music streaming.

Interesting points have been made on the overall environmental impact of music. In the literature, some suggest that downloading music instead of streaming could reduce by 80% CO_2 emissions after the first listen. In other words, nearly all carbon-intensive activities would be mitigated after the initial download (approximately 70,000 tons eliminated)[113]. And indeed, according to Spotify's (2020)[114] sustainability reporting, in 2020, emissions from the user phase (as opposed to the manufacture phase) comprised 42% of total emissions, making it the second largest source of emissions. This equates to approximately 71,000 tons of CO_{2e} and includes emissions from data traffic for streaming content on Spotify, app downloads, battery charges, and power supply for devices used to listen. The majority of these emissions are from the devices themselves. Although some of these emissions are outside a user's direct control, they remain a crucial area to address, especially since Spotify's users continue growing.

Scholars do highlight the need to further research in order to better understand the full energy consumption of music streaming for users[115].

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[112] Devine (2015). Decomposed: a political ecology of music https://www.jstor.org/stable/24736940

[113] RollingStone (2022). Protect the Planet: Stop Streaming Songs https://www.rollingstone.com/music/music-features/earth-day-climate-change-streaming-downloading-ajr-1339228/

[114] Ibid.

[115] University of Glasgow (2019). MUSIC CONSUMPTION HAS UNINTENDED ECONOMIC AND ENVIRONMENTAL COSTS https://www.gla.ac.uk/news/archiveofnews/2019/april/headline_643297_en.html

The estimates collected in the literature are displayed in the table below.

Table 13 Estimates on one hour of music streaming

Name	Author	Date	Estimate	Relevant information about the estimate	Methodology used
Evaluation de l'impact environnemental de la digitalisation des services culturels[116]	ADEME	2022	40 gCO_2eq to 83 gCO_2eq	This study considers different devices.	Multicriteria LCA *ISO 14044:2006*
How much power does your smart home use?[117]	The ambient	2021	≈ 3.3 kWh	This study considers music streaming associated to smart music tools like Sonos for **a month.**	Not provided
the cost of music[118]	Brennan and Devine	2019	0.0097-0.0417 kWh	Streaming music on YouTube per hour	Mixed methods
			0.0003-0.0017 kWh	Streaming music on Spotify per hour	Mixed methods

3.3.5. One hour of social networking

The energy consumption of social networking has also been a subject of interest in recent years, but the topic has been overshadowed by other digital services like streaming. Several studies have attempted to estimate the energy consumption of social networking, with varying results[119]. But again, for this digital behaviour, literature is dominated by papers focusing on carbon footprint or interested in larger numbers such as the energy consumption of Facebook's data centres.

Interestingly, some focus on comparing the energy consumption of different behaviours on social media (scrolling, sending pictures, sending messages). While there are not many numbers on the energy consumption of one average hour on social media, it seems that some behaviours are particularly energy-consuming. For instance, one report argues that energy consumption in the network and end-user devices for photo sharing on Facebook represents approximately 60% of the energy consumption of all Facebook data centres[120]. The Greenspector[121] also found that, by far, the most energy-intensive activity on Instagram

[116] Ademe (2022). Evaluation de l'impact environnemental de la digitalisation des services culturels https://librairie.ademe.fr/dechets-economie-circulaire/5942-evaluation-de-l-impact-environnemental-de-la-digitalisation-des-services-culturels.html

[117] The Ambiant (2021) How much power does your smart home use? https://www.the-ambient.com/features/smart-home-energy-use-costs-bills-2778

[118] Brennan, M., & Devine, K. (2020). The cost of music. Popular Music, 39(1), 43-65. doi:10.1017/S0261143019000552 https://www.cambridge.org/core/journals/popular-music/article/abs/cost-of-music/DEC6AA100C191D510213F9086CF094CC

[119] Duria et al (2018). Measuring the power consumption of social media applications on a mobile device https://iopscience.iop.org/article/10.1088/1742-6596/978/1/012104/pdf

[120] Jalali et al. (2014). Energy Consumption of Photo Sharing in Online Social Networks https://www.researchgate.net/publication/271424990_Energy_Consumption_of_Photo_Sharing_in_Online_Social_Networks

[121] Greenspector (2020). The carbon impact of Instagram app features https://greenspector.com/en/6168-2/

is scrolling. One minute of scrolling on a newsfeed is roughly the equivalent of driving 13 metres in a light vehicle.

As for the methodologies used to produce estimates, direct measurements of estimates seems relatively common for this digital behaviour; it indeed allows gathering exact estimates on the energy consumption of different mobile apps. For instance, according to the Greenspector, Tik Tok is the most energy-consuming social media application[122].

Despite the importance of this topic, the literature on the energy consumption of social networking is still relatively limited compared to other areas, such as gaming and computing, indicating a potential lack of interest or awareness among researchers and industry professionals.

The estimates collected in the literature are displayed in the table below.

Table 14 Estimates on social networking

Title	Author	Date	Estimates	Key information about estimates	Methodology used
The carbon impact of instagram app features[123]	Greenspector	2020	24 to 15.6 gCO_2eq	This describes one hour on social media from the most CO_2 consuming tothe least (Tik Tok to Youtube)	Direct measurement
The overlooked environmental footprint of increasing internet use[124]	Obringer et al	2021	0.025 kWh to 0.26 kWh	The study estimates the energy consumption of social media per hour	combinaiton of methods, literature review, data analysis, LCA, scenario analysis
What is the environmental footprint for social media applications ? 2021 Edition[125]	Greenspector	2021	69 gCO_2eq	This number refers the average carbon impact of the 10 applications measured	Hybrid approach: combination "bottom-up" approach and ''functional unit"[126]

[122] Ibid.

[123] Greenspector (2020). The carbon impact of Instagram app features https://greenspector.com/en/6168-2/

[124] Obringer et al (2012). The overlooked environmental footprint of increasing internet use https://www.researchgate.net/publication/348414802_The_overlooked_environmental_footprint_of_increasing_Internet_use#:~:text=Internet%20use%20has%20a%20carbon,et%20al.%2C%202021)%20.

[125] Greenspector (2021). What is the environmental footprint for social media applications ? 2021 Edition https://greenspector.com/en/social-media-2021/

[126] The functional unit methodology is a systematic approach used in LCA to define a reference unit that represents the functional performance of a product or process, allowing for comparative analysis of environmental impacts.

3.3.6. Write and send an email

The interest regarding the energy consumption associated with sending an email was sparked by the influential study from Ovo Energy, the UK-based energy supplier. The company famously stated that if *'every Brit sent one less thank you email a day; we would save 16,433 tonnes of carbon a year - the same as 81,152 flights to Madrid'*[127]. Berners-Lee also contributed to raising awareness about the topic, estimating that globally emails could account for as much as 150 million tonnes of CO_{2e} in 2019 or about 0.3% of the world's carbon footprint[128].

Still, a lot of the debates in the literature have centred on whether the energy consumption of sending an email is significant enough to warrant concern, given the increasing use of digital communication in modern society. Some argue that while the energy consumption of a single email may be small, it can add up quickly, given the billions of emails sent daily. Others point out that the energy consumption of email sending is still much lower than that of traditional mail, which requires paper production and transportation. And indeed, looking at the estimates collected in the literature review, all scholars found a number below 0.01 kWh. This indicates that emails have a really small energy consumption. Yet, when you look at the bigger picture, one year of unread email attachments is said to be equivalent to driving a car 1,093 miles per office worker [129]

Hence, many argue that reducing the number of emails sent and deleting the ones that can be deleted must become standard practice[130]. According to the ADEME/Arcep 2022 report, an excellent way to reduce the number of emails received can be unsubscribing to mailing lists as they are excessively energy-consuming and have many negative environmental impacts.

Additionally, the literature shows that users can directly reduce their energy consumption by limiting the size of their emails. In his book 'How bad are bananas?', Berners-lee explains that the easiest way to reduce this digital carbon footprint is to use document links instead of email attachments. The switch from attachments to links can reduce CO_2 emissions by an astonishing 92%, or from 50 g to 4 g of CO_2. Sending a short email with no attachment typically requires an energy consumption of around 0.0003 kWh, versus attaching a 1 MB file to an email can result in an energy consumption of around 0.019 kWh[131]. This gain is only for emails where the recipient is not interested in the attachment and does not click the download link. More details about the impact of different types of emails are displayed in Figure 9.

[127]Ovo energy (2019). Think Before You Thank' https://www.ovoenergy.com/ovo-newsroom/press-releases/2019/november/think-before-you-thank-if-every-brit-sent-one-less-thank-you-email-a-day-we-would-save-16433-tonnes-of-carbon-a-year-the-same-as-81152-flights-to-madrid

[128]Berners-Lee (2010, updated in 2020). How Bad are Bananas?: The Carbon Footprint of Everything https://books.google.be/books/about/How_Bad_are_Bananas.html?id=iWVG2Y8nVVwC&redir_esc=y

[129] CW Jobs The hidden cost of your emails on the planet https://www.cwjobs.co.uk/insights/environmental-impact-of-emails/#howMakeContainer

[130] Ovo energy (2019). Think Before You Thank' https://www.ovoenergy.com/ovo-newsroom/press-releases/2019/november/think-before-you-thank-if-every-brit-sent-one-less-thank-you-email-a-day-we-would-save-16433-tonnes-of-carbon-a-year-the-same-as-81152-flights-to-madrid

[131] Berners-Lee (2010, updated in 2020). How Bad are Bananas?: The Carbon Footprint of Everything https://books.google.be/books/about/How_Bad_are_Bananas.html?id=iWVG2Y8nVVwC&redir_esc=y

Figure 9 CO_2 emissions of different types of emails

Email Type	Emissions (CO2e)
Spam email picked up by your filters	0.03 g
Short email sent and received on a phone	0.2 g
Short email sent and received on a laptop	0.3 g
Long email that takes 10 minutes to write and 3 minutes to read sent and received on a laptop	17 g
Email blast that takes 10 minutes to write and sent to 100 people, of whom 1 reads it and the other 99 glance at it for 3 seconds to decide that they should ignore it	26 g

Source: https://carbonliteracy.com/the-carbon-cost-of-an-email/

The estimates collected in the literature are displayed in the table below.

Table 15 Estimates for sending an email

Title	Author	Date	Estimate	Relevant information about this estimate	Methodology used
LEAN ICTTOWARDS DIGITAL SOBRIETY[132]	The Shift Project	2019	0.0000001 KWh	This estimate refers to sending one generic email	Not a traditional LCA, comprehensive method
'Think Before You Thank': If every Brit sent one less thank you email a day, we would save 16,433 tonnes of carbon a year - the same as 81,152 flights to Madrid[133]	Ovo Energy	2019	0.00167 kWh	This refers to an average email.	LCA approach
How Bad are Bananas: The Carbon Footprint of Everything[134]	Mike Berners-lee	2010 (2020 revised)	0.019 kWh	This refers to an email with a 1 MB file attached	Not a traditional LCA[135]
			0.0003 kWh	This refers to an average email.	

[132] The Shift Project (2019). LEAN ICTTOWARDS DIGITAL SOBRIETY https://theshiftproject.org/wp-content/uploads/2019/03/Lean-ICT-Report_The-Shift-Project_2019.pdf

[133] Ovoenergy (2019). 'THINK BEFORE YOU THANK': if every brit sent one less thank you email a day, we would save 16,433 tonnes of carbon a year – the same as 81,152 flights to madrid https://company.ovo.com/think-before-you-thank-if-every-brit-sent-one-less-thank-you-email-a-day-we-would-save-16433-tonnes-of-carbon-a-year-the-same-as-81152-flights-to-madrid/

[134] Berners-lee (2010) Hpw bad are bananas? https://howbadarebananas.com/

[135] More simplified methodology that focused primarily on the energy consumption of the devices and infrastructure involved in email transmission

3.3.7. Download a file to a PC

To this date, only one paper on this digital behaviour was collected. It seems that most of the attention has focused on storing data in the cloud. More research is required to provide a satisfactory overview of this behaviour.

The estimates collected in the literature are displayed in the table below.

Table 16 Estimates on downloading a file

Name	Author	Date	Estimate	Relevant information about the estimate	Methodology
Energy Consumption of Photo Sharing in Online Social Networks[136]	Jalali et al.	2014	355 J (0.1 Wh) and 100 J (0.03 Wh).	This paper has estimated the total incremental energy consumption for uploading and downloading one average sized photo to and from Facebook including the end-user devices and transport network. The energy consumed for uploading and downloading the photo is 355 J (0.1 Wh) and 100 J (0.03 Wh).	Hybrid approach: combination of direct measurements and modelling techniques

3.3.8. Store data in the cloud for N years

The energy consumption of storing data in the cloud has also emerged as a significant concern for the energy consumption of the ICT sector. The amount of data stored in the cloud continues to grow and data centres that power the cloud require large amounts of energy to operate and maintain.

While a large proportion of the literature has highlighted the need for more energy-efficient data centre designs and renewable energy sources to power data centres, a growing proportion of literature started examining the potential for users to adopt more sustainable practices, such as reducing their reliance on cloud storage by using local storage devices or sharing data through peer-to-peer networks.

Regarding estimates, most papers found in the literature review have used different reference years and data to compute the energy associated with storing documents. Still, some argue that in a single year, the power consumption of a single cloud user can be anywhere between 60 kWh and 1,600 kWh[137]. This latest estimate would be the equivalent of running eight extra fridges in a home. For others, ingesting and storing 1Mb office

[136] Jalali et al (2014) Energy Consumption of Photo Sharing in Online Social Networks https://www.cesc.kth.se/polopoly_fs/1.647737.1600688828!/Energy%20Consumption%20os%20Photo%20Sharing%20in%20Online%20Social%20Ntwks%20CCGrid%202014.pdf

[137] ToffeeShare (2020) How much energy does it cost to store data online https://toffeeshare.com/blog/15/How-much-energy-does-it-cost-to-store-data-online/

documents for 1 year has a gross emission equivalent to driving a car for just over 500 miles[138]. Once files are ingested and not frequently accessed or reprocessed, the ongoing carbon cost of storing them is comparable to driving an additional 20 miles per year.

While these estimates are complicated to compare, they can be helpful to envisage a greener and more responsible use of the cloud. Among good practices, the IEEE has found that cloud-based applications consume up to 90 times more energy than local applications. Hence, they suggest that when online real-time collaboration is not required, it is more energy-efficient to do tasks locally and then save the final version to the cloud[139]. Greenly[140] adds that external hard drives still require power to function, but they require significantly less energy to write your files and store them onto the disk than cloud storage.

The estimates collected in the literature are displayed in the table below.

Table 17 Estimates on storing data for N years

Name	Author	Date	Estimate	Relevant information on the estimate	Methodology used
Quantified Carbon Footprint of Long-Term Digital Preservation in the Cloud[141]	Cloud carbon footprint	2022	140 – 63 kg of CO_2eq 5.5 – 2.2 kg of CO_2eq	This estimate refers to the CO_2 needed to ingest and store 1 million office files. 1 million office files stored for 1 year.	Modelling
Energy Consumption Comparison of InteractiveCloud-Based and Local Applications[142]	IEEE Journal On Selected Area in Communic Atio	2020	0,0139 kWh to 0,0183 kWh	This paper estimates the average power consumption **per user** to use Google Drive and Microsoft Skydrive to vary between 13.9 W and 18.3 W for the former, and between 14.7 W and 17.4 W for the latter (depending upon the access technology used). The power consumption is between 13.4 W to 15.4 W for offline file editing and saving in the Google Drive cloud	Power consumption model for inter-active
The Megawatts behind Your Megabytes: Going	ACEEE	2012	3 to 7 kWh	This estimates refers to the power needed to transmit and store 1 gigabyte of data	Modelling

[138]Addis (2022). Quantified Carbon Footprint of Long-Term Digital Preservation in the Cloud https://figshare.com/articles/preprint/Quantified_Carbon_Footprint_of_Long-Term_Digital_Preservation_in_the_Cloud/20653101

[139] Vishwanath et al. (2015). Energy Consumption of Interactive Cloud-Based and Local Applications IEEE Journal https://www.researchgate.net/publication/275156618_Energy_Consumption_of_Interactive_Cloud-Based_and_Local_Applications

[140] Greenly (2023). What is the Carbon Footprint of Data Storage? https://greenly.earth/en-us/blog/ecology-news/what-is-the-carbon-footprint-of-data-storage

[141] Cloud Carbon Footprint (2022). Quantified Carbon Footprint of Long-Term Digital Preservation in the Cloud https://www.dpconline.org/blog/blog-matthew-addis-carbon-footprint

[142]IEEE Journal (2015). Energy Consumption of Interactive Cloud-Based and Local Applications https://www.researchgate.net/publication/275156618_Energy_Consumption_of_Interactive_Cloud-Based_and_Local_Applications

from Data-Center to Desktop[143]					
Carbon and the Cloud[144]	Stanford Magazine	2017	0.2 tons of CO_2	This estimate refers to the energy used if one saves and store 100 gigabytes of data in the cloud during a year, enough space for several thousand photos or a few hours of videos. (based on the U.S. Grid's emission factor)	Not provided

3.3.9. Prolong the lifespan of a phone

Before presenting the findings of the literature review conducted on extending the lifespan of a phone, it is essential to note that it is the only considered digital behaviour where a priority was given to numbers and papers focusing on the whole environmental impact over the full life cycle rather than solely on the energy consumption in the use phase. This is because mobile phones are composed of a variety of materials, including metals, plastics, and chemicals, many of which require significant amounts of energy and resources for extraction and manufacturing. The production of new phones is a complex process which contributes to GHG emissions and other environmental impacts, such as water and air pollution. Considering only the energy consumption would minimise the environmental actual impact of such digital behaviour.

The present review indicates that expanding the lifespan of a phone is one of the most impactful actions to reduce their digital footprint. Indeed, while analysing other digital behaviours, it was observed that the largest part of the carbon footprint usually comes from the device. Such behaviours have been studied by European organisations and institutions extensively. This may be explained by the fact that the topic is closely related to the creation of a circular economy, one of the pillars of the European Green Deal. With this idea in mind, most studies also considered issues like refurnishing devices.

Regarding estimates, reports tend to provide the percentage of carbon savings one can make by extending the lifespan of a phone. Generally, whether it is the Greenspector[145], the EEA[146], the European Investment Bank[147], Green Alliance[148], the EESC, or the EIONET[149], researchers agree that extending a phone by one year can reduce its impact by one-third, up to 50% of its carbon footprint. Looking at the more prominent European scale, extending

[143] ACEEE (2012). The Megawatts behind Your Megabytes: Going from Data-Center to Desktop https://www.aceee.org/files/proceedings/2012/data/papers/0193-000409.pdf

[144] Stanford Managzine (2017) Carbon and the clound https://stanfordmag.org/contents/carbon-and-the-cloud

[145] Greenspector (2020). The Impact of playing a Canal + video study https://greenspector.com/en/impact-playing-canal-video/#resultats

[146] European Environment Agency (2020). Europe's consumption in a circular economy: the benefits of longer-lasting electronics https://www.eea.europa.eu/publications/europe2019s-consumption-in-a-circular/benefits-of-longer-lasting-electronics

[147]European Economic and Social Committee (2019). Identifying the impact of the circular economy on the Fast-Moving Consumer Goods Industry https://circulareconomy.europa.eu/platform/sites/default/files/impact_of_ce_on_fmcg_-_mobile_phones_case_study.pdf

[148]Green Alliance (2015). A circular economy for smart devices Opportunities in the US, UK and India https://www.circularonline.co.uk/wp-content/uploads/2015/02/A-circular-economy-for-smart-devices.pdf

[149] Eionet (2020) EEA Briefing, ETC/WMGE Report 3/2020: Electronics and obsolescence in a circular economy https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/electronics-and-obsolescence-in-a-circular-economy

the lifetime of all smartphones in the EU by 1 year would save 2.1 Mt CO_2 per year by 2030, the equivalent of taking over a million cars off the roads[150].

Again, scholars used very different assumptions to build their estimates. For instance, the ‘base year’ of the normal lifespan of a phone may be a topic of debate leading to variations in estimates.

The estimates collected in the literature are displayed in the table below.

Table 18 Estimates on extending the lifespan of a phone

Name	Author	Date	Estimate	Relevant information about the estimate	Methodology used
Electronic products and obsolescence in a circular economy[151]	EIONET report	2020	50% of impact saved	4.5 years extension	
Reducing the carbon footprint of ICT products through material efficiency strategies: A life cycle analysis of smartphones[152]	Cordella et al. 2021	2021	23/30% of the carbon footprint saved	2 to 3 years extension	LCA
A circular economy for smart devices Opportunities in the US, UK and India[153]	Green Alliance	2015	31% of carbon foorprint saved	1 year extension (baseline 1.81 years)	Modelling
			27% primary energy		
Coolproducts don't cost the earth[154]	EEB	2019	2.1 Mt CO_2	1 year extension	LCA (based on existing lit)
			4.3 Mt CO_2	3 years extension	
			5.5 Mt CO_2	5 years extension	
Identifying the impact of the circular economy on the Fast-Moving Consumer Goods Industry: opportunities and challenges for businesses, workers and consumers mobile phones as an example[155]	European Economic and Social Committee	2019	20.3 Mt of CO_2eq (29% saving)	1 year extension, from 21.6 months to 33.6 months over a 10-year period,	Modelling (scenario analysis)l
			30.5 Mt of CO_2eq (43% saved)	2 years extension, to 45.6 months, over a 10-year period, or 43% of the emissions associated with the baseline scenario	

[150] European Environmental Bureau (2019). Report Briefing COOLPRODUCTS DON'T COST THE EARTH https://eeb.org/wp-content/uploads/2019/09/Coolproducts-briefing.pdf

[151] Eionet (2020). ETC/WMGE Report 3/2020: Electronics and obsolescence in a circular economy https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/electronics-and-obsolescence-in-a-circular-economy

[152] Cordella et al (2021). Reducing the carbon footprint of ICT products through material efficiency strategies: A life cycle analysis of smartphones https://onlinelibrary.wiley.com/doi/10.1111/jiec.13119

[153] Green Alliance (2015) A circular economy for smart devices https://green-alliance.org.uk/publication/a-circular-economy-for-smart-devices/

[154] EEB (2019). Coolproducts don't cost the Earth – Briefing https://eeb.org/library/coolproducts-briefing/

[155] EESC (2019). Identifying the Impact of the Circular Economy on the Fast-Moving Consumer Goods (FMCG) industry: Opportunities and challenges for businesses, workers and consumers – mobile phones as an example https://www.eesc.europa.eu/en/our-work/publications-other-work/publications/identifying-impact-circular-economy-fast-moving-consumer-goods-fmcg-industry-opportunities-and-challenges-businesses

Europe’s consumption in a circular economy: the benefits of longer-lasting electronics[156]	EEA	2020	2.1 Mt of CO_2eq	1-year lifetime extension of all smartphones in Europe per year by 2030	Not provided

3.3.10. Switch off the Wi-Fi router

Since the French government advised in their Plan de Sobriete Energetique that turning off electronic devices such as Wi-Fi routers could save energy, the subject has received increased attention. According to a study by Green IT, an ADSL/ fiber consumes an average of 158 kWh of electricity per year and up to 300 kWh depending on the models. At a household scale, at home, the Wi-Fi router consumes more than some refrigerators (approximately 125 kWh per year for the most economical refrigerators[157]). Across Europe, it has been estimated that Wi-Fi routers mobilise the equivalent of 2 or 3 nuclear reactors[158].

Regarding energy savings, the major scientific contribution to the topic comes from ADEME’s study, which explained that if a household were to unplug its Wi-Fi connection every weekend, as well as during five weeks of vacation (139 days in total), the energy saving would thus be 37 kWh/year, or 0.8% of its annual consumption in electricity[159].

However, this measure is highlighy contested amongst the wider public. Non-scientific paper sources argue that switching off the Wi-Fi could negatively affect internet connectivity and overall network performance. Some argue that constantly turning routers on and off could cause wear and tear and shorten the device's lifespan. Others argue that it could cause connectivity issues or slow down internet speeds. Yet, to our knowledge, no primary telecommunication provider, nor scientific paper, has confirmed this hypothesis.

Instead, telecommunication providers are actively working on making Wi-Fi routers more energy efficient to reduce their carbon footprint. Pushed by EU regulation[160] that sets out a maximum limit on networked standby power, providers have started developing routers with advanced power-saving features, such as automatic sleep mode when not in use and scheduling options that allow users to turn off the router during non-peak hours[161]. In addition, providers have also proposed energy-saving options, such as enabling low-power mode or reducing the range of the Wi-Fi signal, which can significantly reduce energy consumption. Proximus, for instance, explained that while switching off the Wi-Fi router is the most energy-efficient solution, alternative solutions exist on certain routers such as the deep standby (eco standby) mode[162].

The estimates collected from the literature are displayed in the table below. It is important to note that while there are more papers focusing on the yearly energy consumption of Wi-

[156] EEA (2020). Europe’s consumption in a circular economy: the benefits of longer-lasting electronics https://www.eea.europa.eu/publications/europe2019s-consumption-in-a-circular

[157] GreenIT (2020). COVID19 : 4 gestes clés pour réduire mon empreinte numérique https://www.greenit.fr/2020/03/31/covid19-4-gestes-cles-reduire-empreinte-numerique-impacts-environnementaux-teletravail-video-en-ligne/

[158] Arcep (2019). Note n° 5 L’empreinte carbone du numérique https://www.arcep.fr/uploads/tx_gspublication/reseaux-du-futur-empreinte-carbone-numerique-juillet2019.pdf

[159] Ademe (2022). Électricité : combien consomment les appareils de la maison ?https://agirpourlatransition.ademe.fr/particuliers/maison/economies-denergie/electricite-combien-consomment-appareils-maison

[160] EUR-Lex - 02008R1275-20210301 - EN - EUR-Lex (europa.eu)

[161] “Off Mode, Standby and Networked Standby,” accessed May 1, 2023, https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/mode-standby-and-networked-standby-devices_en.

