Evaluating Energy Consumption of Internet Services

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SUMMARY   This paper summarizes recent reports on the internet's energy consumption and the internet's benefits on climate actions. It discusses energy-efficiency and the need for a common standard for evaluating the climate impact of future communication technologies and suggests a model that can be adapted to different internet applications such as streaming, online reading and downloading. The two main approaches today are based on how much data is transmitted or how much time the data is under way. The paper concludes that there is a need for a standardized method to estimate energy consumption and CO_2 emission related to internet services. This standard should include a method for energy-optimizing future networks, where every Wh will be scrutinized.

key words: *optical fiber communication, information and communication technology, telecommunications, energy consumptions, UN Sustainable Development Goals*

1. Introduction

The internet is estimated to consume about 9% of the total produced electricity worldwide [1], [2], and data centres about 1% [3], [4]. Globally, average IP traffic was estimated to be about 850 Tbps in 2021 [5], growing by about 25% per year in the last 5 years, and more than 2/3 of the world population is online today [6]. Forecasts suggest continued growth with e.g., nearly 30 billion networked devices by 2023 [7], of which about 50% will be machine-to-machine (M2M) connections. These forecasts beckon the question: Will this expansion of the internet result in an increase of the energy consumption of the internet, as discussed in [1], [2]?

Historically, increased traffic has not resulted in a massive growth of energy usage, due to technological improvements. For instance, trans-Atlantic systems improved their energy-efficiency per bit by 20% per year the last nearly 100 years, bridging from telegraph cables to fiber links [8]. And network equipment improvements allowed network operators to use slightly less operational energy-per-subscription [9], with a modest 31% increase of total network operational energy, owing to more users, from 2010-to-2015. However, as pointed out in [1], [10], the progress in electronics, as

described by Moore's Law has not been able to keep up in latter years, and a major reason for keeping energy consumption of communications at bay the last ten years, comes more from reducing the overhead in data centres, in particular improving cooling systems and reducing the PUE (power usage effectiveness) by moving to hyper-scale data centres [1], [4].

So, there are genuine concerns that the historic improvement in energy-efficiency may decay, as known technologies can no longer be iterated on, but how much will depend on which technologies will come instead, and how the network architectures may be optimized for higher energy-efficiency. One estimate suggests that we could face needing 20% of all electricity just to sustain the internet by 2030 [2], assuming a reduction of annual efficiency-improvement from 20 down to 5%. This made the authors of [4] conclude that "We will need new more energy-efficient technologies in 3–4 years from now".

One concern is the electricity required, another is how this electricity is produced, i.e., what its CO_2 footprint is. Whether green or not, energy has become a scarce commodity with the recent climate and geo-political situations, and optimizing energy-efficiency has become urgent. Several large information and communication technology (ICT) corporations have already taken upon themselves to go CO_2 neutral or even completely compensate for their CO_2 footprint since they first launched [11]–[15], and there are great expectations to how the internet may help reduce waste and climate change.

This paper will discuss some of the expected climate benefits of the internet and discuss the energy consumption and a simple model to estimate CO_2 footprint of some internet services, and finally discuss the need for a standard for evaluating energy and climate footprint of digital technologies.

2. Climate Benefits of the Internet

Like all energy-consuming activities, communications will also have to weigh its worth over its footprint. It is already suggested today that the internet saves its own weight in CO_2 by 1.5x [16], and that this could be increased in the future, by e.g., supporting multiple UN Sustainable Development Goals (SDGs), such as improved energy-harvesting, optimized industrial processes, sustainable cities and many more [17]. Digitalization will impact most parts of our lives

in the future, and the International Energy Agency (IEA) predicts that large savings of energy can be made by increased and smart digitalization [3]. For instance, the IEA speculates that extended autonomous driving could cut 60% of the energy consumption in the transport sector, under certain conditions, and that 10% of the energy used in buildings could be saved by better temperature sensors, links to weather forecasts and automatic control functions, and that 20% of the electricity used for lighting could be cut with smart lighting [3]. The World Economic Forum recently estimated that digital technologies could help cut global emissions by 15% by e.g., improved industrial production [18]. The Global enabling Sustainability Initiative (GeSI) has conducted a massive investigation for most parts of the world, concluding that the internet roughly compensates its own weight in CO_2 by a factor of 1.5x today, and that this could increase to 10x by 2030 [16]. This would require that the internet energy-efficiency is increased, that green energy sources are more widely employed, and that digitalization is wider spread.

