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Assessing Internet energy intensity: A review of methods and results

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ABSTRACT

Assessing the average energy intensity of Internet transmissions is a complex task that has been a controversial subject of discussion. Estimates published over the last decade diverge by up to four orders of magnitude — from 0.0064 kilowatt-hours per gigabyte (kWh/GB) to 136 kWh/GB. This article presents a review of the methodological approaches used so far in such assessments: i) top–down analyses based on estimates of the overall Internet energy consumption and the overall Internet traffic, whereby average energy intensity is calculated by dividing energy by traffic for a given period of time, ii) model-based approaches that model all components needed to sustain an amount of Internet traffic, and iii) bottom–up approaches based on case studies and generalization of the results. Our analysis of the existing studies shows that the large spread of results is mainly caused by two factors: a) the year of reference of the analysis, which has significant influence due to efficiency gains in electronic equipment, and b) whether end devices such as personal computers or servers are included within the system boundary or not. For an overall assessment of the energy needed to perform a specific task involving the Internet, it is necessary to account for the types of end devices needed for the task, while the energy needed for data transmission can be added based on a generic estimate of Internet energy intensity for a given year. Separating the Internet as a data transmission system from the end devices leads to more accurate models and to results that are more informative for decision makers, because end devices and the networking equipment of the Internet usually belong to different spheres of control.

Contents

1. Introduction

Information and communication technologies (ICT) are credited as potentially important contributors towards a low-carbon economy (Erdmann and Hilty, 2010; European Commission, 2008; Hilty et al., 2013; Laitner, 2010; Laitner and Ehrhardt-Martinez, 2009; Mattern et al., 2010; Pamlin and Pahlman, 2008). There are, however, important controversies regarding the energy consumption and the environmental impact of some parts of ICT themselves. The energy intensity of the Internet, expressed as energy consumed per data transmitted, is one of these controversial issues.

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The Internet is the infrastructure that connects billions of computers worldwide using the TCP/IP family of communication protocols. Some studies we are reviewing include the end devices communicating through the Internet (e.g., PCs and web servers) and their energy consumption in their object of research and therefore answer a different question than the studies addressing only the energy used for Internet data transmission.

Before we go into detail, we would like to point out that we are comparing estimates for *direct* energy consumption in the form of electricity only. The energy supply chain, containing the supply of primary energy, power plants transforming it to electricity, and grids bringing them to the consuming devices, is excluded from the system under study — although the electricity mix used, e.g., by data centers, is an issue of rising importance. We also exclude the "gray" energy embedded in ICT hardware, although the material flows caused by producing and disposing of hardware are significant (Hilty et al., 2011; Schluep et al., 2013). Furthermore, this study does not account for the increasing role of mobile Internet access and its impact on energy intensity. This restricted scope represents the least common denominator of the studies we analyzed.

Existing studies of Internet energy intensity (energy consumption per data transferred) lead to estimates differing by more than four orders of magnitude — from 136 kWh/GB (Koomey et al., 2004) down to 0.0064 kWh/GB (Baliga et al., 2011), a factor of more than 20,000.

This article presents a review of the existing studies, provides explanations for their large spread and concludes with a recommendation on how the system boundary for such studies should be drawn to be most useful for decision-making.

2. Assessments of Internet energy intensity

Our review includes the following ten studies published between 2004 and 2013: Baliga et al. (2007), Baliga et al. (2009), Baliga et al. (2011), Coroama et al. (2013), Koomey et al. (2004), Lanzisera et al. (2012), Pickavet et al. (2008), Schien et al. (2012), Taylor and Koomey (2008), Weber et al. (2010). Not all of them address the same object of research because they define different system boundaries for "the Internet", a crucial issue to which we will return later. Some recent studies, namely CEET (2013) and Masanet et al. (2013), use data of the ten studies mentioned and are therefore not treated as separate sources in our analysis.

The ten studies presenting original data can be roughly classified according to the basic methodological approach they use:

- Top–down approach: According to Chan et al. (2012), *top–down* analyses are the ones taking into account the total electricity consumption estimated for the Internet and the Internet traffic for a region or a country within a defined time period. Dividing the former quantity by the latter yields the average energy consumption per data transferred.
- Model-based approach: By contrast, *model-based* approaches model parts of the Internet (i.e., deployed number of devices of each type) based on network design principles. Such a model combined with manufacturers' consumption data on typical network equipment leads to the overall energy consumption (Hinton et al., 2011), which is then related to the corresponding data traffic.
- Bottom–up analysis: Finally, *bottom–up* analyses are based on direct observations made in one or more case studies, leading to energy intensity values for specific cases, and a discussion of the generalizability of the results.