[162] Proximus (2022). Turn off your appliances or unplug them? We take a look at the different options! https://www.proximus.be/en/id_b_cr_energy_consumtion_tips/personal/blog/news/service/energy-consumption-tips.html

Fi routers, the table below strived to focus on papers that precisely present numbers focusing on the energy saving potential on switching off the router.

Table 19 Estimates on switching off a Wi-Fi router

Name	Author	Date	Estimate	Relevant information about the estimate	Methodology used
Électricité : combien consomment les appareils de la maison ?[163]	ADEME	2020	37 kWh	139 days off (off every weekend and during 5 weeks away from home holidays)	Direct measurement
			0.012 kWh	one hour of use	
Panel usages electrodomestiques[164]	ADEME	2021	97 kWh	Yearly consumption of a Wi-Fi router.	Direct measurement

3.4. Forward looking estimates and technological uncertainties

Digital services are highly dependent and widely impacted by the development and uptake of new technologies such as 5G, Artificial Intelligence, Edge Computing, IoT or Blockchain. This section aims to discuss the expected impacts on the energy consumption of the ICT sector resulting from the uptake and development of those technologies.

The first technology analysed is **5G, the fifth generation of cellular networks** that provides faster connectivity (up to 100 times faster than the previous generation, 4G)[165].

The effect of 5G development on the overall energy consumption of the ICT sector is subject to discussions and diverging views in the literature, with two main schools of thought[166]. Indeed, if most parties agree that the energy consumed per bit for a given data rate will decrease with 5G[167,168] when compared to 4G and previous generations, the overall impact of the 5G on the ICT sector energy consumption is approached differently by different authors.

Some highlight that no net increase in energy consumption is to be expected thanks to the significant estimated energy savings resulting from the improved energy efficiency of 5G (position mostly defended by industry players, as explained in GSMA's 2021 paper[169]). This energy consumption per bit for a given data rate is significantly reduced compared to previous generations, with numbers found in the literature including an energy efficiency

[163] Ademe (2022). Électricité : combien consomment les appareils de la maison ?https://agirpourlatransition.ademe.fr/particuliers/maison/economies-denergie/electricite-combien-consomment-appareils-maison

[164] Ademe (2021). Panel electrodomestique

[165] https://www.ericsson.com/en/5g#:~:text=Up%20to%20100%20times%20faster,day%2Dto%2Dday%20experiences.

[166] GSMA Future Networks (2019). Energy Efficiency: An Overview. https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/

[167] Ellis, D. (2021). 5G 'inherently more energy consuming' than 4G. Energy Magazine. https://energydigital.com/technology-and-ai/5g-inherently-more-energy-consuming-4g

[168] UK Parliament Post (2022). Energy Consumption of the ICT. https://researchbriefings.files.parliament.uk/documents/POST-PN-0677/POST-PN-0677.pdf

[169] GSMA Future Networks (2019). Energy Efficiency: An Overview. https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/

increase from 1000 mW/Mbps/s to 10 mW/Mbps/s in the future[170, 171], or a decrease of 20-fold by 2030, with an estimated consumption of 37kWh/GB for 2G, 2.9kWh/GB for 3G, 0.6kWh/GB for 4G and 0.06kWh/GB for 5G.[172] In addition, 5G technology has the potential to reduce energy consumption in ICT sector by enabling the development of more efficient and flexible networks and enabling many energy-eficient functions such as network slicing, network function virtualization, massive machine type communications and edge computing. In a 2022 study[173], the French government highlighted that the energy efficiency of 5G networks depends highly on the density of an area. The expected energy efficiency gains in high-density areas could amount to a 10-fold reduction when compared to 4G and a 50-fold reduction when compared to 3G. Regarding the energy efficiency improvement from one generation to another, MTN Consulting[174] has attempted to estimate the energy consumption variation of base stations depending on the combination of 5G with legacy networks. Indeed, networks do not yet operate on their own and different technology generations are often combined. According to the study, the adotion of 5G technology could lead to a reduction in base station energy ranging from 30.1% to 39.9%, depending on the network's initial technologies (2G, 3G, 4G or a combination of those technologies) and whether those legacy technologies are decommissioned or not once the upgrade to 5G has been realised

On the other hand, some authors highlight that the uptake of 5G may go hand in hand with an increase in data traffic[175], expected for example to grow by a factor of up to 1,000[176], resulting in an overall energy consumption increase by a factor of 2 to 3 compared to previous technologies[177]. This potential increase is due to the increase in the number of base stations, retail and office space and the maintenance of the 5G networks on top of legacy technologies.[178] Another study[179] anticipates a 37% increase in overall energy consumption by 2030 related to the deployment and widescale adoption of IoT and 5G-enabled technologies. In addition, a French study estimated that the primary energy consumption of networks in the country may rise from 11,1 TWh in 2019, to 13,3TWh in 2025 and 19,4 TWh

[170] European Telecommunications Standards Institute (ETSI). ETSI TR 103 542 V1.1.1 (2018-06): "Environmental Engineering (EE): Study on Methods and Metrics to Evaluate Energy Efficiency for Future 5G Systems"; European Telecommunications Standards Institute: Sophia-Antipolis, France, 2018.

[171] Cisco (2020). Cisco Annual Internet Report (2018-2023). White Paper. https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html

[172] Fédération Française des Télécoms (2020). Les Télécoms : premiers acteurs du numérique. Étude économique 2020. https://www.fftelecoms.org/app/uploads/2020/12/etude-economie-2020-fftelecoms-1.pdf

[173] French Government (2022). Plan de sobriété énergétique. dp-plan-sobriete.pdf (ecologie.gouv.fr)

[174] MTN Consulting (2022). Quantifying the energy cost saving from 2G/3G network shutdowns. https://www.mtn-c.com/quantifying-the-energy-cost-savings-from-2g-3g-network-shutdowns/

[175] Freitag et al. (2020). The climate impact of ICT: A review of estimates, trends and regulations. https://arxiv.org/ftp/arxiv/papers/2102/2102.02622.pdf

[176] Chochliouros, I.P.; Kourtis, M.-A.; Spiliopoulou, A.S.; Lazaridis, P.; Zaharis, Z.; Zarakovitis, C.; Kourtis, A.(2021). Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures. Energies. https://doi.org/10.3390/en14175392

[177] GSMA (2019) **https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/** cited in Chochliouros, I.P.; Kourtis, M.-A.; Spiliopoulou, A.S.; Lazaridis, P.; Zaharis, Z.; Zarakovitis, C.; Kourtis, A.(2021). Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures. Energies. https://doi.org/10.3390/en14175392

[178]GSMA (2019) **https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/** cited in Chochliouros, I.P.; Kourtis, M.-A.; Spiliopoulou, A.S.; Lazaridis, P.; Zaharis, Z.; Zarakovitis, C.; Kourtis, A.(2021). Energy Efficiency Concerns and Trends in Future 5G Network Infrastructures. Energies. https://doi.org/10.3390/en14175392

[179] Data centre Forum (2021). 5G will prompt energy consumption to grow by staggering 160% in 10 years. https://www.datacenter-forum.com/datacenter-forum/5g-will-prompt-energy-consumption-to-grow-by-staggering-160-in-10-years

in 2040, due to the increase of data traffic, that according to that study will fail to be offset by the energy efficiency gains allowed by the 5G technology.[180]

Overall, it was found that there is a gap in the literature for a publicly available, transparent and comprehensive assessment of the impact of the roll out of 5G, including its rebound effects and its impact on customer behaviour.[181, 182, 183]

Highly dependant on the 5G roll out, the impact of the development of **the Internet of Things** should also be considered. The IoT refers to the "*objects with computing devices in them that are able to connect to each other and exchange data using the internet*".[184] The Internet of Things has the potential to significantly impact the energy consumption of the ICT sector[185]. On the one hand, IoT devices can help optimise energy consumption in various applications, from smart homes to industrial systems. On the other hand, the steep adoption curve of IoT devices can also lead to an increase in energy consumption of the ICT sector as a whole. Indeed, it has been estimated by Freitag et al.[186] that the increase in connected devices and the associated data traffic could lead to an increase in energy consumption.

The third technology that was investigated as part of the present study is **Artificial Intelligence**, meaning the leverage of *"computers and machines to mimic the problem-solving and decision-making capabilities of the human mind".*[187] If artificial intelligence is recognised as a crucial potential enabler for a lower carbon future and an improved energy efficiency in numerous industries[188], its own impact on the energy consumption of the ICT sector is often overlooked. Indeed, AI requires significant computational resources and there is no doubt that the uptake of AI is a driver of the growth in data processing and storage, which may lead to an increase in the overall ICT sector consumption.[189, 190] However, the increased energy consumption of the ICT sector attributable to AI is dependent on numerous factors, including the 5G network energy efficiency[191]. Therefore, it is challenging to estimate so far and literature currently lacks estimates of AI's rebound effect on energy consumption[192].

[180] Sénat (2020). Rapport d'information fait au nom de la commission de l'aménagement du territoire et du développement durable par la mission d'information sur l'empreinte environnementale du numérique. r19-5551.pdf (senat.fr)

[181] https://www.sciencedirect.com/science/article/pii/S1364032121012958Foxon, T.J., Sovacool, B.J., Williams, L. (2021). The energy use implications of 5G: Reviewing whole network operational energy, embodied energy, and indirect effects. https://doi.org/10.1016/j.rser.2021.112033

[182] GSMA Future Networks (2019). Energy Efficiency: An Overview. https://www.gsma.com/futurenetworks/wiki/energy-efficiency-2/

[183] Williams, Laurence and Sovacool, Benjamin K. and Foxon, Timothy J., The energy use implications of 5G: Reviewing whole network operational energy, embodied energy, and indirect effects (January 13, 2022). Renewable and Sustainable Energy Reviews 157 (2022) 112033, Available at SSRN: https://ssrn.com/abstract=4008530

[184] THE INTERNET OF THINGS - Cambridge English Dictionary

[185] 6GWorld (2021). Sustainability in New and Emerging Technologies. https://www.6gworld.com/sustainability-in-new-and-emerging-technologies/

[186] Freitag et al. (2021). The real climate and transformative impact of ICT: a critique of estimates, trends, and regulations. https://www.sciencedirect.com/science/article/pii/S2666389921001884

[187] What is Artificial Intelligence (AI) ? | IBM

[188] Freitag et al. (2021). The real climate and transformative impact of ICT: a critique of estimates, trends, and regulations. https://www.sciencedirect.com/science/article/pii/S2666389921001884

[189] ibid

[190] Gailhofer et al. (2021). The role of Artificial Intelligence in the European Green Deal. European Parliament. https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662906/IPOL_STU(2021)662906_EN.pdf

[191] Gailhofer et al. (2021). The role of Artificial Intelligence in the European Green Deal. European Parliament. https://www.europarl.europa.eu/RegData/etudes/STUD/2021/662906/IPOL_STU(2021)662906_EN.pdf

[192] ibid

The fourth technological trend is **edge computing**, which refers to the "*processing of data closer to where it is being generated, enabling processing at greater speeds and volumes*".[193] The concept of edge computing essentially allows to reduce the amount of data being transferred on the network, which represents in some cases a large part of the energy consumption of ICT[194, 195] (e.g. for Youtube video services).[196] One of the main contributors to the energy consumption of the ICT sector are data centers. Some authors argue that if all data centers have significant energy consumption, edge data centers could be more efficient than cloud data centers. One of the main differences could be that cloud data centers often need to run 24/7, while the high variation of use for edge data centers might lead to a design made to be more efficient (i.e. by adding a "dormant" mode to the resources)[197]. On the other hand, literature also highlights that large-scale data tend to be more energy efficient than smaller ones due to better optimisation of the systems (including cooling).[198]

Finally, another technological trend that was deemed relevant to include is **blockchain**, which can be defined as "*a shared, immutable ledger that facilitates the process of recording transactions and tracking assets in a business network*".[199] The energy impact of blockchain is a controversial topic and depends mosty on the computing power required to validate a transaction on the network. Currently, blockchain is mostly known for its use in relation to cryptocurrencies and most precisely the Bitcoin. According to the Cambridge Bitcoin Electricity Consumption Index, the annual power demand for Bitcoin alone in the period going from March 2022 to March 2023 amounted to 124.40 TWh.[200] However, it is essential to note that Bitcoin is not the sole usage of blockchain and that the energy consumption of a blockchain protocol depends on its consensus mechanism and the number of its users.[201] If Bitcoin's energy consumption is commonly known as being consequent, as for other cryptocurrencies based on the Proof-of-Work, it should not be generalised to the assessment of the energy consumption of all blockchain technologies or even cryptocurrencies. Indeed, some literature highlights that a majority of cryptocurrencies have adopted different consensus mechanisms that are less energy-intensive[202,203]. That is for example the case of the Ethereum that switched from a proof-of-work to a proof of stake consensus mechanism, which led its energy consumption to reduce by more than 99.98%[204].

193 Flower,D. (2022). How Machine Learning and Edge Computing Power Sustainability. Forbes. https://www.accenture.com/us-en/insights/cloud/edge-computing-index

194 ibid

195 Mocnej et al. (2018). Impact of Edge Computing Paradigm on Energy Consumption in IoT. Elsevier. https://www.sciencedirect.com/science/article/pii/S2405896318308917

196 STL Partners (2020). Edge computing: Changing the balance of energy in networks. https://stlpartners.com/articles/edge-computing/edge-computing-changing-the-balance-of-energy-in-networks/

197 Ibid

198 Stackscale (2022). Energy efficiency measures in large-scale data centers. https://www.stackscale.com/blog/energy-efficiency-measures-data-centers/#Energy_efficiency_measures_in_large-scale_data_centers

199 What is Blockchain Technology? - IBM Blockchain | IBM

200 Cambridge Bitcoin Electricity Consumption Index (CBECI) (ccaf.io)

201 ADAN (2021). Blockchain protocols and their footprint. https://www.adan.eu/en/publication/blockchain-protocols-and-their-energy-footprint/#:~:text=The%20annual%20energy%20consumption%20of,not%20reflect%20its%20environmental%20footprint

202 Ibid

203 Huestis, S. (2023). Cryptocurrency's Energy Consumption Problem. RMI. https://rmi.org/cryptocurrencys-energy-consumption-problem/#:~:text=Bitcoin%20alone%20is%20estimated%20to,fuel%20used%20by%20US%20railroads.

204 https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/pos-vs-pow/

4. Quantified estimates of the energy consumption of day-to-day digital behaviours

In this chapter, we present the findings from the life cycle assessment performed to produce estimates relating to the energy consumption of day-to-day digital actions and services. The results from this LCA will be disseminated by the European Commission through various channels of communication.

Below is the list of the 10 day-to-day digital behaviours studied.

Table 20 List of the 10 day-to-day digital behaviours

List of 10 day-to-day digital behaviours	
	Video streaming
	Video gaming
	Video conferencing
	Music streaming
	Social networking
	Write and send an email
	Download a file to a PC
	Store data in the cloud fo N year(s)
	Prolong the lifespan of a phone
	Switch off the Wi-Fi router

Before jumping to the results, here are some general definitions and notions that will help the reader throughout the text.

Average European end-user device: for each of the behaviours we have modeled the preferred device that Europeans use to perform a specific behaviour.

Table 21 Average European Network

Average European network: We have modeled the average network in Europe consisting of mobile and fixed network. It is the same one for the 10 behaviours. It is modeled below.

Network European mix	Unit	Value

xDSL	%	72.57
FTTx	%	18.14
2G	%	0.56
3G	%	0.81
4G	%	7.60
5G	%	0.32
Note: These percentages were taken from GSMA[205] and Etno[206].		

Number of subscribers

The number of subscribers is a parameter that is used to quantity the impact of the network (see Section 8.2). For the case of mobile networks, we consider an average of 1000 subscribers per radio unit[207]. In the case of fixed networks, we consider an average of 2.2 persons per household/line[208].

Average Data centre: The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its energy consumption.

Video / Audio Quality

For most of the behaviours, a video or audio quality has been selected. This corresponds to the amount of data that is transferred per second throught the network to perform the behaviour. The different tables with the different “quality values” are listed in Section 7.2.4

Before reading: the results you will find for the following behaviours have been averaged for the european population. They do not correspond to the consumption of a single individual but represent an estimate of the european panorama normalized for one user.

Therefore, the environmental impacts associated to someone who changes its smartphone every year are different from someone who has used the same smartphone for the past 6 year. In addition, two users performing the same behaviour in different countries will have a different environmental impact as the associated electricity mix is different. These variations have not been accounted in this study.

[205] “The Mobile Economy 2023,” n.d.

[206] ETNO. "Fixed and mobile data usage in Europe and selected countries (in gigabytes per capita per month)." Chart. January 28, 2020. Statista. Accessed April 09, 2023. https://www-statista-com.budistant.univ-nantes.fr/statistics/1180156/fixed-mobile-data-usage-gigabytes/

[207] “Proceedings_EGG2020_v2.Pdf,” accessed April 30, 2023, https://online.electronicsgoesgreen.org/wp-content/uploads/2020/10/Proceedings_EGG2020_v2.pdf.

[208] “Household Composition Statistics,” accessed April 30, 2023, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Household_composition_statistics.

4.1. Video streaming

4.1.1. Scope definition

This section is aimed at specifying the scope of the analysis performed on video streaming. This LCA studies the energy consumption and environmental impact of **video streaming** under different scenarios:

- **Smartphone** scenario: watching video streaming with a smartphone, a Wi-fi connection at low resolution.
- **TV** scenario: watching video streaming with a TV and a 4G connection at high resolution.
- **European** scenario: watching video streaming considering an average european end-user device and a european network at a medium resolution.

The chosen **functional unit** that was used to compare the scenarios is the following:

"Watching 1h of video streaming in Europe in 2023"

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

Technological boundaries: all three "tiers" (see 2.3.4) have been included to model this behaviour. Users / Network / Data Centres
Temporal boundaries: secondary data from literature is from 2019 to 2023.
Geographical boundaries: secondary data from literature represents the Europe Region.

4.1.2. Life Cycle Inventory

Three scenarios are being modeled for this behaviour. Table *22* shows the input data flows used to estimate the impacts of video streaming.

Table 22 Input data flows for video streaming

Input Data Flows		Scenario 1	Scenario 2	Scenario 3
Overall parameters	Time spent watching	1h	1h	1h
End user environment	Connected Speaker			
	Equipment used	Smartphone	TV	European Device

Network	Video Quality[209]	Mobile Low (0,37 Mbps)	4K (15,6 Mbps)	Medium (1,6 Mbps)
	Type of Network	xDSL	4G	European Network
	Network Saturation	100%	100%	100%
	Number of subscribers[210]	2,2	1000	
Data centre	Equipment used	Average Data centre	Average Data centre	Average Data centre
	kWh/h[211]	7,49E-03	7,49E-03	7,49E-03

Video Streaming – Tier 1

Users

Below we have modeled the **Average European device** used to perform this behaviour. It is defined as the average of the **share of terminals** used to perform this behaviour in Europe in Table 23.

EU

Table 23 Share of terminals used for video streaming in Europe

Device preferences for video streaming in Europe by type	Unit	Value
Desktop	%	6.19
Laptop	%	6.19
Tablet	%	8.25
Smartphone	%	64.95
TV	%	14.43

Note:These percentages were taken from Netflix and YouTube user's preference[212].

The impacts on the end-user environment equipment (smartphones, laptop, connected speaker, etc.) for the fabrication, transport, and end of life phases are calculated with a temporal allocation (see section 8.1). The impacts of the **use phase** are also modeled with a temporal allocation and are defined in section 7.1.8 .

[209] See Section 4 for more information on the Data Quality

[210] See Section 4, after Table 21 for more information on the number of subscribers

[211] See Tier 3 section of Video Streaming for more information

[212] Plum Research. "Number of unique viewers of TV shows on Netflix in Germany in January 2023, by device (in millions)." Chart. January 31, 2023. Statista. Accessed April 07, 2023. https://www-statista-com.budistant.univ-nantes.fr/statistics/1314347/devices-netflix-tv-shows-germany/?locale=en

eMarketer. "Distribution of worldwide YouTube viewing time as of 2nd quarter 2021, by device." Chart. September 8, 2021. Statista. Accessed April 07, 2023. https://www-statista-com.budistant.univ-nantes.fr/statistics/1173543/youtube-viewing-time-share-device/

Digital TV Research. "Number of Netflix subscribers in Western Europe from 2015 to 2027 (in millions)." Chart. September 30, 2022. Statista. Accessed April 07, 2023. https://www-statista-com.budistant.univ-nantes.fr/statistics/671557/netflix-subscribers-in-western-europe/?locale=en

https://blog.youtube/news-and-events/you-know-whats-cool-billion-hours/

Video Streaming – Tier 2

Network

The Average European network used is defined in Table 21. The impacts on the network (fixed and mobile) for the fabrication, transport, use, and end of life phases are calculated with the allocation defined with the PCR (see section 7.2).

Video Streaming – Tier 3

Data Centres

The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its consumption.

We have estimated its electricity consumption using Netflix's[213] annual electricity consumption.

Table 24 Netflix consumption information

Netflix parameters	Unit	Value
Number of users	#	167 000 000
Number of video hours watched per year	Billions h	60[214]
Total direct electricity consumed per year	MWh	94 000
Total indirect electricity consumed per year	MWh	357 000
Corresponding power use of video streaming	kW	7,49E-03

⚠ **Model:** The source to model the impact of Tier 3 comes from a single company. This is a limitation as we are only relying on information of a company whose services we are trying to model.

4.1.3. Results

It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

Electricity consumption

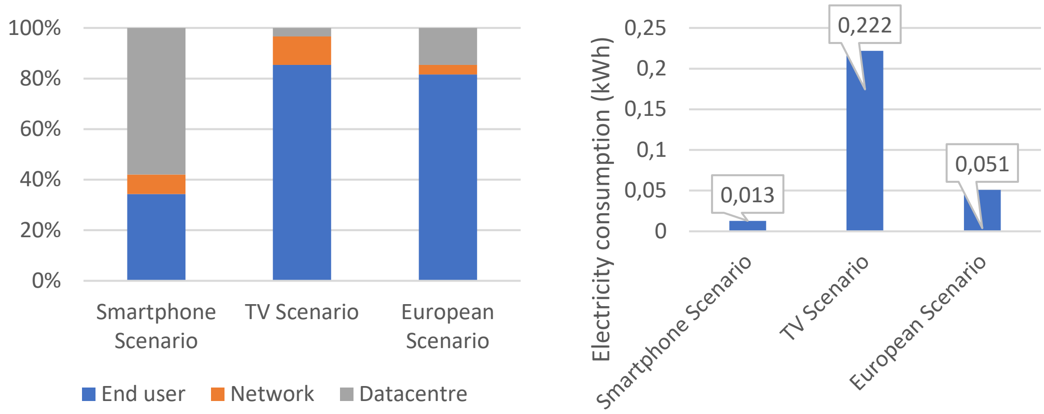
The figure below summarises the estimated electricity consumption of 1 hour of video streaming in the three considered scenarios:

[213] Netflix Environmental Social Governance Report - Sustainability Accounting Standards Board (SASB), 2019

[214] Note: We have estimated that an average user watches 2h of Netflix per day.

- Smartphone scenario: watching video streaming a smartphone, a Wi-Fi connection at low resolution.
- TV scenario: watching video streaming with a TV, a 4G connection at high resolution.
- European scenario: watching video streaming an average european end-user device and a european network at a medium resolution.

Figure 10 Electricity consumption of 1h of video streaming per tier / per scenario



Large energy consumption devices (TV, desktops) accounts for most of the energy consumption. When using less energy-intensive devices, data centres accounts for an important part of the impact. In the smartphone scenario, the Tier 3 infrastructure accounts for almost 60% of the consumption. Fixed networks consume much less than mobile networks. Because video streaming is mostly performed on smartphones, the European scenario is much smaller than the TV scenario. On average, in Europe, 1h of video streaming (using our model) requires 0.051 kWh.

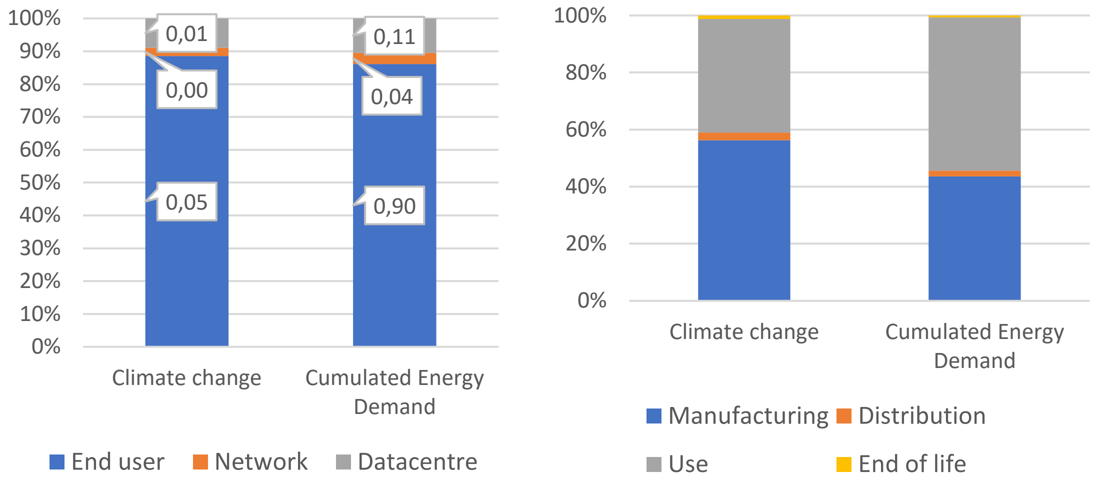
Below are listed good practices to reduce the energy consumption (in order of priority).

