Background report to 'A guide to your digital climate impact'

Report

Abstract

This is a longer version of 'A guide to your digital impact - Deconstructing information and communication technologies' carbon emissions', Ericsson report GFTL-19:001288 Uen (Ericsson 2019-a).

The text from the original report is included in italic with references where appropriate. Further explanations, details of calculations etc. are provided in each section.

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Contents

1 Background

Carbon emissions from digital solutions are generating a lot of interest and debate. Some argue that gaming is comparable in carbon footprint to taking a flight, while others condemn the climate impact of streaming or social media, using flawed or inaccurate figures. This report aims to explore the issue in greater detail and debunk common myths.

Ericsson has spent more than 20 years researching the carbon emissions of digital, while building extensive data sets and publishing findings in peer-reviewed scientific journals and at conferences. Having reviewed multiple statements about the carbon emissions of digital solutions and compared these to our published results, we are sharing some of our findings here. Further explanations, calculations and references behind the statements and figures in this report can be found in a supplementary background report. The main study cited in this report was published in 2018 after scientific review (Malmodin and Lundén 2018-a).

This report focuses on the Information and Communication Technology (ICT) sector, which includes IT and telecommunications, as defined in the text box to the right. In this report, we adopt a traditional sector definition from the Organization for Economic Cooperation and Development (OECD). In reality, however, carbon footprints of sectors overlap, as each uses one another's services.

In this report we explore ICT's carbon footprint. The carbon footprint concept goes beyond just the electricity usage of products. It incorporates greenhouse gas emissions associated with energy and materials used throughout the life cycle of a product. This includes raw material acquisition, production and assembly, transportation, operation and end-of-life treatment. The indirect impacts of ICT usage are not included in the carbon footprint. These effects are often much more significant than the footprint itself. In this report we consider the carbon footprints of all products within the ICT sector. More specifically, the carbon footprint of the ICT sector includes both mobile and fixed access networks, data centers and enterprise networks, as well as all user equipment such as phones, computers, small routers, new Internet of Things (IoT) devices and other tools.

Information and Comunication Technology and the climate

The Information and Communication Technology sector is commonly referred to as the ICT sector[1].

It impacts the climate in three ways:

1. *Direct carbon emissions associated with ICT manufacturing, use and disposal (ICT's carbon footprint)*
2. *Indirect positive or negative emission effects from using ICT (e.g. travel substitution, transportation optimization)*
3. *Impacting behaviors and preferences (reshaping how we lead our lives on a societal level)*

This report focuses on the first category, which is frequently addressed in public discussions, but not always in an accurate way. However, the other two are often much more significant.

[1]) *ICT refers to the combined sector for information technology (IT) and telecommunications. ICT includes fixed and mobile networks, data centers and user devices such as computers (IT) and phones (communications). However, the other two are often much more significant.*

In this report we consider the carbon footprints of all products within the ICT sector. More specifically the carbon footprint of the ICT sector includes both mobile and fixed access networks, data centers and enterprise networks, as well as all user equipment from phones, computers and small routers, new Internet of Things (IoT) devices and other tools.

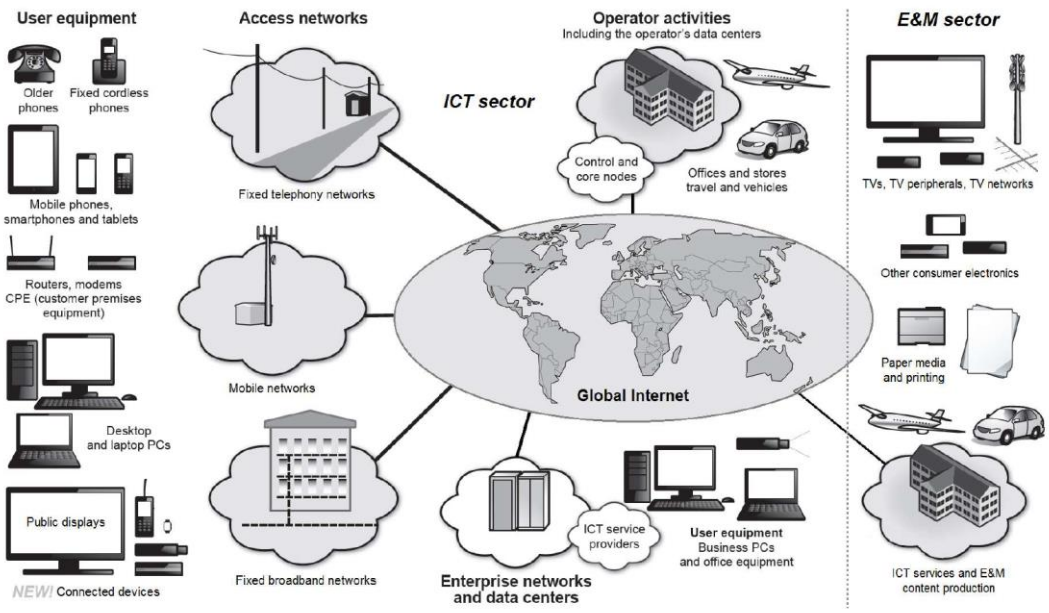


Figure 1 The ICT sector, from Malmodin and Lundén (2018)

We use the ICT sector definition of OECD (2008) and ITU (2018) and thereby include both mobile and fixed access networks, data centers and enterprise networks as well as all user equipment from phones, computers, customer premises, new small internet-of-things (IoT) devices and others, see Figure 1.

1.1 True or false – why is it so complicated

Rapidly changing technologies make estimating carbon emissions difficult.

ICT technology is used by most of the global population to aid home and work life. Increasing access to this kind of technology to reach more people is an integral part of the UN Global Goals for Sustainable Development (UNDP 2019).

Examples are:

- *SDG: Target 5.b Enhance the use of enabling technology, in particular information and communications technology, to promote the empowerment of women*
    - *Indicator 8.10.2 Proportion of adults (15 years and older) with an account at a bank or other financial institution or with a mobile-money-service provider*
- *SDG: Target: 9.c Significantly increase access to information and communications technology and strive to provide universal and affordable access to the Internet in least developed countries by 2020*
    - *Indicator: 9.c.1 Proportion of population covered by a mobile network, by technology)*

Thus, it is important to understand the footprint of this expanding technology and how it develops.

As the ICT sector is constantly evolving in terms of usage, equipment and improvements in energy efficiency, it can be challenging to keep its carbon footprint information up to date.

Due to these challenges, the media often has a hard time accurately representing the footprint of ICT and incorrect statements occur every now and then. Our extensive data sets show that numbers in the media (or even research papers) related to electricity consumption and the carbon emissions of data centers, streaming, gaming and other digital activities are often exaggerated. Sometimes, such numbers are more akin to comparing apples to oranges, and unfairly pitch a particular aspect of one service against the full life cycle of another.

So, is it important? Yes; with the world needing to halve overall carbon emissions every decade,3 correctly understanding the carbon footprint of different activities is crucial.

Especially as incorrect information will lead to increased uncertainty and confusion. It can also lead to either inaction or poor decisions, resulting in people chasing only minor carbon reductions while unknowingly leaving the real reduction opportunities untouched.

Comparing different media articles shows that there are common factors behind why incorrect statements materialize. For example, figures can originate from insufficient knowledge about the technology and its electricity usage, or outdated data combined in erroneous ways.

Simple reality checks can easily prove incorrect figures wrong, but these numbers often spread and come to define people's understanding of the footprint of digital solutions.

Halving the carbon emissions every decade, with the first halving to 2030 to meet the 1.5-degree target is a must according to IPCC (IPCC 2018). In 2019 solutions for halving until 2030 were presented in the Exponential Roadmap (Exponential Roadmap 2019).

Key reasons for incorrect statements on carbon emissions:

- *Comparing "apples to oranges" (whole life cycle impact vs. electricity use alone).*
- *Using outdated figures and data due to insufficient technology knowledge.*
- *Incorrect combinations of data.*

In this report there will be calculations and comparisons of both the overall carbon footprint (including both operation and the embodied emissions) and of the electricity use of ICT during operation.

2 Information and communication technology sector

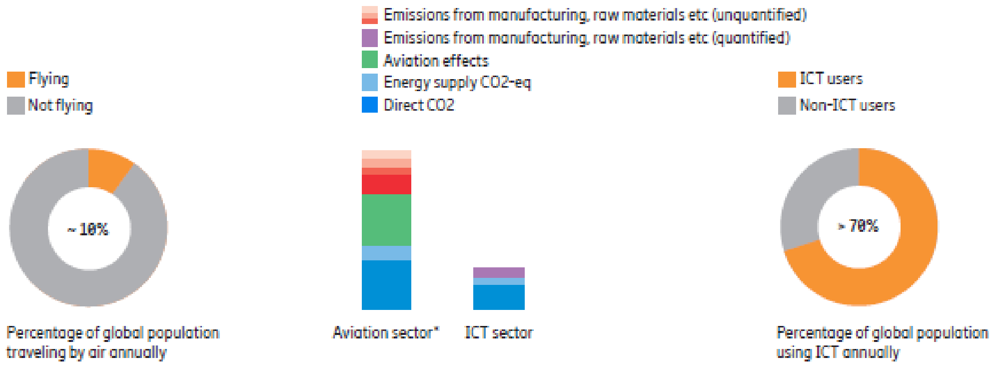
2.1 Minimum footprint while benefitting many

Comparing the carbon footprint of ICT with emissions of the aviation sector.

The ICT sector is often described as having a similar footprint as the aviation sector in terms of carbon emissions, see examples in 0. Let's dive deeper and see how the two compare, keeping in mind that ICT is used by a large share of the world's population compared to aviation.

