Calculating electrical footprint of personal internet use

Gerrit-Willem Smit
University of Twente
P.O. Box 217, 7500AE Enschede
The Netherlands
g.w.smit@student.utwente.nl

ABSTRACT

With data centers growing in both numbers and size, the electric cost to keep them running keeps increasing. But how much are these data centers affecting the electrical footprint for any individual? Is it as much as leaving one light bulb on for a day or do you have to consider using the internet less since your use of it would be ten times the power cost of your electricity bill? To get a grasp on the scale of this usage, this paper will dive into the current internet's power footprint and how this is divided and influenced per user.

Keywords

internet consumption; Electrical footprint; Personal use; internet growth

1. INTRODUCTION

It is becoming more and more popular to live carbon or environmentally neutral[2]. Even cities are starting to advertise such a living style. In the UAE and China they are even building completely carbon-neutral cities[18]. However, this usually just means that the electricity and other carbon emissions that are caused locally must be regained or saved locally. These calculations never include someones internet use (outside of their local router power usage or phone charge). Unfortunately the internet does not work like that. Data centers require a large amount of energy to run and give you the data you request and send. In this paper, the goal is to calculate the average use of the internet for yourself or a group to calculate how much you would have to compensate to be truly net-neutral when it comes to your electrical footprint.

Knowing how much electricity your personal internet use costs would provide an important insight into how the internet is growing. It would be misleading to only focus at the total power usage as the user base is expanding rapidly as well. It is like saying that we are having traffic problems everywhere because the cars became bigger without mentioning the amount of people that drive cars. This paper will provide a better insight as to where the real cause is for the increasing electricity cost or how much each aspect of the growth has an influence on it.

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A secondary goal is to also move the focus from the big internet companies back to the consumer. Like the movement to minimize meat consumption to improve the climate, it wasn't done by shutting down all slaughterhouses. People make their own decisions and once the support is large enough the industry will adjust their production accordingly. If they don't they will be replaced by companies that do provide other options. If this paper would only change the mindset of a few it could have a major impact.

2. BACKGROUND

The concept of the internet started back in 1969 with the first message being transferred between two universities. By the time 1982 came around there were 1000 different hosts connected to the network and it had expanded outside of the United States. In 1989 the amount of connections reached 100.000, and 100 million in 2002[16]. From there on forward its reach and capabilities have expended to the internet that we know today. A global network that connects all countries and roughly half the population of the earth.

Part of the rapid expansion was the rise of the mobile phone and therefor mobile computers. This started the acceleration from using the internet on a singular device at home through a cable to being able to access it anywhere and anytime. Rapid innovations after that blurred the lines between a single device per family to multiple connections to the internet per person. A person in 2020 could be responsible for over 10 device connections such as a smartphone, laptop, tablet, smartwatch, home system or other IOT devices. All of them are connected and all use a part of the 'capacity' of the internet. Is it still possible to define any internet use back to one person now that there is so much of our life connected to the internet that a point is reached where people don't even realise what 'the internet' knows about them[9].

At the beginning everything on the internet was man made, entered manually and received manually. Over time most of these processes have been automated. For example the encrypting of internet packages and formatting any web page or data. But over time, more and more systems work automatically or autonomously. This makes it hard to really point it back to a person for any type of responsibility. A great example is the traffic option for Google maps. They use both historical data as well as current traffic reports to generate predictions for the current situation. This doesn't require any manual processing per road but it still sends the data everywhere through Maps. This example can still be traced through the use of Google Maps but most other autonomous systems aren't for instant consumer use. How would that electrical cost be distributed to anyone's responsibility?

3. METHODOLOGY

This paper will be written based on literary research. The start for this will be a Cisco report that uses data inside data centers to categorize the workload. This makes it possible to distribute the energy cost from the internet to different categories. To then calculate this back to the electricity cost per use or time used.

To calculate these numbers back to personal internet use will require data on average use or total use per application. To achieve this knowledge, any paper with relevant information to the categorical uses or growth of them will be used. Besides this, there will be a reliance on statistical data.

This calculation will not use any devices local electricity costs. This paper focuses on the remote internet's electrical cost that are invisible to the users. Any computer, router or phone normally gets power locally which will be paid for by the user already through their power bill.

The goal is to transfer these findings into an application that will turn these numbers into understandable knowledge to make clear how much electricity is being used and how much that would cost or be similar too.