- Try to use smaller devices
- When possible, use fixed network
- Try to decrease the resolution of the video

Energy and Global Warming Potential

Below we have calculated the environmental impact of this behaviour following the PEF 3.0 norms described before. In this case the results are showed in terms of Global Warming Potential (GWP), expressed in kgCO_2eq, and Cumulative Energy Demand (CED), expressed in MJ.

Figure 11 Environmental impact of video streaming for an average European by tier / per life cycle phase



The total equivalent CO_2 emissions related to the energy consumption of 1h of video steaming in Europe account for 56 gCO_2eq. In terms of CED, the impact rises to 1.04 MJ. To put these numbers in perspective, this is equivalent to:

- Driving 0.59 km in a car[215], assuming 95 gCO_2/km as the European fleet-wide target for 2021

As we can see from Figure 11; most of the impact comes from the Tier 1 (end-user). This is coherent with the results on the energy consumption. With regards to the energy indicator (Cumulative Energy Demand), it is also interesting to see that a large part of the environmental impact (Climate Change and Cumulative Energy Demand) comes from the “use” phase; that is actually performing the behaviour. As is the case in the ICT sector, a significant amount of the impact stems from the manufacturing of the equipment (Manufacturing phase) needed to perform the behaviour. This means that when we perform the behaviour, around 50% of the energy involved is related to performing the behaviour while the rest relates to the energy used to build the proportion of the material (smartphone, computer) needed to perform the behaviour.

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators. Figure 12 shows that most of the impact of the behaviour comes from the end-user device (Tier 1). Table 25 and To stay within the planetary boundaries, we should not exceed the 100% threshold per day. Engaging in 1 hour of video streaming per day already consumes 2.38% of our CO2 eq. budget and 3.66% of our mineral and metal resources budget. This means that we need to carefully allocate the rest of our budget to account for additional consumption in the ICT sector, as well as food, shelter, clothing, and transportation.

Table 27 provide the figures to support the choosen indicators.

Below are listed additional good practices to reduce the behaviour environmental footprint.

	• Prolong the lifespan of your equipments

[215] “CO2 Performance of New Passenger Cars in Europe,” accessed April 10, 2023, https://www.eea.europa.eu/ims/co2-performance-of-new-passenger.

- Reduce your daily video streaming usage

Figure 12 Environmental impact of video streaming per indicator and tier

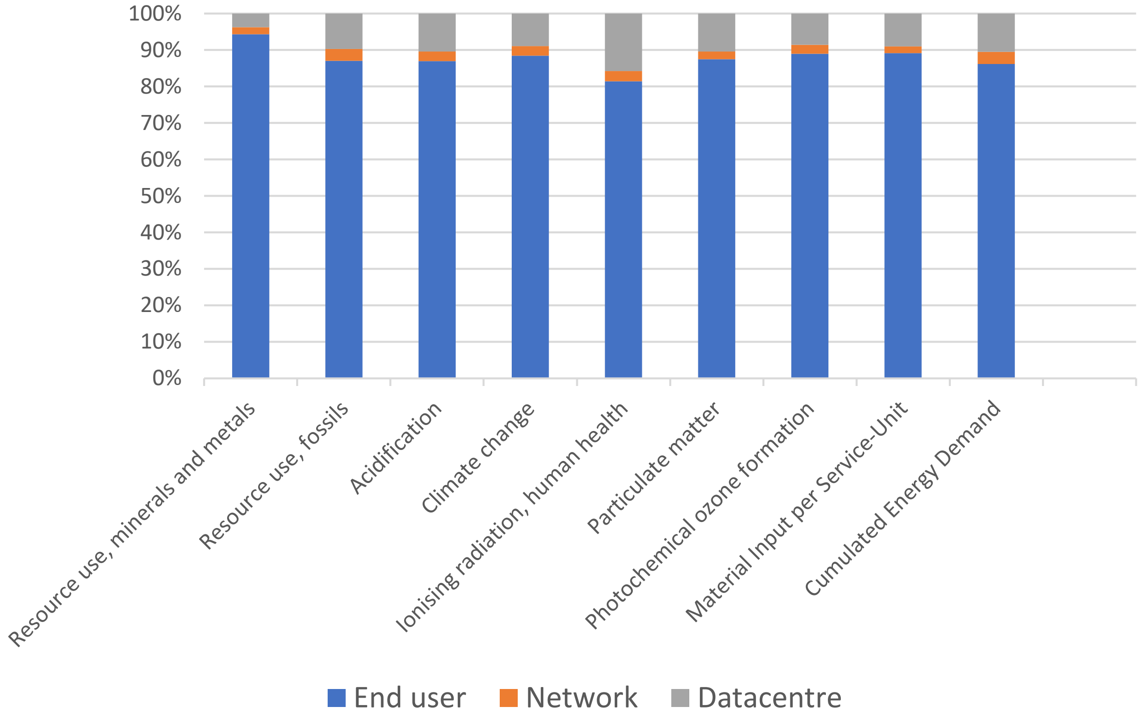


Table 25 Environmental impact of video streaming

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO_2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	2,6E-06	8,1E-01	3,0E-04	5,0E-02	5,3E-02	1,4E-09	1,3E-04
Network	5,1E-08	2,4E-02	7,5E-06	1,2E-03	1,6E-03	3,0E-11	2,9E-06
Data centre	1,0E-07	9,0E-02	3,7E-05	5,0E-03	1,0E-02	1,7E-10	1,2E-05
Total	2,8E-06	9,2E-01	3,5E-04	5,6E-02	6,5E-02	1,6E-09	1,4E-04
Associated planetary boundary per capita per day	7,55E-05	7,7E+01	3,45E-01	2,35E+00	1,82E+02	1,78E-07	1,40E-01

Table 26 Percentage associated to the planetary boundaries per capita per day for 1h of video streaming

	Resource use, minerals and	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO_2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)

	metals (kg SB eq.)						
	3,66%	1,19%	0,10%	2,38%	0,04%	0,92%	0,10%

To stay within the planetary boundaries, we should not exceed the 100% threshold per day. Engaging in 1 hour of video streaming per day already consumes 2.38% of our CO2 eq. budget and 3.66% of our mineral and metal resources budget. This means that we need to carefully allocate the rest of our budget to account for additional consumption in the ICT sector, as well as food, shelter, clothing, and transportation.

Table 27 other indicators on the impact of video streaming

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	1,5E-01	9,0E-01
Network	3,0E-03	2,8E-02
Data centre	1,5E-02	1,1E-01
Total	1,7E-01	1,0E+00

4.1.4. Conclusion

The environmental footprint of 1h of video streaming has been calculated following three different sscenarios to be able to cover different behaviours.

The study shows the importance of the contribution of the devices we use on a daily basis and its correlation to the consumption of the behaviour. The larger the device is, the more energy it generaly consumes to perform a certain behaviour. This is one of the first studies that has been conducted following the PCR Internet Service Provision guidelines from ADEME and results indicate that mobile networks have overall a larger impact than fixed networks. This is reassuring as it follows the trend observed in the literature. On the impact of service providers, our estimate is in the same range of other results found in the literature. However, this evaluation comprises several limits that are necessary to be communicated:

- The temporal allocation used to model the consumption of an end-user device does not take into account the fact that other applications might be running at the same time. As an example, if someone is watching video streaming at the same time that the user is surfing on social media or texting someone, an additional allocation related to the CPU, GPU, memory, usage should be incorporated.
- The temporal allocation used to model the consumption of an end-user device does not take into account the quality of the data. The consumption of the end-user device remains the same if the user is streaming at HD or at 360p.It however has an impact on the energy consumption of the network.
- The general model for data centres and the assumptions made about the proportionality between the amount of data and their electricity consumption do not take into account the different infrastructures behind different service providers. In addition, the data centre impact modeling only relies on the information of the service provider we are trying to model.

4.2. Video gaming

4.2.1. Scope definition

This section is aimed at specifying the scope of the analysis performed online gaming. This LCA studies the energy consumption and environmental impact of **online gaming** under different scenarios:

- **Desktop** scenario: playing 1h of online gaming with a desktop, a fixed network at medium resolution.
- **Laptop** scenario: playing 1h of online gaming with a laptop, a fixed network at medium resolution. .
- **European** scenario: playing 1h of online gaming with an average european device, a european network at medium resolution.

The chosen **functional unit** that was used to compare the scenarios is the following:

" 1h of online gaming in Europe"

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

	Technological boundaries: all three "tiers" (see 2.3.4) have been included to model this behaviour. 
	Temporal boundaries: secondary data from literature is from 2019 to 2023.
	Geographical boundaries: secondary data from literature represents the Europe Region.

4.2.2. Life Cycle Inventory

Three scenarios are being modeled for this behaviour. Table 28 shows the input data flows used to estimate the impacts of online gaming.

Table 28 Input data flows for online gaming

Input Data Flows		Scenario 1	Scenario 2	Scenario 3
Overall parameters	Time spent playing	1h	1h	1h
End user environment	Connected Speaker			
	Equipment used	Desktop	Laptop	European Device

Network	Video Quality[216]	Medium (1,56 Mbps)	Medium (1,56 Mbps)	Medium (1,56 Mbps)
	Type of Network	xDSL	xDSL	European Network
	Network Saturation	100%	100%	100%
	Number of subscribers[217]	1 000	2,2	
Data centre	Equipment used	Average Data centre	Average Data centre	Average Data centre
	kW[218]	9,94E-04	9,94E-04	9,94E-04

Online gaming – Tier 1

Users

Below we have modeled the **Average European device** used to perform this behaviour. It is defined as the average of the **share of terminals** used to perform this behaviour in Europe in **Table 29**.

EU

Table 29 Share of terminals used for online gaming in Europe

Device preferences for online gaming in Europe by type	Unit	Value
Desktop	%	13.01%
Laptop	%	13.01%
Tablet	%	13.01%
Smartphone	%	11.30%
TV	%	45.34%

Note:These percentages were taken from DataReportal[219]. .

The impacts on the end-user environment equipment (smartphones, laptop, connected speaker, etc.) for the fabrication, transport, and end of life phases are calculated with a temporal allocation (see section 8.1). The impacts of the **use phase** are also modeled with a temporal allocation and are defined in section 7.1.8.

Online gaming – Tier 2

Network

The Average European network used is defined in **Table 21**. The impacts on the network (fixed and mobile) for the fabrication, transport, use, and end of life

[216] See Section 4 for more information on the Data Quality

[217] See Section 4, after Table 21 for more information on the number of subscribers

[218] See Tier 3 section of Online gaming for more information

[219] DataReportal, und We Are Social, und Meltwater. "Share of internet users worldwide playing games on selected devices as of 3rd quarter 2022." Chart. January 26, 2023. Statista. Accessed April 10, 2023. https://www-statista-com.budistant.univ-nantes.fr/statistics/533047/leading-devices-play-games/?locale=en

phases are calculated with the allocation defined with the PCR (see section 7.2).

Online gaming – Tier 3

Data Centres

The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its consumption.

We have used the factor 9,94E-04 kWh/hour[220] as the estimate to model the Tier 3 impacts.

4.2.3. Results

It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

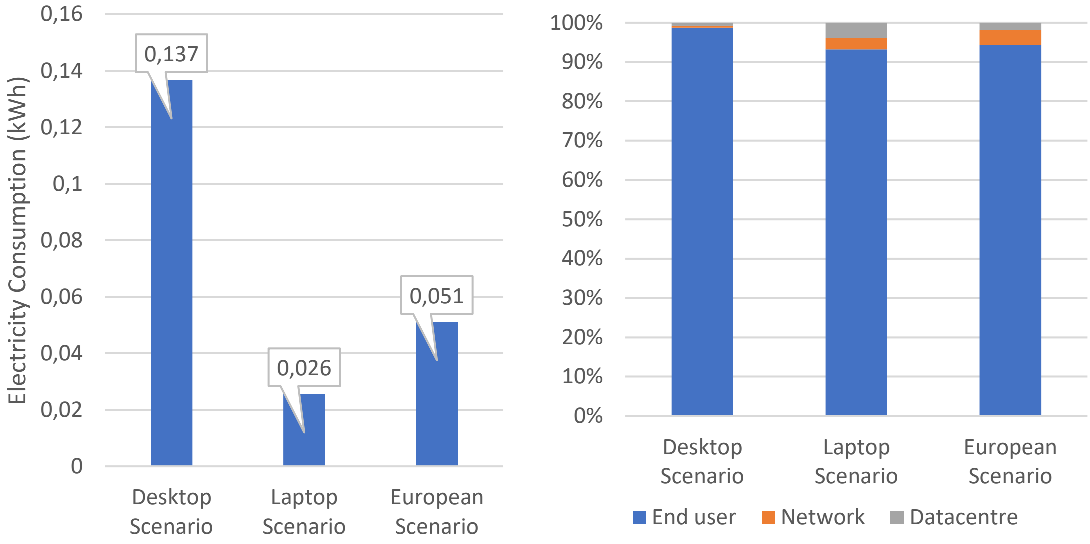
Electricity consumption

The figure below summarises the estimated electricity consumption of 1 hour of online gaming in the three considered scenarios:

	• **Desktop** scenario: playing 1h of online gaming with a desktop, a fixed network at medium resolution.
	• **Laptop** scenario: playing 1h of online gaming with a laptop, a fixed network at medium resolution.
	• **European** scenario: playing 1h of online gaming with an average european device, a european network at medium resolution.

[220] This impact comes from the Resilio Database, modeled after working from different actors from the video games industry

Figure 13 Electricity consumption of 1h of online gaming per tier / per scenario



Most online gaming is performed using smartphones, laptops, and desktops. Therefore, the European scenario has a bigger impact that the laptop scenario. As expected, playing online gaming with a desktop and a computer monitor consumes more power than with a laptop.

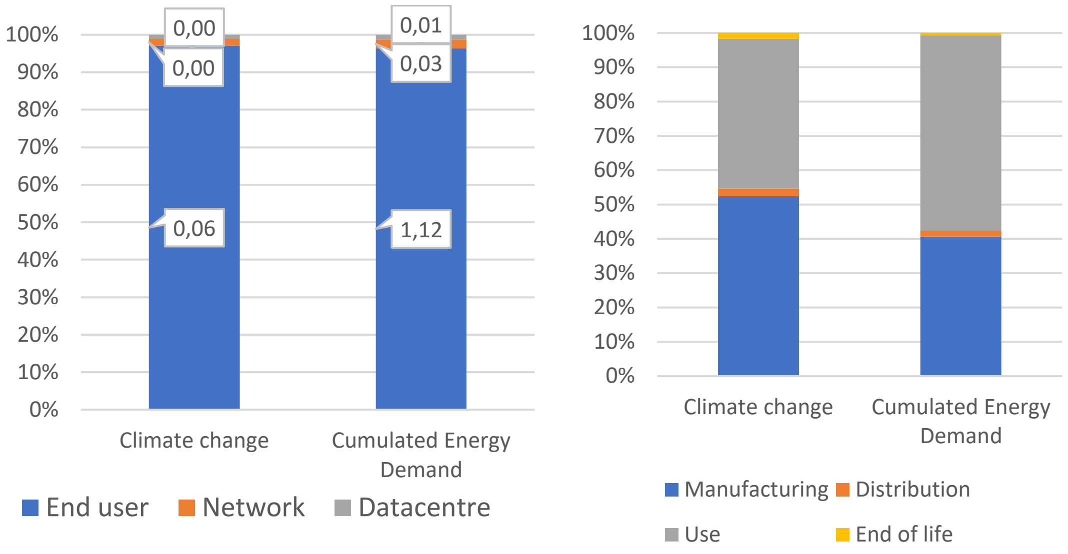
Below are listed good practices to reduce your energy consumption (in order of priority).

	• Try to use smaller devices
	• Use fixed networks

Energy and Global Warming Potential

Below we have calculated the environmental impact of this behaviour following the PEF 3.0 norms described before. In this case the results are showed in terms of Global Warming Potential (GWP), expressed in $kgCO_2eq$, and Cumulative Energy Demand (CED), expressed in MJ.

Figure 14 Environmental impact of online gaming for an average European by tier / per life cycle phase



The total equivalent CO_2eq emissions related to the energy consumption of 1h of online gaming in Europe accounts for 60 gCO_2eq. In terms of CED, the impact rises to 1,155 MJ. To put these numbers in perspective, this is equivalent to:

- Driving 0.63 km in a car[221], assuming 95 gCO_2eq/km as the European fleet-wide target or 2021

As we can see from Figure 14 ; most of the impact comes from the Tier 1 (end-user). This is coherent with the results on the energy consumption. It is also interesting to see a large part of the environmental impact (Climate Change and Cumulative Energy Demand) comes from the “use” phase; that is actually performing the behaviour. As it is the case in the ICT sector, a significant amount of the impact stems from the manufacturing of the equipment (Manufacturing phase) needed to perform the behaviour.

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators. Figure 15 shows that most of the impact of the behaviour comes from the end-user device (tier 1). Table 30 and Table 31 provide the figures to support the choosen indicators.

Below are listed additional good practices to reduce the behaviour environmental footprint

	• Prolong the lifespan of your equipments
	• Reduce the number of hours playing video games

[221] “CO2 Performance of New Passenger Cars in Europe.”

Figure 15 Environmental impact of online gaming per indicator and tier

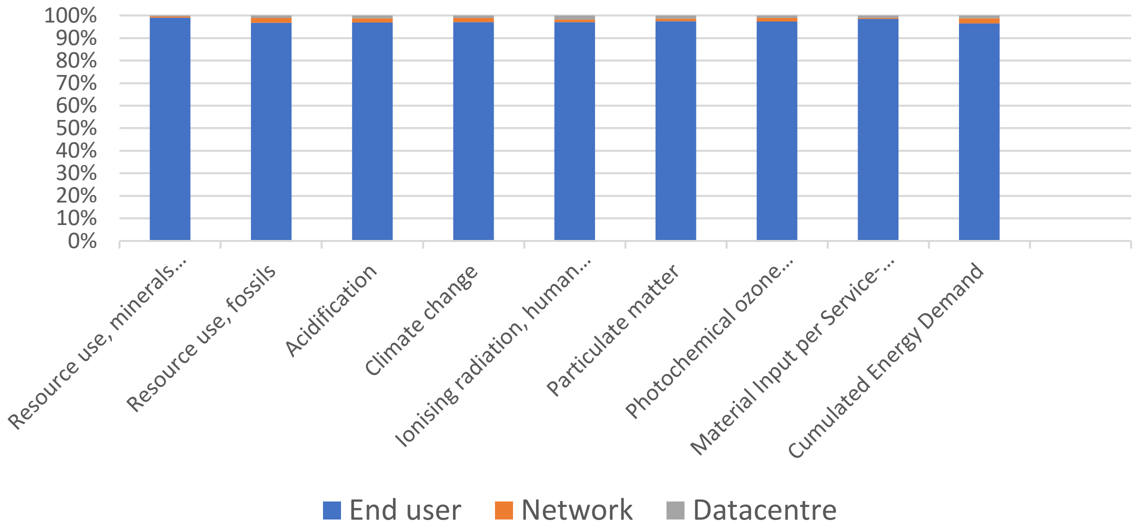


Table 30 Environmental impact of online gaming

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	3,1E-06	1,0E+00	3,6E-04	5,9E-02	7,4E-02	1,6E-09	1,5E-04
Network	1,4E-08	1,7E-02	4,8E-06	8,1E-04	6,4E-04	1,5E-11	1,9E-06
Data centre	1,4E-08	1,2E-02	4,9E-06	6,6E-04	1,4E-03	2,3E-11	1,6E-06
Total	3,1E-06	1,0E+00	3,6E-04	5,9E-02	7,4E-02	1,6E-09	1,5E-04

Table 31 other indicators on the impact of online gaming

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	1,7E-01	1,1E+00
Network	5,9E-04	2,0E-02
Data centre	2,1E-03	1,5E-02
Total	1,7E-01	1,1E+00

Table 32 Percentage associated to the planetary boundaries per capita per day for 1h of online gaming

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
	4,10%	1,33%	0,11%	2,55%	0,04%	0,94%	0,11%

To stay within the planetary boundaries, we should not exceed the 100% threshold per day. Engaging in 1 hour of online gaming per day already consumes 2.55% of our CO2 eq. budget and 4.10% of our mineral and metal resources budget. This means that we need to carefully allocate the rest of our budget to account for additional consumption in the ICT sector, as well as food, shelter, clothing, and transportation.

4.2.4. Conclusion

The environmental footprint of 1h of online gaming has been calculated following three different scenarios to be able to cover different behaviours.

The study shows the importance of the contribution of the daily devices that we use and its correlation to the consumption of the behaviour. The larger the device is, the more energy it generaly consumes to perform a certain behaviour. This is one of the first studies that has been conducted following the PCR Internet Service Provision PCR guidelines from ADEME. On the impact of service providers, our estimate is in the same range of other results found in literature. However, this evaluation comprises several limits that are necessary to be communicated:

- The temporal allocation used to model the consumption of an end-user device does not take into account the fact that other applications might be running at the same time. As an example,if someone is playing videogames at the same time that he or she is surfing on social media or texting someone, an additional allocation related to the CPU, GPU, memory,… usage should be incorporated.
- The temporal allocation used to model the consumption of an end-user device does not take into account the quality of the data. The consumption of the end-user device remains the same if the user is streaming at HD or at 360p.It however has an impact on the energy consumption of the network. Therefore with this current model we cannot quantify how much additionnal energy is used at the Tier 1 level when playing very heavy video games.
- The general model for data centres and the assumptions made about the proportionality between the amount of data and their electricity consumption do not take into account the different infrastructures behind different service providers.

4.3. Video conferencing

4.3.1. Scope definition

This section is aimed at specifying the scope of the analysis performed on video conferencing. This LCA studies the energy consumption and environmental impact of **video conferencing** under different scenarios:

- **Laptop** scenario: 1h of videoconference with a laptop, fixed network and medium resolution with 2 participants.
- **Tablet** scenario: 1h of videoconference with a tablet, fixed network and a medium resolution with 2 participants.
- **European** scenario: 1h of videoconferencing with an average european end-user device, a european network and a medium resolutions with 2 participants.

The chosen **functional unit** that was used to compare the scenarios is the following:

“ 1h of videoconferencing in Europe in 2023 for 2 participants ”

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

Technological boundaries: all three “tiers” (see 2.3.4) have been included to model this behaviour. Users / Network / Data Centres
Temporal boundaries: secondary data from literature is from 2019 to 2023.
Geographical boundaries: secondary data from literature represents the Europe Region.

4.3.2. Life Cycle Inventory

Three scenarios are being modeled for this behaviour. Table 33 shows the input data flows used to estimate the impacts of video conferencing.

Table 33 Input data flows for video conferencing

Input Data Flows		Scenario 1	Scenario 2	Scenario 3
Overall parameters	Time spent on videoconference	1h	1h	1h
End user environment	Connected Speaker			
	Equipment used	Laptop	Tablet	European Device

Network	Video Quality[222]	Medium (1,6 Mbps)	Mobile automatic (0,56 Mbps)	Medium (1,6 Mbps)
	Type of Network	xDSL	xDSL	European Network
	Network Saturation	100%	100%	100%
	Number of subscribers[223]	1 000	2,2	
Data centre	Equipment used	Average Data centre	Average Data centre	Average Data centre
	kW[224]	7,49E-03	7,49E-03	7,49E-03

Video Conferencing – Tier 1

Below we have modeled the **Average European device** used to perform this behaviour. It is defined as the average of the **share of terminals** used to perform this behaviour in Europe in **Table 34**.

Table 34 Share of terminals used for video conferencing in Europe

Device preferences for video conferencing in Europe by type	Unit	Value
Desktop	%	35.00
Laptop	%	35.00
Tablet	%	8.00
Smartphone	%	22.00
TV	%	0

Note:These percentages were taken from Google[225] and Zoom[226] user's preference.

The impacts on the end-user environment equipment (smartphones, laptop, connected speaker, etc.) for the fabrication, transport, and end of life phases are calculated with a temporal allocation (see section 8.1). The impacts of the **use phase** are also modeled with a temporal allocation and are defined in section 7.1.8 .

Video Conferencing – Tier 2

The Average European network used is defined in **Table 21**. The impacts on the network (fixed and mobile) for the fabrication, transport, use, and end of life

[222] See Section 4 for more information on the Data Quality

[223] See Section 4, after Table 21 for more information on the number of subscribers

[224] See Tier 3 section of Video Conferencing for more information

[225] "Google.Com Website Traffic, Ranking, Analytics [January 2023]". Semrush, 2023, https://www.semrush.com/website/google.com/overview/. Accessed 10 Mar 2023.

[226] "Zoom.Us Website Traffic, Ranking, Analytics [January 2023]". Semrush, 2023, https://www.semrush.com/website/zoom.us/overview/. Accessed 10 Mar 2023.

phases are calculated with the allocation defined with the PCR (see section 7.2).

Video Conferencing – Tier 3

Data Centres

The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its consumption.

We have estimated its electricity consumption using Netflix's[227] annual electricity consumption.