The total life cycle carbon footprint of the ICT sector is approximately 730 million tonnes CO2 equivalents (Mt CO_2-eq) or 1.4% of the total global greenhouse gas emissions (Malmodin and Lundén 2018-a). This includes the electricity used of all equipment in the system during their use but also all other parts of the life cycle, like the manufacturing of networks, data centers, phones, computers and other user equipment. Furthermore, the figure includes the construction of ICT-related buildings and, for instance, employee travel and transport.

Figure 2: Carbon footprint comparison between the aviation and digital sectors



*For the aviation sector, the emissions for fuel production and aviation effects are estimated based on ICCT and IEA figures.

The emissions from burning fuel across the aviation industry were about 800 Mt CO2 in 2015 (IEA 2017-a). Air travel, excluding air transport and military flying, forms about 80 percent of the total aviation sector footprint (ICCT 2019).

So, in an unbalanced way the ICT sector could be compared to the aviation sector (fuel only) – a similarity in terms of numbers but not in terms of scope. A more well-balanced comparison of the two sectors' overall carbon footprints could be carried out if figures for manufacturing of airplanes, the operation of airports including ground vehicles, end-of-life-treatment and an accurate estimate of any other greenhouse gases (GHG) produced by the sector, including the high-altitude effects, were readily available.

Seventy percent of people globally currently use ICT, while it is estimated that only 10 percent of the global population use aviation services (i.e. airplane travel) each year, with only the wealthiest 1 percent being frequent flyers. This means that even if the footprints of the sectors were of similar magnitude (a small percentage of global overall carbon emissions at current usage levels in the unbalanced comparison), the impact per user would still differ a lot.

2.1.1 Carbon footprints

In Figure 2 the carbon footprint of the ICT sector is compared to the aviation sector. The ICT figures are based on an extensive data set where data the electricity consumption and operational carbon emissions data have been collected from telecom operators (Malmodin and Lundén 2018-b). The collected data represented approximately 15% of all global fixed subscriptions, 40% of global mobile subscriptions and covered more than 35 countries (Malmodin and Lundén 2018-b).

The carbon emissions for fuel used by the aviation sector of 800 Mt CO2 from (IEA 2017-a) has been added together with the emissions from manufacturing of the fuel which adds about another 200 Mt CO_2-eq (IEA 2017-b), denoted 'Energy supply CO2-eq' in Figure 2. The calculation for the energy supply is in the same range as reported in (O'Connell et al. 2019).

There are uncertain long-term impacts from CO_2 and short-term impacts from non-CO_2 emissions, here called high-altitude aviation effects that should also be included in any estimations. In these calculations we have used a factor of 1,9 on the direct emission, based on (Lee et al. 2009, and Larsson et al. 2018) to account for these emissions and effects.

For 2018, the total CO_2 emissions from all commercial operations, including passenger movement, belly freight, and dedicated freight, were 918 million tonnes (ICCT 2019). The passenger transport accounted for 747 Mt CO_2, or 81%, of total emissions from commercial aviation in 2018 (ICCT 2019). These figures include all air travel hence also military and private jets, which is not part of the statistics from ATAG (ATAG 2019).

2.1.2 Percentage of people using ICT and air travel

The ICT penetration is 71% according to GSMA (GSMA 2019-a). Whereas the unique mobile subscribers are 5150 million persons (Oct 2019) (GSMA 2019-b).

It is a difficult task to find out how large part of the global population that flew a specific year, as there are no data on unique passengers. In 2017 Boeing stated that 80% of the world's population had never flown (CNBC 2017).

According to ATAG there were nearly 4.4 billion passengers flying in 2018 (ATAG 2019, Statista 2019). In total they flew 8200 billion person-kilometers, that gives 1900 km per flight (ICAO 2019). From Figure 2, the carbon emissions from air travel is 1520 Mt CO_2-eq without manufacturing. However, most people who flew, fly more than once. Gössling and Upham (2009) estimated that 1% of the world's population stood for about 50% of all emissions from air travel in the world. The world population was 7511 million in 2018 (World Bank 2019).

We assume that about 10% of the global population fly annually based on the above statements that 20% of the world population has flown at least once and that 4.4 billion passenger flights were made. Note that a passenger flight is just one single flight. Hence flying to a destination via a connection and back again would count as four flights. Ten percent of the world's population is about 750 million people. If we also assume that it is still about 100 million people who fly the most based on the estimation by Gössling and Upham (2009). That means that 1.3% of global population do about half of all flights. The assumptions are tested by the following calculations:

In total, we estimate that globally about 10% of all people are flying every year. Their personal air travel emissions are on average 1,8 tonnes CO_2-eq per year. This is slightly higher than the 9 percent presented by Gössling and Upham in 2009. Figure 2 is a summary of the calculations made for comparing the aviation industry to the ICT industry sector.

750 million people have flown in a year (10% of world population)
4,4 billion passenger flights (one direction)
100 million people stood for 50% of all emissions (called 'Frequent flyers')

For the 100 million most frequent flyers: If every frequent flyer on average do 16 flights per year (for instance 12 flights where four flights have a connection). These would result in about 700 Mt CO2-eq or about 7 tonnes CO2-eq per person and year.

For the remaining 650 million air passengers: If the other air passengers on had 4 flights per year, these would result in 830 Mt CO2-eq of about 1,3 tonnes CO2-eq per person and year.

Based on the above, we conclude that seventy percent of people currently use ICT, while it is estimated that about 10 percent of the global population use aviation services (i.e. airplane travel) each year.

2.1.3 Fifty years smartphone vs one overseas return flight

The CO_2 emissions connected to combustion fuels for one return flight over the Atlantic is about 2000-3000 kg CO_2e according to Flight emission map web site (Flight Emission Map 2019-a), see examples in

> **50 years**
>
> For the carbon emissions of a person making a transatlantic return flight, a smartphone could be used for over 50 years.

Table *1*. The calculations in Flight emission map uses a global average of 90 g CO_2 emission per person km caused by burning fuel. In addition, aviation effects like contrails and emissions of aerosols, are included by increasing the emissions with 90% (factor of 1.9). This leads to a total emission of 170 g CO_2-eq per person km (Flight Emission Map 2019-b).

A smartphone can be said to cause 19 kg CO_2-eq per year based on an average usage scenario, including everything from raw material acquisition to end-of-life treatment (Ercan et al. 2016). By also including the smartphone's share of using the ICT networks, data centers etc. the emissions are about 44 kg CO2-eq[1] based on figures in (Malmodin and Lundén 2018-a).

Continuing the unfair comparison of full life time carbon footprint of a smartphone to emissions from fuel burnt during flying including some aviation effects, but excluding manufacturing of airplanes, operation of airports etc. the following could be stated:

The emission for combusting fuels per air passenger for one return flight overseas, including aviation effects equals about 50 years use of a smartphone (all inclusive), see

[1] In Ercan et al. 2016 62 kg CO2-eq was stated when including share of networks and data centers, but this figure has now been revised with newer data from (Malmodin and Lundén 2018).

Table *1*.

Table 1 Comparing emissions from overseas flights to years of carbon emissions from smartphone (Flight Emission Map 2019-a)

Flight destinations	Emissions from fuel combustion and aviation effects per passenger for one return flight [kg CO2-eq]	Number of years of smartphone usage (all life cycle + share of network and data center included) [years]
Paris – New York	1985	45
Paris -Los Angeles	3089	70
Paris - Orlando	2457	56
Paris - Bangkok	3211	73
Berlin – New York	2171	49
Berlin – Los Angeles	3165	72
Berlin - Orlando	2664	61
Berlin - Bangkok	2925	66

2.1.1 Six years smartphone vs London-Barcelona return flight

The CO_2 emissions connected to combustion fuels for one return flight London-Barcelona is 387 kg CO_2e according to Flight emission map web site (Flight Emission Map 2019-a) including the same emissions and factors as presented in 2.1.3. The emission for combusting fuels when flying per passenger for one return flight London-Barcelona equals about 6 years use of a smartphone (all inclusive) if using the total life cycle emissions for a smartphone for a year (44 kg CO2-eq as in section 2.1.3).

2.2 More data - same carbon footprint

Exploring the limited impact of ever-increasing data usage on ICT's carbon footprint.

Rapid digitalization and ongoing increases in data traffic might raise questions about how the carbon footprint of ICT could change in the near future, particularly with the building of larger data centers and the launch of new communications networks. The best starting point for understanding the future is to dig into the past, analyzing historical developments and evaluating real-world measurements of electricity consumption and data traffic.

Looking at the actual development, it is clear that the electricity consumption and carbon footprint of the ICT sector do not follow the same trends as data traffic. Since 2010, total data traffic has increased approximately tenfold, while electricity consumption for the ICT sector has remained constant.

Energy efficiency improvements across the sector, together with replacing larger devices with smartphones, continues to limit ICT's footprint, despite ongoing build-out and the rising number of subscribers. Looking ahead, it is likely that data traffic will continue to increase further, but that ICT's carbon footprint and electricity consumption will not, due to continued developments in efficiency and the phasing out of older technologies. Arguments that the ICT industry will consume most of the world's electricity within a couple of decades are, therefore, unreasonable. Especially given that operator cost frames would not allow such expansion of operational expenditures.

