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New perspectives on internet electricity use in 2030

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Abstract: The main problems with several existing Information and Communication Technology (ICT) power footprint investigations are: too limited (geographical and temporal) system boundary, overestimation of power saving potential in the next decade, assume that historical power use can predict future global power use in the next decade despite unprecedented data traffic growth, assume that Mooret's law relation to digital circuitry can continue "forever" and that no problems with extra cooling power will occur for several decades. The highly variable outlooks for the future power consumptions depend on "starting values", disruptions, regional differences and perceptual estimations of electricity intensity reductions and data traffic increase. A hugely optimistic scenario - which takes into account 20% annual improvement of the J/bit in data centers and networks until 2030 is presented. However, the electric power consumption of the present ICT scope will be significant unless great efforts are put into power saving features enabling such improvements of J/bit. Despite evident risks, it seems though that planned power saving measures and innovation will be able to keep the electricity consumption of ICT and the World under some kind of control. The major conclusion is based on several simulations in the present study - that future consumer ICT infrastructure cannot slow its overall electricity use until 2030 and it will use more than today. Data traffic may not be the best proxy metric for estimating computing electricity. Operations and J/operation seem more promising for forecasting and scaling of bottom-up models.

Keywords: Communication, computing, data center, data traffic, devices, electricity use, electricity intensity, 5G, forecast, information, instructions, networks, operations, video streaming.

1. Introduction

In recent years some controversy has emerged concerning the potential electric power use of Information and Communication Technology (ICT) technology going forward in the present decade. The electricity consumption is important as there are more or less sustainable ways of producing electricity. Most schools of thought agree that with the current moderate data traffic the power consumption of ICT has - so far - been kept more or less under control. There are conflicting messages regarding the path to a power consumption under control. Depending on scope, in 2020 ICT stands for up to 7% of the total global electricity use. Researchers have used different ways to measure, different ways to model and have also used different kind of statistics. The rise of ICT electric power use is far from a "phantom" problem. A recent review [1] confirmed that ICT systems - despite a large number of energy saving technologies at hand are at a critical point regarding current and future energy consumption of telecommunication networks, data centers and user-related devices. Most evidence speaks against flattening or reducing ICT power. For example, Weldon estimated that the electricity use of all connected devices - including all consumer devices with network connections - would rise from 200 TWh in 2011 to 1100 TWh in 2019 and 1400 TWh in 2025 [2]. Hintemann argued credibly against too pessimistic (e.g. expected and worst case in [3]) and optimistic scenarios for global data center power by listing indisputable global trends such as cryptocurrency mining, relentless speed of data center construction and cloud to hybrid cloud [4]. Moreover, for 2018 Hintemann estimated as much as 400 TWh for global data center electricity use [4]. Then it has been argued that the efficiency gains will continue unhindered between 2022 and 2030 thanks to Artificial Intelligence (AI) [[5]. Nevertheless, on computing level Khokhriakov et al. found that multicore processor computing is not energy proportional as the optimization for performance alone results in increase in dynamic energy consumption by up to 89% and optimization for dynamic energy alone results in performance degradation by up to 49% [6]. Actual electricity measurements from Leibniz

Supercomputing Centre in Germany showed that between 2000 and 2018 - despite higher power efficiency - the increase in system density and overall performance lead to increase in electricity consumption [7]. The electricity generated by renewable energy is increasing. In 2015 the share of hydro, wind, solar and biomass power was 25% on average in China [8] which is of importance as the growth of ICT construction will be of huge significance there compared to more developed nations.

Truthfully it is challenging to make accurate predictions of global ICT electric power use as it is problematic to account for unknown unknowns. Most researchers agree that the data traffic - no matter how it is defined - will increase exponentially for several years as it has been doing the last decade. The disagreement concerns how fast and how large the ICT related power use will become in around 2030. Probably there is a parallel to linear or exponential thinking of how fast some entity will increase. Further discussions concern whether the anticipated extra electricity use by ICT really is a concern if the additional power can drive the corresponding share of sustainable electric power in specific grids used by the ICT infrastructure. The cost of electricity has to date been rather small for ICT Service providers compared to other expenditures [9], but this could change if the electricity prices and electricity use increase. There is not much expectation that future consumer ICT infrastructure can actually slow its overall electricity use until 2030. With the current knowledge, there are more circumstances pointing towards rising - 1-2 PWh - power consumption of ICT than slowing or flattening.