All ten studies reviewed apply an average allocation rule, distributing the equipment energy consumption evenly among the total traffic volume over a certain period of time. Applying a consequential instead of an attributional approach as discussed in LCA methodology (Finnveden et al., 2009), which means to focus on marginal instead of average effects, would be a reasonable alternative, but would raise allocation issues for the fixed part of the energy input (the power consumed even when no traffic would occur). We have not found any study applying a consequential approach to Internet energy intensity.

There are a significant number of studies presenting LCAs of electronic media (often in comparison to print media). The product systems investigated in these studies naturally include data transport over the Internet. However, as Bull and Kozak report in a recent review (Bull and Kozak, 2014), the existing studies either assume that its contribution to environmental impact is negligible, or they use very rough estimates of the energy used for Internet data transmission. We therefore didn't include these studies in the present review.

Some newer industry studies on the energy consumption of cloud computing could be expected to provide better insight into the energy consumption induced by network traffic. However, these studies either do not account for network energy (Google, 2011; Verdantix, 2011), do not disclose it separately from the data center's energy consumption (Accenture, 2010; WSP Environmental, 2011), or assume proportionality to the servers' consumption (Google, 2012). A report on cloud computing by Greenpeace (Cook, 2012) has been excluded as well because it considers only the data centers providing the cloud services and no Internet data transmission.

Two research labs have recently provided studies on the energy consumption of cloud services: University of Melbourne's "Centre for Energy-Efficient Communications" (CEET, 2013) and the Lawrence Berkeley National Laboratory (Masanet et al., 2013). Both studies include in their calculation the results of third-party assessments of the energy intensity of the wired Internet that are already part of the present review: CEET (2013) uses the data from Baliga et al. (2009), and Masanet et al. (2013) build on data from several sources such as Baliga et al. (2009), Coroama et al. (2013), and Lanzisera et al. (2012). A recent study by Hischier and colleagues on electronic media (Hischier et al., under review) builds on other data sources as well.

2.1. Studies using a top-down approach

Top-down analyses are based on two relatively coarse estimates: 1) the overall energy demand of either the entire Internet or a part of it (e.g., a country or a continent), and 2) the total Internet traffic of that region, and can thus produce a relatively large estimation error (Chan et al., 2012).

One of the early top-down studies refers to the year 2000 and places the US Internet energy consumption at 47 terawatt-hours per year (TWh/a) and the corresponding Internet data flows at 348,000 terabytes per year (TB/a) (Koomey et al., 2004). The transmission of 1 gigabyte (GB) would thus need on average 136 kWh. For the Internet traffic, the study used estimates by the Minnesota Internet Traffic Studies (MINTS) group. For the Internet energy consumption, the study builds on estimates of the total energy consumption of office and telecommunications equipment in the US (Roth et al., 2002). The study was explicitly designed to be an upper-bound estimate: "For purposes of estimating network electricity use, we erred on the side of being more inclusive, with the understanding that this approach would result in an overestimate" (Koomey et al., 2004).

An update of this study was later published referring to the year 2006. Estimating again the US Internet energy consumption and using three existing estimates of the US Internet traffic per year, the new study presented a range of 8.8–24.3 kWh/GB, depending on the traffic estimate used (Taylor and Koomey, 2008). This study was again designed to be pessimistic rather than optimistic in terms of energy consumption. By interpolating between these two results 6 years apart (considering for 2006 the median figure of 15.7 kWh/GB), the authors conclude that the energy needed per amount of data transmitted over the Internet decreases by 30% per year.

This 2006 estimate was updated in a later article for the year 2008 (Weber et al., 2010). For this period, the authors assumed that total Internet traffic increased by 50% per year, and that total Internet electricity use grew at a yearly rate of 14%, which had been the average global growth rate of data center electricity use between 2000 and 2005. These assumptions resulted in an average Internet electricity intensity of about 7 kWh/GB for 2008.