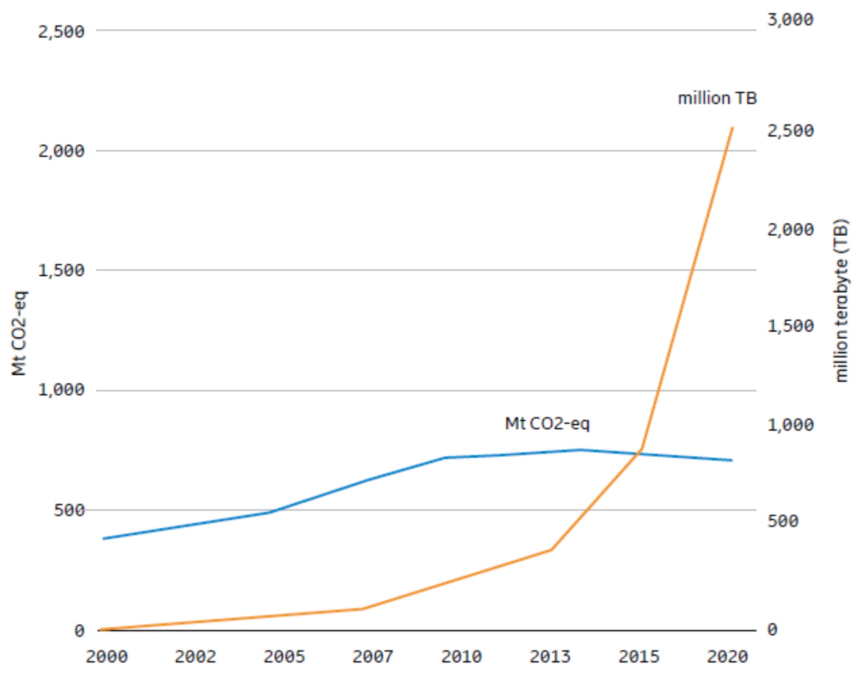


Figure 2 Carbon footprint of ICT and data traffic development

The overall ICT carbon footprint in million tonnes (Mt) CO2-equivalents for 2000-2020 (estimate) is shown in Figure 3 for together with the data traffic usage globally in million terabytes (Malmodin and Lundén 2018-a). This is based on the extensive data set where real electricity data and carbon emissions were collected from several telecom operator (Malmodin and Lundén 2018-b). ICT equipment uses about 3.6 percent of global electricity consumption and accounts for about 1.4 percent of total carbon emissions (Malmodin and Lundén 2018-a).

> 1.4%
>
> ICT equipment accounts for about 1.4 percent of total carbon emissions and uses about 3.6 percent of global electricity consumption, while making up around 6 percent of the global economy.

The market intelligence analysts IDC estimated the global ICT spending for 2018 to be 4800 billion dollars (IDC 2019). Their definition of ICT differs from the one used in this report. According to OECD, the ICT value added is about 6 % of the global economy (OECD 2019). The value added is defined as is the difference between the ICT sector gross output and the intermediate consumption.

Data traffic has increased about ten times since 2010, but the electricity consumption of the ICT sector has been about constant (Malmodin and Lundén 2018-a). Data traffic is the traffic going between the end users through the networks to the data centers.

> 80%
>
> The ICT sector's carbon footprint could be reduced by over 80 percent if all electricity consumed came from renewable energy sources.

2.2.1 What is driving ICT energy consumption? (FACT BOX)

In 1965, the advent of Moore's Law brought about the idea that the number of transistors on a microchip should double every two years (Moore 1965). It is this concept that today drives consumers to exchange their phones and computers every two or three years to gain access to faster and more powerful devices. Since 2012/13, development has slowed down (Malmodin and Lundén 2018-a). However, as several parameters work alongside each other, a slowing down of Moore's Law does not directly translate into worse energy performance. For real products, energy performance also depends largely on configuration, cooling, processing algorithms, system setup and many other factors (ITU 2019).

2.3 Decarbonizing ICT

Exploring what the sector can do to reduce its footprint.

User devices, networks and data centers are the three main parts of the ICT sector. In addition, the ICT sector footprint includes ICT related emissions of services like gaming, social media and online advertising. Currently, user devices (including phones, tablets and computers) account for the largest chunk of the sector's overall carbon footprint.

Looking at the total carbon footprint, carbon emissions (e.g. GHG emissions) are divided between operation and embodied emissions, including raw material acquisition, production, assembly, transportation and end-of-life treatment. Operation includes electricity consumption for the use of products, and emissions for operation and maintenance activities.

A large part of the sector's carbon footprint can be linked back to electricity consumption (Malmodin and Lundén 2018-a), but many key ICT players invest in renewable energy such as solar and wind power, in a bid to lower their carbon emissions. The emissions during use emerge almost entirely from electricity consumption, but the other life cycle stages consume electricity too, for instance in manufacturing (Malmodin and Lundén 2018-a).

If the ICT industry and its users only consumed electricity produced by renewable energy sources, more than 80% of the ICT's carbon footprint could be reduced.

80%

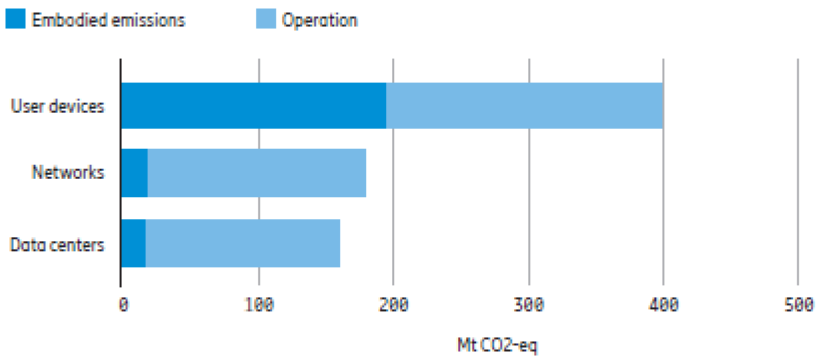
The ICT sector's carbon footprint could be reduced by over 80 percent if all electricity consumed came from renewable energy sources.

The calculation of the 80 percent reduction is made on the figures presented in the supplementary material to (Malmodin and Lundén 2018-a).

Figure 4 is showing the ICT carbon footprint in 2015 in million tonnes CO2-eq divided into user devices, networks and data centers (Malmodin and Lundén 2018-a). The emissions are divided into operation and embodied emissions (manufacturing, disposal etc.). For the operation emissions a global average emission factor has been used. An emission factor is used converting the electricity usage to CO_2-equivalents (CO_2-eq). The emission factor is dependent of how the electricity is produced. Renewable energy sources like solar and wind has emission factors close to zero, while coal-based electricity has much higher factors, see for instance (Koffi et al. 2017). Greenhouse gases from the ICT sector

Google, Apple and Microsoft are examples of ICT companies investing in renewable energy (Google 2019, Apple 2019, Microsoft 2019).

Figure 4: Distribution of ICT's carbon footprint (2015)



2.3.1 What is the impact of artificial intelligence?

New technologies sometimes cause concerns of potential rising electricity consumption. Machine learning and artificial intelligence (AI) use deep learning algorithms to compile and process large data volumes in computers. AI can be used either on a small scale, such as for spellchecking, or on a larger scale, such as empowering supercomputers to predict the weather, calculate the likelihood of natural disasters, or quickly interpret medical scan images. Rapid progress in terms of technology development creates both a risk of increased electricity consumption and opportunities in terms of mitigating climate impact. However, this is still a relatively young technology and it is difficult to lump the electricity consumption of current learning activities together with a future, broader AI education system. Increasing energy efficiency of learning processes overall should be an important task for AI developers moving forward. However, any AI will have substantially lower electricity usage once it has been educated. In the end, the most significant impact will probably be based on what it is used for.

A few media articles have raised the question on the electricity consumption of this new technology, see 0.

2.4 Setting boundaries – a complex task

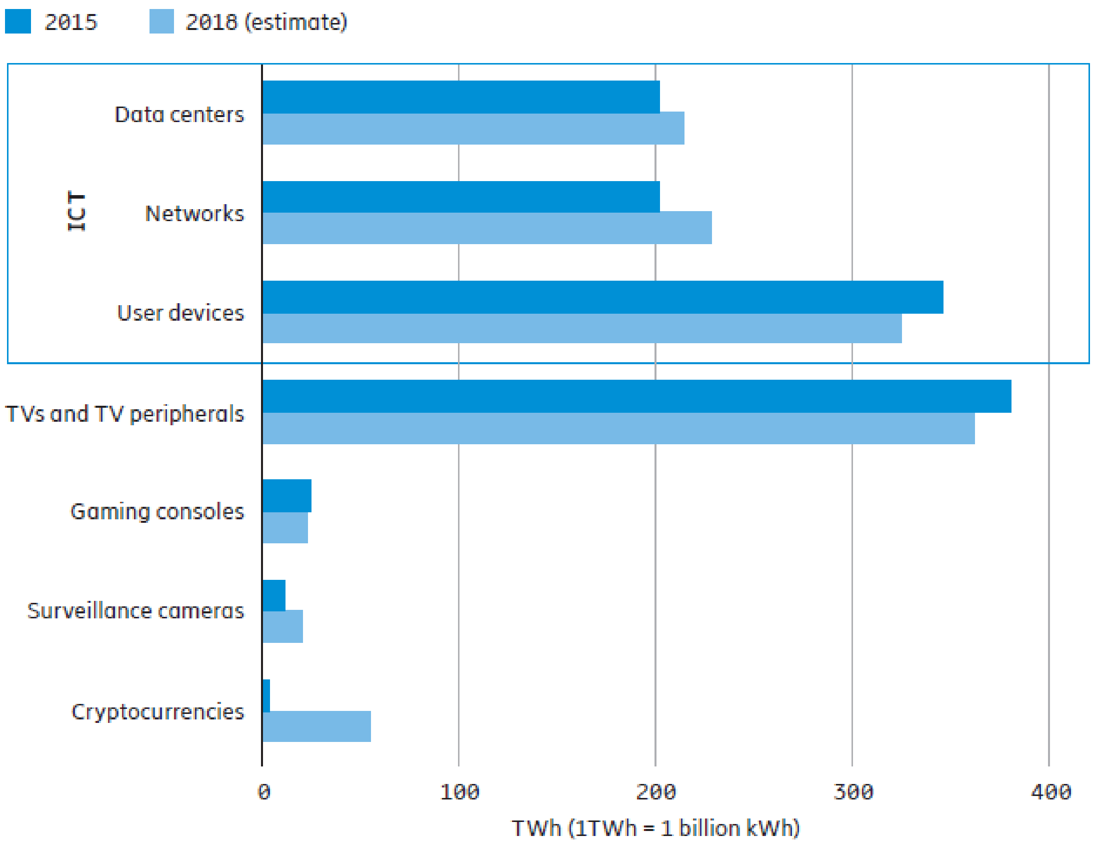
New and overlapping activities blur the traditional boundaries

Traditionally, the ICT's footprint includes devices like computers, phones and tablets, regardless of activity, but excludes entertainment and media devices like TVs and gaming consoles. Today, new complexities arise, such as the increasing number of surveillance cameras, and the advent of smart meters and cryptocurrencies, which do not fit clearly into existing industry sector definitions.