4. ANALYSIS

4.1 Electricity usage per internet user

The first information needed for all further research is the electricity footprint of the internet. With this information it will be possible to divide any responsibility accordingly. This amount has been very stable over the past years due to efficiency gains of power usage keeping up with the increase of data transfer and storage. According to Masanet et al.[14] the worldwide internet energy footprint for the internet is 286 TWh in 2016 and further research by Koot and Wijnhoven[13] moves the estimate made in 2016 of 286 TWh to a staggering 566 TWh in 2030. This is caused by the slower rate of energy efficiency improvement which would start having a serious effect on the electricity usage in the coming years. However, this is an average. The 95 percent certainty ranges from 343 to 1031 TWh depending on when exactly the efficiency gains start to slow down. For this paper the average estimation of 566 TWH will be used for any further calculations as seen in table 1.

The second necessary information, world population, is more easily estimated. According to statistics[15] it was at 7.46 billion in 2016. Estimations will put the world population in 2030 at 8.61 billion. This results in a net internet power usage per person of 38.3 kWh for 2016 and an estimated one of 65.7 in 2030 as seen in table 1 under "Per user". To put that into perspective, with your year worth of internet, according to EIA the average American home uses 10399 kWh. So with your share of internet you would be able to power a house for more than a day which would on average be 28.5 kWh and over 2 days in 2030. This is not a very fair comparison as an American household is not an average one for the world. Most of the world has a significant lower average which would make this estimate on the low side. In the more remote areas of the world there isn't even electricity everywhere, let alone a power bill or internet for every home. It does illustrate that your yearly internet use's electrical cost is nothing to be indifferent about as it is possibly quite significant.

To make a more fair calculation we will have to take a look at how many people actively use the internet. Statistics[16] show that in 2016 the internet counted 3.406 billion users which is expected to grow to 7.5 billion in 2030 according to Cybercrime magazine[17]. Which would put the power usage per user at 84.0 kWh and rather unexpectedly at 75.5 kWh in 2030. This would mean that even though the total power usage would substantially increase, the power usage per person will most likely drop due to the immense amount of people that would get access to the internet.

Looking back, this might have been the case since the internet started like any other tech, high in price, due to the limited infrastructure and the limited use world wide. However as the number of users grew, so did the infrastructure and production efficiency. The total world electricity consumption was 70.8 TWh in 2000 and 152.5 TWh in 2005[12]. If this was divided amongst the internet users of then 414.37 million and 1.03 billion[16] it would reach 170.9 kWh in 2000 and 148.1 kWh in 2005 which shows the continued decline of electricity cost per internet user. Especially in the early years, there was a lot of fluctuation in both costs and users. Between 2005 and 2016 the average yearly decline in electricity use per user was 5 percent whereas with the current estimations this would only be 1 percent for the time between 2016 and 2030. Once we approach the 90 percent of humans being connected to the internet in 2030, the growth will decrease and stagnate. This would mean that the power usage would eventually start to rise again per user as the power cost will continue to rise. That is, if this will not have an impact on the growth of the total electrical requirements of the internet.

4.2 Consumer versus business internet use

To make a more precise distinction of how much people could be held responsible for the internet's electrical footprint you would have to dissect it's use distribution. Not all internet use is from people, some of it is from corporate use. Some companies also use their infrastructure to enhance their process, but in the end it is all to streamline any process that will produce or process things that are useful or meant for the use of all humans. This would then also put this responsibility at the people that don't use any internet themselves. As this distribution of products is similarly skewed to the developed world it would be unfair to simply distribute it to all people or internet users. Besides that the companies are still responsible for their own electricity bills, they would simply be able to compensate the cost into their product price and compensate for it in a way that makes the cost distributed to those that 'use' that companies internet's footprint. The moral dilemma then comes from the companies that provide the data centers. Of course they get paid for them through hosting sites and getting paid by their companies, but are they responsible for minimizing the electricity need and providing green energy? In the end people will want to use the internet, if a data center isn't hosted by one company, another one will. It is not in the data center companies power to limit consumerism of the internet.

So if the corporate use of the internet traffic is disregarded for consumers, there are two ways to dissect these two types of traffic. The first one is to simply look at the origin of the request. Simple IP addresses can show you where data request come from. This way you can dissect most of the data by location. VPN providers do somewhat alter this data but this is minimal as most people working from home use a VPN to their company that will provide them access to their data. As this is also not traceable in this calculation, it will be assumed to be insignificant in this paper.