All in all, these reports point to a positive impact of the internet, which has great potential for energy and CO2 savings. At the same time several ICT-companies are pushing for using more green energy, and actively investing in production of more green energy. However, the internet needs to grow to support greater digitalization, and this must be done while controlling its own energy consumption. This in turn requires a standardized method for monitoring and reporting energy consumption for the different applications considered.

3. Energy Consumption and Carbon Footprint of the Internet

Evaluating the energy consumption of the internet in a bottom-up approach is a daunting task but may be necessary for getting accurate numbers for specific internet services and applications. And this may very well be needed soon, as low energy-use and low CO_2-emission become competitive measures, when e.g., bidding for public tenders on ICT hardware, software and services. So far, top-down approaches and studies have widely been used, estimating the total energy use and CO_2 emission from e.g., the global internet, or in some cases for specific regions, resulting in estimates like close to 10% of all electricity is used for the internet today [1]. However, a higher granularity of the energy consumption is necessary for more detailed and fair evaluations, as needed when having to choose a product living up to coming requirements of green ICT.

3.1 Estimating Energy Consumption

A large study of the operational energy consumption and carbon footprint [9], [19], collected data of actual energy usage directly from operators, covering 40% of mobile subscriptions from 35 countries, in a collaboration with the Global e-Sustainability Initiative (GeSI) and the Euro-

pean Telecommunications Network Operators' Association (ETNO). This study gives a very accurate picture of the energy used in running the installed mobile and fixed networks. This benchmark report is very useful to evaluate general trends in levels of electricity consumption in networks. To attempt to evaluate a specific internet application, such as streaming, one would need to detail the path the streaming data takes from the specific data centre, through the network, to the end user's receiver, and include user devices, which is very challenging.

A data-based power consumption model is discussed in [8]. The specifications provided for representative network equipment and the access rate of the network node are used to evaluate power consumption of the various parts of the network. Today there seems to be two major schools of thought on how to evaluate the energy usage for specific applications, a *data* dependent and a *time* dependent approach. The total energy consumption as reported in [9], [19] for various parts of the network is accepted and used by both. The differences between the two approaches become visible when attempting to use the overall energy-usages to predict how much energy it costs to perform a certain internet service, e.g., film streaming. The data dependent approach attempts to follow the data through the network and is based on how much energy is used per transmitted bit [2]. The time dependent approach considers that the energy consumption of such network equipment is not really limited by how much data is sent through it today, but rather for how much time it is used to service the application under consideration [20]. The data dependent approach considers an average *energy efficiency* (*EE*, energy per bit). Energy efficiency is mathematically defined as

$$EE \left[\frac{Wh}{GB} \right] = \frac{E_{network}}{Data} \tag{1}$$

where $E_{network}$ in *Wh* is the total energy used in a certain network segment and *Data* in *GB* is the total data transported in that network segment. Both parameters are reported in annual industry reports [2], so energy efficiency can be evaluated. The time dependent approach considers the average *power* (*P*, energy per used time). Interestingly, both approaches usually derive their *EE* or *P* from the same source [9], [19].

Yet another difference between estimates given in literature is how much of the used energy is included when evaluating a specific service. Some more or less propose to include all energy used for the internet, including building infrastructure and user devices, while others attempt to narrow it down to the energy used directly in sending the data through its path in the network. This is like discussing the energy usage of the aviation industry and including building and running of airports and aircraft maintenance vs only considering the fuel usage. Both are interesting and valid numbers but should be used with care and not directly compared. This discrepancy is one of the main reasons there is such a large spread on the numbers reported for internet energy consumption [21], [22]. We believe it is useful to con-

sider both the full *gross* energy consumption of networks, including all overhead, to e.g., compare operators, as well as to consider more focused *net* energy consumptions when comparing e.g., internet services. Likewise, the data and time dependent models may both offer insights and paths to optimize certain parts of the network. One would need a global discussion on what to include for which evaluation, and which method is most appropriate.