Based on numerous inventory surveys, together with annual power growth estimates and "comparison with the power consumption of data centers and PCs in the same surveys," Pickavet et al. (2008) put forward a worldwide average power consumption of 25 gigawatts (GW) for networking equipment in 2008, which corresponds to an energy demand of 219 TWh/a. To make their result comparable with the other studies, we add our own estimate for Internet data traffic for 2008 to calculate the energy intensity. According to Cisco's "Visual Networking Index", global IP traffic grew 45% during 2009 to reach an annual run rate of 176 exabytes (EB) per year (Cisco, 2010). We therefore assume a traffic volume of 121 EB for the year 2008. Dividing the study's estimate for Internet energy demand by this estimate for Internet traffic yields an energy intensity of 1.80 kWh/GB. According to the system boundary chosen by Pickavet and colleagues, this value includes only equipment used for transmission (i.e., network equipment and optical fibers with amplifiers), but no end devices.

Lanzisera et al. (2012) include only networking equipment in their top–down analysis (no fibers, no end devices). Estimating the total of both the US and the world networking equipment stock for 2008, the power of each device and their individual usage patterns, the article computes an annual electricity consumption of 18 TWh for all networking equipment in the US and of 50.8 TWh for the world. Using the same 121 EB/a derived from Cisco (2010) as worldwide traffic estimate for 2008 yields then an energy intensity of 0.39 kWh/GB for the world average.

The considerable divergence among the results of the five top–down studies is mainly explained by the use of different system boundaries, as we will discuss in Section 3.

2.2. Studies using a model-based approach

This approach is based on modeling parts of the Internet according to network design principles together with manufacturers' data on typical network equipment (Hinton et al., 2011).

Detailed and broadly documented model-based analyses have been presented by a University of Melbourne group (Baliga et al., 2007, 2008, 2009, 2011; Hinton et al., 2011), and by Kilper et al. (2011). Most of their articles analyze a part of the typical Internet transmission path (Baliga et al., 2008), or have distinct focuses such as the Internet power consumption per user (Baliga et al., 2007) or future developments (Kilper et al., 2011). Some of these results may, nevertheless, be adapted to become compatible with our analysis.

We will do this adaptation for the paper by Baliga et al. (2007), who analyze the Internet-related power consumption of 2 million Australian homes (corresponding to 4 million users). The analysis is based on the following system boundary: it considers the power consumption in the access network close to the users, the metropolitan network, the core Internet network, and along the optical fiber links. It results in a range of power consumption depending upon the peak and average Internet access rates. Considering the 2007 values of 100 Mbit/s peak and about 1–2 Mbit/s average access rates yields a consumption of 20 megawatts (MW), which is a rounded value. In order to calculate the energy intensity per amount of data, we again have to add our own estimate of the amount of traffic, in this case for 4 million Australian users in 2007. According to Cisco, Australia's Internet traffic reached 72 petabytes per month in 2010 (Cisco, 2011), or 864 petabytes per year (PB/a). Cisco further indicates that "Australian Internet traffic in 2010 was equivalent to 8 × the volume of the entire Australian Internet in 2005″ (Cisco, 2011). Assuming steady exponential growth with a growth rate of 51.5% (leading to an eightfold increase over 5 years) yields a traffic volume of 248 PB/a for 2007. In the same year, 71.7% of Australians were using the Internet, and 23.94% were broadband subscribers (The World Bank, 2011). In other words, around 1/3 of Australian Internet users had a broadband connection. Depending on whether we distribute the Australian Internet traffic evenly among all users or exclusively among the ones with a broadband connection, the broadband-connected users caused a traffic volume of either 82.7 or 248 PB/a. Because we can safely assume that the reality is somewhere between these extremes (users with broadband connection caused an over-proportional part of the traffic, but not 100%), it follows that the traffic of broadband users was in the range of 82.7–248 PB/a. Together with the average power consumption of 20 MW (Baliga et al., 2007), which amounts to 175 GWh/a, this yields an energy intensity of 0.7–2.1 kWh/GB.

A second model-based study we reviewed (Baliga et al., 2009) provides a direct estimate for the energy intensity of Internet data transmission: 75 micro-Joules per bit (μJ/bit), equal to 0.179 kWh/GB, at the relatively low access rates typical for 2008. As the authors point out, their result represents a lower bound or optimistic estimate in terms of energy consumption, because the model assumes only state-of-the-art equipment and ignores the fact that legacy network equipment is less energy efficient. They further state that they expect this energy intensity to drop in the near future to 2–4 μJ/bit with increasing access rates. In their 2011 article Baliga et al. (2011) use a value from this envisioned range, 2.7 μJ/bit. This value corresponds to 0.0064 kWh/GB and represents the lowest value put forward thus far.