Table 35 Netflix consumption information

Netflix parameters	Unit	Value
Number of users	#	167 000 000
Number of video hours watched per year	Billions h	60
Total direct electricity consumed per year	MWh	94 000
Total indirect electricity consumed per year	MWh	357 000
Corresponding power use of video streaming	kW	7,49E-03

Note: We have estimated that an average user watches 2h of netflix per day[228]

Model: The source to model the impact of Tier 3 comes from a single company. This is a limitation as we are only relying on information of a company whose services are different from the ones we are trying to model

4.3.3. Results

It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

Electricity consumption

The figure below summarises the estimated electricity consumption of 1 hour of video conferencing in the three considered scenarios:

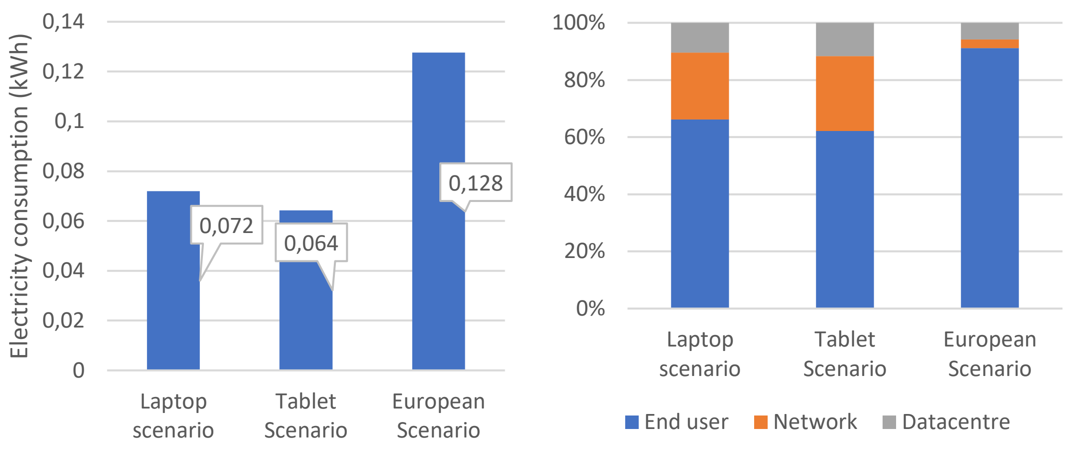
- **Laptop** scenario: 1h of videoconference with a laptop, fixed network and medium resolution with 2 participants.
- **Tablet** scenario: 1h of videoconference with a smartphone, fixed network and a medium resolution with 2 participants.

[227] Netflix Environmental Social Governance Report - Sustainability Accounting Standards Board (SASB), 2019

[228] Keslassy, "Netflix's Cindy Holland Says Subscribers Watch an Average of Two Hours a Day."

	• **European** scenario: 1h of videoconferencing with an average European end-user device, a European network and a medium resolutions with 2 participants.

Figure 16 Electricity consumption of 1h of video conferencing per tier / per scenario



Many video conferences are performed using desktops that consume more than laptops. This explains why the European scenario has a bigger consumption than the laptop scenario. The electricity from the Tier 3 infrastructure is the same one for all three scenarios (additionally, it doesn't depend on the number of users).

i

Key Message: 1h of videoconferencing with an average European end-user device, a European network and a medium resolutions with 5 participants consumes 0,311 kWh. This value was used as a key message for communication pourposes.

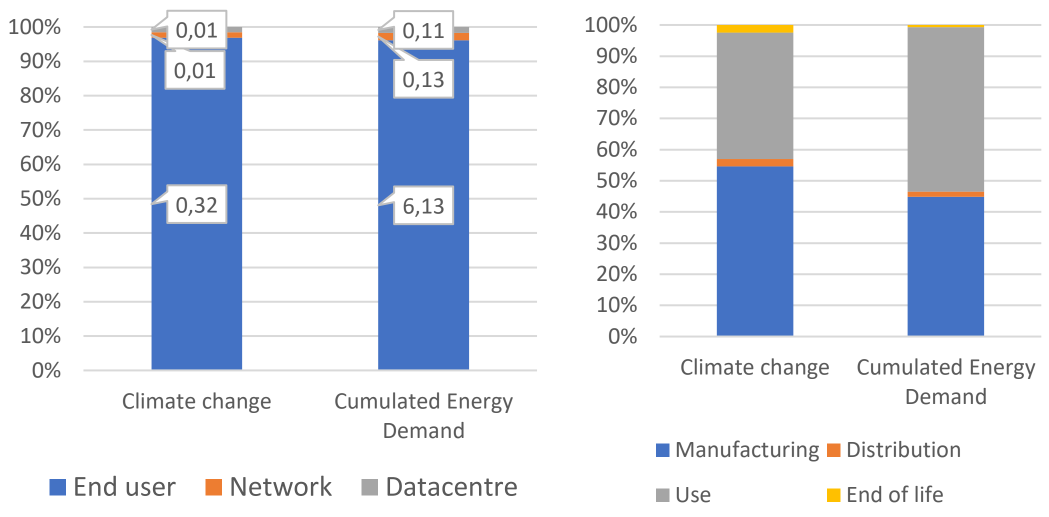
Below are listed good practices to reduce your energy consumption (in order of priority).

	• Try to use smaller devices
	• Limit the number of participants
	• Use fixed networks

Energy and Global Warming Potential

Below we have calculated the environmental impact of this behaviour following the PEF 3.0 norms described before. In this case the results are showed in terms of Global Warming Potential (GWP), expressed in $kgCO_2eq$, and Cumulative Energy Demand (CED), expressed in MJ.

Figure 17 Environmental impact of video conferencing for an average European by tier / per life cycle phase



The total equivalent CO_2 emissions related to the energy consumption of 1h of video conferencing in Europe for two participants account for 135 gCO_2eq. In terms of CED, the impact rises to 2,62 MJ. To put these numbers in perspective, this is equivalent to:

- Driving 1.41 km in a car[229], assuming 95 gCO_2/km as the European fleet-wide target for 2021

As we can see from Figure 17; most of the impact comes from the Tier 1 (end-user). This is coherent with the results on the energy consumption. As this scenarios account for fixed networks and not mobile networks, the Tier 2 impacts are lower. Results from these charts are comparable to those for the video streaming behaviour (c.f. 4.1), with "Manufacturing" and "Use" phase accounting for most of the impacts over diverse environmental indicators.

This implies that when engaging in the behaviour, around half of the energy pertains to its performance, while the remaining energy has been consumed in manufacturing the necessary devices for the behaviour (e.g. tablet, desktop).

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to many environmental indicators. shows that most of the impact of the behaviour comes from the end-user device (tier 1).

Below are listed additional good practices to reduce the behaviour environmental footprint.

	• Prolong the lifespan of your equipments
	• Reduce the time of the meetings

[229] "CO2 Performance of New Passenger Cars in Europe."

Figure 18 Environmental impact of video conferencing per indicator and tier

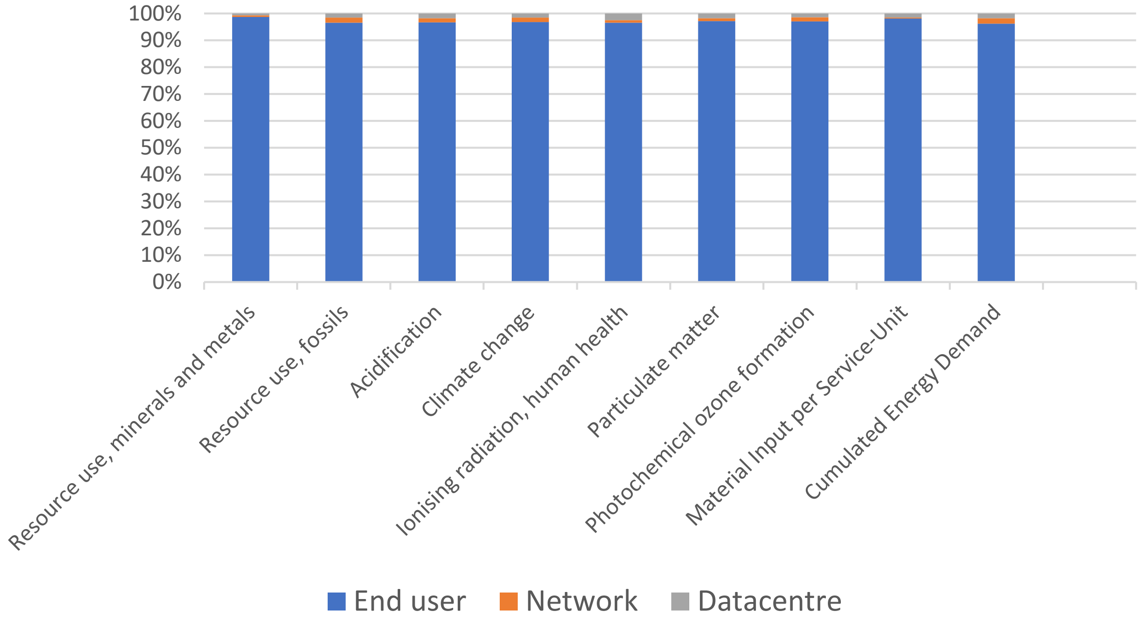


Table 36 Environmental impact of video conferencing

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	3,0E-06	8,4E-01	3,8E-04	6,3E-02	1,8E-02	2,1E-09	1,6E-04
Network	1,6E-08	1,5E-02	4,3E-06	7,3E-04	6,9E-04	1,5E-11	1,7E-06
Data centre	1,0E-07	9,0E-02	3,7E-05	5,0E-03	1,0E-02	1,7E-10	1,2E-05
Total	3,0E-06	8,4E-01	3,8E-04	6,3E-02	1,8E-02	2,1E-09	1,6E-04
Associated planetary boundary per capita per day	7,55E-05	7,72E+01	3,45E-01	2,35E+00	1,82E+02	1,78E-07	1,40E-01

Table 37 Percentage associated to the planetary boundaries per capita per day for 1h of video conferencing

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
	3,94%	1,52%	0,12%	2,86%	0,05%	1,09%	0,12%

To stay within the planetary boundaries, we should not exceed the 100% threshold per day. Engaging in 1 hour of videoconferencing per day already consumes 2.86% of our CO_2eq. budget and 3.94% of our mineral and metal resources budget. This means that we need to carefully allocate the rest of our budget to account for additional consumption in the ICT sector, as well as food, shelter, clothing, and transportation.

Table 38 Other indicators on the impact of video conferencing

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	2,3E-01	8,8E-01
Network	7,8E-04	1,8E-02
Data centre	1,5E-02	1,1E-01
Total	2,3E-01	8,8E-01

4.3.4. Conclusion

The environmental footprint of 1h of video conferencing has been calculated following three different scenarios to be able to cover different behaviours.

The study shows the importance of the contribution of the daily devices that we use and its correlation to the consumption of the behaviour. The larger the device is, the more energy it generaly consumes to perform a certain behaviour. This is one of the first studies that has been conducted following the PCR Internet Service Provision guidelines from ADEME. On the impact of service providers, our estimate is in the same range of other results found in literature. However, this evaluation comprises several limits that are necessary to be communicated:

- The temporal allocation used to model the consumption of an end-user device does not take into account the fact that other applications might be running at the same time. As an example, if someone is attending a videoconference at the same time that is he or she is surfing on social media or texting someone, an additional allocation related to the CPU, GPU, memory,… usage should be incorporated.
- The temporal allocation used to model the consumption of an end-user device does not take into account the quality of the data. The consumption of the end-user device remains the same if the video conference quality is set to at high or low definition.It however has an impact on the energy consumption of the network. Therefore with this current model we cannot quantify how much energy is saved at the Tier 1 level when turning off the camera.
- The general model for data centres and the assumptions made about the proportionality between the amount of data and their electricity consumption do not take into account the different infrastructures behind different service providers.

4.4. Music streaming

4.4.1. Scope definition

This section is aimed at specifying the scope of the analysis performed music streaming. This LCA studies the energy consumption and environmental impact of **music streaming** under different scenarios:

- **Laptop** scenario: listening to 1h of music streaming with a laptop, a fixed connection and a low resolution .
- **Smartphone** scenario: listening to 1h of music streaming with a smartphone, a mobile connection at low resolution.
- **European** scenario: listening to 1h of music streaming with an average european device, a european connection at low resolution.

The chosen **functional unit** that was used to compare the scenarios is the following:

“ 1h of music streaming in Europe”

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

Technological boundaries: all three “tiers” (see 2.3.4) have been included to model this behaviour. 
Temporal boundaries: secondary data from literature is from 2019 to 2023.
Geographical boundaries: secondary data from literature represents the Europe Region.

4.4.2. Life Cycle Inventory

Three scenarios are being modeled for this behaviour. Table 39 shows the input data flows used to estimate the impacts of music streaming.

Table 39 Input data flows for music streaming

Input Data Flows		Scenario 1	Scenario 2	Scenario 3
Overall parameters	Time spent listening	1h	1h	1h
End user environment	Connected Speaker			
	Equipment used	Laptop	Smartphone	European Device

Network	Video Quality[230]	Fixed average (0,36 Mbps)	Mobile low (0,36 Mbps)	Fixed average (0,36 Mbps)
	Type of Network	xDSL	4G	European Network
	Network Saturation	100%	100%	100%
	Number of subscribers[231]	1000	2,2	
Data centre	Equipment used	Average Data centre	Average Data centre	Average Data centre
	kWh/h[232]	9,94E-07	9,94E-07	9,94E-07

Music streaming – Tier 1

Users

Below we have modeled the **Average European device** used to perform this behaviour. It is defined as the average of the **share of terminals** used to perform this behaviour in Europe in **Table 40**.

Table 40 Share of terminals used for music streaming in Europe

Device preferences for music streaming in Europe by type	Unit	Value
Desktop	%	11.41%
Laptop	%	16.85%
Tablet	%	15.76%
Smartphone	%	39.67%
TV	%	16.30%

Note:These percentages were taken from Statista[233].

The impacts on the end-user environment equipment (smartphones, laptop, connected speaker, etc.) for the fabrication, transport, and end of life phases are calculated with a temporal allocation (see section 8.1). The impacts of the **use phase** are also modeled with a temporal allocation and are defined in section 7.1.8 .

Music streaming – Tier 2

Network

The Average European network used is defined in **Table 21**. The impacts on the network (fixed and mobile) for the fabrication, transport, use, and end of life

[230] See Section 4 for more information on the Data Quality

[231] See Section 4, after Table 21 for more information on the number of subscribers

[232] See Tier 3 section of Music streaming for more information

[233] Statista. "Digital audio usage by device in Germany in 2022." Chart. March 8, 2023. Statista. Accessed April 10, 2023. https://www-statista-com.budistant.univ-nantes.fr/forecasts/998784/digital-audio-usage-by-device-in-germany?locale=en

phases are calculated with the allocation defined with the PCR (see section 7.2).

Music streaming – Tier 3

Data Centres

The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its consumption.

We have estimated its electricity consumption using Spotify[234] annual electricity consumption and the annual number of hours listened[235].

Table 41 Spotify consumption information

Spotify parameters	Unit	Value
Number of hours listened per year	h	1,07918E+11
Total direct electricity consumed per year	MWh	107,23

Model: The source to model the impact of Tier 3 comes from a single company. This is a limitation as we are only relying on information of a company whose services we are trying to model.

4.4.3. Results

It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

Electricity consumption

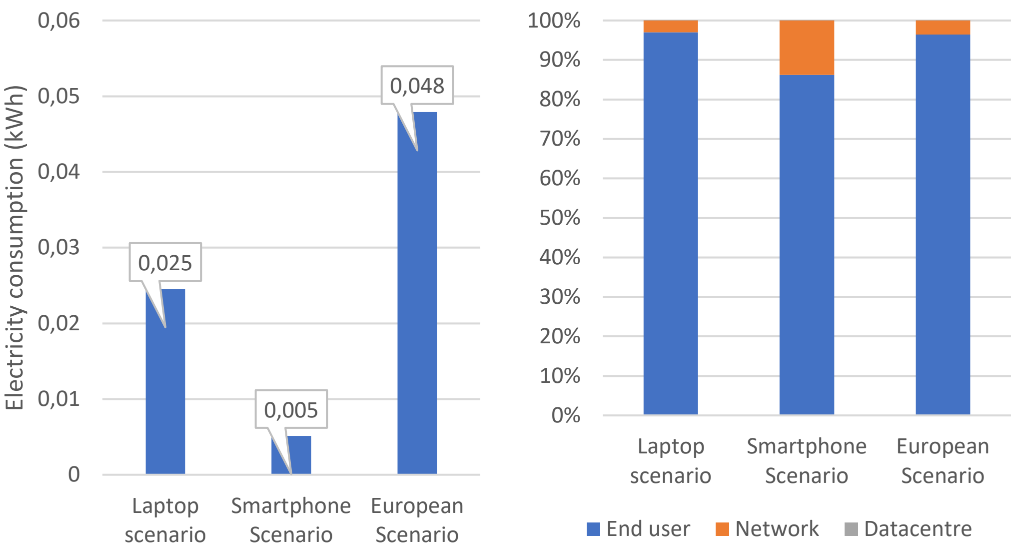
The figure below summarises the estimated electricity consumption of 1 hour of music streaming in the three considered scenarios:

- **Laptop** scenario: listening to 1h of music streaming with a laptop, a fixed connectionand a low resolution.
- **Smartphone** scenario: listening to 1h of music streaming with a smartphone, a mobile connection at low resolution.
- **European** scenario: listening to 1h of music streaming with an average European device, a European connection at low resolution.

[234] "Spotify-Equity-Impact-Report-2021.Pdf," accessed April 10, 2023, https://www.lifeatspotify.com/reports/Spotify-Equity-Impact-Report-2021.pdf.

[235] "2021 Artist Wrapped," accessed April 10, 2023, https://spotifyforartistswrapped.byspotify.com/.

Figure 19 Electricity consumption of 1h of music streaming per tier / per scenario



It is interesting to see the impact of the European scenario. As over 16% of the music is streamed via smart TVs and 11% is streamed via desktops, the corresponding impact is very high. Overall, using a smartphone via mobile connection has a lower impact. The impacts related to the Tier 3 are very small.

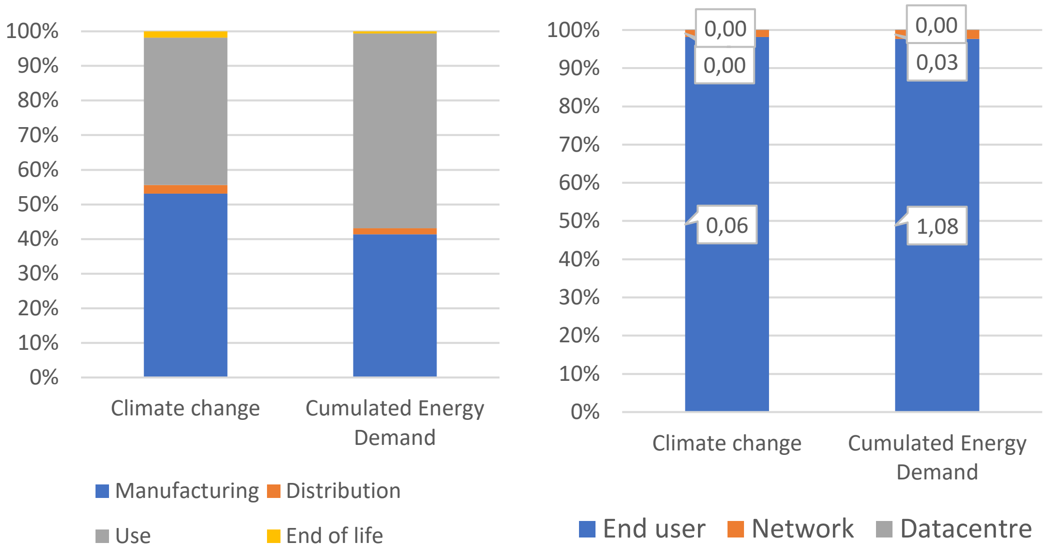
Below are listed good practices to reduce the energy consumption (in order of priority).

	• Try to use smaller devices
	• Use fixed networks
	• Try not to watch videos only for the music

Energy and Global Warming Potential

Below we have calculated the environmental impact of this behaviour following the PEF 3.0 norms described before. In this case the results are showed in terms of Global Warming Potential (GWP), expressed in $kgCO_2eq$, and Cumulative Energy Demand (CED), expressed in MJ.

Figure 20 Environmental impact of music streaming for an average European by tier / per life cycle phase



The total equivalent CO_2eq emissions related to the energy consumption of 1h of music streaming in Europe accounts for 58 gCO_2eq. In terms of CED, the impact rises to 1,104 MJ. To put these numbers in perspective, this is equivalent to:

- Driving 0.61 km in a car[236], assuming 95 gCO_2eq/km as the European fleet-wide target or 2021

As we can see from Figure 20 ; most of the impact comes from the Tier 1 (end-user). This is coherent with the results on the energy consumption. It is also interesting to see a large part of the environmental impact (Climate Change and Cumulative Energy Demand) comes from the "use" phase; that is actually performing the behaviour. As it is the case in the ICT sector, a significant amount of the impact stems from the manufacturing of the equipment (Manufacturing phase) needed to perform the behaviour.

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators. Figure 12 shows that most of the impact of the behaviour comes from the end-user device (Tier 1). Table 42 and Table 43 provide the figures to support the choosen indicators.

Below are listed additional good practices to reduce the behaviour environmental footprint

	• Prolong the lifespan of your equipments
	• Reduce your daily music streaming usage

[236] "CO2 Performance of New Passenger Cars in Europe."

Figure 21 Environmental impact of music streaming per indicator and tier

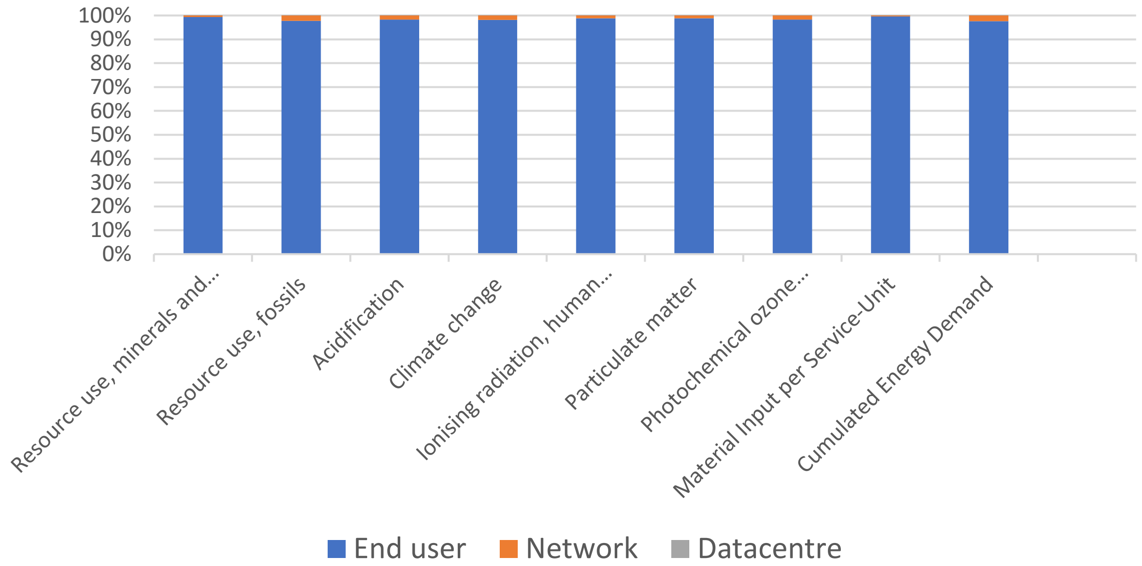


Table 42 Environmental impact of music streaming

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	3,0E-06	9,7E-01	3,5E-04	5,7E-02	6,9E-02	1,6E-09	1,5E-04
Network	1,4E-08	1,6E-02	4,6E-06	7,9E-04	6,3E-04	1,5E-11	1,8E-06
Data centre	1,4E-11	1,2E-05	4,9E-09	6,6E-07	1,4E-06	2,3E-14	1,6E-09
Total	3,0E-06	9,7E-01	3,5E-04	5,7E-02	6,9E-02	1,6E-09	1,5E-04

Table 43 other indicators on the impact of music streaming

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	1,7E-01	1,1E+00
Network	5,9E-04	2,0E-02
Data centre	2,1E-06	1,5E-05
Total	1,7E-01	1,1E+00

Table 44 Percentage associated to the planetary boundaries per capita per day for 1h of music streaming

	Resource use, minerals and	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)

	metals (kg SB eq.)						
	3,96%	1,27%	0,10%	2,47%	0,04%	0,91%	0,11%

To stay within the planetary boundaries, we should not exceed the 100% threshold per day. Engaging in 1 hour of music streaming per day already consumes 2.47% of our CO_2eq. budget and 3.96% of our mineral and metal resources budget. This means that we need to carefully allocate the rest of our budget to account for additional consumption in the ICT sector, as well as food, shelter, clothing, and transportation.

4.4.4. Conclusion

The environmental footprint of 1h of music streaming has been calculated following three different scenarios to be able to cover different behaviours.