3.2 Data Dependent Energy Estimation

From a physics perspective it is interesting to explore the fundamental limit on energy needed to transmit a bit, and in future highly energy-efficient systems such a metric could become necessary for evaluating communication systems. The essential parameter is the energy efficiency defined in Eq. (1). For simplicity, the transport network segment, $EE_{network}$ comprises an energy efficiency representing data transmission, $EE_{transmission}$, and an EE representing data centres, EE_{DC}, and may be even more granulated if needed. If the amount of data transported is known, then one may calculate the energy used for transporting that amount of data in the network. Energy consumption in an end user device is most often accepted as being time limited and not data limited. The power usage of the device under consideration multiplied with the duration of usage may be added to retrieve the total energy (E_{total}) in Wh for that operation. This can be mathematically represented as

$$E_{total}[Wh] = E_{network}[Wh] + P_{device}[W] \cdot \frac{T_{use}[s]}{3600} \quad (2)$$

where

$$E_{network} = (EE_{transmission} + EE_{DC}) \cdot Data \quad (3)$$

includes the energy efficiency of (a) data transmission ($EE_{transmission}$) in the network (can be expanded to higher granularity) and (b) the data centre (EE_{DC}). Both the efficiencies are multiplied by the amount of data transmitted to evaluate the energy consumption in the network. The energy consumed in the end-user device (can also be expanded to more devices and more details) is evaluated by multiplying the power consumed (P_{device}) with the duration it is being used for the considered application. The transmission energy consumption ($EE_{transmission}$) depends on the network type, e.g., 4G, 5G or wired. Local wifi networks are often time-limited and may be included as a device. Power consumed in a typical wifi-router times the time it is 'on' for transmitting that throughput represents the energy consumption of that router. If one knows the actual physical path of the data, and the energy-efficiency through that path that number can be used directly for $EE_{transmission}$. An average value may also be used for estimates, and world averages are often available. For example, EEs for different parts of the network, backbone, metro, access, and wired and wireless are given in [2]. As described in the overview paper [23], there are large variations in reported EEs [23], which

is often caused by differences in how much is included from the total network. This clearly needs to be standardized.

Regarding data centres, it is often possible to look up a specific data centre's power usage effectiveness (PUE_{DC}) which is the inverse of power usage efficiency and is defined as

$$PUE_{DC} = \frac{E_{DC}}{E_{DC-compute}} \quad (4)$$

where E_{DC} represents the total energy consumed by a data centre and $E_{DC-compute}$ represents the energy used for computing. Estimation of a specific DC's energy-efficiency can be done by scaling it's PUE to the world averages, as

$$EE_{DC} = \langle EE_{DC} \rangle \cdot \frac{PUE_{DC}}{\langle PUE_{DC} \rangle} \quad (5)$$

where PUE is the power usage effectiveness of the specific data centre and $\langle PUE_{DC} \rangle$ is the world average PUE of DCs.

Figure 1(a) shows a schematic of a network with data being transported from a data centre to various nodes. It also shows world average values for energy-efficiencies from data centres through various paths of a network such as wired, wireless updated to expected 2022 values [2]. The table in Fig. 1(a) lists average values for some common user devices [20]. Fig. 1(b) shows variation of total consumed energy in the past years since 2015 for different user devices. This plot shows an example calculation using Eq. (2) for the case of sending and viewing 3 GB data for 1 hour, which is similar to streaming a 1-hour HD quality film. Wireless (4G) is quickly recognized as the most energy-hungry communication form, completely dominating the contribution from the devices. The LCD 50" TV screen using wifi is the next heaviest energy consumer, mostly due to the power consumed by the device itself. Wired and wifi connections for phone, tablet and laptop are the lowest energy consuming options. Even though power consumption in these devices is slightly different, the data transport energy consumption dominates over power consumed by the device. For smaller data amounts transmitted, the devices would play a bigger role.