2.3. Case studies using a bottom–up approach

In Coroama et al. (2013), we presented an assessment using a pure bottom–up approach. The assessment was based on the case study of a 40 megabits per second (Mbit/s) videoconferencing transmission between Switzerland and Japan, introduced in Coroama et al. (2012). For a system boundary that included network devices and optical fibers but no end devices, and making pessimistic assumptions in terms of energy consumption where specific data was not available, the study yielded an energy intensity of 0.2 kWh/GB for 2009. As we argued in Coroama et al. (2013), the case has many characteristics (such as a high number of hops) that justify taking it as above-average in terms of energy intensity. This implies that the case-study result, when generalized, should be considered an over-estimation of the average energy intensity.

The case study conducted by Schien et al. (2012) analyzed the download of the UK newspaper "The Guardian", as well as the download of a 640 second video from the Guardian's video section. The newspaper's homepage was located on a server within the UK, while the video was outsourced to a Content Distribution Network (CDN) and mirrored on several continents within the CDN's network. Downloads from clients in Oceania, Northern America, and Europe were studied. It turned out that geography played only a minor role; the energy consumptions of the downloads from different continents were similar. On average, for both the homepage and the video, they were just below 25 Joules per megabit (J/mbit), which corresponds to 0.057 kWh/GB.

3. Comparison of the studies and explanation of diverging results

The surveyed studies present a very large variation among their results: from the 136 kWh/GB of (Koomey et al., 2004) down to the 0.006 kWh/GB of (Baliga et al., 2011), there is a spread of four orders of magnitude. Table 1 summarizes the most important characteristics and the results of the studies surveyed in this review. Some of the energy intensity results had to be calculated by the current authors to make the studies compatible, as described in Section 2 above. These values are marked with an asterisk (*). In the following, we will discuss the influence of the most important factors on the results.

3.1. Reference year

An important part of the large differences can be explained by the year of reference for the individual studies, ranging from 2000

Table 1
Estimates for the energy demand of Internet transmissions.

Study	Method	System boundary			Data for	Energy intensity
		Networking equipment	Optical fibers	End devices		
Koomey et al. (2004)	Top–down	X	X	X	2000	<136 kWh/GB
Taylor and Koomey (2008)	Top–down	X	X	X	2006	8.8–24.3 kWh/GB
Weber et al. (2010)	Top–down	X	X	X	2008	7 kWh/GB
Pickavet et al. (2008)	Top–down	X	X		2008	1.8 kWh/GB[a]
Lanzisera et al. (2012)	Top–down	X			2008	0.39 kWh/GB[a]
Baliga et al. (2007)	Model-based	X	X		2007	0.7–2.1 kWh/GB[a]
Baliga et al. (2009)	Model-based	X	X		2008	>0.179 kWh/GB
Baliga et al. (2011)	Model-based	X	X		2011 (?)	0.006 kWh/GB
Schien et al. (2012)	Bottom–up	X	X		2009	0.057 kWh/GB[a]
Coroama et al. (2013)	Bottom–up	X	X		2009	<0.2 kWh/GB

[a] Calculated by the authors based on the results provided in the cited study.

(Koomey et al., 2004) to 2009 (Coroama et al., 2013; Schien et al., 2012). ICT is a very dynamic sector, and the equipment is becoming ever more energy efficient, needing less energy per amount of data being processed or transmitted. According to the observation from Taylor and Koomey (2008) that the energy intensity of Internet data transfers decreases by 30% each year, this technological progress alone leads to a reduction by a factor of 25 over the period of 9 years covered by the studies. In Baliga et al. (2011) it is not explicitly stated which year the study refers to. Assuming it refers to the year of publication, 2011, would imply a factor of 50 between 2000 and 2011.

The plot of the energy intensity over time shows the general decreasing trend (Fig. 1).

3.2. System boundary

The other determining factor is the system boundary, in particular, whether end devices (i.e., end-user devices such as desktop, notebook or tablet computers, and servers running to provide services through the Internet) are viewed as part of the system under study or not. This decision has a large impact on the result: As shown in Table 1, for the year 2008, which has been referred to by several studies, the study including end devices yields a result of 7 kWh/GB (Weber et al., 2010), while the three studies not including end devices result in energy intensities of 1.8 kWh/GB (Pickavet et al., 2008), 0.39 kWh/GB (Lanzisera et al., 2012), and 0.179 kWh/GB (Baliga et al., 2009) — all at least a factor of 4 below the study that includes end devices. Google (2012) implicitly assumes that the energy consumption caused by the Internet transfer of data is small in comparison to the consumption of the data centers, estimating the transfer by adding an extra 10% on top of the data center consumption. The study by Pickavet et al. (2008) computes the average worldwide power consumption in 2008 for different classes of ICT devices. Their analysis yields 25 GW for network equipment and 29 GW for data centers, 30 GW for PCs, 44 GW for TVs and displays, and 40 GW for other devices — the network part thus being 15% of the total. Finally, Williams and Tang (2013) analyze the energy consumption of five cloud-based services, indicating the consumption of data centers, network, and end devices separately. Their analysis that considers the entire life cycle of devices and is thus not directly comparable to the studies reviewed here, results in much lower shares for the network: 0.01–0.50% of the life-cycle wide energy, depending on the service and type of end device used.