Cisco's annual report[8] examines this and determined that

Table 1. Yearly electrical cost overview

	2016	2030
Worldwide (TWh)	286	566
Per person (kWh)	38.3	65.7
Per user (kWh)	84.0	75.5
Per consumer 1* (kWh)	67.2	66.4
Per consumer 2* (kWh)	51.1	56.2

in 2016 the distribution, when combining the workload, storage and network computations, would be 1,291 zetabytes of traffic for business and 5,097 zetabytes of traffic for consumers. This is an 80 percent rate for the consumers which would put the total electric power down from 286 to 229 in 2016. And it would contribute from 566 to 453 in 2020 if both were to grow at the same rate. However the growth rate of the consumer part is 6% higher than the 20% of the business growth. If that were to stay at a similar rate for both parts until 2030, this 80/20 rate would shift to a 88/12 rate. Calculating that back to every internet user you would reach 67.2 kWh in 2016 and 66.4 kWh in 2030 as shown in table 1. The high rate of consumer data versus business can be explained by most major corporations running their own servers for company data and processes as this is safer and gives them more control. In this way they are already paying for the electricity needs of their systems.

The second option is to look at the data inside data centers. Koot and Wijnhoven[13] have also split up the data from Cisco into the different types of data coming through the data centers. Although almost everything gets encrypted these days on the internet, the size, package frequency and many other factors can be categorized to retrieve any categorical data. Cisco managed to split the data up in Search, social networking, video streaming, other consumer apps, ERP and business apps, database, analytics, IoT, collaboration and computations. The first 4 are split off from the others which are the more consumer based products and then a different number is reached compared to the first method. Only 61 percent is now for consumer use rather than 80 per cent. This would result in a total power usage of only 51.1 kWh per consumer. This shift is partially to blame on the hard cuts in certain categories that could be used for personal use as well. For instance IoT or computing could be used for personal use. Not all categories that are largely business focused are 100 percent business focused. Then again, the same can be said about some consumer categories. An example of this is corporate social media accounts.

Looking at the growth, the CAGR (compound annual growth rate) of the consumer categories are larger than those of the business categories. This would mean that in this calculation the numbers would also lean more to the consumer side over time[13]. This would produce a 75 percent share for the consumption side by 2030. This would mean a power usage per user of 56.2 kWh which would mean a small increase again compared to 2016. This is the first time an increase is visible again when you calculate it from total power usage to internet users.

4.3 Electricity use per application category

To recalculate the use of an average user to an individual requires extensive knowledge of the entire internet infrastructure, use, data transfer and users. However, a more rough estimate can be made using the data from the different types of applications that are provided from the Cisco report[8] in table 2.

Firstly, the search queries. The market here is limited due to the large share Google has. From a 92% average throughout 2016 and all the way up to 2020 we can safely say that they are dominating the market with other search engines such as Bing and Yahoo not reaching much higher than 3%[1]. Unfortunately Google does not provide any exact statistic per year. However in 2016 Google stated that they were processing more than 2 trillion search queries per year. Anything more exact than that would be an estimate. With 3.4 billion users this would result in a minimum of 588 searches per internet user per year. Assuming the efficiency of the other search engines is similar to that of Google, the total amount of searches per average user would be 640 queries. This would result into an average of 1.75 a day. Without calculating the time spent on a google search, but assuming a 'search' always costs the same amount of energy, it is possible to ask the users a question to estimate their daily or weekly google search counts to the nearest 10. This would result in a accurate representation of the electric footprint for searches. 17.2 percent of 51.1 kWh would be 8.79 kWh or 13.7 Wh per search. At this point the costs are smaller than a cent per search but not immeasurable, especially when converted to yearly use.

Secondly there is social media, one of the main defining parts of the internet in the latest decade. Statistics provide the average daily time spent per internet user[11] which gives us a clear starting point. All we have to do is convert it to minutes. 20.7 percent of 51.1 kWh would provide 10.5 kWh per user spent on social media. Divide this by the amount of days and the 128 minutes of time spent you would get 0.32 Wh per minute spent on social media. Why this is so much 'cheaper' than googling is mostly because of the workload it creates. Google has of course a lot of sites queried, however every search requires calculations whereas with visiting social media you could look multiple minutes at the same picture that is already loaded. On social media there is also a very finite amount of media that is shown to you which would also limit calculation costs. This deficit could also be explained by a lot of social media companies having large private data centers to process all the data, including the tracking and marketing of individuals that will provide them with income (to pay for those same data centers).

Then there is video streaming, a growing phenomenon the last few years, which is a very broad genre from YouTube to Netflix to the regular TV-channels. First of all, it is very easy to see different categories as those are the main uses and different markets. One is the digitized version of TV whereas the others started as on-demand movie and series provider or as private video host. Since they all use similar programs to compile video data for transfer, we will assume that they will use a similar power usage per hour of viewing. Thankfully there is no need to analyze these categories apart as there are statistics for hours watched by people which comes down to on average 4 hours a day per internet user[6]. This includes all types of video streaming categories. If this divides the 31.1 percent that video streaming uses you would reach 15.9 kWh or 1.0 kWh for every 15 minutes watched on average per day.