The study shows the importance of the contribution of the daily devices that we use and its correlation to the consumption of the behaviour. The larger the device is, the more energy it generaly consumes to perform a certain behaviour. This is one of the first studies that has been conducted following the PCR Internet Service Provision PCR guidelines from ADEME and results indicate that behaviours with relative small bandwith have a very low impact. This is reassuring as it follows the trend observed in literature. On the impact of service providers, our estimate is very low compared to the model for other day-to-day behaviours. The modeling does not seem to be wrong as audio formats use much less space than video formats. This evaluation comprises several limits that are necessary to be communicated:

- The temporal allocation used to model the consumption of an end-user device does not take into account the fact that other applications might be running at the same time. This is specially important in this behaviour as most of the users perform other taks while listening to music. Therefore, an additional allocation related to the CPU, GPU, memory,… usage should be incorporated.
- The temporal allocation used to model the consumption of an end-user device does not take into account the quality of the data. The consumption of the end-user device remains the same if the user is streaming at HD or at 360p.It however has an impact on the energy consumption of the network. Therefore with this current model we cannot quantify how much energy is consumed when you turn off the screen of your phone to listen to music or you watch a videoclip on it.
- The general model for data centres and the assumptions made about the proportionality between the amount of data and their electricity consumption do not take into account the different infrastructures behind different service providers.

4.5. Social networking

4.5.1. Scope definition

This section is aimed at specifying the scope of the analysis performed on social networking. This LCA studies the energy consumption and environmental impact of **social networking** under different scenarios:

- **Low resolution** scenario: surfing for 1 hour on the newsfeed of a news-type[237] social media with a smartphone and a mobile network.
- **High resolution** scenario: surfing for 1 hour on the newsfeed of video-type social media with a smartphone and a mobile network.
- **European** scenario: surfing for 1 hour on the newsfeed of an average social media with an average european device and a european network.

The chosen **functional unit** that was used to compare the scenarios is the following:

" 1h of social networking in Europe in 2023"

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

	Technological boundaries: all three "tiers" (see 2.3.4) have been included to model this behaviour. 
	Temporal boundaries: secondary data from literature is from 2019 to 2023.
	Geographical boundaries: secondary data from literature represents the Europe Region.

4.5.2. Life Cycle Inventory

Three scenarios are being modeled for this behaviour. Table 45 shows the input data flows used to estimate the impacts of social networking.

Table 45 Input data flows for social networking

Input Data Flows		Scenario 1	Scenario 2	Scenario 3
Overall parameters	Time spent on newsfeed of social networks	1h	1h	1h
End user environment	Connected Speaker			
	Equipment used	Smartphone	Smartphone	European Device

[237] The terms "news-type;" "video-type" and "average" relate to different video qualities. It will be specified in the Inventory table below

Network	Video Quality[238]	News-type (1,48 Mbps)	Video-type (12,83 Mbps)	Average (4,59 Mbps)
	Type of Network	4G	4G	European Network
	Network Saturation	100%	100%	100%
	Number of subscribers[239]	1 000	2,2	
Data centre	Equipment used	Average Data centre	Average Data centre	Average Data centre
	kWh/h[240]	6,59E-04	6,59E-04	6,59E-04

Social Networking – Tier 1

Users

Below we have modeled the **Average European device** used to perform this behaviour. It is defined as the average of the **share of terminals** used to perform this behaviour in Europe in **Table 46**.

Table 46 Share of terminals used for social networking in Europe

Device preferences for social networking in Europe by type	Unit	Value
Desktop	%	9,7
Laptop	%	9,7
Tablet	%	10,3
Smartphone	%	69,7
TV	%	0

Note:These percentages were taken from Facebook[241], Instagram[242] and Twitter[243] user's preference.

The impacts on the end-user environment equipment (smartphones, laptop, connected speaker, etc.) for the fabrication, transport, and end of life phases are calculated with a

[238] See Section 4 for more information on the Data Quality

[239] See Section 4, after Table 21 for more information on the number of subscribers

[240] See Tier 3 section of Social Networking for more information

[241] We Are Social, und Hootsuite, und DataReportal. "Device usage of Facebook users worldwide as of January 2022." Chart. January 26, 2022. Statista. Accessed April 10, 2023. https://www-statista-com.budistant.univ-nantes.fr/statistics/377808/distribution-of-facebook-users-by-device/

[242] IAB Spain. (June 30, 2019). Devices used to access Instagram in Spain in 2019 [Graph]. In Statista. Retrieved April 10, 2023, from https://www-statista-com.budistant.univ-nantes.fr/statistics/772084/users-from-instagram-according-he-device-from-access-in-spain/?locale=en

[243] "Twitter Lite PWA Significantly Increases Engagement and Reduces Data Usage," web.dev, accessed April 10, 2023, https://web.dev/twitter/.

temporal allocation (see section 8.1). The impacts of the **use phase** are also modeled with a temporal allocation and are defined in section 7.1.8 .

Social Networking – Tier 2

Network

The Average European network used is defined in **Table 21**. The impacts on the network (fixed and mobile) for the fabrication, transport, use, and end of life phases are calculated with the allocation defined with the PCR (see section 7.2).

Social Networking – Tier 3

Data Centres

The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its consumption.

We have estimated its electricity consumption using Snapchat's[244] annual electricity consumption, number of users[245] and average usage per day[246].

Table 47 Snapchat consumption information

Snapchat parameters	Unit	Value
Number of users	#	319 000 000
Number of video hours watched per year	Billions h	30
Total direct electricity consumed per year	kWh	19 850 000
Corresponding power use of social networking	kW	6,59E-04

Model: The source to model the impact of Tier 3 comes from a single company. This is a limitation as we are only relying on information of a company whose services we are trying to model.

4.5.3. Results

It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

Electricity consumption

[244] "2022_CitizenSnap_Report.Pdf," accessed April 10, 2023, https://storage.googleapis.com/snap-inc/citizen-snap/2022_CitizenSnap_Report.pdf.

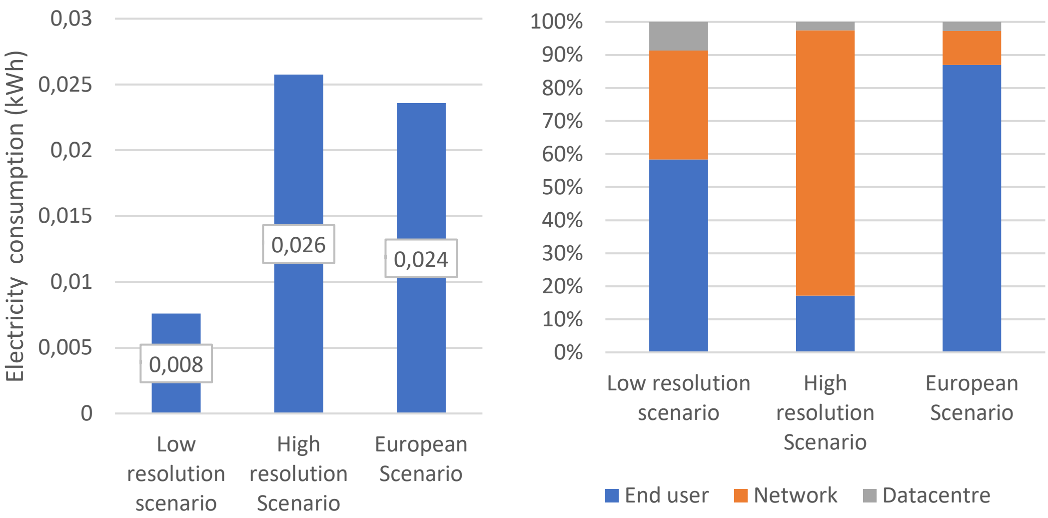
[245] "Snap-Inc-2021-Annual-Report.Pdf," accessed April 10, 2023, https://s25.q4cdn.com/442043304/files/doc_downloads/2022/Snap-Inc-2021-Annual-Report.pdf.

[246] "Snapchat Users Now Spend 25 to 30 Minutes Every Day on the App," accessed April 10, 2023, https://www.businessinsider.com/how-much-time-people-spend-on-snapchat-2016-3?r=US&IR=T.

The figure below summarises the estimated electricity consumption of 1 hour of social networking in the three considered scenarios:

	• **Low resolution** scenario: surfing for 1 hour on the newsfeed of a news-type social media with a smartphone and a mobile network.
	• **High resolution** scenario: surfing for 1 hour on the newsfeed of video-type social media with a smartphone and a mobile network.
	• **European** scenario: surfing for 1 hour on the newsfeed of an average social media with an average european device and a european network.

Figure 22 Electricity consumption of 1h of social networking per tier / per scenario



Most of the impact of the high resolutions scenario comes from the Tier 2 (networks). When combining mobile networks with a high resolution the impact is very important (over 20Wh). Most of the impact of the European scenario comes from the Tier 1 (end-user) devices. While the resolution in this case is lower; the small use of laptops and desktops for social media compensates for that difference.

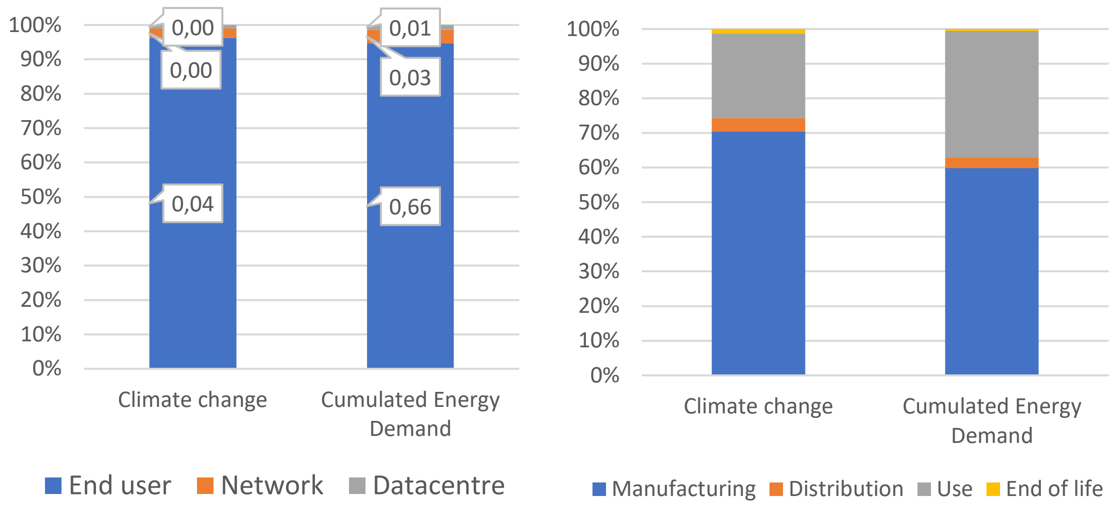
Below are listed good practices to reduce the energy consumption (in order of priority).

	• Try to use smaller devices
	• Try to use fixed networks
	• Use social networks with more static content (less videos)

Energy and Global Warming Potential

Below we have calculated the environmental impact of this behaviour following the PEF 3.0 norms described before. In this case the results are showed in terms of Global Warming Potential (GWP), expressed in $kgCO_2eq$, and Cumulative Energy Demand (CED), expressed in MJ.

Figure 23 Environmental impact of social networking for an average European by tier / per life cycle phase



The total equivalent CO_2 emissions related to the energy consumption of 1h of social networking in Europe accounts for 42 gCO_2eq. In terms of CED, the impact rises to 0.694 MJ. To put these numbers in perspective, this is equivalent to:

- Driving 0.44 km in a car[247], , assuming 95 gCO_2/km as the European fleet-wide target or 2021

As we can see from Figure 23; most of the impact comes from the Tier 1 (end-user). This is coherent with the results on the energy consumption. It is also interesting to see a significant part of the environmental impact (Climate Change and Cumulative Energy Demand) comes from the "use" phase; that is actually performing the behaviour. As it is the case in the ICT sector, a significant amount of the impact stems from the manufacturing of the equipment (Manufacturing phase) needed to perform the behaviour.

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators. Figure 24 shows that most of the impact of the behaviour comes from the end-user device (Tier 1). Table 48 and Table 49 provide the figures to support the choosen indicators.

Below are listed additional good practices to reduce the behaviour environmental footprint.

	• Prolong the lifespan of your equipments
	• Reduce the daily usage of social networks

[247] "CO2 Performance of New Passenger Cars in Europe."

Figure 24 Environmental impact of social networking per indicator and tier

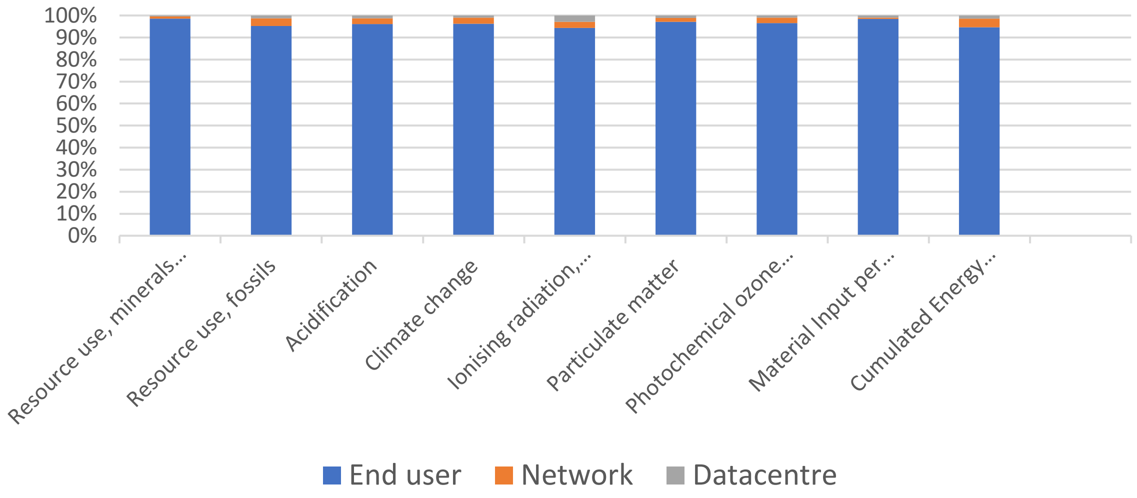


Table 48 Environmental impact of social networking

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	1,9E-06	6,1E-01	2,5E-04	4,0E-02	2,9E-02	1,3E-09	1,0E-04
Network	1,4E-08	1,8E-02	5,1E-06	8,6E-04	6,7E-04	1,6E-11	2,0E-06
Data centre	9,1E-09	8,0E-03	3,2E-06	4,4E-04	9,1E-04	1,5E-11	1,1E-06
Total	1,9E-06	6,1E-01	2,5E-04	4,0E-02	2,9E-02	1,3E-09	1,0E-04

Table 49 other indicators on the impact of social networking

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	1,3E-01	6,6E-01
Network	5,9E-04	2,1E-02
Data centre	1,4E-03	9,7E-03
Total	1,3E-01	6,6E-01

Table 50 Percentage associated to the planetary boundaries per capita per day for 1h of social networking

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)

	2,53%	0,83%	0,07%	1,77%	0,02%	0,72%	0,08%

To stay within the planetary boundaries, we should not exceed the 100% threshold per day. Engaging in 1 hour of social networking per day already consumes 1.77% of our CO_2eq. budget and 2.53% of our mineral and metal resources budget. This means that we need to carefully allocate the rest of our budget to account for additional consumption in the ICT sector, as well as food, shelter, clothing, and transportation.

4.5.4. Conclusion

The environmental footprint of 1h of social networking has been calculated following three different scenarios to be able to cover different behaviours.

The study shows the importance of the contribution of the daily devices that we use and its correlation to the consumption of the behaviour. The larger the device is, the more energy it generaly consumes to perform a certain behaviour. This is one of the first studies that has been conducted following the PCR Internet Service Provision guidelines from ADEME and results indicate that mobile networks have overall a larger impact than fixed networks. For this behaviour, the PCR model is pushed to its limits as 20Wh seems to be significant amount of power. On the impact of the service provider, it is likely that the impact has been underestimated as companies don't disclose the consumption of their IT providers (if they have data centres off-premise i.e Cloud). This evaluation comprises several limits that are necessary to be communicated:

- The temporal allocation used to model the consumption of an end-user device does not take into account the fact that other applications might be running at the same time. As an example, if someone is listening to music at the same time that he or she is surfing on social media or texting someone, an additional allocation related to the CPU, GPU, memory,… usage should be incorporated.
- The temporal allocation used to model the consumption of an end-user device does not take into account the quality of the data. The consumption of the end-user device remains the same if the user is streaming at HD or at 360p. It however has an impact on the energy consumption of the network. As we can see in the high resolution scenario, this can have a significant change in the energy consumption.
- The general model for data centres and the assumptions made about the proportionality between the amount of data and their electricity consumption does not take fully into account services hosted on the cloud by third-party providers.

4.6. Write and send an email

4.6.1. Scope definition

This section is aimed at specifying the scope of the analysis performed on emailing. This LCA studies the energy consumption and environmental impact of **emailing** under different scenarios:

- **2 recipients** scenario: sending a mail to 2 recipients with a 1Mb attached file with a desktop and a fixed network.
- **5 recipients** scenario: sending a mail to 5 recipients with a 10Mb attached file with a desktop and a fixed network.
- **European** scenario: sending a mail to two recipients with a 1Mb attached file with an average european device and and a european network.

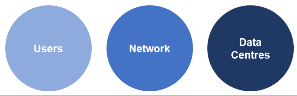
The chosen **functional unit** that was used to compare the scenarios is the following:

“ Write, send, read, store an email in Europe in 2023”

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

Technological boundaries: all three “tiers” (see 2.3.4) have been included to model this behaviour.



Temporal boundaries: secondary data from literature is from 2019 to 2023.

Geographical boundaries: secondary data from literature represents the Europe Region.

4.6.2. Life Cycle Inventory

Three scenarios are being modeled for this behaviour. Table 51 shows the input data flows used to estimate the impacts of emailing.

Table 51 Input data flows for emailing

Input Data Flows		Scenario 1	Scenario 2	Scenario 3
Overall parameters	Time spent writing/reading the email	3 min	3 min	3 min
	Number of recipients	2	5	2
	Size of the attached file	1 Mb	10 Mb	1 Mb

End user environment	Equipment used	Desktop	Desktop	European Device
Network	Data Quality[248]	High (2,22 Mbps)	High (2,22 Mbps)	High (2,22 Mbps)
	Type of Network	xDSL	xDSL	European Network
	Network Saturation	100%	100%	100%
	Number of subscribers[249]	2,2	2,2	
Data centre	Equipment used	Average Data centre	Average Data centre	Average Data centre
	Annual kWh/Gb[250]	1,47E+00	1,47E+00	1,47E+00

Emailing – Tier 1

Below we have modeled the **Average European device** used to perform this behaviour. It is defined as the average of the **share of terminals** used to perform this behaviour in Europe in **Table 52**.

Table *52 Share of terminals used for emailing in Europe*

Device preferences for emailing in Europe by type	Unit	Value
Desktop	%	15%
Laptop	%	21%
Tablet	%	10%
Smartphone	%	54%
TV	%	0%

Note:These percentages were taken from Spotler[251].

The impacts on the end-user environment equipment (smartphones, laptop, connected speaker, etc.) for the fabrication, transport, and end of life phases are calculated with a temporal allocation (see section 8.1). The impacts of the **use phase** are also modeled with a temporal allocation and are defined in section 7.1.8 .

[248] See Section 4 for more information on the Data Quality

[249] See Section 4, after Table 21 for more information on the number of subscribers

[250] See Tier 3 section of Section 4.10.2 for more information

[251] Spotler. "Which electronic device do you use most to read your e-mails?." Chart. October 15, 2019. Statista. Accessed April 10, 2023. https://www-statista-com.budistant.univ-nantes.fr/statistics/632305/distribution-of-devices-used-to-read-e-mails-in-the-netherlands-by-device/?locale=en

Emailing – Tier 2

Network

The Average European network used is defined in **Table 21**. The impacts on the network (fixed and mobile) for the fabrication, transport, use, and end of life phases are calculated with the allocation defined with the PCR (see section 7.2).

Emailing – Tier 3

Data Centres

The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its consumption.

We have modeled the impact with Google's green Computing figures[252].

Table 53 Google's parameters

Google's parameters	Unit	Value
Associated storage per user[253]	Gb	15
Annual energy consumption by user	kWh	2,2
Associated annual kWh/Gb	kWh/Gb	1,47

⚠ **Model:** The source to model the impact of Tier 3 comes from a single company. This is a limitation as we are only relying on information of a company whose services we are trying to model.

4.6.3. Results

It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

Electricity consumption

The figure below summarises the estimated electricity consumption emailing is presented in three scenarios:

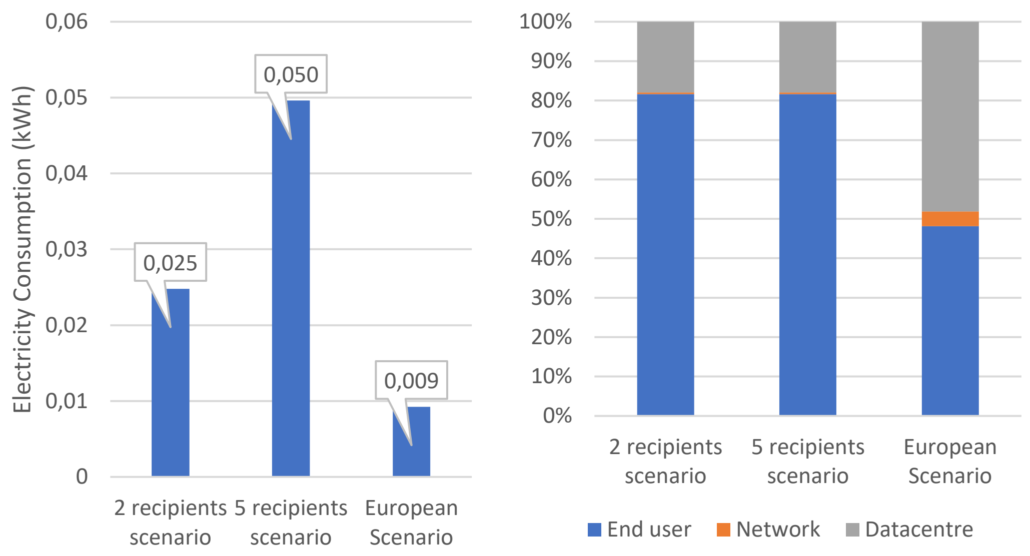
- **2 recipients** scenario: sending a mail to 2 recipients with a 10Mb attached file with a desktop and a fixed network.
- **5 recipients** scenario: sending a mail to 5 recipients with a 10Mb attached file with a desktop and a fixed network.

[252] "Google-Green-Computing.Pdf," accessed April 11, 2023, https://static.googleusercontent.com/media/www.google.com/en//green/pdfs/google-green-computing.pdf.

[253] This value is an arbitrary assumption

	• **European** scenario: sending a mail to two recipients with a 10Mb attached file with an average european device and and a european network.

Figure 25 Electricity consumption of emailing per tier / per scenario



On average, writing, sending, reading, and storing an email in Europe consumes 0,009 kWh (for the defined characteristics). Most emailing is performed using smartphones. Therefore, the European scenario has a smaller impact that the laptop or desktop scenario. Interestingly a non negligeable part of the impact can be attributed to Tier 3 (service providers).

Key Message: sending one mail with a 1 MB attached piece to 2 recipients and storing it for 2 years consumes 0,009 kWh. This scenario was corresponds to using an average european device and an average european network. This value was used for communication pourposes.

Below are listed good practices to reduce your energy consumption (in order of priority).

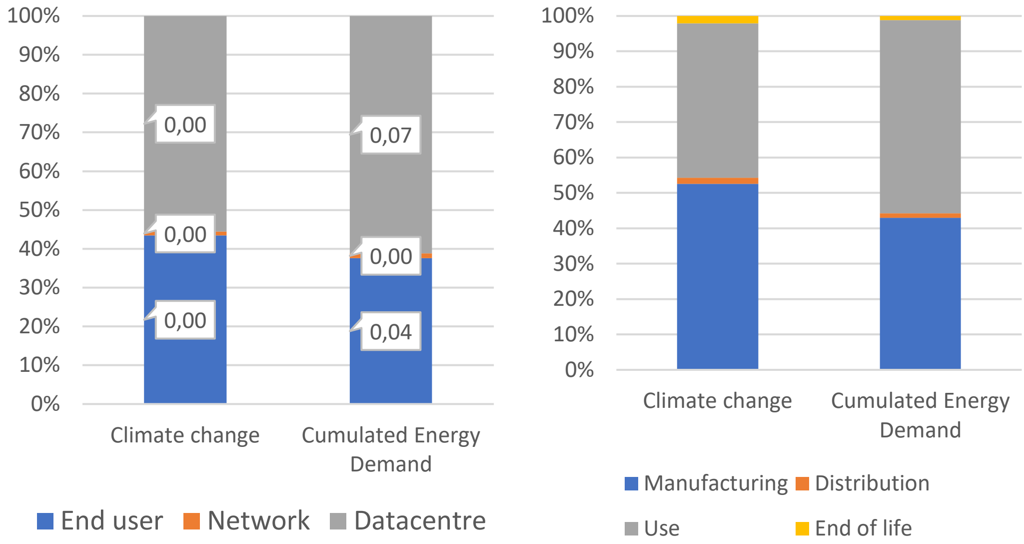
	• Try to limit the number of recipients
	• Try to limit the size of the attached files

Energy and Global Warming Potential

Below we have calculated the environmental impact of this behaviour following the PEF 3.0 norms described before. In this case the results are showed in terms of Global Warming

Potential (GWP), expressed in $kgCO_2eq$, and Cumulative Energy Demand (CED), expressed in MJ.

Figure 26 Environmental impact of mailing by tier / per life cycle phase



The total equivalent CO_2eqemissions related to emailing following the European scenario account for 5 gCO_2eq. In terms of CED, the impact rises to 0,107 MJ. To put these numbers in perspective, this is equivalent to:

- Driving 0.05 km in a car[254], assuming 95 gCO_2eq/km as the European fleet-wide target or 2021.