Figure 5 shows the annual electricity consumption of these devices and activities, but it is not at all clear whether these should be directly counted as ICT in the future.

FACT BOX: The impact of cryptocurrencies
Cryptocurrencies are sometimes associated with ICT. Although their sector categorization is not clear, cryptocurrency mining consumes a lot of electricity, but only benefits a select few. Total electricity use in this sub-sector is affected by the number of servers and their efficiency and computational load, as well as mining difficulty, location of equipment and overall cost. All these parameters change quickly, which is why estimating total electricity use can prove challenging. For example, Bitcoin mining accounted for 0.2 percent of global electricity usage in mid-2018.6 (Koomey 2019).

Figure 5: The operation aspects of ICT electricity consumption in perspective



Data centers include enterprise networks (intranet)
Company offices, transport, etc. are included in ICT electricity consumption

*) NOTE Cryptocurrencies also includes the use of some standard ICT equipment/devices (hence there is a small double accounting)

In our ICT carbon footprint for 2015, the surveillance cameras were included in the total ICT sector, but they were not that significant then (Malmodin and Lundén 2018-a).

Figure 5 shows the operational electricity consumption of the ICT sector's three parts - data centers including enterprise networks, access networks and user devices - for 2015 (Malmodin and Lundén 2018-a) and preliminary figures for 2018 which is an estimate based on ongoing research. Furthermore, estimations of TVs and gaming consoles are presented together with estimations of cryptocurrency mining and surveillance cameras.

All TVs, TV peripherals and gaming consoles are allocated to the entertainment & media (E&M) sector. Figures for 2015 from (Malmodin and Lundén 2018-a) and figures 2018 extrapolated market development 2015-2018.

Surveillance cameras could possibly be allocated to the ICT sector, due to the high connected share and use of media servers, but it may just as well be allocated to the security sector, similar to ATM machines allocated to the finance sector. Traditional cameras belong to the entertainment and media sector. Figures of electricity consumption for surveillance cameras are calculated from IHS (2019).

The main hardware for cryptocurrencies, hence the "mining machines", could be allocated to the financial sector like ATM's and traditional payment media. Cryptocurrency mining is dependent on ICT and could like surveillance cameras possibly be seen as ICT, though it does not provide any information or communication. There are different estimates of the electricity used for cryptocurrency mining. Koomey (2019) has done review of several different sources and removed those being unrealistic. These where often theoretical assumptions and not based on any real measured data. From the remaining results Koomey concluded that a realistic estimate for the bitcoin mining in mid-2018 was 44 TWh, which would be 0,2% of the global electricity usage (Koomey 2019). Bitcoin is estimated to be about 70% of the total cryptocurrency sector (CoinMarketCap website 2019). In 2015 there was hardly no cryptocurrency mining at all, it took off in end 2017 (Koomey 2019).

2.5 ICT as driver for a more sustainable world - the enabling effect

Just like all other sectors, ICT needs to reduce its footprint to help decarbonizing the world. For this reason, Ericsson is working to reduce its carbon footprint and has a 1.5-degree aligned Science-Based Target (SBT) in place (SBT 2019, Ericsson 2019-b). We are also working with others to halve the emissions of the sector by 2030. However, it is important to understand the ICT sector's footprint in relation to its decarbonization effects, and to make use of its potential to help other sectors decarbonize.

In this context ICT´s footprint is relatively small compared to its potential impacts as all sectors of the economy get digitalized. This makes ICT a wildcard of the economy - in the right framing the technology could be a main tool to implement low-carbon and circular solutions in all sectors - used wrongly it can also accelerate carbon-intensive processes and businesses.

The potential opportunities, however, are profound. ICT can bring remote healthcare to rural areas, improve efficiency of electricity grids and introduce smoother traffic flows.

15%

ICT has an identified potential to reduce carbon emissions by up to 15 percent in other sectors.

ICT solutions, including IoT, machine learning and automation, have great potential to reduce carbon emissions globally, in numerous sectors and industries. Existing ICT solutions have an estimated potential to reduce global carbon emissions by up to 15 percent (Malmodin and Bergmark 2015). In terms of global decarbonization, this equals around one-third of the halving of emissions deemed crucial by 2030. With new technologies like 5G, IoT and AI, additional emission reduction opportunities will materialize. Whether these opportunities are realized, and whether adverse use is avoided, will be important to how the world manages to limit global warming.

3 Personal digital carbon footprint and specific services

The ICT carbon footprint is depending on the electricity used, mainly during operation. Sometimes there are comparisons in electricity usage between ICT activities like streaming or internet surfing and other activities or electrical appliances. In this chapter we sometimes look at only the electricity during use and sometimes the total ICT carbon footprint of for instance a smartphone.

3.1 Streaming compared to boiling kettles and running fridges?

The electricity consumption of downloads and streaming are significantly lower than commonly believed.

It is sometime said that streaming videos and downloading music consumes enormous quantities of electricity. The media has compared boiling water for tea, running refrigerators and even the electricity consumption of entire countries (see 0) to the electricity usage of digital. Let's set the record straight.

The electricity consumption for streaming depends on your device, phone, tablet, computer or screen. The electricity is not directly related to usage, which is one reason why some comparisons end up being incorrect. Instead, the part connected to networks, data centers and customer premises equipment (CPE) is fairly constant.

Electricity consumption of networks and data centers should be based on large measures of data from real networks to make estimations more accurate. In a rough comparison, streaming 400 two-hour movies on a laptop connected to an external screen would consume as much electricity as a modern fridge does in a year. If the streaming was on a smartphone, 2,900 films could be streamed using the same amount of electricity.

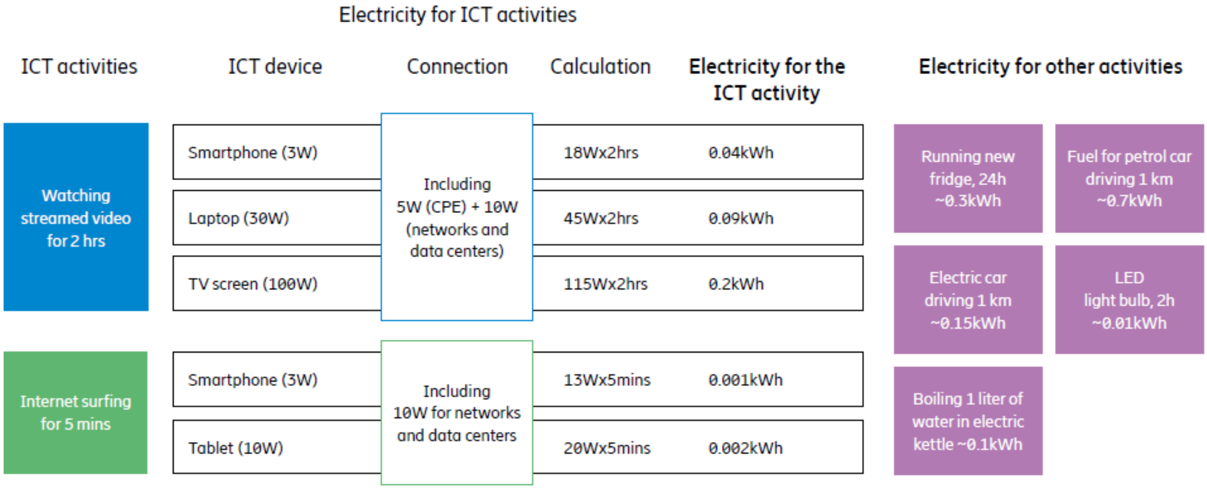


Figure 3a Streamed video and internet surfing compared to electricity consumption of other activities

Figure 6a allows you to make comparisons of the electricity needed for different devices. Calculations for these are provided below. As there might be difficult to compare the electricity consumption figures in the figure above, a diagram is provided in Figure 6b.

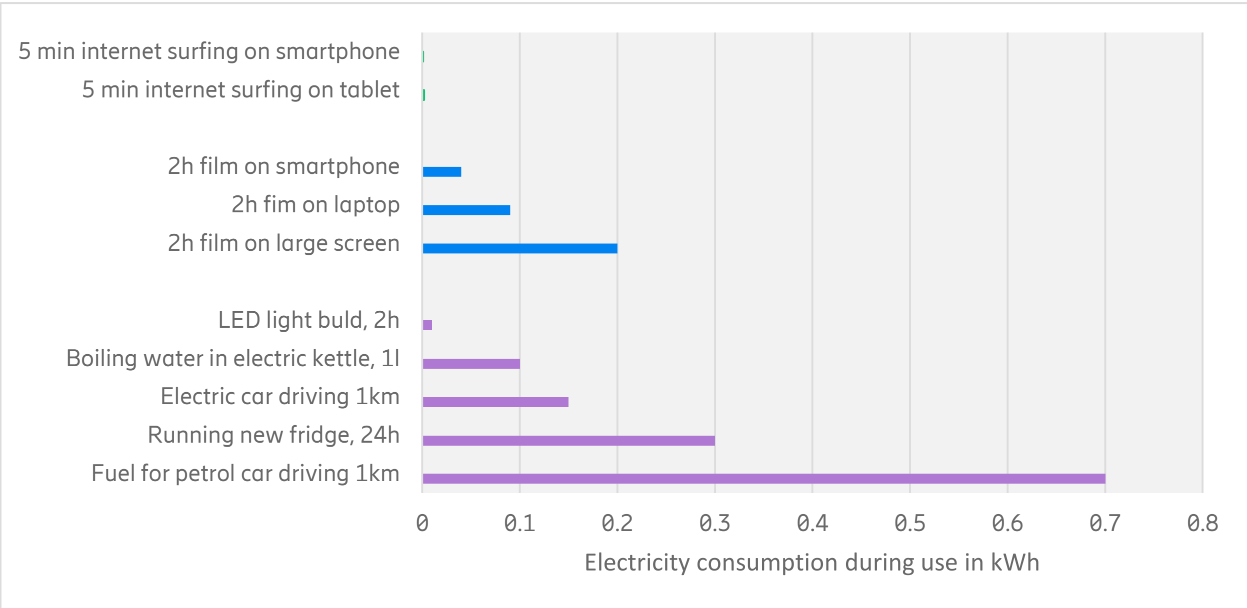


Figure 6b Diagram of the comparisons

3.1.1 Calculations for ICT

The electricity consumption for using ICT services, such as surfing the Internet or streaming will depend on your device, phone, tablet, computer and screen. Table 2 shows the electricity for different user devices.