3.3 Time Dependent Energy Estimation

In networks of today, most network equipment apparently uses so much energy that the time it is used dominates over how much data is handled, according to [20]. This varies a bit with the type of network, with mobile networks being slightly more data dependent. But overall, the idea, as described in [19], [20], is that a power for a relevant network segment is constructed by using the same total energy used over a year in that segment and dividing by the number of seconds in a year. By furthermore dividing by the number of subscriptions, a power per subscriber is thus constructed. A network operation performed by a subscriber, like e.g., streaming, is then simply evaluated to consuming a total energy as
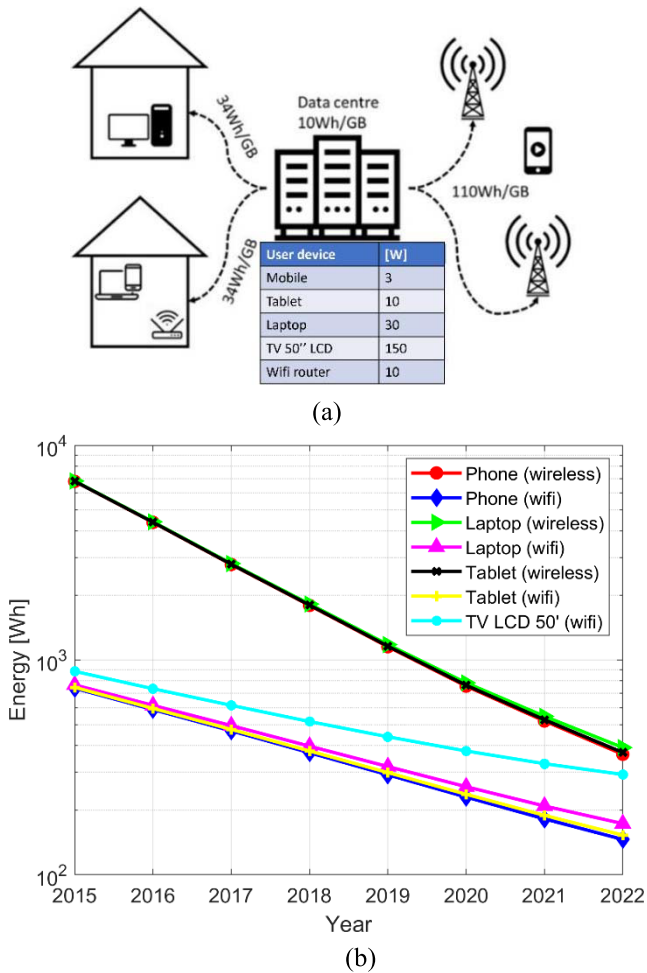
(a)

(b)

Fig. 1 (a) Energy efficiencies of various connection types from a data centre through a network to the user considering only the data transmission extrapolated to 2022 (numbers extracted from [2]) and table with power of commonly used end user devices ([20]). (b) Plot of energy consumption for transmitting 3GB over 1 hour (~1 hour HD quality film streaming) over different connection types to various end user devices.

$$E_{total}[Wh] = [P_{network}[W] + P_{device}[W]] \cdot \frac{T_{use}[s]}{3600} \quad (6)$$

where

$$P_{network}[W] = \frac{E_{total,network}[Wh]}{sec_{year}[hour] \cdot N_{subscriber}} \quad (7)$$

Again, the network can be divided into several segments, like access, core, data centres etc. This construction of power implies that the energy is used evenly distributed all year round, and that all subscribers use the same average power. According to [24], a home router today has a power consumption of about 10 W, and the data routed only changes the power with about 1%. The data dependence of power for mobile networks can change with up to 20%, though. Thus, for some network segments, the time dependent model is very accurate, whereas for others, there may be a relevant variation due to the data amount sent.