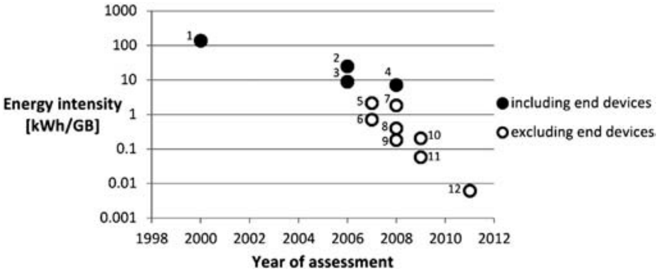

Fig. 1. Results of the reviewed studies, together with the year their data refers to. Filled circles represent studies that took into account end devices; empty circles represent studies that considered only the energy needed for data transmission. Legend: 1. (Koomey et al. (2004); 2. Taylor and Koomey (2008): high end, as computed by the authors; 3. Taylor and Koomey (2008): low end; 4. Weber et al. (2010); 5. Baliga et al. (2007): high end, as computed by us depending on the distribution of Australian Internet traffic between high bandwidth users and low bandwidth users; 6. Baliga et al. (2007): low end, as computed by us; 7. Pickavet et al. (2008), computed by us based on the author's estimate of worldwide Internet energy consumption divided by an estimate of the worldwide Internet traffic for that year; 8. Lanzisera et al. (2012), computed by us based on the author's estimate of worldwide Internet energy consumption divided by an estimate of the worldwide Internet traffic for that year; 9. Baliga et al. (2009), value for low access rates of a few Mbits/s; 10. Coroama et al. (2013); 11. Schien et al. (2012), value approximated from Figs. 6 and 7 of the paper; 12. Baliga, Ayre (2011), uncertain which year the data refers to, probably 2011.

From all these considerations, it is evident that the decision of whether or not to include end devices within the system boundary will influence the result substantially. The difference between including or excluding end devices is also made visible in Fig. 1.

In Section 4 below, we will argue against the inclusion of end devices within the system boundary of studies analyzing the energy intensity of the Internet.

3.3. Assumptions regarding access networks

Several authors point out that the access network (the network connecting users to the nearest switch of the Internet service provider, nowadays ADSL lines, public WiFi hotspots or mobile networks) can dominate the energy consumption (Baliga et al., 2009; Coroama et al., 2013; Hinton et al., 2011). With increasing access rates, however, it is also possible that the core network components will become increasingly important and might, in the end, be the major factor of the energy intensity of the wired Internet (Baliga et al., 2009). A more detailed investigation of the access versus core networks will therefore be a crucial part of future studies on Internet energy intensity.

3.4. Other factors influencing the results

The facilities (rooms, buildings) hosting ICT networking equipment and datacenters induce a power overhead due to non ICT-related consumption such as cooling or lighting. The measure widely used to account for this consumption is the so-called Power Usage Effectiveness (PUE). The PUE is computed as a facility's total power divided by the power needed to run the ICT equipment only (Rawson et al., 2008). As the former includes the latter, the PUE is larger than, or equal to, 1. The closer the PUE is to 1, the less power is "wasted" for activities other than information processing, such as power transformation or cooling. The average PUE for datacenters nowadays is slightly lower than 2 (Stansberry and Kudritzki, 2012) with decreasing tendency; for the facilities hosting Internet routers it was around 1.7 in 2009 (Moth and Norris, 2010).

Most studies include an estimate of the PUE in their considerations; Lanzisera et al. (2012) do not, i.e., they assess the energy directly entering ICT devices. The study by Pickavet et al. (2008) is unclear on this point. It is obvious from the considerations above that the PUE can influence the results considerably, namely up to a factor of 2. We favor taking into account the PUE, as the additional energy covered by the PUE, in particular the cooling energy, is consumed only because of the ICT equipment.