Table 2 Power consumption for different user devices and references

User device	Power consumption	Reference / Comment
Smart phone	3 W	Total including charging Based on Malmodin and Lundén (2018-a)
Tablet	10 W	Based on Malmodin and Lundén (2018-a)
Laptop	30 W	Based on Malmodin and Lundén (2018-a)
50" screen	100 W	(Energy usage calculator 2019), (Urban et al. 2017)
PC with screen	150 W	Based on Malmodin and Lundén (2018-a)
PC with screen (gaming)	200 W	(Energy usage calculator 2019), (Urban et al. 2017), (Malmodin and Lundén 2018-a)

It is difficult to allocate the share of electricity used by networks and datacenters for specific users and activities. Table 3 summarizes the figures used in the calculations in this report. Calculations in this report and the considerations behind are shown below the table. In addition to the user device, many users have some kind of customer premises equipment (CPE), a small router or similar.

Table 3 Figures used for CPE, share of network and data center

	Energy consumption	Reference / Comment
CPE/user	5 W	See below
Network share per user	5 W	
Data center share per user	5 W	

The rational for these numbers are as follows: A CPE might use 10W (Malmodin and Lundén 2018-a), but as it is often shared by several users in the household and might deliver other functions such as IP-telephony or TV. For these reasons 5W will be used in these calculations meaning that 50% of the CPE energy usage will be allocated to ICT and the specific user.

Networks share per ICT user is set to ~5W. In our Swedish case study, the access network was about 3W and 2W for the core network (Malmodin and Lundén 2016). The 5W was confirmed in a report on network operation based in data reported by several operators in the world (Malmodin and Lundén 2018-b). An update of the operator's data is being performed, and the 5W approximation aligns well with the new yet unpublished data. The figure 5W for network share includes both fixed and mobile networks. However, the mobile network varies more and depends on how the network is used. A typical value could be in the range 1-5W, but for mobile networks alone the average is probably rather 2W (Malmodin and Lundén 2016, 2018-b + yet unpublished operator's data).

Data centers has an average electricity consumption of 200 TWh/year (Malmodin and Lundén 2018-a). This figure includes the servers used for the public internet (120 TWh/year (Malmodin and Lundén 2018-a), but also local servers and data centers used within companies and authorities etc. These so-called intranets have a higher electricity consumption per user than the public data centers available to all.

Calculation of energy used for Internet (one year): 14 GW (=120 TWh/ 8766h) In 2015, there were 3,2 billions Internet users (ITU statistics 2018). If the 5W figure for data centers proposed in Table 3, the energy per internet user is 16 GW (3,2 billions x 5W). That could be compared to and concluded to be in the same range as the energy for the public internet servers of 14 GW (120TWh/year x 8766h (=one year in hours)).

3.1.1.1 Calculations for streaming video 2h and surfing internet

Streaming video or surfing the internet requires about the same amount of electricity. Though it will differ depending on what device you use and whether you surf/stream at home where you have some kind router (CPE) or if directly connecting to the mobile access network.

Table 4 shows the electricity for streaming 2 hours video at home (hence including CPE) using different devices.

Table 4 Calculations for streaming 2h video to different devices, being at home as the customer premises equipment (CPE) is included.

User device	Device power	CPE power	Energy for network and data center	Calculation of electricity needed	Electricity for streaming 2h
Smartphone	3 W	5 W	10 W	18W x 2h= 36Wh	0,04 kWh
Tablet	10 W	5 W	10 W	25W x 2h=50Wh	0,05 kWh
Laptop	30 W	5 W	10 W	45W x 2h=90Wh	0,09 kWh
TV screen	100 W	5 W	10 W	115W x 2h=230Wh	0,23 kWh

PC + screen	150W	5 W	10 W	165W x 2h=330 Wh	0,33 kWh

Average internet usage could be for instance to do searches, web browsing or downloading music. The electricity needed will also here depend on the device used and where it is used. Table 5 shows the calculations for average internet usage for five minutes on a smartphone and a tablet when connecting directly to the mobile network. If at home also electricity for the CPE needs to be added.

Table 5 Electricity used for average Internet usage for five minutes directly connected to the mobile network

User device	Device power	Energy for network and data center	Calculation of electricity needed	Electricity for 5 min internet usage
Smartphone	3 W	10 W	13W x 5min= 1,1 Wh	0,001 kWh
Tablet	10 W	10 W	20W x 5min= 1,7 Wh	0,002 kWh

3.1.2 Calculations for comparisons

The streaming and internet usage figures can be put in relation to other activities to better understand how much a certain amount electricity it is. In media there are numbers of different comparisons, which is why these activities have been chosen for this section see 0.

3.1.2.1 Boiling 1 liter of water in electric kettle

To boil a liter of water in an electric kettle about 0,1kWh electricity is needed, as calculated in Table 6. This is just above the span of 0,06-0,098kWh per single kettle use, without knowing how much water there was in the kettle, reported by Murray et al. (2016).

Table 6 Electric kettle power consumption and calculation of electricity needed to boil one liter of water

Product	Power consumption	Time to boil 1 liter water	Reference
Electric kettle	1500 W	4min	Based on different models from looking at (Amazon web 2019 and Elon 2019)
Electric kettle	2200 W	3 min	

Product	Power consumption	Time to boil 1 liter water	Calculation of electricity needed	Electricity boiling 1l of water
Electric kettle	2200 W	3 min	2200 W x 3 min = 100 Wh	~0,1 kWh
Electric kettle	1500 W	4 min	1500 W x 4 min = 110 Wh	~0,1 kWh

If 1l water is said to be enough for 4 cups of tea (à 2,5dl), the electricity for heating the water for one cup of tea is ~25 Wh, or 0,025 kWh. Note that is only the electricity in the use stage, not including manufacturing of kettle or water distribution.

Streaming a 2h-video to a laptop uses 0,09kWh electricity (calculated in Table 4), about equals the electricity used for boiling a liter of water using a modern electric kettle, or water for about four cups of tea. If streaming is done to a smartphone or a tablet water for the 8-15 cups of tea could be heated for the same amount of electricity. These figures could be compared to media articles, where streaming one movie has been compared to making 60 cups of tea, see 0.

3.1.2.2 Running a fridge 1

Modern refrigerators consume less electricity than their forerunners. The consumption is also very much lower than the state maximum energy value for the product. A modern refrigerator can run on 117 kWh per year (Electrolux web 2019). Table 7 shows the electricity consumption of a modern fridge.

Table 7 Electricity for running a modern refrigerator per day

Product	Electricity consumption for one year	Calculation of electricity per day	Electricity per day
Fridge (modern)	117 kWh/year	117 kWh/365= 0,32 kWh	0,3 kWh per day

In a rough comparison streaming a movie to a laptop connected to a large screen including its share of networks and data centers and the CPE, consumes about 290 Wh (145W x 2h). Compared to running a refrigerator (117 kWh/year) you could stream about 400 films a year (117/0,29=~400) to equal the refrigerators consumption.

If instead the streaming a 2-hour video to a smartphone including its share of networks and data centers and the CPE, you could stream 2900 films a year. (Calculation: 117/0,04=~2900).

3.1.2.3 LED light bulb lit for 2h

A LED light bulb consumes 7W when giving the same amount of light as an old classic light bulb of 40W (Philips website 2019). Table 8 shows the calculations for 2 hours usage.

Table 8 Electricity used by modern LED and old classic light bulbs

Product	Power consumption	Time on	Calculation of electricity needed	Electricity for 2h light
LED light bulb	7 W	2h	7Wx2h=14 Wh	0,014 kWh
Old classic light bulb	40 W	2h	40Wx2h =80 Wh	0,08 kWh

3.1.2.4 Car driving 1km

The electric car's electricity usage depends on the type of car. Tesla communicates the following for two of their car models: large vehicle: 0,19 kWh/km, small vehicle: 0,14 kWh/km (Tesla 2019).

In this report we use an electricity consumption of 0,15 kWh per kilometer in the comparisons to electric vehicles.

Electricity used when driving an electric car for about 0,6 km equals the electricity used for streaming a 2h video to a laptop (network and data centers included).

Streaming a 2-hour video to a laptop (network and data centers included) uses ~0,09 kWh electricity which corresponds to electricity used when driving an electric car ~0,6 km. Calculation: 0,09kWh/0,15kWh/km =0,6km

If instead the energy used when driving a petrol car is converted to electricity it can also be compared to ICT's electricity consumption. One liter petrol corresponds to about 9 kWh electricity, which is calculated from 12,5 kWh per kg petrol and the petrol density (BP 2019).

Fuel consumption is set to 0,8l petrol per 10 km driven distance combined city and highway driving (NRC 2018). Table 9 shows the calculation made for the corresponding electricity for driving one kilometer.