As we can see from Figure 26 ; most of the impact comes from the Tier 2 (Network). This is coherent with the results on the energy consumption. It is also interesting to see a large part of the environmental impact (Climate Change and Cumulative Energy Demand) comes from the “use” phase; that is actually performing the behaviour. As it is the case in the ICT sector, a significant amount of the impact stems from the manufacturing of the equipment (Manufacturing phase) needed to perform the behaviour.

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators. Figure 27 shows that most of the impact of the behaviour comes from the service providers (Tier 3). Table 54 and Table 55 provide the figures to support the choosen indicators.

Below are listed additional good practices to reduce the behaviour environmental footprint.

	• Unsubscribe from newsletters
	• Limit the number of emails that you send per day

[254] “CO2 Performance of New Passenger Cars in Europe.”

Figure 27 Environmental impact of emailing per indicator and tier

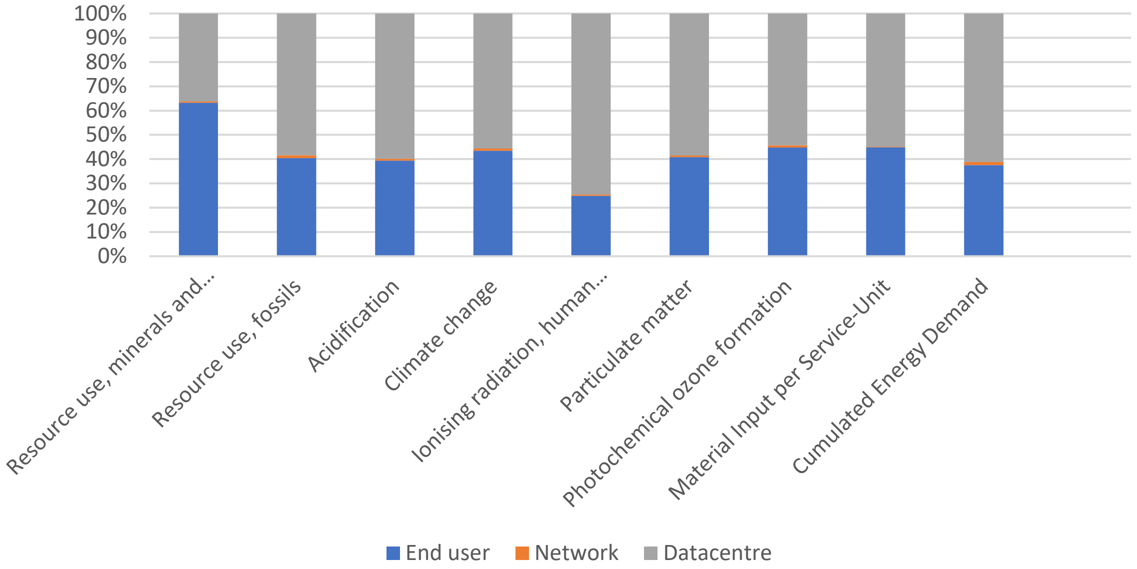


Table 54 Environmental impact of emailing

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	1,1E-07	3,7E-02	1,4E-05	2,3E-03	2,0E-03	7,0E-11	6,0E-06
Network	6,9E-10	8,1E-04	2,3E-07	3,9E-05	3,2E-05	7,6E-13	9,2E-08
Data centre	4,1E-08	3,6E-02	1,4E-05	2,0E-03	4,1E-03	6,7E-11	4,8E-06
Total	1,5E-07	7,4E-02	2,9E-05	4,3E-03	6,2E-03	1,4E-10	1,1E-05

Table 55 Percentage associated to the planetary boundaries per capita per day for emailing

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
	0,02%	0,01%	0,34%	7,32%	0,14%	3,15%	0,31%

In the above table we have considered that an average working professional sends around 40 emails[255]. To stay within the planetary boundaries, we should not exceed the 100% threshold per day. Sending 40 emails (as well as reading and storing the data associated)

[255] "How Many Emails Does the Average Person Receive Per Day in 2023? - EarthWeb," April 17, 2023, https://earthweb.com/how-many-emails-does-the-average-person-receive-per-day/.

following the European scenario consumes 7.32% of our CO_2eq. budget. This means that we need to carefully allocate the rest of our budget to account for additional consumption in the ICT sector, as well as food, shelter, clothing, and transportation.

Table 56 other indicators on the impact of emailing

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	7,5E-03	4,0E-02
Network	2,9E-05	9,8E-04
Data centre	6,1E-03	4,4E-02
Total	1,4E-02	8,5E-02

4.6.4. Conclusion

The environmental footprint of emailing has been calculated following three different scenarios to be able to cover different behaviours.

The study shows how fast can impacts scale. By simply adding more recipients and larger attached files, the overall impact is much more important. However, emailing needs to be put in perspective. It's impacts are very small compared to other ICT bevahiours. In this example, a 10MB attached piece was added. Usually, emails are just text formats, weighing much more and so with an even smaller impact. This evaluation comprises several limits that are necessary to be communicated:

- The temporal allocation used to model the consumption of an end-user device does not take into account the fact that other applications might be running at the same time. As an example,if someone is listening to music at the same time that he or she is sending emails, an additional allocation related to the CPU, GPU, memory, usage should be incorporated.
- The general model for data centres and the assumptions made about the proportionality between the amount of data and their electricity consumption do not take into account the different infrastructures behind different service providers. Additionnaly, the 15 GB associated per user is an arbitrary value that is subjected to change.

4.7. Download a file to a PC

4.7.1. Scope definition

This section is aimed at specifying the scope of the analysis performed on downloading data to a PC. This LCA studies the energy consumption and environmental impact of **downloading data to a PC** under one scenario:

- **1 GB** scenario: download a 1GB file via a fixed network.

The chosen **functional unit** that was used to compare the scenarios is the following:

" Download a file from to a PC"

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

	Technological boundaries: Tiers two and three (see 2.3.4) have been included to model this behaviour. (Network, Data Centres)
	Temporal boundaries: secondary data from literature is from 2019 to 2023.
	Geographical boundaries: secondary data from literature represents the Europe Region.

4.7.2. Life Cycle Inventory

Two scenarios are being modeled for this behaviour. Table 57 shows the input data flows used to estimate the impacts of downloading data to a PC.

Table 57 Input data flows for downloading data to a PC

Input Data Flows		Scenario 1	Scenario 2
Overall parameters	Time spent		
End user environment	Connected Speaker		
	Equipment used		
Network	Video Quality[256]	Fixed high (2,27 Mbps)	Fixed high (2,27 Mbps)
	Type of Network	European Average	European Average

[256] See Section 4 for more information on the Data Quality

	Network Saturation	100%	100%
	Number of subscribers[257]		
Data centre	Equipment used	Average Data centre	Average Data centre
	kWh/h[258]	7,49E-03	7,49E-03

Model: The source to model the impact of Tier 3 comes from a single company. This is a limitation as we are only relying on information of a company whose services we are trying to model.

Download a file to a PC – Tier 2

The Average European network used is defined in **Table 21**. The impacts on the network (fixed and mobile) for the fabrication, transport, use, and end of life phases are calculated with the allocation defined with the PCR (see section 7.2).

Download a file to a PC – Tier 3

The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its consumption.

We have estimated its electricity consumption using Netflix's[259] annual electricity consumption.

Table 58 Netflix consumption information

Netflix parameters	Unit	Value
Number of users	#	167 000 000
Total data transfer	Go	2,46923E+11
Total direct electricity consumed per year	MWh	94 000
Total indirect electricity consumed per year	MWh	357 000
Corresponding power use of video streaming	kW	7,49E-03

Note: We have estimated that an average user watches 2h of netflix per day[260] consuming 4,1 Go/h

[257] See Section 4, after Table 21 for more information on the number of subscribers

[258] See Tier 3 section of Section 4.7.2 for more information

[259] Netflix Environmental Social Governance Report - Sustainability Accounting Standards Board (SASB), 2019

[260] Keslassy, "Netflix's Cindy Holland Says Subscribers Watch an Average of Two Hours a Day."

4.7.3. Results

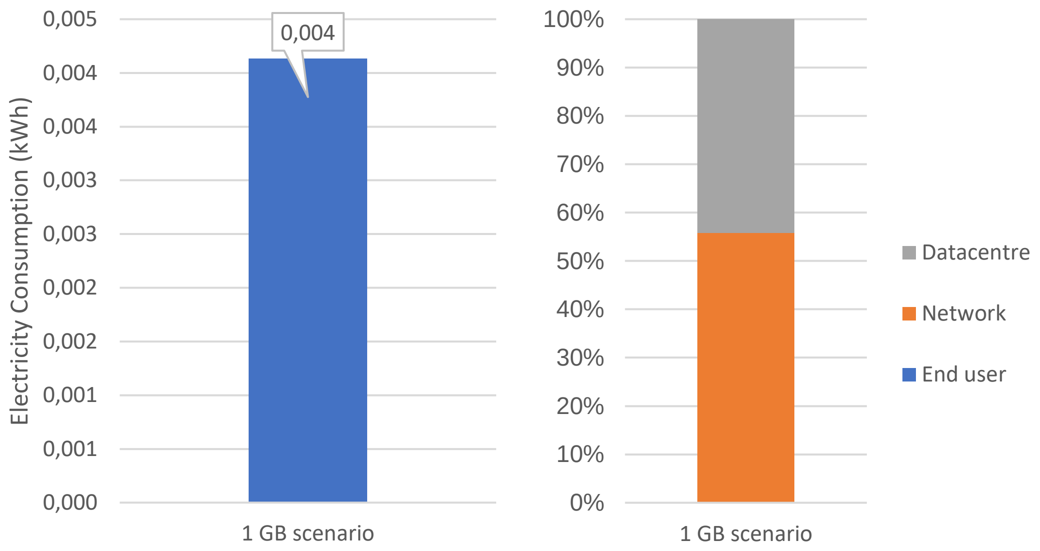
It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

Electricity consumption

The figure below summarises the estimated electricity consumption of downloading data to a PC in the considered scenario:

	• **1 GB** scenario: download a 1GB file via a fixed network.

Figure 28 Electricity consumption of downloading a file to a PC per tier / per scenario



The electricity consumption associated to downloading a file from to a PC accounts for 0,004 kWh. The consumption is evenly split between Tier 2 and Tier 3.

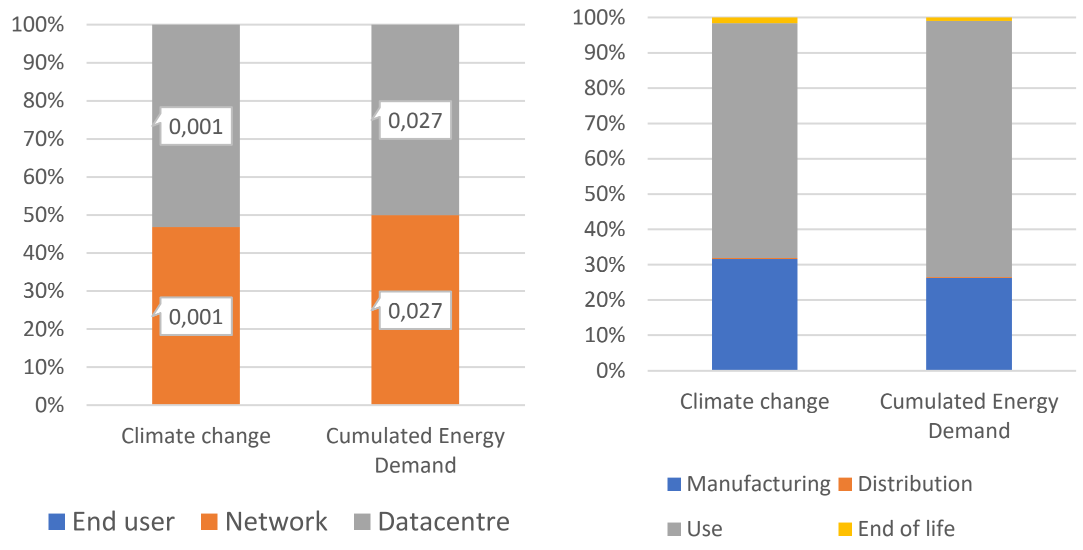
Below are listed good practices to reduce your energy consumption (in order of priority).

	• Try to use fixed networks to download files
	• Try to download the least number of documents

Energy and Global Warming Potential

Below we have calculated the environmental impact of this behaviour following the PEF 3.0 norms described before. In this case the results are showed in terms of Global Warming Potential (GWP), expressed in $kgCO_2eq$, and Cumulative Energy Demand (CED), expressed in MJ.

Figure 29 Environmental impact of downloading a file to a PC for an average European by tier / per life cycle phase



The total equivalent CO_2eqemissions related downloading a file to a PC for the European scenario account for 2 gCO_2eq. In terms of CED, the impact rises to 0,047 MJ. To put these numbers in perspective, this is equivalent to:

- Driving 0.02 km in a car[261], assuming 95 gCO_2eq/km as the European fleet-wide target or 2021

As we can see from Figure 29**Error! Reference source not found.**; most of the impact comes from the Tier 2 and Tier 3. This is coherent with the results on the energy consumption. It is also interesting to see a large part of the environmental impact (Climate Change and Cumulative Energy Demand) comes from the "use" phase; that is actually performing the behaviour. As it is the case in the ICT sector, a significant amount of the impact stems from the manufacturing of the equipment (Manufacturing phase) needed to perform the behaviour.

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators.

[261] "CO2 Performance of New Passenger Cars in Europe."

Figure 30 Environmental impact of downloading data to a PC per indicator and tier

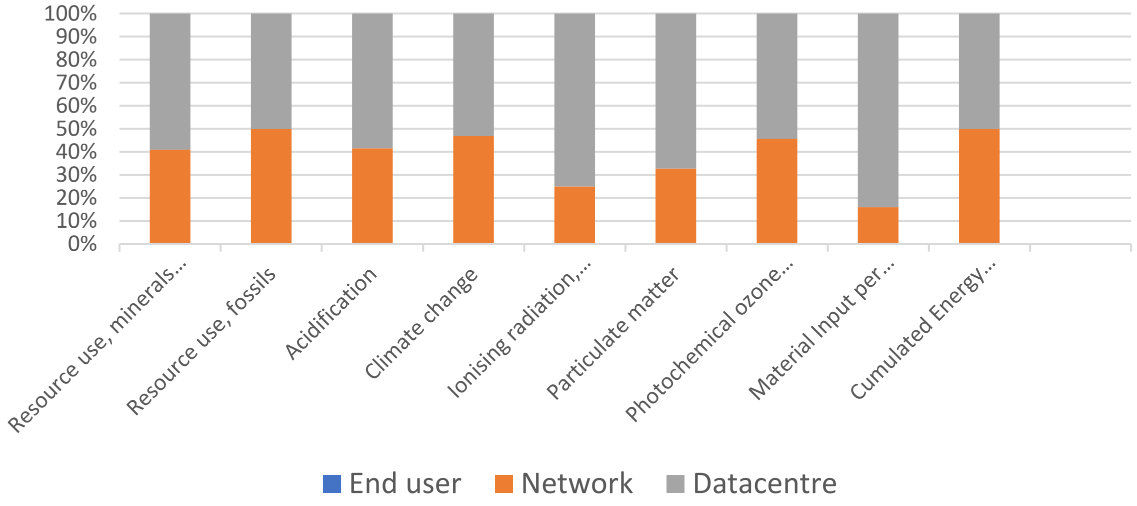


Table 59 Environmental impact of downloading data to a PC

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00
Network	1,4E-08	1,6E-02	4,7E-06	8,0E-04	6,4E-04	1,5E-11	1,9E-06
Data centre	2,5E-08	2,2E-02	8,9E-06	1,2E-03	2,5E-03	4,2E-11	3,0E-06
Total	3,9E-08	3,8E-02	1,4E-05	2,0E-03	3,2E-03	5,7E-11	4,9E-06

Table 60 other indicators on the impact of downloading data to a PC

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	0,0E+00	0,0E+00
Network	5,9E-04	2,0E-02
Data centre	3,8E-03	2,7E-02
Total	4,4E-03	4,7E-02

4.7.4. Conclusion

The environmental footprint of downloading data to a PC has been calculated following one single scenario.

The study shows the often neglected impact of Cloud services and data downloaded.

- The general model for data centres and the assumptions made about the proportionality between the amount of data and their electricity consumption do not take into account the different infrastructures behind different service providers.

- Additionnaly, the 15 GB associated per user is an arbitrary value that is subject to change or debate.

4.8. Store data in the cloud for N year(s)

4.8.1. Scope definition

This section is aimed at specifying the scope of the analysis performed on storing data in the cloud. This LCA studies the energy consumption and environmental impact of **storing data in the cloud** under different scenarios:

- **1GB** scenario: storing 1GB of data for 1 year in Europe with a fixed network.
- **10GB** scenario: storing 10GB of data for 10 years in Europe with a fixed network.

The chosen **functional unit** that was used to compare the scenarios is the following:

“ Storing Data in the Cloud in Europe”

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

	Technological boundaries: Tiers two and three (see 2.3.4) have been included to model this behaviour. Network Data Centres
	Temporal boundaries: secondary data from literature is from 2019 to 2023.
	Geographical boundaries: secondary data from literature represents the Europe Region.

4.8.2. Life Cycle Inventory

Two scenarios are being modeled for this behaviour. Table 61 shows the input data flows used to estimate the impacts of storing data in the cloud.

Table 61 Input data flows for storing data in the cloud

Input Data Flows		Scenario 1	Scenario 2
Overall parameters	Time spent		
End user environment	Connected Speaker		
	Equipment used		
Network	Data Quality[262]	High (2,22 Mbps)	High (2,22 Mbps)
	Type of Network	European Average	European Average

[262] See Section 4 for more information on the Data Quality

	Network Saturation	100%	100%
	Number of subscribers[263]		
Data centre	Equipment used	Average Data centre	Average Data centre
	Annual kWh/GB[264]	1,47	1,47

Storing Data in the Cloud – Tier 2

The Average European network used is defined in **Table 21**. The impacts on the network (fixed and mobile) for the fabrication, transport, use, and end of life phases are calculated with the allocation defined with the PCR (see section 7.2).

Storing Data in the Cloud – Tier 3

The impact on the service providers follows the model in section 6.3. An average data centre has been modelled for all behaviours. Its impact depends proportionally on its consumption.

We have modeled the impact with Google's green Computing figures[265].

Table 62 Google's parameters

Google's parameters	Unit	Value
Associated storage per user[266]	Gb	15
Annual energy consumption by user	kWh	2,2
Associated annual kWh/Gb	kWh/Gb	1,47

Model: The source to model the impact of Tier 3 comes from a single company. This is a limitation as we are only relying on information of a company whose services we are trying to model.

4.8.3. Results

It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

[263] See Section 4, after Table 21 for more information on the number of subscribers

[264] See Tier 3 section of Store Data in the Cloud for more information

[265] "Google-Green-Computing.Pdf."

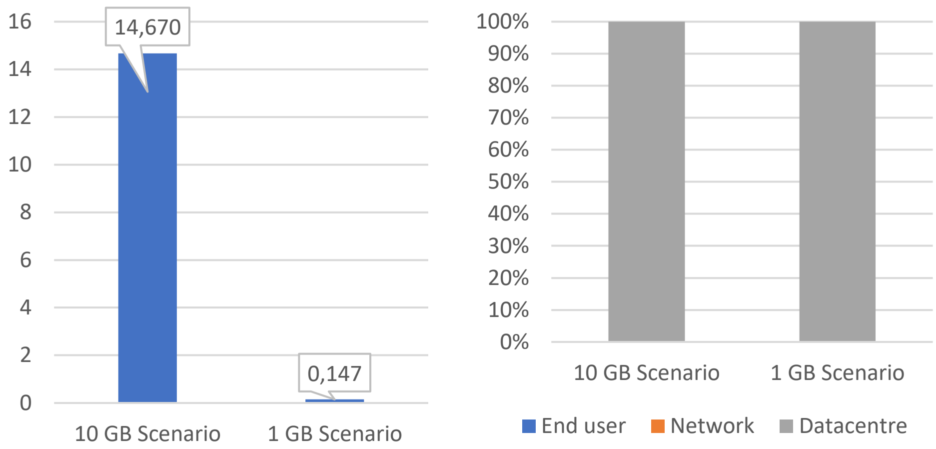
[266] This value is an arbitrary assumption

Electricity consumption

The figure below summarises the estimated electricity consumption storing data in the cloud in the three considered scenarios:

- **1 GB** scenario: storing 1GB of data for 1 year in Europe with a fixed network.
- **10 GB** scenario: storing 10GB of data for 10 years in Europe with a fixed network.

Figure 31 Electricity consumption for storing data in the cloud per tier / per scenario



Storing 1 GB of data in the Cloud for one-year accounts for 0,147 kWh. In both cases all the impact comes from the service provider (Tier 3). The contribution of the network is negligeable and the one from the end user is consider null, as we only focus on the storing and neglect the uploading.

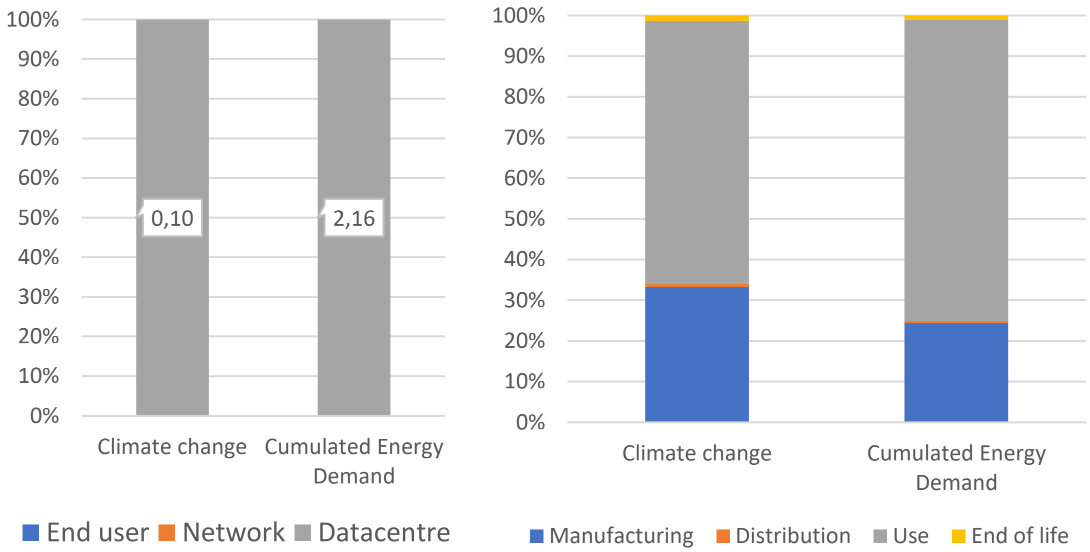
Below are listed good practices to reduce the energy consumption (in order of priority).

- Limit the amount of data stored in the cloud
- Clean regularly the data stored in the cloud

Energy and Global Warming Potential

Below we have calculated the environmental impact of this behaviour following the PEF 3.0 norms described before. In this case the results are showed in terms of Global Warming Potential (GWP), expressed in $kgCO_2eq$, and Cumulative Energy Demand (CED), expressed in MJ.

Figure 32 Environmental impact of storing data in the cloud for an average European by tier / per life cycle phase



In both cases the 1 GB scenario is represented. The total equivalent CO_2eq emissions related to the energy consumption of storing 1 GB of data in the Cloud for one-year in Europe accounts for 98 gCO_2eq. In terms of CED, the impact rises to 2,17 MJ. To put these numbers in perspective, this is equivalent to:

- Driving 1.03 km in a car[267], assuming 95 gCO_2eq/km as the European fleet-wide target or 2021

As we can see from Figure 32; a considerable portion of the environmental impact in terms of climate change and cumulative energy demand is attributed to the 'use' phase. In the case of the ICT sector, a less important but still significant amount of impact also arises from the manufacturing phase that involves building the equipment necessary to engage in the behaviour.

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators. Table 63 and Table 64 provide the figures to support the choosen indicators.

Table 63 Environmental impact of storing data in the cloud

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00	0,0E+00
Network	2,7E-10	7,6E-04	2,2E-07	3,7E-05	2,0E-05	6,2E-13	8,5E-08
Data centre	2,0E-06	1,8E+00	7,2E-04	9,8E-02	2,0E-01	3,3E-09	2,4E-04
Total	2,0E-06	1,8E+00	7,2E-04	9,8E-02	2,0E-01	3,3E-09	2,4E-04

[267] "CO2 Performance of New Passenger Cars in Europe."

Table 64 other indicators on the impact of storing data in the cloud

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	0,0E+00	0,0E+00
Network	0,0E+00	9,4E-04
Data centre	3,0E-01	2,2E+00
Total	3,0E-01	2,2E+00

4.8.4. Conclusion

The environmental footprint of storing data in the cloud has been calculated following two different scenarios to be able to cover different behaviours.

The study shows the often neglected impact of Cloud services. In most cases, limiting the quantity of data stored in the cloud is a solution to lower the impact. Storing data locally is a recommended alternative (very low passive consumption – not calculated in this model) . We are confident on the electricity consumption of service providers. However, this evaluation comprises several limits that are necessary to be communicated:

- The general model for data centres and the assumptions made about the proportionality between the amount of data and their electricity consumption do not take into account the different infrastructures behind different service providers.
- Additionnaly, the 15 GB associated per user is an arbitrary value that is subjected to change.