3.4 Modified Data Dependent Energy Estimation

As the two models described above both start from the same total energy, and then either divide it out on time and subscribers or on the known amount of data transmitted over the relevant period, they should be equivalent, and it should be possible to make them converge in agreed scenarios of gross and net energies for specific well-defined applications. In order to approach this, and inspired by [23], Eq. (2) can be modified to also include more or less of the overhead associated with the network, e.g., buildings and maintenance through the two factors Utilization Factor (UF) and $PUE_{transmission}$. UF describes how much over-provisioned capacity is in the network related to how much is really used. The network may be built to support a certain capacity in peak hours, and thus use energy to support this, but most of the time only half of the installed capacity may be used. Thus, one may adapt this parameter UF to represent a case where all energy is considered, or where one only follows the data transmitted. $PUE_{transmisison}$ is the power usage effectiveness for networks (similar to PUE for data centres). It describes how much energy is used specifically to support data transport and how much is used to keep the network running, by e.g., keeping network node buildings running. We can then modify the total energy consumption given by Eq. (1) as

$$E_{total}[Wh] = E_{network}^{modified}[Wh] + P_{device}[W] \cdot \frac{T_{use}[s]}{3600} \quad (8)$$

where

$$E_{network}^{modified} = \left(EE_{transmission} \cdot \frac{UF}{PUE_{transmission}} + EE_{DC} \right) \cdot Data \quad (9)$$

Figure 2 shows calculations using all three models; a data-based model, with only user devices as time-dependent, a pure time-based model, and a modified data-based model, The modified data-based model also includes time-dependence of user devices, including home wifi-routers. For reference, the IEA estimated the middle case to 77 Wh, based on a time-dependent model [22], where the Shift Project estimated 780 Wh, relying on a data-based model including all overhead. For the time-based case, the data amount is not included. Hence, for the fastest possible download of 3 GB, only 0.3 Wh is predicted. If the same amount of data is viewed/streamed over 1 hr, 45 Wh is predicted. Reading a newspaper (consisting of 20 MB) online for 1 hour uses the same low energy of 45 Wh. For the data-based case, the model estimates data transport, as if all installed capacity is used for all services i.e., $PUE = 1$.

For the data-based model, the amount of data sent makes a clear difference. However, some time dependence is also observed, owing to the user device being considered as time dependent. For the 1 hour, 3-GB streaming case, 252 Wh is consumed. This is still notably smaller
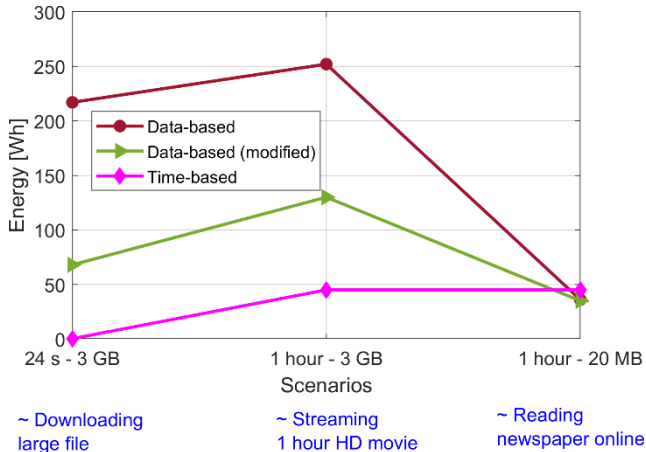
Fig. 2 Example calculations using time-based, data-based and modified data models for three network use cases corresponding to downloading a large file, streaming an HD film for 1 hour and reading a newspaper online. All examples assume a laptop as user device, $UF = 0.5$, and $PUE_{transmission} = 1.8$.