The last factor that influences the results is the power consumption along the optical fibers. All studies except Lanzisera et al. (2012) include them. While optical fibers as such do not need any power, the optical amplifiers needed every 80–100 km do. This power, however, is relatively small compared to the power of the networking devices (routers and switches); the exclusion of the fiber connections thus does not substantially change the results.

4. Discussion

Our analysis has shown that there is one outstanding problem that must be solved when assessing the energy intensity of the Internet: the definition of the system boundary. The extreme case to view all ICT equipment connected to the Internet as part of the Internet leads to results that include energy consumption needed for various types of devices and tasks. Average energy intensity, in this case, does not say much about a specific task carried out by specific devices because of the high variability. The other extreme is to assess only the energy needed for data transmission.

Including end devices is undoubtedly valuable for numerous purposes. If, for example, the objective of the research is to determine the energy consumption caused by streaming and watching a video from the Internet, the system under study should include (a) the end-user device's electricity consumption for the duration of the video being watched, (b) the consumption caused in the Internet by transmitting the data, and (c) a properly allocated share of the consumption of the server providing the video. (a) and (c) refer to end devices in our terminology, while (b) refers to the Internet as a data transmission infrastructure.

However, it is hard to imagine how an average value given for Internet energy intensity that includes unspecified end devices can be of use to make a statement about a specific case, because it cannot differentiate between different user devices (such as a PC or a tablet), nor between the servers at the other end (and their utilization, which may also play a role). Moreover, this approach is also incapable of differentiating between client–server and peer-to-peer communication, which could make a significant difference for energy consumption and allocating energy to tasks.

It therefore seems to be more useful and also more transparent to first estimate (a), (b), and (c) separately and adding the partial results up when necessary, as opposed to calculating just the total from the outset. In general, knowing which fraction of the overall energy demand is caused by which part of the supply chain of a final service is key to efficiently allocate investments in energy efficiency. If such results are to be used by decision-makers, they should clearly differentiate between the three components.

Assessments of Internet energy that include end devices can even lead to misleading conclusions when applications running on identical end user equipment are compared. While a peer-to-peer file exchange, for example, can use a bandwidth of several Mbit/s, a Skype voice call uses a bandwidth of only 60 kbit/s. Assuming exclusive usage of two identical client devices at the end nodes, in the low-bandwidth case the relatively high energy consumption *per bit* at the terminal nodes (due to low utilization) would dominate any mixed calculation of transmission energy and end device energy. This could lead to the seriously misleading conclusion that “the Internet” uses more energy per amount of data for a Skype call than for a file exchange (roughly two orders of magnitude more). Although a small part of the difference can be explained by the fact that short packets, as they are typical for Skype, attract a higher proportion of overhead than large packets (Hinton et al., 2012), making Skype indeed less energy efficient than file transfer, the lion's share of this large difference is a consequence of the different utilization of end devices during their exclusive use for the given activity.

While the energy consumed for transporting data is indeed proportional to the amount of data transmitted, the applications causing the traffic might induce very different consumption per amount of data transmitted at the end devices. We thus conclude that even for the purpose of assessing the total energy cost of an Internet-based application, a sound approach should assess the three components (a), (b), and (c) mentioned above separately.

A basic methodological problem is that there are devices whose energy consumption scales with traffic, and devices (including the end devices) where this is usually not the case. This would in principle require to measure energy intensity in energy per data in the first case and in energy per time (i.e., just power) in the second case, because the load will make no difference. Such a combined approach seems to be imperative when investigating the energy intensity of access networks in more detail.

5. Conclusion and outlook

We reviewed ten studies that assessed the average energy intensity of the Internet or quantities from which we could derive such an estimate. We found that the reference year had an obvious influence on the result. The most important conclusion is that the decision to either include end devices into such an assessment or to define the Internet as a pure data transmission system is crucial, both for the order of magnitude of the results as well as for the usability of the result to assess specific cases or applications and to support decision-making.

We therefore recommend the clear differentiation between data transmission via the Internet and data processing at the end nodes (done by end-user devices or servers) when assessing energy consumed for performing tasks involving the Internet, and to limit the validity of the results to the year of reference.

This study does not account for the increasing role of mobile Internet access and its impact on energy intensity. Newer results (CEET, 2013) suggest that future research should also systematically differentiate between access technologies (in particular, between mobile access and most other wireless or wired access technologies), which seem to have a substantial effect on energy intensity.

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