Table 9 Conversion between petrol and electricity

Fuel consumption	Converting to electricity	Corresponding electricity
0,8 l petrol per 10 km	1 liter petrol is ~9 kWh	7,2 kWh per 10 km or ~0,7 kWh per 1 km

Streaming a 2-hour video to a laptop (network and data centers included) uses ~0,09 kWh electricity which corresponds to fuel used for driving ~130 m. Calculation: 0,09kWh/0,7kWh/km =0,13km

3.1.3 The 'Despacito' example

"Five billion downloads and streams clocked up by the song, Despacito (released in 2017), consumed as much electricity as Chad, Guinea-Bissau, Somalia, Sierra Leone and the Central African Republic put together in a single year." This was a statement made in several media articles around spring 2018. The electricity consumption of the above countries was about 1TWh in 2017 (1TWh = 1 billion kWh). In comparison, let us look at YouTube, which contributes towards Google's overall electricity consumption, being about 7.6TWh in 2017. It cannot be true that one song, even if downloaded a billion times, consumes as much as one-seventh of Google's overall electricity usage.

More accurately, 5 billion downloads of this song to a smartphone requires about 0.005TWh (a factor 200 less), including its share of networks and data centers. Typically, a download of one song requires 0.001kWh.

The electricity consumption of Chad, Guinea-Bissau, Somalia, Sierra Leone and the Central African Republic, being the countries mentioned in the media article was about 0,6 TWh in 2017, see Table 10.

Table 10 Electricity consumption in some countries from the World Factbook (2019)

Country	Domestic electricity	Year
Chad	200 GWh	2015 est.
Guinea-Bissau	32 GWh	2015 est.
Sierra Leone	163 GWh	2015 est.
Central African Republic	162 GWh	2015 est.
	557 GWh = ~0,6TWh	

Youtube consumes part of Google's overall electricity consumption being about 7.6 TWh in 2017 (Google 2018). For comparison Youtube in total has one billion hours of videos watched daily, generating billions of views (Youtube 2019). Some sources write that almost five billion videos are watched per day (MergeDope 2019).

In total a five-minute long song requires 0,001 kWh electricity to download to a smartphone, including its share of networks and data centers, see calculations in Table 11. The length of Despacito is 4:10 min. Hence, instead downloading it 5 billion times would require 0,005 TWh.

Though all downloads may not be to smartphones. If instead we assume that 1/3 each of the downloads are made to smartphones, tablets and laptops respectively, each download would on average require 0,002 kWh, see calculations in Table 11. Note that electricity for a CPE is included in the tablet and laptop cases.

For 5 billion downloads of a 5-min song, the electricity required would then be 0,01 TWh – a substantial amount but a factor 200 lower than what was claimed.

Table 11 Downloading a five-minute song to a smartphone over the mobile network.

User device	Energy for the device	Energy for network and data center + CPE	Calculation of electricity needed for a 5min song	Electricity for a 5min song
Smartphone	3 W	10 W	13W x 5min= 1,1 Wh	0,001 kWh
Smartphone	3W	10W	(13W+25W+45W) x5min = 5,8 Wh	0,06 kWh
Tablet	10W	10+5W		
Laptop	30W	10+5W		

3.2 Would it be better without streaming?

Comparing modern trends with outdated traditions.

As streaming is sometimes put forward as a key footprint contributor, one may wonder: should we go back to local storage and traditional video recorders?

The simple answer is no. The correct calculations indicate that streaming a two-hour video on a laptop would require considerably less electricity than an older solution, such as local video storage on DVDs or Blu-ray discs, as indicated in Figure 7.

In early days, consumers might drive to rent a movie, and were required to also rent or buy a specific player to watch it on their television screens. Today, many have fully connected homes and can stream a film to almost any device effortlessly. Large screens have become more energy efficient over the years, but many consumers have purchased larger screens than previously for their homes. This means that electricity consumption when watching a movie remains largely the same. However, if the production and distribution of discs, the specific players etc. are included, there is a significant reduction overall. If the film itself is viewed on a smaller device, such as a laptop or smartphone, there is an even bigger difference in electricity consumption.

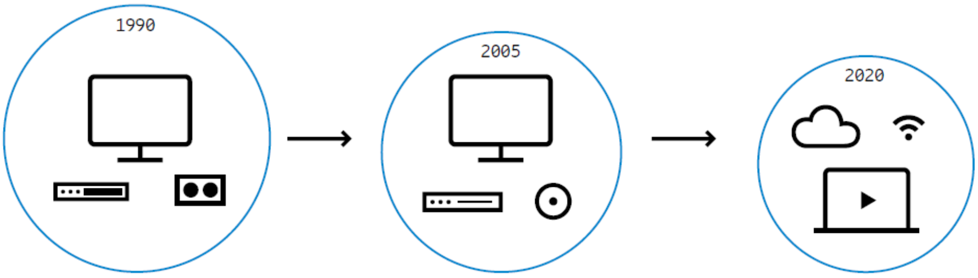


Figure 7 Advancements in movie-watching technology. Shrinking circles illustrates less electricity consumption for movie-viewing.

Streaming gives less electricity consumption per film compared to using a DVD/BD disc player, see calculations in Table *12*. Using the same screen, it is possible just to compare the electricity consumption of the disc player to a device for streaming. A modern DVD/BD disc player requires 10-20W when used (Energyusecalculator 2019). Older versions consumed a bit more and also had a larger stand-by electricity consumption. A TV screen of 40" could consume 125W (Urban et al. 2011). In the calculations in Table 12, we use 20W for the DVD player for 2010. A plasma screen would have used even more electricity.

A solution like Apple TV uses about 3-6W when streaming and 0,3 W when in standby mode (Apple 2017). A large LED screen 50" can consume about 100W (see Table 2) and a CPE would be needed together with share of networks and data centers. In the calculations 5W is used for the Apple TV.

Table 12 Comparison of setup for watching films at home

Year	Product/ activity	Energy consumption	Calculation of electricity needed	Electricity for 2h film
2010	DVD/BD disc player	20 W	145W x 2h = 290 Wh	0,3 kWh
	TV screen, 40" LCD	~125 W		
2018 Streaming to laptop	Laptop	30W	45W x 2h =90 Wh	0,09 kWh
	CPE	5W		
	Network and datacenter	10W		
2018	Apple TV	5W	120W x 2h = 240 Wh	0,2 kWh
	50" LED screen	100 W		
	CPE	5W		
	Network and datacenter	10W		

From Table *12* it is clear that the solution when watching a movie at home on a large screen requires about the same amount of electricity in 2010 as in 2018. However, the screen is much larger in 2018. In 2018 the distribution of the film is included, whereas it is not in the 2010 example. In a full comparison also the production of discs, players and screens as well as all transports, etc. need to be added. That would change the comparisons in favor of the streaming solutions as the manufacturing, storage and distribution of discs are not needed.

3.2.1 Moving to the cloud

Nowadays often store data in the cloud instead of on private hardware. From a carbon emission point of view, looking at the entire life cycle, it is always better to store data in the cloud than on specific hardware at home. The cloud and all data available on the internet forms part of the data centers included in ICT's overall carbon footprint. Data storage is only a small share of this footprint (Shehabi et al. 2016).

The data centers used for public internet consumed approximately 110TWh in 2015,10 which was about 0.5 percent of the world's electricity consumption (Malmodin and Lundén 2018-a). If these data centers were a country, their electricity consumption would be the same as the Netherlands' usage (the country placed 32nd for electricity consumption).

If ICT's internet servers were a country, their electricity consumption would be the same as the Netherlands' usage - the country placed 32nd for electricity consumption.

The total operational electricity footprint was about 240 TWh for data centers shown in Figure 5, which is also including enterprise networks (Malmodin and Lundén 2018-a).

Table *13* shows the domestic electricity consumption per country in the world for 2017. There are different figures on the electricity consumption, only some include the losses during transmission. According to IEA (2019-a) the world electricity consumption for 2015 was 21372 TWh without losses, etc. By also including the energy sector i.e. losses etc. the consumption was 22366 TWh (calculated energy generation, energy consumption from (IEA 2019-a)).

Table 13 Electricity consumption per country 2017 (Enerdata 2017) and the total population of these countries (UN 2017)

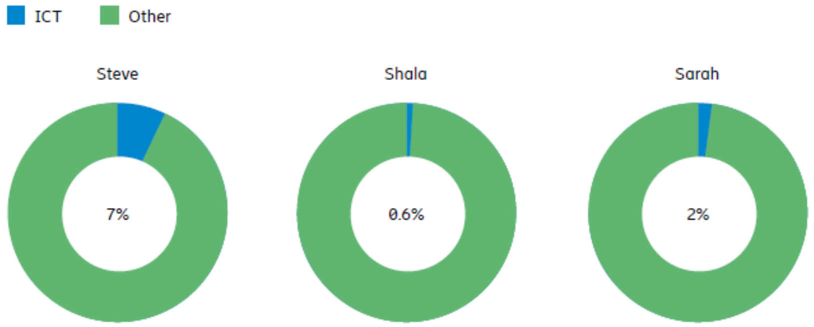
Country	Total population 2017 (millions)	Electricity consumption 2017
World	7550	22190 TWh
China	1410	5726 TWh
US	324	3884 TWh
India	1339	1179 TWh
Japan	127	1005 TWh
Russia	144	915 TWh
South Korea	51	543 TWh
Germany	82	532 TWh
Canada	37	520 TWh
Brazil	209	517 TWh
France	65	447 TWh
United Kingdom	66	307 TWh
Italy	59	302 TWh
…		…
South Africa	57	207 TWh
Thailand	69	198 TWh
…		…
Sweden	10	133 TWh
…		…
Netherlands	17	111 TWh

3.3 The carbon footprint of gaming

What might heavy gaming mean for the environment?

There is a large difference in electricity consumption and carbon emissions between different ICT users. Generally, the carbon footprint is connected to the time spent and equipment used, and to what extent the networks, server and data centers are utilized. Powerful gaming computers and large screens are the greatest electricity consumers among user devices (Mills et al. 2018).