4.9. Prolong the lifespan of a phone

4.9.1. Scope definition

This section is aimed at specifying the scope of the analysis performed on extending the lifetime of a smartphone. This LCA studies the energy consumption and environmental impact of **extending the lifetime of a smartphone** under one scenario:

- **3 to 5 years** scenario: extending the lifespan of a smartphone from 3 to 5 years.

The chosen **functional unit** that was used to compare the scenarios is the following:

"Extend the lifespan of a smartphone from 3 to 5 years"

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

	Technological boundaries: Tier one (see 2.3.4) has been included to model this behaviour. Users
	Temporal boundaries: secondary data from literature is from 2019 to 2023.
	Geographical boundaries: secondary data from literature represents the Europe Region.

4.9.2. Life Cycle Inventory

The scenario is being modeled for this behaviour. Table 65 shows the input data flows used to estimate the impacts of extending the lifetime of a smartphone.

Table 65 Input data flows for extending lifetime of smartphone

Input Data Flows		Scenario
Overall parameters	Initial smartphone lifespan (years)	3
	Final smartphone lifespan (years)	5

Extending the lifetime of a smartphone – Tier 1

Users

The impacts on the end-user environment equipment (smartphones) for the fabrication, transport, and end of life phases are calculated with a temporal allocation (see section 7.1). The impacts of the use phase are also modeled with a temporal allocation and are defined in section 7.1.8.

4.9.3. Results

It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

Environmental impact

The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators. Table 66 and Table 67 provide the figures to support the choosen indicators.

Table 66 Environmental savings per year of extending the lifetime of a smartphone

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
End user	4,3E-04	1,1E+02	5,3E-02	8,7E+00	2,4E+00	3,0E-07	2,2E-02

Extending the lifespan of a smartphone allows you to save up to 8.7 kg CO_2eq per year. This is equivalent to:

- Driving 91.6 km in a car[268], assuming 95 gCO_2eq/km as the European fleet-wide target or 2021.

Over five years such saving accounts for 43.5 kg CO_2eq which represent a 40% reduction of the impact associated to the manufacturing of an average smartphone.

Table 67 other indicators on the savings per year of extending the lifetime of a smartphone

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
End user	3,4E+01	1,1E+02

4.9.4. Conclusion

The environmental footprint of extending the lifetime of smartphone has been calculated following one single scenario.

The study shows the importance of the contribution of the daily devices that we use and the "hidden" impact behind. Fabricating a smartphone has a non negligeable environmental impact. Not only because of the CO_2eq emissions, but all ICT devices are built using rare earth metals that become more and more difficult to extract, as their concentration keeps decreasing. We should prolong the lifespan our of ICT equipments, repair them instead of replacing them. Below are some of the limitation of the study for this behaviour:

- This study does not take into account the fact that old devices may be less energy-efficient than new ones.

[268] "CO2 Performance of New Passenger Cars in Europe."

- The study does not consider that in reality, certain devices may be difficult or expensive to repair, or may not be designed to be repaired at all, which could limit the potential environmental benefits of extending their lifespan.

4.10. Switch off the Wi-Fi router

4.10.1. Scope definition

This section is aimed at specifying the scope of the analysis performed on switching off a Wi-Fi router for a number of weeks. This LCA studies the energy consumption and the environmental impact of **switching off a Wi-Fi router** under one scenario:

- **2 weeks** scenario: Switch off a Wi-Fi router for two weeks.

The chosen **functional unit** that was used to compare the scenarios is the following:

"Switching off a Wi-Fi router in Europe in 2023"

Following the methodology in section 2.3.4; we provide with specific methodological assumptions.

Product system to be studied:

	Technological boundaries: Tier two (see 2.3.4) has been included to model this behaviour. Network
	Temporal boundaries: secondary data from literature is from 2019 to 2023.
	Geographical boundaries: secondary data from literature represents the Europe Region.

4.10.2. Life Cycle Inventory

One scenario is being modeled for this behaviour. Table 68 shows the input data flows used to estimate the impacts of switching off a router.

Table 68 Input data flows for switching off a router

Input Data Flows		Scenario
Overall parameters	Time off	2 weeks
	Type of network device	Wi-Fi router

Switching off a router – Tier 2

Network

The impact of the router has been calculated using information on the table below; with a temporal allocation (see section 7.1).

Table 69 Router specifications

Router specifications	Active W	Standby W	Active h	Standby h
xDSL	14,4	10,5	4,5	19,5
FTTx	11,25	8,86	4,5	19,5

4.10.3. Results

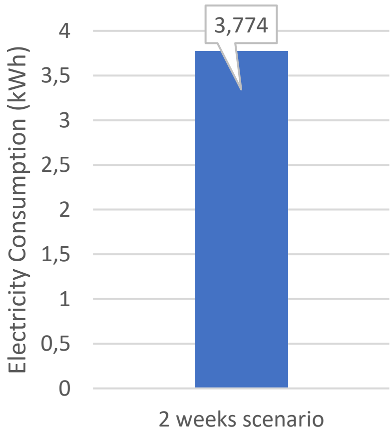
It is important to remember that according to ISO 14044:2006 standard, the results of the LCA are relative expressions and do not predict effects on final impact categories, exceeding thresholds, safety margins, or risks. Below the detailed results for each of the selected scenarios are presented.

Electricity consumption

The figure below summarises the estimated electricity consumption of switching off a router in the single scenario considered:

	• **2 weeks** scenario: Switch off a Wi-Fi router for two weeks.

Figure 33 Electricity consumption of switching off a router per tier / per scenario



Switching off a router for two weeks allows you to save **3.77 kWh**. This is equivalent to:

- Turning on a **kettle** for **one hour and 15 minutes**[269]
- Using a laptop for 194 hours[270].

[269] https://www.tameside.gov.uk/EnergyEfficiency/Top-Tips-%E2%80%93-June-Don%E2%80%99t-Fill-The-Kettle-Too-Full#:~:text=The%20average%20kettle%20is%20between,of%20kilowatts%20used%20per%20hour

[270] https://librairie.ademe.fr/changement-climatique-et-energie/4473-panel-usages-electrodomestiques.html

Network-connected standby devices: since January 2019, devices in networked standby must not consume more than 8W[271] in the EU. When turned off for two weeks, a router of these characteristics would save 2,69 kWh. To be coherent with the rest of the study, we have however decided to communicate using the LCA methodology.

Environmental impact

- The results of a LCA allows us to extend the environmental impact of the behaviour to a large number of environemental indicators. Table 70 and Table 71 provide the figures to support the choosen indicators. .

Table 70 Environmental impact of switching off a router

	Resource use, minerals and metals (kg SB eq.)	Resource use, fossils (MJ)	Acidification (mol H+ eq.)	Climate change (kg CO2 eq.)	Ionizing radiation, human health (kg U235 eq.)	Particulate matter (Disease occurrence)	Photochemical ozone formation (kg NMVOC eq.)
Network	9,6E-05	4,1E+01	1,3E-02	2,2E+00	1,5E+00	4,7E-08	5,1E-03

Switching your router for two weeks allows you to save up to 2,2 kg CO_2eq. This is equivalent to:

- Driving 23.2 km in a car[272], assuming 95 gCO_2eq/km as the European fleet-wide target or 2021

Table 71 other indicators on the impact of switching off a router

	Material Input per Service-Unit (kg)	Cumulative Energy Demand (MJ)
Network	3,4E+00	4,9E+01

4.10.4. Conclusion

The environmental footprint of switching off a router for two weeks has been calculated following a single scenario.

The study shows the importance of the contribution of the daily devices that we use and the simple actions we can do to limit the impact that we have. This evaluation comprises several limits that are necessary to be communicated:

- Wi-Fi routers have very different configurations. Its consumption can vary from different models.

[271] "Off Mode, Standby and Networked Standby," accessed May 1, 2023, https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/energy-label-and-ecodesign/energy-efficient-products/mode-standby-and-networked-standby-devices_en.

[272] "CO2 Performance of New Passenger Cars in Europe."

5. Best practices to save energy, limitations, and recommendations

In this chapter, we first present the recommended best practices to save energy that have been identified from the literature review and from the performed modelling exercise. Then, the limitations of the study are introduced together with relevant policy recommendations.

5.1. Recommended best practices to save energy

The table below summarises the recommended best practices that have been identified from the literature review to save energy for each of the ten digital behaviours considered in the study. As presented in the previous section, the energy savings that can be achieved through some of these best practices have been estimated and confirmed when quantifying the energy consumption of the day-to-day digital behaviours.

Reducing the video resolution when streaming a movie or watching a video, for example, proved to be an effective way of reducing the energy consumption associated with this digital behaviour, and has been largely confirmed in the scientific literature.

Switching off the Wi-Fi router when not needed, for example when leaving for an extended period of time, is another example of a proven best practice that can effectively generate significant energy savings when compared with the typical energy consumption of other IT equipment such as a laptop or a PC.

Table 72 Good practices found in the literature

Behaviour	Quote from literature
Video streaming	*Reduce video resolution if the content does not really demand high resolution can save energy* (Contellation, 2020[273]; Ejenbi et al, 2015[274]; Tabata and Wang, 2021[275]) *Watching a video on the Wi-Fi is less energy consuming than with a 4G* (Ademe, 2022[276])
Video gaming	*Reduce time spent on video gaming* (Contellation, 2020[277]) *Activate power-saving settings* (Contellation, 2020[278]) *Reduce the definition of game play* (The computer games journal, 2019[279])
Video conferencing	*Switching off the camera can minimise the energy used* (Greenspector, 2022[280])

[273] https://blog.constellation.com/2020/05/15/energy-consumption-of-streaming-services/

[274] https://research-repository.st-andrews.ac.uk/handle/10023/9353?show=full

[275] https://www.mdpi.com/2076-3417/11/9/3992

[276] https://librairie.ademe.fr/dechets-economie-circulaire/5942-evaluation-de-l-impact-environnemental-de-la-digitalisation-des-services-culturels.html

[277] https://blog.constellation.com/2020/05/15/energy-consumption-of-streaming-services/

[278] https://blog.constellation.com/2020/05/15/energy-consumption-of-streaming-services/

[279] https://link.springer.com/article/10.1007/s40869-019-00084-2

[280] The impact of our videoconferencing uses on mobile and PC! 2022 edition - Greenspector

	Using headphones during a video conference can reduce energy consumption by up to 25% (Greenspector, 2022[281])
Music streaming	*Download instead of streaming music* (Rolling Stone, 2022[282])
Social networking	*Reducing scrolling time* (Greenspector, 2022[283])
Writing or sending an email	*Unsubscribe from mailing lists when unnecessary* (Ademe/Arcep, 2022[284]) *Reduce the number of emails sent* (Ovoenergy, 2019)
Download a file to a PC	No relevant information was found in the literature coming from reliable sources.
Store data in the cloud of N years	*Limit cloud use when possible* (Green IT, 2020[285]) (Toffeshare, 2020[286]) (Cloud carbon footprint, 2022[287]) *Use local applications instead when possible* (IEEE, 2015[288]); *Use external hard drive* (Greenly, 2022[289])
Prolong the use life of a smart phone	*Extending the life of a smartphone as much as possible* (Greenspector, 2020[290]) (EEA, 2020[291]) (European Investment Bank, 2019[292]) (Green Alliance, 2015[293]) (EIONET, 2020[294]) (Cordella et al, 2021[295]) (EEB, 2019[296])
Switch off the Wi-Fi router	*Switching off the Wi-Fi router is the most energy-efficient solution*, (Green IT, 2020) (Les Numeriques, 202) (Ademe, 2022), *alternative solutions can be deep standby (eco standby) mode* (Proximus, 2022)

Building an energy and environmental model has allowed us to find the scenarios to minimize the energy consumption and the environmental impacts of the ten digital

[281] The impact of our videoconferencing uses on mobile and PC! 2022 edition - Greenspector

[282] https://www.rollingstone.com/music/music-features/earth-day-climate-change-streaming-downloading-ajr-1339228/

[283] https://greenspector.com/en/6168-2/

[284] https://www.arcep.fr/actualites/actualites-et-communiques/detail/n/environnement-190122.html

[285] https://agirpourlatransition.ademe.fr/particuliers/maison/economies-denergie/electricite-combien-consomment-appareils-maison

[286] https://toffeeshare.com/blog/15/How-much-energy-does-it-cost-to-store-data-online/

[287] https://figshare.com/articles/preprint/Quantified_Carbon_Footprint_of_Long-Term_Digital_Preservation_in_the_Cloud/20653101

[288] https://www.researchgate.net/publication/275156618_Energy_Consumption_of_Interactive_Cloud-Based_and_Local_Applications

[289] https://greenly.earth/en-us/blog/ecology-news/what-is-the-carbon-footprint-of-data-storage

[290] https://greenspector.com/en/impact-playing-canal-video/#resultats

[291] https://www.eea.europa.eu/publications/europe2019s-consumption-in-a-circular/benefits-of-longer-lasting-electronics

[292] https://www.eib.org/en/stories/digital-footprint

[293] https://www.circularonline.co.uk/wp-content/uploads/2015/02/A-circular-economy-for-smart-devices.pdf

[294] https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/electronics-and-obsolescence-in-a-circular-economy

[295] https://onlinelibrary.wiley.com/doi/10.1111/jiec.13119

[296] https://eeb.org/wp-content/uploads/2019/09/Coolproducts-briefing.pdf

behaviours. Table 73 summarizes the recommendations to lower the environmental impact of the day-to-day digital behaviours.

Table 73 Good practices found with the model

Behaviour	Recommendations to limit the impact of the behaviours based on the model
Video streaming	*As a rule of thumb, smaller devices (smartphones, tablets) consume less energy than TV's and desktops. Where possible, try to use fixed networks rather than mobile networks. If you are going to see a video several times, then downloading it might be a good option (but don't forget, most of the impact comes from the size of the device that you use in your home).*
Video gaming	*Turn off the speaker and play on smaller devices such as smartphone or laptop instead of your desktop. Also, reducing the number of screens, the size of them, using fixed networks instead of 4G or 5G will have less impact.*
Video conferencing	*Use smaller devices if the purpose of the meeting is simply to make a call. Turning off your camera might improve the stability of the connection but most of the impact will still come from your desktop or your laptop.*
Music streaming	*Use smaller devices to listen to music. Instead of using your TV to watch music, use your phone. If it is connected to a speaker, it will still consume less energy and have less impact that a desktop or TV.*
Social networking	*The recommendations are very similar to the ones of video streaming. If you want to limit your impact, simply limit your usage. Scrolling through your social media platform only twice a day will lower the energy consumption and most probably improve your focus. Also, using smaller devices and fixed networks instead of 4G or 5G is effective as it consumes less energy. Finally, social media with more static content and less or no video will also have less environmental impact.*
Writing or sending an email	*Limit the number of emails that you send per day, especially the time spent writing and reading them. Reduce the number of recipients and the size of the attached files. Finally, unsubscribe from unnecessary newsletters.*
Download a file to a PC	*Use fixed networks to download files, like Wi-Fi or Ethernet instead of 4G or 5G. Limit the number of files to download.*
Store data in the cloud for N year(s)	*Cloud allows to mutualize resources and be more efficient. However, by limiting the number of connections to the servers, you will reduce the amount of information that goes through the network and so the energy consumption. You should save your files on the cloud only if necessary and delete the files that are not needed anymore. The less information you store, the less consumption associated. For more energy savings, you can also turn off automatic syncing of photo uploads, for example.*
Prolong the lifespan of a phone	*Extend the lifetime as much as possible. It has a significant impact. The environmental impact of the ICT sector is significant. Not only in terms of CO_2eq. emissions, but mostly related to the consumption of rare earth metals that are harder and harder to find. The pollution associated with the manufacturing of a*

	smartphone, or any other ICT equipment is not negligeable, and these objects are hard to recycle.
Switch off the Wi-Fi router	*Switching off the Wi-Fi router while on holidays/away from home is a simple behaviour that will take a few seconds of your time and will save a significant amount of energy. You can even turn it off when you do not need it like at night.*

5.2. Limitations and recommendations

In order to estimate the energy consumption of the behaviours, a number of assumptions have been made to allocate, interpolate and complete information when data was missing. The following section illustrates the main limitation of the study and suggest recommendations to limit those assumptions.

Environmental impact of Products: The NegaOctet Database has been used to estimate the environmental footprint of the ICT products used in the LCA. The impacts of the elements in this database do not come from manufacturers information, but they have rather been retroengineered, broken down, weighted and measured. This allows to have a consistent database which is critical when performing a LCA, but does not represent entirely the associated impacts. In order to solve this issue, the Ecodesign and energy labelling working plan 2022-2024[297] could explore product specific requirements on other environmental impacts (followig the PEF guidelines or the PCRs). The imposition of industry standards for environmental reporting for the ICT sector is critical towards transparency for consumers.

Environmental footprint of Networks: The environmental footprint of the Tier 2 infrastructure (networks) has been calculated using the the PCR Internet Service Provision guidelines from ADEME. This methodology is clear and allows to communicate on a transparent manner to consumers. However, the application of these guidelines is limited to the French geography and does not yet cover the whole European region. In France, the guidelines are currently being tested with telecom operators and will become mandatory from January 2024 onwards.

Environmental footprint of Data centres: A major limitation of this study stems from the modelling of the environmental footprint of Tier 3 infrastructure. Large Hyperscalers don't communicate their environmental footprint using standardized methodologies. In 2022, Data centres and data transmission networks accounted for nearly 1% of GHG emissions[298]. Even if these companies communicate their GHG annual emissions, this does not allow companies and public actors to measure the environmental impact of the services hosted in those data centres. We are confident that the introduction of an "environmental labelling scheme for data centres"[299] by the EU commission by 2025 will help solving this issue.

Environmental footprint of Services: Another limitation related to the environmental modeling of the Tier 3 infrastructure is the lack of information on the impact of digital services. For example, in order to estimate the energy consumption of video streaming, we needed information on the service provider, for instance on the annual electricity consumption, the type of hardware supporting the infrastructure and annual use of the service in Europe. Most of the targeted companies have this information, but they often do not disclose the information. In an effort of promoting transparency, it is recommended to work towards a transparency on energy efficiency end environmental reporting label for consumer services.

Additional LCA reporting standards: one last recommendation is related to the LCA allocation methods for the environmental impact of apps and other services running on the same device. To date, there is no consensus on the allocation technique that should be preferred to quantify the impact of using an app on a phone (for example) when multipe systems are running at the same time. An allocation by % of CPU or Memory could be used. In addition, it should be considered that this allocation should be consistent with different

[297] "The Ecodesign and Energy Labelling Working Plan 2022-2024," accessed May 1, 2023, https://commission.europa.eu/news/ecodesign-and-energy-labelling-working-plan-2022-2024-2022-04-06_en.

[298] "Data Centres and Data Transmission Networks – Analysis," IEA, accessed May 1, 2023, https://www.iea.org/reports/data-centres-and-data-transmission-networks.

[299] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0552&from=EN

models, different equipments in different configurations. As this represent a major limitation of the study, it could be interesting to conduct a follow-up study aimed at establishing guidelines on the environmental reporting of these services.

6. Appendix 1 – Literature used to map existing estimates

List of papers used to map existing estimates in the literature
"A circular economy for smart devices
"Calculating the Carbon Footprint of Streaming Media: Beyond the Myth of Efficiency", Makonin et al, 2020
"Electronic products and obsolescence in a circular economy", EIONET report, 2020
"Quantified Carbon Footprint of Long-Term Digital Preservation in the Cloud, Cloud carbon footprint , 2022
"the global e-waste monitor 2017
'How Bad are Bananas?: The Carbon Footprint of Everything , Mike Berners-Lee, 2020
'Think Before You Thank': If every Brit sent one less thank you email a day, we would save 16,433 tonnes of carbon a year - the same as 81,152 flights to Madrid, Ovoenergy, 2019
2020 Sustainabiliy reporting Spotify 2020
Best Environmental Management Practice in the Telecommunications and ICT Services sector Joint Research Center - European Commission 2020
Carbon and the Cloud, Stanford Magazine, 2017
Clarifying the Confusion Over Turning Off Wi-Fi vs Broadband at Nigh, ISPreview, 2020
Client-side energy costs of video streaming Ejembi et al. 2020
Comparison of the energy, carbon and time costs of videoconferencing and in-person meetings, Ong et al.
Coolproducts don't cost the earth EEB, 2019
COVID19 : 4 gestes clés pour réduire mon empreinte numérique, GreenIt, 2020
Decomposed: The Political Ecology of Music Kyle Devine 2017
DIGITAL TECHNOLOGIES IN EUROPE: an environmental life cycle approach, The Greens/EFA 2021
Drivers and effects of digitalisation on energy demand in low carbon scenarios, University of Sussex, 2022
Ecodesign Impact Accounting Annual Report 2020 European Commission 2020
Électricité : combien consomment les appareils de la maison ?, Ademe , 2020
Energy Consumption Comparison of InteractiveCloud-Based and Local Applications, IEEE Journal On Selected Area in Communication Atio, 2020
Energy Consumption of Streaming Services Constellation, 2020
ENQUETE ANNUELLE « POUR UN NUMERIQUE SOUTENABLE » edition 2022 ARCEP
Europe's consumption in a circular economy: the benefits of longer-lasting electronics, EEA, 2020
EVALUATION DE L'IMPACT ENVIRONNEMENTAL DU NUMERIQUE EN FRANCE (note de synthese, 1er volet 2eme volet de l'etude) Arcep/Ademe 2022

Evaluation de l'impact environnemental de la digitalisation des services culturels, ADEME, 2022

How Bad are Bananas: The Carbon Footprint of Everything Mike Berners -lee 2010(2020 revised)

How Much Energy Do Game Consoles Really Use?, Constellation, 2020

How To Reduce Your Carbon Impact In An Expanding Digital Ecosystem ENGIE Impact 2022

ICT Impact study European Commission 2020

Identifying the impact of the circular economy on the Fast-Moving Consumer Goods Industry: opportunities and challenges for businesses, workers and consumers mobile phones as an example , European Economic and Social Committee, 2019

Is Streaming Music Dangerous to the Environment? One Researcher Is Sounding the Alarm Rolling Stone 2019

L’empreinte carbone du numérique" Arcep 2020

Life Cycle Assessment of CO2 Emissions of Online Music and Videos Streaming in Japan, Tabata and Wang, 2021

Life cycle environmental impacts of a smartphone, Ericsson, 2016

Opportunities in the US, UK and India", Green Alliance , 2015

Plan sobriete energetique , French gov, 2022

Pour un numerique soutenable 2020 ARCEP 2020

Powering a google search, Google

Protect the Planet: Stop Streaming Songs, Rolling Stone, 2022

Quantities, Flows, and Resources", UN, 2020

Reducing the carbon footprint of ICT products through material efficiency strategies: A life cycle analysis of smartphones Cordella et al. 2021

Save the Planet: Replace Email Attachments With File Share Links, Medium, 2020

Study on Greening Cloud Computing and Electronic Communicaitons Services and Networks , European Commission , 2022

The Carbon Benefits of Cloud Computing: a Study of the Microsoft Cloud Microsoft, 2020

the carbon impact of Instagram app features Greenspector 2020

the cost of music Brennan and Devine 2019

The Dark Side of the Tune: The hidden Energy Cost of Digital Music Consumption, DAGFINN Bach, 2012

The Global Internet Phenomena report. COViD 19 spotlight. Sanvine, 2020

The Impact of playing a Canal + video study, Greenspector, 2020

The Latest-Generation Video Game Consoles How Much Energy Do They Waste When You’re Not Playing? A study by the Natural Resources Defense Council (NRDC), 2014

The Megawatts behind Your Megabytes: Going from Data-Center to Desktop, ACEEE, 2012

The overlooked environmental footprint of increasing Internet use	Obringer et al, 2021
Turn off your appliances or unplug them? We take a look at the different options!, Proximus, 2022	
What colour is the cloud? European Investment Bank , 2019	
What is the Carbon Footprint of Data Storage?, Greenly, 2022	
Which video conferencing mobile application to reduce your impact? 2021 Edition, Greenspector, 2021	

7. Appendix 2 – Life Cycle Inventory

To estimate the energy consumption levels of the ten digital behaviours considered, we modelled each of the behaviours according to their impacts in relation to the following three different blocks:

- The first block covers all the end-user equipment used by the person who is performing the behaviour (laptop, smartphone, speaker, etc.).
- The second block covers the network equipment needed to transport the information from the user to the service provider through the core and the edge network.
- The third bock covers the infrastructure from the service provider, that is the data centres used by services like Netflix or Spotify.

7.1. *LCI of End-User environment*

This section presents the **main assumptions and the main LCIA factors** used to characterise the end user environment. This one is composed of a terminal (smartphone, laptop, PC & monitor, TV, tablet) and, in some cases, of an external audio device.

7.1.1. *Life Cycle Inventory of a Desktop*

This equipment has been modelled using the NegaOctet database. **Different configurations** of this equipment have been used. These factors cover the impacts of the fabrication, distribution, and end of life of the equipment.