Finally, looking at the rest is also very difficult. This contains anything from gaming, music streaming to online shopping. As Cisco does not provide any further details on how large each portion is here it is not possible to make any accurate estimation. The growth in some of these areas are interesting and will be included in the future research part, but for now all that is possible is to transfer this

Table 2. Traffic distribution in Zetabytes[8, 13]

	server	network	storage	total	%
Search	10	776	23	809	17.2
Social networks	12	931	29	972	20.7
Video streaming	18	1397	48	1463	31.1
Other consumer apps	18	1397	43	1458	31.0
Consumer total	48	4501	143	4698	100
ERP & business apps	57	718	148	923	30.5
Database & IoT	33	416	128	577	19.1
Collaboration	48	605	90	743	24.6
Computing	46	580	154	780	25.8
Business total	184	2319	520	3023	100

equally to the internet users. This would give everyone an average of 31 percent of 51.1 kWh which is 15.841 kWh per year. It might be possible to define it slightly more by asking for total hours spent on the internet minus the other categories, but as it is very hard to define the rest of your internet use this would be unreliable. Spending two hours on your email would be much less power-intensive compared to playing online games.

5. CONCLUSION

The goal of this paper was to calculate the electrical cost of personal internet use. This would provide different insights into both the power usage of the internet as well as the distribution and growth of this power.

It is very difficult to pinpoint any type of usage to a set amount of electricity being used, all we can do is estimate and approach any relevant data. According to all the data gathered we can define the following categories with a certain amount of power usage. Massive data analysis of the current data centers would be necessary to update these numbers to relevant numbers for any time past 2016.

So the answer to how someone would calculate the electrical footprint of personal internet use would be:

Search engines: Per search a day 5.013 kWh

Social Media: Per hour spent a day 7.008 kWh

Video streaming: Per hour spent a day 3.975 kWh

Other consumer applications: Per user on average 15.841 kWh per year

Other non-consumer applications: Per user on average 32.9 kWh per year

This is already calculated per year. So if someone was to watch 2 hours a day for an entire year it would cost 14.016 kWh approximately. The last two categories are already per year as they can't be devided or categorized any more precisely. For the consumer application we provide a base cost for every internet user and the non-consumer part gets added proportionally to how much you spend compared to the average internet user. This is also the calculation that was used in the created tool[19].

If the non-consumer applications were to be blamed on persons rather than corporations as well there would be two ways to distribute this. One would be to give a user a share based on his personal use share compared to an average internet user. This would give a more fair distribution as people with high use generally would use the internet more and therefore could bare more of the cost. The other option would be to distribute it equally amongst everyone which would again disadvantage any people in more impoverished areas that might only be able to access the internet for emails for instance. For the tool[19] provided, the first option is used.

To transfer this data over to any more recent year would require a value of optimization that Moore's Law would have provided in the time in between. This number would be used to lower the existing categories costs. The main missing items would be any new technology that arrived in the mean time which would cost a lot of electricity such as the recent block-chains. This would be part of any of the other categories so it wont be lost. Those new technologies combined with a changing proportion between the categories would mean that both the consumer and the non-consumer applications outside of the three main categories will not have any relevant data anymore. To be able to update those numbers, a full rework would have to be done for the proportions per categories.

6. DISCUSSION

6.1 Limitations

The distribution between applications is failing in some business categories that could be defined as a consumer use. This would also explain the difference in the two calculations. For instance IoT solutions or any bitcoin mining could be done at home or for personal use. Thankfully bitcoin mining mainly takes power where you are mining rather than overloading any data center with data. This way the electricity bill will be paid by the user directly. Bitcoin for instance was estimated to have a power usage of around 6 TwH in 2016[7] which would be more than 3 percent of the total cost provided by Koot and Wijnhoven[13]. In 2020 this number has already increased towards 100 TwH[5][7]. Similarly IoT often gets most of his electricity from the devices on location and only communication with databases and data goes over the internet. But as IoT and databases are combined into one category it is not possible to split them up. This makes it very difficult to pinpoint any percentage to consumers.

Another potential problem here is that the leading distribution of application use that was provided by Cisco provides the amount of data workload rather than a direct power distribution. Although we can assume that any calculation or data transfer uses a similar amount of energy this is not completely accurate due to different types of data centers using different types of aging technology that might have a higher or lower efficiency.