than the $780\,Wh$ predicted by [21]. This is because [21] includes more overhead from building the internet infrastructure, which could be argued as fair, as it is a prerequisite for using the internet after all. On the other hand, for specific applications, it may not be as interesting to evaluate the infrastructure of the network, but more the services in terms of how long it takes and how data-intensive it is. For the data-based case of fast download of 3 GB, the energy predicted is still high, 217 Wh, as the amount of data dominates in this case. And for the 1-hour long 20-MB reading scenario, the energy drops to 36 Wh, i.e. even less than the 45 Wh as predicted by the time-based model. In the modified data-based case, the overhead is extracted through the UF and PUE values. The values predicted in this case are lower than the data-based case and closer to the time-based case, and strong dependence on both time and data is observed. 68 Wh is predicted for the 24-sec, 3-GB download. 130 Wh is predicted for the 3-GB streaming case and only 35 Wh for the 1-hr, 20-MB case.

To improve on the modified data-based model, the actual transmission path may be needed. In [23] this is suggested to be included as hops, to evaluate how many routing or switching incidences the data experiences. As a practical implementation, we propose to use *trace route*, to track the IP routers that the data packets encounter, and then look up the geo-locations by GPS, and based on that estimate number of amplifiers encountered in the optical layer, and subsequently count their energy consumption.

3.5 Need for Standardized Evaluation Tool

Green ICT is becoming a differentiating competitive parameter, and tender processes are beginning to include requirements on sustainability. One will therefore need to be able to present the energy-status as well as the CO2 impact of one's technology. As seen from the above discussion, one needs

to be very specific when trying to adapt the presented models to specific applications. To be fair, it should be noted that data- and time-based models were never originally intended to be used to estimate specific internet services, but rather to provide an overview of average energy consumption. However, it is inevitable that models for specific services will be needed to assess different technologies in the future, and deriving the most fair, transparent, and correct model will be important.

As the energy becomes a more important factor to optimize on, future networks may be embracing energy-saving actions such as [25]: implementing sleep mode in most equipment, optical bypass routers, mixed line rates, protection resources in low power state when idle, optimizing network topology, optimizing distributed cloud-content distribution, network equipment virtualization, and improved network components with lower power consumption. When all of this is implemented, the resulting networks may indeed be both data- and time-dependent, or time and data may become equivalent. Furthermore, according to [26], expectations are that the energy use for data transport will dominate over devices soon, so a good model will have to include this, and be useful as an optimization tool of the networks.

4. Estimating CO_2 Emission

Energy consumed by an internet application has a direct correlation with its CO_2 footprint. The main purpose of critically analyzing the energy budget of the internet is to understand its environmental impact on the globe. The advancements in the green energy sector has created an opportunity for reducing the CO_2 footprint of the internet. Since internet has become an indispensable requirement, it is crucial to understand the correlation between energy consumption and CO_2 emission. Once the energy is derived, one may consider how this energy is produced, and hence estimate the CO_2 emission. This can be done by using the average CO_2 emission factor for electricity generation, aka the electricity mix factor (EM). From [27], [28], this is about 0.6 kg CO_2 per kWh when taking into account the electricity production and electricity supply chain. If one knows how large a fraction of the electricity produced in a specific country is CO_2 neutral, one may then calculate the emitted CO_2 as

$$CO_2[kg] = E_{total}[kWh] \cdot \left(1 - x_{green}\right) \cdot EM \left[\frac{kg}{kWh}\right] \quad (10)$$