- Desktop “Basical desktop (model type : 1 CPU 126 mm² 14 nm lithography, 4 GB RAM, 256 GB SSD, integrated graphic card) - office use”
- Desktop “Middle-range desktop (model type : 1 CPU, 8 GB RAM, 1000 GB HDD, 256 GB SSD, separated graphic card). Default configuration.”
- Desktop “Gaming desktop (model type : 1 CPU, 8 GB RAM, 1000 GB HDD, 256 GB SSD, separated graphic card)”
- Desktop “High performance desktop (model type : 1 CPU, 16 GB RAM, 2000 GB HDD, 512 GB SSD, separated graphic card)”
- Desktop “Power user desktop (model type : 1 CPU, 16 GB RAM, 2000 GB HDD, 1024 GB SSD, separated graphic card)”

To estimate an average laptop used at European level, **we considered the share of market per type of computer used in the study** “Digital technologies in Europe: an environmental life cycle approach, 2021”[300]:

- Desktop *“Basic desktop”;* 18% of the market share in Europe
- Desktop *“Middle-range desktop”;* 16% of the market share in Europe
- Desktop “Gaming desktop”; 31% of the market share in Europe
- Desktop “*High performance desktop”;* 14% of the market share in Europe
- Desktop “*Power user desktop”;* 21% of the market share in Europe

[300] http://extranet.greens-efa-service.eu/public/media/file/1/7388

For the use phase of this equipment, we have considered the annual electricity consumption of a desktop. The detailed calculations for the corresponding consumption are found in the section 7.1.8.

7.1.2. *Life Cycle Inventory of a laptop*

This equipment has been modelled using the NegaOctet database. Different configurations of this equipment have been used. These factors cover the impacts of the fabrication, distribution, and end of life of the equipment.

- Laptop "Chromebook laptop (computer model type : 14.5 inches display, 1 CPU, 13 GB RAM, 427 GB SSD, integrated graphic card)"
- Laptop "Office laptop (computer model type : 14.5 inches display, 1 CPU, 8 GB RAM, 564 GB SSD, integrated graphic card)"
- Laptop "Gaming laptop (computer model type : 15.6 inches display, 1 CPU, 16 GB RAM, 512 GB SSD, separated graphic card)".

To estimate an average laptop used at European level, we considered the share of market per type of computer used in the study *"Digital technologies in Europe: an environmental life cycle approach, GreenIT.fr, 2021"*

- Laptop "Chromebook laptop"; 39% of the market share in Europe
- Laptop "Office laptop"; 49% of the market share in Europe
- Laptop "Gaming laptop"; 12% of the market share in Europe

For the use phase of this equipment, we have considered the annual electricity consumption of a laptop. The detailed calculations of the corresponding consumption are found in the section 7.1.8.

7.1.3. *Life Cycle Inventory of a computer monitor*

This equipment has been modelled using the NegaOctet database. **Different configurations** of this equipment have been used. These factors cover the impacts of the fabrication, distribution, and end of life of the equipment.

- Screens "Computer monitor; 24 inches, LCD"
- Screens "Computer monitor; 39 inches, OLED".

To estimate the average computer monitor used at European level, we considered the **share of market per type of computer monitor** used in the study *"Digital technologies in Europe: an environmental life cycle approach, GreenIT.fr, 2021"*

- Screens *"Computer monitor; 24 inches, LCD*; 99% of the market share in Europe
- Screens "Computer monitor; 39 inches, OLED"; 1% of the market share in Europe.

For the use phase of this equipment, we have considered the annual electricity consumption of a computer monitor. The detailed calculations of the corresponding consumption are found in the section 7.1.8.

7.1.4. *Life Cycle Inventory of a tablet*

This equipment has been modelled using the NegaOctet database. **Different configurations** of this equipment have been used. These factors cover the impacts of the fabrication, distribution, and end of life of the equipment.

- Tablet "Entry-Level - Small storage capacity tablet (model type : 10.2 inches display LCD, 1 CPU, 4 GB RAM, 32 GB SSD)"
- Tablet "Mid-range - Mid storage capacity tablet (model type : 10.3 inches display LCD, 1 CPU, 4 GB RAM, 256 GB SSD)"
- Tablet "High-end - High storage capacity tablet (model type : 11.1 inches display LCD, 1 CPU, 6 GB RAM, 512 GB SSD)".

To estimate the average tablet used at the European level, we considered the **share of market per type of tablet** used in the study *"Digital technologies in Europe: an environmental life cycle approach, GreenIT.fr, 2021"*

- Tablet *"Entry-Level";* 20% of the market share in Europe
- Tablet *"Mid-range";* 60% *of the market share in Europe*
- Tablet *"High-end"; 20% % of the market share in Europe*

For the use phase of this equipment, we have considered the annual electricity consumption. The detailed calculations of the corresponding consumption are found in the section 7.1.8.

7.1.5. *Life Cycle Inventory of a smartphone*

This equipment has been modelled using the NegaOctet database. **Different configurations** of this equipment have been used. These factors cover the impacts of the fabrication, distribution, and end of life of the equipment.

- Smartphone "Entry-Level - Entry-level smartphone (model type : 6.59 inches display LCD, 1 CPU, 6 GB RAM, 128 GB SSD)"
- Smartphone "Mid-range - Mid-range smartphone (model type :6.57 inches display OLED, 1 CPU, 7 GB RAM, 160 GB SSD)"
- Smartphone "High-end - High-end smartphone (model type : 6.72 inches display OLED, 1 CPU, 11 GB RAM, 341 GB SSD)"

To estimate the average smartphone used at European level, we considered the **share of market per type of smartphone** used in the study *"Digital technologies in Europe: an environmental life cycle approach, GreenIT.fr, 2021"*

- Smartphone *"Entry-Level";* 30% of the market share in Europe
- Smartphone *"Mid-range";* 50% *of the market share in Europe*
- Smartphone *"High-end";* 20% *of the market share in Europe.*

For the use phase of this equipment, we have considered the annual electricity consumption of a smartphone. The detailed calculations of the corresponding consumption are found in the section 7.1.8.

7.1.6. *Life Cycle Inventory of a television*

This equipment has been modelled using the NegaOctet database. **Different configurations** of this equipment have been used. These factors cover the impacts of the fabrication, distribution, and end of life of the equipment.

- Television “45 in, LCD”
- Television “68 in, OLED”

To estimate the average TV used at European level, we considered the **share of market per type of TV** used in the study *“Digital technologies in Europe: an environmental life cycle approach, 2021”*.

- Television *“45 in, LCD”;* 98,6% of the market share in Europe
- Television *“68 in, OLED”;* 1,4% of the market share in Europe.

For the use phase of this equipment, we have considered the annual electricity consumption of a television. The detail calculations of the corresponding consumption are found in the section 7.1.87.1.8

7.1.7. *Life Cycle Inventory of a connected Speaker*

This equipment has been modelled using the NegaOctet database. These factors cover the impacts of the fabrication, distribution, and end of life of the equipment.

- Connected speaker

For the use phase of this equipment, we have considered the annual electricity consumption. The detail calculations of the corresponding consumption are found in the section 7.1.8

7.1.8. *Use phase of end-use equipment*

For the use phase (that is the electricity consumption when using any end-user elements), we have used the **annual kWh consumption** of the element (see the table below). When combined with the **average number of hours used in a day** (see the table below), we can easily estimate the corresponding power as depicted in the equation below.

The associated electricity consumption is then calculated. The electricity mix used to calculate the environmental impact during the use phase comes from the Eco Invent Database, version 3.8: “**Electricity Mix; market for; Low voltage; UE-27**”. The impact is calculated using the equation below.

$$Power\ (kW) = \frac{Annual\ consumption(kWh)}{number\ of\ days\ in\ a\ year * average\ use\ of\ a\ device\ per\ day}$$

$$Behaviour\ Energy\ Consumption(kWh) = Power\ (kW) * duration\ of\ behaviour(h)$$

$$CO2\ emissions = Behaviour\ Energy\ Consumption(kWh) * CO2\ content\ of\ electricity\ mix$$

Table 74 End-User equipment description

Equipment	Unit	Average power of digital equipment	Unit	Average usage per person per day	Unit	Lifetime	Source
Desktop	kWh/year/device	104.39	h	3.54	years	2.5	[Digital technologies in Europe: an environmental life cycle approach, GreenIT.fr, 2021]()
Laptop	kWh/year/device	30.96	h	3.56	years	3	
Monitor	kWh/year/device	70	h	3.54	years	4	
Tablet	kWh/year/device	17.57	h	2.41	years	5.5	
Smartphone	kWh/year/device	3.9	h	2.41	years	6	
TV	kWh/year/device	179	h	3.65	years	6	
TV box	kWh/year/device	73	h	3.65	years	5	
Speaker	kWh/year/device	23	h	4	years	5	

7.2. *LCI of Fixed and Mobile network*

This section introduces the main assumptions as well as the main LCIA factors used to characterize the **transmission of the information** that goes from the user environment to the data centres of the service providers. In this case we will be modelling fixed network (xDSL, FFTx) and mobile networks (2G, 3G, 4G and 5G).

7.2.1. *LCI of fixed network*

We modelled this infrastructure with the NegaOctet Database. This factor covers the impacts of the fabrication, distribution, use and end of life of the equipment.

- Fixed-line network; at consumer; xDSL, FFTx average mix ; EU-28 (**line**)

This element covers both edge and core network (modem included). The unit of this element is expressed in “annual impact per line”. In order to have an impact in GB of data transferred, we divide the impact per 220GB/month[301] x 12 months/year. This results in:

$$Fixed - line\ network; at\ consumer(GB): \frac{Fixed - line\ network; at\ consumer(line)}{220\frac{GB}{month} * 12\ months/year}$$

As a result, we have now a **second factor**:

- Fixed-line network; at consumer; xDSL, FFTx average mix ; EU-28 (**GB**)

[301] https://presse.economie.gouv.fr/06032023-etude-ademe-arcep-evaluation-de-lempreinte-environnementale-du-numerique-en-france-en-2020-2030-et-2050/ .This value corresponds to the average amount of data transferred per household in France per month.

7.2.2. *LCI of mobile network*

We modelled this infrastructure with two sources. These factors cover the impacts of the fabrication, distribution, use and end of life of the equipment. Both elements cover the edge infrastructure (cellules, towers, stations) as well as the core network. They both come from the NegaOctet Detabase:

- Mobile network; at consumer; 2G, 3G, 4G, 5G average mix ; EU-28 (GB)

This element covers both edge and core network. The unit of this element is expressed in "annual impact per line". In order to have an impact in GB of data transferred, we multiplied the impact per 220GB/month[302] x 12 months/year. This results in:

- Mobile network; at consumer; 2G, 3G, 4G, 5G average mix ; EU-28 (per subscriber).

7.2.3. *Use phase of network equipment*

The electricity mix used to calculate the environmental impact during the use phase comes from the Eco Invent Database, version 3.8: "**Electricity Mix; market for; Low voltage; UE-27**". No other mix has been considered.

Equipement vs infrastructure mix: During the third party review, it was argued that a more accurate choice would have been to have considered a "medium" or "high" voltage instead of "low".

7.2.4. Video/Audio Quality values

In order to quantity the impact of the Network, we used the bandwith of the connection as an input parameter. The associated Audio/Video to Mpbs tables are below:

Table 75 Video streaming Quality[303]

Video Streaming Quality	Mbps	GB/h
Low	0.7	0.3
Medium	1.6	0.7
High (SD)	2.2	1
High (HD)	6.7	3
High (4K)	15.6	7
Mobile automatic	0.56	0.25
Mobile low	0.37	0.17
Mobile maximum	6.67	3.00

[302] https://presse.economie.gouv.fr/06032023-etude-ademe-arcep-evaluation-de-lempreinte-environnementale-du-numerique-en-france-en-2020-2030-et-2050/ .This value corresponds to the average amount of data transferred per household in France per month.

[303] "How to Control How Much Data Netflix Uses," Help Center, accessed May 1, 2023, https://help.netflix.com/en/node/87.

Table 76 Audio Quality

Audio quality	Bitrate (Mbps)
Fixed_low	0.216
Fixed_average	0.36
Fixed_high	2.268
Mobile_low	0.36
Mobile_high	2.268

7.3. *LCI of Data centres*

This section explains the main assumptions as well as the main LCIA factors used to characterize the infrastructure of the service providers. This one is composed of **IT equipment** (rack servers, blade servers, switches, routers, firewalls) and **non IT equipment** (power systems, corrugators, climatization, generators, batteries).

7.3.1. *Life Cycle Inventory of IT and non-IT Equipment in Data centres*

We modelled this infrastructure with the NegaOctet Database. This factor covers the impacts of the fabrication, distribution, use and end of life of the equipment.

- Rack server (2 processor high-end; 4 SSD (2048 GB each) ; 0 HDD ; 48 RAM (64 GB each) ; 1 GPU)
- Blade server (2 processor high-end ; 1 SSD (1024 GB each) ; 0 HDD ; 2 RAM (16 GB each) ; 0
- Switch (24 ports per U ; 1 processor ; 4 GB RAM)GPU)
- Router (24 ports per U ; 1 processor ; 2 GB RAM)
- Firewall
- Hard disk drive; mix of 2.5" and 3.5", mix of aluminium and glass disks
- Solid State Drive (SSD); 2,5", QLC, 2048 GB ; production mix, at plant; CN.

The following equipment is considered as non-IT.

- Uninterruptible power supply (UPS); 33 KTL
- Air conditioning group; 0.8 MW

7.3.2. *Life Cycle Inventory of an average Data centre*

We modelled the infrastructure with the same type and repartition of equipment. To **build a common service provider infrastructure**, we used the data from the model of the "*Digital technologies in Europe: an environmental life cycle approach, 2021".* By doing so, we can create a **simplified data centre per unit of kWh consumed**.

We assume that the services that are modelled are **stored in Cloud Data** centes type.

We use the EU-Cloud Study[304] data:

[304] Hintemann, R., Hinterholzer, S., Montevecchi, F., & Stickler, T. (2020). Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. Borderstep Institute & Environment Agency Austria. Available at: [Accessed 30 September 2021].

Table 77 Information on the Cloud Infrastructure from the EU Cloud Study

Cloud study information	Unit	Value
PUE	#	1.17
Annual Energy consumption, (2019) for Cloud Data centres	TWh	29.8
Percentage of annual IT energy consumption (2019) for servers	%	73%
Percentage of annual IT energy consumption (2019) for storage	%	21
Percentage of annual IT energy consumption (2019) for network	%	6
Estimated MW of Generators installed	MW	27.493
Estimated MW of chillers installed	MW	11.081
Percentage of energy for generators (over non-IT energy consumption)	%	71
Percentage of energy for chillers (over non-IT energy consumption)	%	29

Note: the percentage of IT energy sums up to 1. The energy correponding to non-IT equipment corresponds to the 0.17 of the PUE (1.17-1).

With the above information, one can figure out how much electricity do servers use. Let's say for instance that we have a data centre that consumes 1kWh per year; we can actually calculate how many servers are being used in this data centre.

$$Number\ of servers = \frac{\%\ of\ annual\ energy\ consumption\ for\ servers}{consumption\ of\ a\ server} * \frac{DC\ Consumption}{PUE}$$

To make this formula more illustrative, let's consider as an example that a server consumes 0,4kWh per year and that we have a Data center PUE of 1,17.

In this case we have:

$$Number\ of servers = \frac{0{,}73}{0{,}4} * \frac{1}{1{,}17}$$

$$Number\ of servers = 1{,}56$$

For this given data centre and the annual given electricity consumption, we are using 1,56 servers. We can make the same reasoning to estimate the amount of material needed for storage, network equipment, etc.

In the case of non-IT equipment, the reasoning is almost the same. The only change is that we replace 1/PUE by (PUE-1)/PUE. The formula then becomes:

$$\#\ generators = \frac{\%\ of\ annual\ elec.for\ generators}{generator\ consumption} * \frac{DC\ Consumption}{PUE} * (1 - PUE)$$

Using Resilio's internal data and the results of the 2021 Benchmark done by Green IT, we assumed that:

- 76% of the servers are rack type
- 24% of the servers are blade type
- 53% of the network are switches
- 45% of the network are routers
- 2% of the network are firewalls
- 53% of the storage is HDD
- 47% of the storage is SSD

As a result, we obtained the following average data centre. Its content is proportional to the electricity used by the service provider to the number of associated hours.

Table 78 Average data centre

Data centre equipment	% of annual energy consumption per unit
Rack server ; 2 processor ; 4 SSD: 2048 GB each ; 24 RAM, 16 GB each	47,2%
Blade server ; 2 processor high-end ; 1 SSD: 1024 GB each ; 0 HDD ; 2 RAM, 16 GB each ; 0 GPU	14,91%
Switch/Router ; 24 ports per U ; 1 processors ; 2 GB RAM	3,05%
Switch/Router ; 24 ports per U ; 1 processors ; 4 GB RAM	2,59%
Firewall	0,11%
Hard disk drive; mix of 2.5" and 3.5", mix of aluminium and glass disks	9,33%
Solid State Drive (SSD); 2,5", QLC, 2048 GB ; production mix, at plant; CN	8,28%
Uninterruptible power supply (UPS); 33 KTL	10,36%
Air conditioning group; 0.8 MW	4,17%

We then used the allocation defined in section "*Allocations for data centres*" to model the environmental impact of it.

7.3.3. *Use phase of the Data centre equipment*

The electricity mix used to calculate the environmental impact during the use phase comes from the Eco Invent Database, version 3.8: "**Electricity Mix; market for; Low voltage; UE-27**". No other mix has been considered.

⚠ **Equipement vs infrastructure mix:** During the third party review, it was argued that a more accurate choice would have been to have considered a “medium” or “high” voltage instead of “low”.

8. Appendix 3 – Allocation in LCA

The allocation is defined (in the ISO 14044:2006 norm) as "*partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems*". This section describes the allocations used for the different equipments.

8.1. *Allocations for end-user environment*

Temporal allocation: this allocation means that we have allocated a percentage of the total impact of an equipment corresponding to the time spend on the behaviour divided by the total lifetime of the equipment:

$$temporal\ allocation\ (\%) = \frac{time\ spend\ on\ the\ behaviour}{lifespan\ (in\ years) * nb.\ of\ days\ in\ a\ year * use\ of\ the\ equipment\ \ per\ day}$$

As an example, let's say someone watches on average 2h of TV per day. There is a pollution associated to building and transporting the TV. But how much of that impact is related to watching 1h of your favourite series? The reasoning is very simple, we will divide 1h by the total amount of hours that the person will watch TV (in the TV's lifetime). So, one divided by 5 years divided by 365 days in a year divided again by 2h per day.

8.2. *Allocations for network equipment*

The allocations regarding network equipment follow the **PCR FAI** published by ADEME. This methodology was published to establish guidelines to help telecom companies report the impacts of its services. The distribution of the impacts depends on the life cycle step as well as on the type of network. More generally, the text states that:

"It was agreed by the operators that the environmental impact over the whole life cycle of a telecoms network (fixed or mobile) is mainly due to two components:

- *A variable component depending on the amount of data exchanged on the network by users*
- *A fixed component depending on the number of users on the network*".

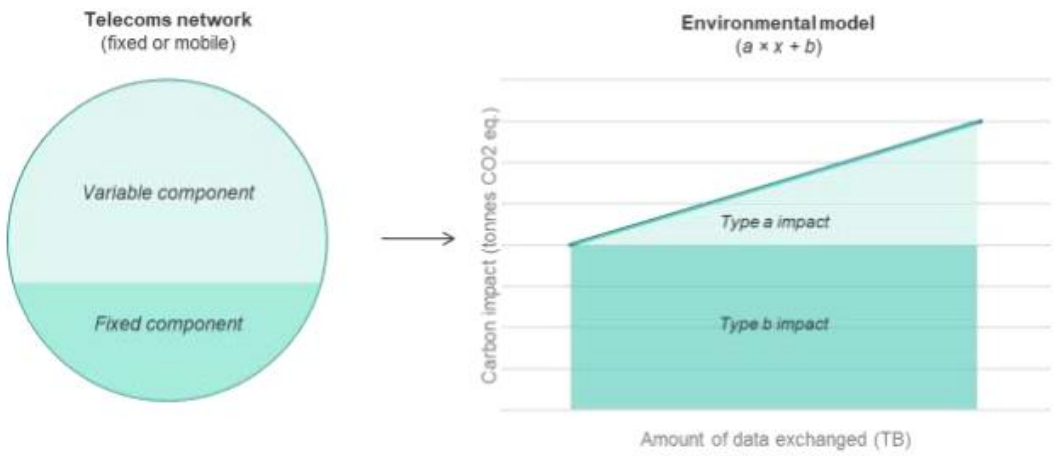
This is modeled as:

$$\boldsymbol{environmental\ impact\ (x) = ax + b}$$

where:

- "a: Leading coefficient related to the amount of data exchanged on the network
- x: Amount of data exchanged on the network by a user
- b: Origin ordinates corresponding to network impacts in the absence of data exchange on the network".

Figure 34 Allocation for network Equipment



8.2.1. *Allocation of equipment according to the type of coefficient (a,b) of the environmental model for fixed networks*

Below, the corresponding table indicating the coefficients for **FTTx communications**. As it can be seen, all impacts corresponding to the fabrication, distribution and end of life are allocated to the coefficient b (that is the number of users of the line). In the case of the use phase, the allocation is **80% for type b** and **20% for type a** (allocation by % of data transmitted).

Figure 35 Allocation for FTTx network

Technology	Equipment family	Manufacture		Distribution		Installation		Use		End of life	
		Type a	Type b	Type a	Type b	Type a	Type b	Type a	Type b	Type a	Type b
ACCESS											
Common	Collection router/switch on OCN and/or SCN site	100	0	100	0	100	0	20	80	100	0
FTTH fibre	ONT (external)	0	100	0	100	0	100			0	100
	DSLAM/OLT	0	100	0	100	0	100			0	100
AGGREGATION											
All types	Aggregation router	100	0	100	0	100	0	20	80	100	0
	Aggregation loop WDM equipment	100	0	100	0	100	0			100	0
BACKBONE & CORE NETWORK											
All types	WDM backbone equipment	100	0	100	0	100	0	20	80	100	0
	P-PE peering router	100	0	100	0	100	0			100	0
	Fixed DNS	100	0	100	0	100	0			100	0

The allocation for **xDSL** for the use phase (electricity consumption) is not the same. In this case the allocation is **95% for type b** and **5% for type a**.

Figure 36 Allocation for xDSL Network

Technology	Equipment family	Manufacture		Distribution		Installation		Use		End of life	
		Type a	Type b	Type a	Type b	Type a	Type b	Type a	Type b	Type a	Type b
UNIT											
ADSL	IAD/CPE unit with integrated Wi-Fi router	0	100	0	100	0	100	5	95	0	100
FTTH fibre	IAD/CPE unit	0	100	0	100	0	100			0	100
	without ONT/SFP										
	IAD unit with integrated ONT/SFP (Wi-Fi router with integrated ONT or SFP)	0	100	0	100	0	100			0	100
FTTLA fibre	IAD unit/CPE cable (Wi-Fi router with integrated DOCSIS modem)	0	100	0	100	0	100			0	100

In our model the environmental factors that have a ***GB*** **unit** are associated to **type a** impacts.The environmental factors that have a ***line*** unit are associated to **type b** impacts.

8.2.2. *Allocation of equipment according to the type of coefficient (a, b) of the environmental model for mobile networks*

Like fixed network technologies, the allocations depend on the life cycle step of the assessment for mobile network communications. **The PCR differentiates between 2G, 3G, 4G and 5G**. This is very helpful as most of these communications use the same infrastructure.

Figure 37 Allocation for Mobile network

Technology	Equipment family	Manufacture		Distribution		Installation		Use		End of life	
		Type a	Type b	Type a	Type b	Type a	Type b	Type a	Type b	Type a	Type b
ACCESS											
Common	Multi-band passive antenna (1.4 to 2.7 m)	0	100	0	100	0	100			0	100
	RU amplifier (700, 800, 900, 1800, 2,100, 2,600 MHz)	35	65	35	65	35	65			35	65
	RRU/RRH amplifier (1,800, 2,100, 2,600 MHz)	35	65	35	65	35	65			35	65
	RRU/RRH amplifier (700, 800, 900 MHz)	35	65	35	65	35	65			35	65
2G (GSM)	2G BBU	0	100	0	100	0	100			0	100
3G (UMTS)	3G BBU	0	100	0	100	0	100			0	100
4G (LTE)	4G BBU	60	40	60	40	60	40	40	60	60	40
5G (NR)	5G BBU	100	0	100	0	100	0			100	0
	AAS - Active Antenna 3.5 GHz	100	0	100	0	100	0			100	0
Transport	Radio site collection router	100	0	100	0	100	0			100	0
	Microwave ODU - Passive antenna	0	100	0	100	0	100			0	100
	Microwave ODU - RF Amplifier	0	100	0	100	0	100			0	100
	Microwave IDU	0	100	0	100	0	100			0	100
AGGREGATION											
All types	Aggregation router	100	0	100	0	100	0	100	0	100	0
	Aggregation loop WDM equipment	100	0	100	0	100	0			100	0

In our model the environmental factors that have a ***GB* unit** are associated to **type a** impacts.The environmental factors that have a ***subscriber*** unit are associated to **type b impacts**.

This is one of the first studies that uses this allocation. We have decided to use this allocation because it is the one that will become mandatory for telecom operators in France from 2024. Compared to other LCA studies, the impact of the network becomes generally smaller (specially for mobile networks). We are confident that this approach is more precise that other methods used in the literature. The same norms will be tested by Telecom Operators in Q2 of 2023; the results of this study will be used to adjust the disclosure norms.

8.3. *Allocations for data centres*

Temporal allocation for fabrication, transport and end of life : as most of the functional units are temporal based, we chose to allocate temporally.

$$temporal\ allocation\ (\%) = \frac{number\ of\ hours\ spent\ on\ the\ behaviour}{total\ hours\ streamed\ per\ year * lifespan\ of\ equipment}$$

As a result, for any given electricity consumption associated with a data centre, we associated a given amount of material *pro rata* the temporal allocation.

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