Let's look at the ICT carbon footprint of Steve, a gamer and major ICT user, Shala, a smartphone user and Sarah an intermediate ICT user. On average, Steve is connected for 13 hours a day. Of these, 4 hours are spent playing games on a powerful gaming computer with a large screen. Meanwhile, Shala is only connected through her smartphone for 4 hours a day. Sarah uses a smartphone, laptop and tablet in total 6 hours per day. Steve's annual ICT carbon emissions are 500kg CO2-eq, including all life cycle stages and the share of networks and data centers. For Shala, the corresponding figure is 44kg CO2-eq and for Sarah it is 170 kg CO2-eq. Compared to the global average carbon footprint of 7,000kg CO2-eq per person, ICT stands for 7, 0.6 and 2 percent of Steve's, Shala's and Sarah's respective carbon footprints. If Steve was able to purchase electricity from solely renewable sources, his ICT carbon footprint could be reduced to 2



percent of his overall footprint.

Figure 8 Personal digital carbon footprint of a major, minor and intermediate ICT user.

3.3.1 User profiles

The details for the three user profiles can be found in Table 14-15. References for the electricity use of different user devices are presented in Table 2 in section 4.1.1. The embodied carbon footprint figure can be calculated from the supplement material to (Malmodin and Lundén 2018-a).

The ICT usage and time per day are set to relevant figures for a minor, intermediate and major ICT user. Together these will form a span for the ICT percentage of a total personal carbon footprint.

The ICT carbon footprint of these ICT user profiles have been compared to the global average carbon footprint which is about 7000 kg CO_2-eq per person. It is calculated from the global greenhouse gas emissions of 53,5 Gtonnes CO_2-eq in 2017 and the global population of 7,6 billion people (UN Environment 2018, UN 2017).

In real life distribution and the size of your ICT carbon footprint is very dependent on how you live your life, how much you travel and by what, the food you eat and the building you live in. Also, your ICT carbon footprint is dependent of how the electricity is produced in your country.

Table 14 ICT usage and carbon footprint calculation for a major ICT user (Steve)

ICT	**Energy**		**Time per day**	
Smart phone	3	W	2	h
Laptop	30	W	6	h
PC + large screen (gaming)	200	W	4	h
Tablet	10	W	1	h
Router at home (CPE)	10	W	24	h
Share of network and data center	20	W	24	h
Electricity consumption				
Sum of electricity per day	1716	Wh		
Sum of electricity per year	626	kWh		
Carbon emissions				
Emission factor (global average)	0,6	kg CO2-eq/kWh		
Carbon footprint for operation	376	kg CO2-eq / year		
Embodied carbon footprint	124	kg CO2-eq / year		
Personal ICT carbon footprint	500	kg CO2-eq / year		
Percentage of ICT in total personal carbon footprint	7%	(=500/7000)		

Table 15 ICT usage and carbon footprint calculation for Shala, a minor ICT user using only a smartphone

ICT	Energy		Time per day	
Smart phone	3	W	4	h
Share of network and data center	5	W	24	h
Electricity consumption				
Sum of electricity per day	132	Wh		
Sum of electricity per year	48	kWh		
Carbon emissions				
Emission factor (global average)	0,6	kg CO2-eq/kWh		
Carbon footprint for operation	29	kg CO2-eq / year		
Embodied carbon footprint	15	kg CO2-eq / year		
Personal ICT carbon footprint	44	kg CO2eq /year		
Percentage of ICT in total personal carbon footprint	0,6%	(=44/7000)		

Table 16 ICT usage and carbon footprint calculation for Sarah, an intermediate ICT user

ICT	Energy		Time per day	
Smart phone	3	W	2	h
Tablet	10	W	2	h
Laptop	30	W	2	h
Router at home (CPE)	5	W	24	h
Share of network and data center	5	W	24	h
Electricity consumption				
Sum of electricity per day	446	Wh		
Sum of electricity per year	163	kWh		
Carbon emissions				
Emission factor (global average)	0,6	kg CO2-eq/kWh		
Carbon footprint for operation	98	kg CO2-eq / year		
Embodied carbon footprint	75	kg CO2-eq / year		
Personal ICT carbon footprint	173	kg CO2eq /year		
Percentage of ICT in total personal carbon footprint	2%	(=173/7000)		

The ICT carbon footprint of the smartphone use (minor ICT user Shala, 44 kg CO2-eq per year) is somewhat lower than the 62 kg CO2-eq per smartphone reported in Ercan (2016). The reason for the difference is that in this calculation we have used a figure of 5W for the share of the network and data center for smartphone user. The 62 kg CO2-eq corresponds to 8,5 W network usage.

If the three ICT users, Steve, Shala and Sarah, would only use renewables when charging their devices, the ICT carbon footprint would become 2%, 1% and 0,2 % respectively, still compared with the global average of 7000 kg CO2-eq/person, see Figure 8. The emission factor used in these calculations is the one for Norway presented in Table *19*.

3.3.2 Smartphone usage compared to driving

The electricity used when driving an electric car for about 0.6 km is equal to the electricity used when streaming a 2-hour video to a laptop (network and data centers included).

One year's smartphone usage (full life cycle including the share of networks and data centers) is comparable to the level of fuel combusted driving for 2 hours on the motorway (not including manufacturing of car or infrastructure)

There is a divergence between official and real-world CO2 emission values for combusting fuel while driving. In some cases, the real consumption is 50% higher than stated (IEA 2019-a). In Europe there is a target of 130 grams of CO2 per kilometer that applies to new passenger cars, since 2015 (EU 2019).

However, fuel consumption of newly registered light-duty vehicles is 7,2 l gasoline-equivalent per 100km (IEA 2019-a) and 1 l gasoline produces approximately 2,3 kg CO2 (Comar 2019). Depending on the car, the emission intensity varies to values between 1,6 and 2,87 kg CO2/liter petrol (NRC 2014). The emission per driven kilometer becomes 0,17 kg CO2 (7,2l/100km x 2,3 kg CO2/km).

If also taking into account the production of the gasoline another 25% should be added to the direct emissions (Roland Berger study 2016). In (EU JRC 2014) there is a figure of +20% but that is related to energy/fuel and not the carbon emissions. In UK a factor between 23 and 28% are given for different mixes of fuel and diesel (UK 2019). In our calculations we use 25% to account for the production of the fuel. Table 17 shows the CO2 emissions for fuel consumption while driving on the motorway – using two different emissions per kilometer. Then there are also emissions from the car itself etc. if the entire life cycle should be included.

Table 17 Carbon emissions for driving

	European target level		Fuel consumption of newly registered light-duty vehicles	
Emission per km	0,13	kg CO2/km	0,17	kg CO2/km
Speed driving on motorway	120	km/h	120	km/h
Calculations	0,13 kg/km x 120 km/h =15,6 kg/h		0,17 kg/km x 120 km/h =20,4 kg/h	
Emissions for fuel combustions while driving on motorway	15,6	kg CO2/h	20,4	kg CO2/h
Addition (25%) for producing the fuel	3,9	kg CO2	5,1	kg CO2
Emissions for fuel (supply + combustions)	19,5	kg CO2/h	25,5	kg CO2/h

Smartphone carbon footprint per year is 44 kg CO2-eq (assuming 4h/day including networks and data centers) based on (smartphone itself: Ercan et al. 2016; network and data center figures: Malmodin and Lundén 2018-a).

Table 18 shows how long time you can drive on the motorway (only fuel usage) for the same amount of carbon emissions as the whole lifecycle emissions from one year's usage of a smartphone.

Note that if do not include carbon emissions related to manufacturing the car and its share of the road.

Table 18 Comparing emissions from fuel consumption while driving to annual lifecycle carbon emissions of a smartphone.

Calculation comparing to fuel used for driving on the motorway	Smartphone carbon footprint per year (44 kg CO2-eq/year assuming 4h/day in this report) [2]	
European target level including fuel supply	44/19,5=2,3h	2h
newly registered light-duty vehicles including fuel supply	44/25,5=1,7h	2h

If instead calculating the corresponding time for an electric car consuming 0,15 kWh/km (see section 3.1.2.4) and the global emission factor (0,6 kg CO2-eq/kWh) the carbon emissions would be 0,09 kg CO2-eq/km (0,15 x 0,6). Assuming driving at a speed of 120 km/h result in carbon emissions of 10,8 kg CO2-eq/h (0,09 x 120).

[2] If instead comparisons are made to 62 kg CO2-eq (Ercan 2016) it would be between 2,5 and 4h driving on the motorway.

An electric car could drive for about 4 hours (44/10,8) for the same amount of carbon emissions as one year's smartphone usage. Note that only the electricity needed for the electric car is compared to the full life-cycle emissions related to the smartphone.

3.4 Reduce your digital carbon footprint

What can we all do to minimize the impact of our online life?

3.4.1 Carbon footprint comparisons in different countries

Your digital carbon footprint is greatly influenced by the number of devices you have and how long you use them for, as well as where you live and use them. The carbon emissions stemming from electricity usage is dependent on how electricity is produced in your country (i.e. hydropower, nuclear, fossils, wind and solar). Hence, the ICT carbon footprint of the smartphone user Shala on the previous page, will depend on where she lives.

Figure 9 shows how Shala's digital carbon footprint differs per region based on how the electricity itself is produced (size of person ~size of ICT carbon footprint).