where x_{green} is the fraction of green energy used. x_{green} could be the country's average or the vendor's choice on purchased energy composition e.g., in Japan $x_{green} = 29\%$ whereas for Sweden $x_{green} = 98\%$ [29]. The EM corresponding to zero green energy is used in Eq. (10), where we assume that green energy does not create emissions i.e. it does not include life cycle analysis. Some companies choose only green energy for their data centers in which case $x_{green} = 100\%$. Using this approach, one may derive an expression for CO_2 emission at a certain data centre for a full year as
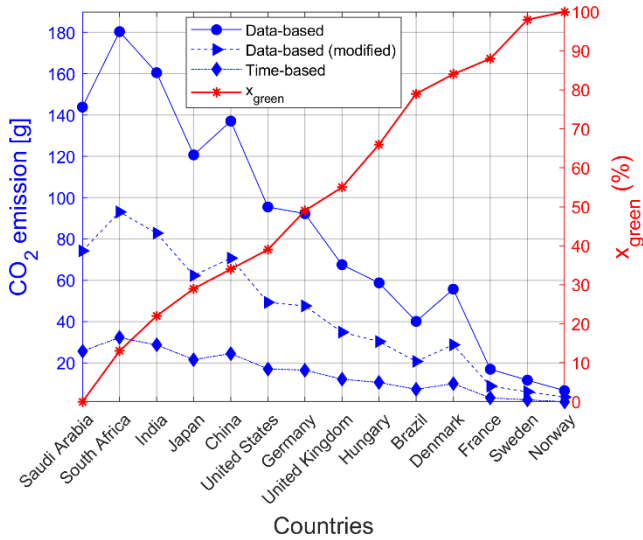
Fig. 3 Left: CO_2 emission for different countries for 1 hour 3 GB streaming in 2021 [29] for the three energy consumption models. Right: percentage of green energy for different countries.

$$CO_2 \left[\frac{ton}{year} \right] =$$

$$\langle EE_{DC} \rangle \left[\frac{Wh}{GB} \right] \cdot MS \cdot Data \left[\frac{GB}{year} \right] \cdot \frac{PUE}{\langle PUE \rangle} \cdot \left(1 - x_{green} \right)$$

$$\cdot EM \left[\frac{ton}{MWh} \right] \tag{11}$$

where MS is the market share of the specific service, $Data$ is the world data traffic through DCs for the year, x_{green} is the fraction of green energy used by the DCs.

Figure 3 shows the CO_2 emission in grams involved in streaming of 3 GB data for a duration of 1 hour for different countries using the three discussed models. The percentage of green energy usage for these countries is shown in the right axis of the plot (from [29]). We use the country's average x_{green} value for these calculations.

4.1 Online Calculators

Although there is still a need for a standardized method to evaluate ICT energy consumption and CO_2 emission, there are already several online tools available, where one can get a hint of what the consumption and emission is on the applications one is using. For instance, for streaming, the IEA has an online calculator, which is in the same ballpark as the analyses presented in this paper [30]. In [31], an assessment method of environmental footprint based on life-cycle analysis (LCA) is presented. LCA provides a quantitative assessment of the environmental footprint for the entire life cycle of a product or service, whether it is footprint due to manufacturing, the facilities, or the user of that product or service. However, the introduced method in [31] is simplified but based on LCA. For a network-based assessment, this model ensures inclusion of all aspects of LCA but is limited to the usage time of network. Finally, in [32] the model is

applied to estimate the CO_2 footprint while using various social media in a particular cellphone.

5. Conclusions

Estimating the energy and CO_2 footprint of the internet has become an important objective, as it seems ICT products and services will be evaluated on these metrics soon. For more than a decade now, global averages have been established with good credibility. Taking these efforts even further and applying them to specific technologies and applications will be a necessary next step. This is, however, by no means an easy task, especially if the product is not a single unit piece of hardware, as for many internet services.

In this paper, we have attempted to provide, to some level of detail, an overview of the main approaches to evaluate the footprint of internet services. The time-based model may be the most useful today, and the data-based model, with modifications, may gain more traction in the future, as the networks become increasingly energy-efficient. As the requirement for energy-efficiency becomes more widespread, the whole industrial value chain may be impacted, so that service providers will pose requirements on network operators, who in turn will pose requirements on system vendors etc., all the way down to chip-developers. And all links in this chain may need a standardized model for self-evaluation. Correspondingly, the footprint estimations may need to be developed on many levels.

It is therefore important to arrive at standardized methods to evaluate energy consumption and CO_2 emission for online products. Such methods should be objective, transparent, fair, comprehensive, and cover equipment, services/applications and be relevant to hardware as well as software. Finally, the added value of the internet service shouldn't be forgotten, as internet applications often provide a source of joy, entertainment, usefulness and/or improvements over existing solutions.

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