This widget would also not show how much energy you could save the world by not using the internet. Some of this data that you request will still have to be stored and be made available so it should not be considered as a 1:1 saving. Especially considering that part of the electrical footprint comes from the infrastructure already in place. The goal here was to point out the footprint that someone would have from their use so someone could compensate this in some form by for instance producing green energy through solar panels. Besides this, the main goal was to give everyone some insight into something that for most is considered a free thing and to put it into any number people would understand.

Something that will be more difficult to add to these calculations are any edge or fog computing. However since these types of calculations usually happen outside the data centers and often on site this would already be paid by with your own electricity bill. The same is true for most IoT applications in the future. Since these products often already run on your own electricity network you already pay for it directly. For the communication that it will send to the data centers, it should already be included in the total calculation that were provided by Cisco.

Lastly there is a concern about the part of the internet that is not indexed by google. Think of the dark web, data garbage or any data behind password securities. How much of the internet's storage or infrastructure cost can be attributed to this part. Although it might not be indexed by anyone, this does not mean it is unused or data garbage. Large portions of this data is data about social networks, emails and other password protected data. The part that is data waste still takes power. In this current calculation it is practically being transferred equally to all parts as it is not able to calculate the costs of this data as the costs are based on data transfers. Any unused data would not be noticed by Cisco's report as it is not being transferred or sent. Any more accurate calculation is not possible as there is no data about the deep web. The only real consensus there is is that the deep web is many times larger than the indexed web[10].

This also shows the fault in the tool[19]. Because only three main categories are used to calculate your use. Everything that is outside of that scope gets distributed amongst everyone for the consumer part and then based on the amount of electrical usage compared to the average user the business part would be added proportionally. If the consumer remains would be added in a similar way as the business remains then if someone were to still use cable TV, doesn't use social media and doesn't use any search engines then the footprint would be 0. This would be more inaccurate than the current estimation as emails, online shopping or any other activity outside of those three categories would still use electricity.

6.2 Future research

One large activity that is also growing fast for consumers is online gaming. With the technology providing the means and speed to make competitive online gaming more accessible for more people the community keeps growing. Growing number of members will also increase the data used. How this differs from video streaming is that most data, like a map or other visuals are usually already on your own device. Only your movement or input has to be transferred over the internet and to the other players. This of course will become larger with more and more possibilities but it will still be very limited compared to a video stream. However, recent progress in both cloud gaming and the growth of mobile gaming will strongly increase the growth here.[3] If the online gaming community will change into servers of hundreds of people this can explode the workload of course. Currently the biggest online games where latency is important usually only allow servers of up to 50 people. Anything more than that usually means you are playing an MMO which isn't as dependent on super fast latency. Pokemon GO is a great example of an online game that everyone played where latency was not an issue but it would still communicate with it's servers. If a game like that would transfer into a cloud game where all the calculations are being done remotely, and the video feed would be sent in a similar way as any video stream, it would increase the power cost immensely.

One of the main indications that unexpectedly revealed itself was the immense influence the growing population of internet users would have on the total power usage. To see the personal power cost drop from 2016 to 2030 indicates that this is a major influence for the total power growth. It could be interesting to move estimates forward past 2030 to see if the growth keeps following the same trend or if it will reach a plateau where there are no more users to be added and the advancement of technology will be able to keep up again with the growing amount of data being send.

Cisco provided some sources as to the growth of data being processed for certain categories. However, this data is from just five years. Who is to say that certain categories will grow at an equal rate as for that long of a time period? Categories like searching will likely grow at a much slower pace than video streaming, IoT or any new category emerging in the next ten years like NFT's that has grown in popularity in recent years and is very costly on processing. Besides this it is also lacking in some categories. Recent spikes in the popularity of both blockchains[7], IoT[4], gaming[3] and other up and coming technology could be very interesting to extrapolate from any future data.

Part of the reason why some more outdated data was used is because, besides that Cisco did not provide more up to date data, from 2020 the data is very likely not reliable for future growth due to a large pandemic that forced a lot of people to spent more time behind their TV indoor, streaming videos or working from home. This would have heavily influenced the worldwide internet use. It would be a very interesting case study for both the growth in users and in different categories. Besides that, it is very interesting to see what will remain afterwards or if everything would return back to 'normal' from before the pandemic.

The tool[19] provided will also still need to be validated. Once there would be more recent data the tool would have to be updated as well as made globally more relevant with different electricity prices for instance. What could be the most interesting development is to make it into not just an informative tool but into a measuring tool that would either monitor your computer use or your browser use to calculate your internet use. Privacy will be a major issue to solve, but it would provide similar insight as smart thermostats do and could enhance the usability of this data.

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