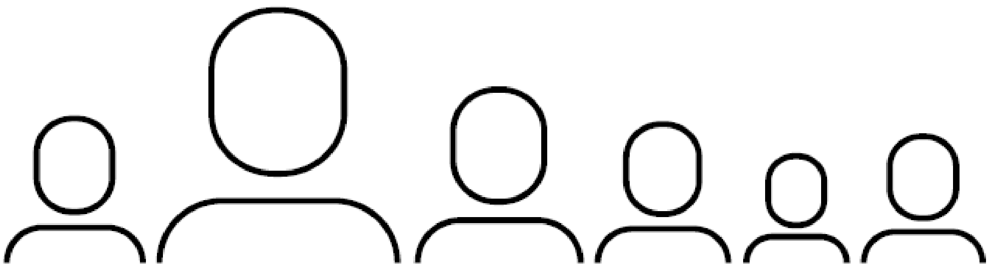


Figure 9 Digital carbon footprint of Shala, a smartphone user (4h/day) living in different regions with different energy supplies.

The global average emission factor is 0,6 kg CO2eq/kWh, used converting the electricity usage to CO_2-equivalents (CO_2-eq). Emission factors for different regions can be found in Table 19. Note that these are derived from the reported GHG emissions and the reported electricity consumption for each country.
In Table 20 the ICT carbon footprint for the smartphone user (presented in Table 15) is calculated based on the region of the smartphone user. Note that in reality also the average personal carbon footprint depends on the region. In Table 21 the carbon footprint per person in each country is shown. These figures are calculated based on emissions data from (PBL 2018). The 'rest of the world' figure is calculated from a total figure minus the other countries reported.

Table 19 Emission factors for 2018 including references

Country	Emission factor (LCA scope) [kg CO2-eq/kWh]	References
Global average	0,60	IEA (2019-b, 2019-c)
India	1,04	Enerdata (2019)
China	0,79	Enerdata (2019)
US	0,55	EIA (2018)
EU	0,32	Estimate based on 2017 figures for EU in (IEA 2019-b, 2019-c)
Rest of the World	0,53	Estimate calculated from the global average and the countries/regions above
Sweden	0,045	Estimated based on (IEA 2019-d) and (WNA 2011)
Norway	0,025	Estimated based on near 100% hydropower and (WNA 2011)

Table 20 ICT carbon footprint for the smartphone user for different regions

Country	Electricity consumption during operation [kWh/year]	Emission factor [kg CO2-eq/kWh]	Embodied emissions [kg CO2-eq]	ICT carbon footprint minor user [kg CO2-eq]
Global average	48	0,60	15	44
India		1,04	15	65
China		0,79	15	53
US		0,55	15	42
EU		0,32	15	30
Rest of the World		0,53	15	40
Sweden		0,045	15	17
Norway		0,025	15	16

Table 21 Average personal carbon footprint in different countries/regions 2017 (PBL 2018)

Country	Average personal carbon footprint in country/region [kg CO2-eq/year]
Global average	7000
India	3000
China	10000
US	23000
EU	10000
Rest of the World	6000

3.4.2 A skipped trip is a skipped trip – but what do you do instead?

As an ICT user, you might be able to use your smartphone or laptop to save time and money, such as by shopping online, working from home or skipping a business trip in favor of a video conference. However, any reduced carbon emissions might be offset or even outnumbered by what you choose to do with your saved time or money, and how carbon-intense these activities are. This is known as the rebound effect. It is important to be mindful of your footprint and use time and money wisely. Fortunately, it has been shown that ICT solutions helping people who want to live a more sustainable life tend to have little rebound (Coroama and Mattern 2019).

We all need to help stabilize the climate and safeguard planetary boundaries. Even though the ICT share of your individual carbon footprint is small, we can all contribute to lowering our collective carbon emissions further.

3.4.3 Optimizing your ICT use to reduce your digital carbon footprint

There are many ways of reducing your digital carbon footprint, but the most important thing is to take care of your device so it can be used for many years. You can also:

- *Use your smartphone or other ICT devices longer before upgrading*
- *Make sure you recycle or reuse the ICT equipment*
- *Consume digital services on smaller devices*
- *Charge the batteries with electricity from renewable sources*
- *Avoid buying more ICT devices than you have time for (pass unused devices on)*
- *Show your suppliers that their footprint matters to you and request renewable electricity supply*
- *Buy your digital devices and services from companies that have science-based targets (see section 2.5)*
- *And, last but not least: Use ICT services that help to reduce carbon emissions*

4 Key takeaways

- *Digital devices are becoming increasingly widespread, but the carbon footprint of the ICT sector remains fairly stable, at around 1,4 percent of overall global emissions.*
- *The ICT sector's carbon footprint could be reduced by over 80 percent if all electricity consumed came from renewable energy sources.*
- *The digital footprint of individuals makes up a small percentage of their total carbon footprint and could be reduced further e.g. by switching devices less frequently.*
- *Calculating carbon footprints is not rocket science but does demand sufficient understanding of the technology itself in order to give accurate results.*
- *Beyond its carbon footprint digital technologies are powerful tools that could be used for better or for worse, depending on societal framing. Used well, digital technologies give us a great opportunity to accelerate the decarbonization of society to limit global warming to 1.5 degrees Celsius. However, in the wrong framing, they can also accelerate carbon intensive activities.*

5 Key figures

- Fifty years' use of a smartphone (including share of networks and data centers) results in less carbon emissions than fuel used per person on a return flight over the Atlantic Ocean (including aviation effects)
- ICT sector carbon footprint in the same range as only the carbon emissions related to fuels combusted in the aviation sector per year.
- ICT sector accounts for about 1.4 percent of total carbon emissions and uses about 3.6 percent of global electricity consumption, while making up around 6 percent of the global economy.
- The ICT sector's carbon footprint could be reduced by over 80 percent if all electricity consumed came from renewable energy sources.
- One year's smartphone usage (full life cycle including the share of networks and data centers) is comparable to the level of fuel combusted driving for 2 hours on the motorway (not including manufacturing of car or infrastructure)
- ICT has an identified potential of 15 percent to reduce carbon emissions in other sectors

- If ICT's internet servers were a country, their electricity consumption would be the same as the Netherlands' usage - the country placed 32nd for electricity consumption.
- One year's smartphone usage (full life cycle including the share of networks and data centers) is comparable to the level of fuel combusted driving for 2 hours on the motorway (not including manufacturing of car or infrastructure).
- The personal digital carbon footprints of a minor, intermediate and major ICT user are 0,6%, 2% and 7% when compared to the global average carbon footprint per person.

Table 22 Streaming 2h video (including share of network and data center) compared to electricity consumption of other devices and activities

The electricity used when streaming 2h video to a ...	...smartphone... ...tablet... ...laptop...	...is approximately like having...	4 5 9	...LED light bulbs lit for 2h
The electricity used when streaming 2h video to a ...	...smartphone... ...tablet... ...laptop...	...is approximately like running a modern refrigerator for...	3h 4h 7h	
The electricity used when streaming 2h video to a ...	...smartphone... ...tablet... ...laptop...	...is approximately like the electricity for driving...	0,3km 0,3km 0,6km	... with an electric car
The electricity used when streaming 2h video to a ...	...smartphone... ...tablet... ...laptop...	...is approximately like driving...	60m 70m 130m	... with fuel car (only fuel)
The electricity used when streaming 2h video to a ...	...smartphone... ...tablet... ...laptop...	...is approximately boiling...	0,4l 0,5l 0,9l	... of water in an electric kettle

6 Terminology

6.1 Glossary and abbreviations

CO_2 - carbon dioxide

CO_2 – CO_2-eq - carbon dioxide equivalents, could also be denoted CO_2e

GHG - greenhouse gas

ICT - Information and Communication Technology

IoT - Internet of Things

LCA - life cycle assessment

6.2 Concepts

Information and Communication Technology sector: the ICT industry sector is divided into three main subsectors:

- User devices, including for instance all phones, smartphones, computers, home routers (customer premises equipment – CPE) and small internet of things devices like wearables, the connectivity part of surveillance cameras, smart meters and payment terminals
- Networks, includes both mobile and fixed networks for telephony and broadband connectivity, core networks and operators' and manufacturers' overhead activities like offices, stores, travel etc.
- Data centers also include the enterprise networks and the operators' own data centers, and the data center companies' overhead activities.

Embodied emissions: emissions that do not come from the use or operation of a product, service or system. Hence, the embodied emissions relate to raw material acquisition, manufacturing, transportation and end-of-life treatment.

Peer-reviewed: the process of subjecting an author's scholarly work, research, or ideas to the scrutiny of others who are experts in the same field, before a paper describing this work is published in a journal, conference proceedings or as a book

7 References

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7.1 Examples of media articles

Quote	Year	Source
'Tsunami of data' could consume one fifth of global electricity by 2025	2017	The Guardian
Overall, the digital economy is estimated to account for about 7% of the world's electricity consumption and forecast to rise to 12% by 2020	2018	Schröder
Data centers already consume roughly 3% of all globally generated power and account for approximately 2% of greenhouse gas emissions – a carbon footprint equivalent to the airline industry.	2017	Data economy
Internet (ICT sector) emits as much CO_2 as the aviation industry	2007	Gartner. Green IT: The new industry shock wave. In Proceedings of the Symposium/ITXPO Conference, San Diego, CA, USA, 22–26 April 2007
The energy used in our digital consumption is set to have a bigger impact on global warming than the entire aviation industry	2018	The Guardian
Your iPhone consumes as much energy as two US fridges	2018	From report 'The cloud begins with coal' by Mark P Mills August 2013
'Despacito' has a footprint roughly the equivalent of the annual emissions of about 100,000 taxis	2018	Financial Times
Five billion downloads and streams clocked up by the song Despacito, released in 2017, consumed as much electricity as Chad, Guinea-Bissau, Somalia, Sierra Leone and the Central African Republic put together in a single year.	2018	BBC
Watching a single feature-length film online uses up the same power needed to make a whopping 60 cups of tea.	2019	The Sun
Training a single AI model can emit as much carbon as five cars in their lifetimes	2019	MIT Technology Review June 6. 2019

The gigabytes of data we're using — although invisible — come at a significant cost to the environment. Some experts say it rivals that of the airline industry. And as more smart devices rely on data to operate (think internet-connected refrigerators or self-driving cars), their electricity demands are set to skyrocket.	2020	CBC