2030 is rather far away and unprecedented changes in economic activity is hard to predict as the first quarters of 2020 has showed. Here it is assumed that the trend of more ICT and data will not be affected dramatically until 2030 as a result of the slow-down Q1-2 2020. Therefore trends are more important than "exact" use patterns and numbers, as we do not exactly know how and which devices will be used in the future. Blockchain, artificial intelligence (AI), virtual reality (VR), and augmented reality (AR) might be the biggest trends for ICT power use. Anyway, a proper power analysis of the ICT Sector should include production of hardware including embedded chips, use of data centers, use of networks, and use of consumer communication devices.

Production is today around 20% of ICTs footprint but there is room for improving the precision. The digital revolution may possibly in itself help optimize the power use of production. However the total emission of ICT production - and thereby the power use - may well be heavily underestimated [10]. Use stage power of data centers is now around 15%, but is expected to become one of the most important drivers for ICT electricity use. Use stage power of Networks (wireless and core) is now at around 15% of ICT, but its share is expected to increase. There is however considerable uncertainty about 5G's power use depending on point of introduction, learning curve and regional differences.

Use stage power of consumer devices (including Wi-Fi modems) is now at some 50% of ICT total power use but is ideally expected to decrease thanks to advanced power saving features. Current downward trend is expected to continue if no "dramatic processing power saving problems related to Moores law" happen around 2022. The speed of electricity intensity reduction vs. the speed of data traffic increase is the determinant of ICT power. As hypothesized in Section 5, other more fundamental determinants are possible.

1.1. Objectives

The objective of this prediction study is to estimate the global electric power use in 2030 associated with computing and communication - the Information and Communication Technology (ICT) infrastructure - consisting of the use stage of end-user consumer devices, network infrastructure and data centers as well as the production of hardware for all. The specific purpose is to update previous predictions [3] and understand if the power consumption is still likely to develop as previously understood.

1.2. Hypothesis

The hypothesis is that the electric power consumption of the ICT Sector will increase along something in between the best and expected scenario as outlined by Andrae and Edler in 2015 [3] when adding new assumptions of data traffic and electricity intensity improvements.

Table 1. Differences between [3] expected case and the present prediction for data centers.

	Global Data Center IP Traffic (ZettaBytes/year)		Electricity use (TWh)	
	\cite{10}	Present	\cite10	present
2020	13	19	660	299
2021	16	25	731	311
2022	20	33	854	328
2023	25	43	998	320
2024	30	56	1166	377
2025	37	72	1362	412
2026	46	94	1592	471
2027	56	122	1860	551
2028	69	159	2173	652
2029	85	206	2539	788
2030	105	268	2967	

2. Materials and methods

The approach follows the one outlined in [3] however with several new assumptions for parameters such as electricity intensity improvements and data traffic growth. The expected case scenario in [3] constitute the baseline for the present research, however, the best case scenario is also shown occasionally for entities of the ICT Sector. The baseline year is 2020 and only one trend curve - for ICT total - will be proposed toward 2030. All assumptions made are available in the Supplementary Information.

2.1. Alternate assumptions for data centers use stage

Compared to the expected case scenario in [3] the following assumptions have been made

- The annual electricity intensity improvement taking place from - 2010 to 2022 - has been increased to 20% instead of 10%. This implies a lower starting point in 2020 than in [3].
- A much higher amount of data will be processed in the data centers (see Table 1).

Data traffic is a crude proxy for power use but the numbers are reported frequently [10]. Operations/s [11] may be a better proxy as will be discussed in Section 5.

3. Alternate assumptions for Networks

3.1. Wireless access

Compared to expected case scenario in [3] the following assumptions have been made

- The factor of historical improvement of the TWh/EB factor between 2010 and 2020 as assumed in [3] has been corrected.

Andrae and Edler [3] arrived at an accumulated improvement factor of 0.083 in 2030 for 5G by assuming 22% improvement between 2010 and 2022 and 5% improvement from 2022 to 2030. However, it is wrong to assume an improvement for 5G from 2010 to 2020 as 5G did not (more or less) exist then. Due to gradually introduced Moore's law problems, the accumulated improvement factor is assumed to be 0.229 in 2030. On top of this, a gradually waning Moore's law is introduced for all mobile technology Gs from 2022 so that the improvement factors run from 19% in 2022 to 5% in 2030, instead of 5% from 2022 to 2030. This leads to more than 4 times more TWh from 5G in the latest understanding mentioned in [12] than in [3]. Tables 2 and 3 show some of the new assumptions.

According to [13], in 2020 4G networks deliver 20 kbit/J while [3] predicted (better) 40 kbit/J in 2020. For 5G [13] predicted 10 Mbit/J while [3] predicted (worse) 0.8-2.8 Mbit/J for 2030. The starting point in 2020 for 5G in [3] is 0.05 Mbit/J. As shown in Table 2, the energy efficiency prediction for 5G has decreased - compared to [3] - to 0.18-0.22 Mbit/J [12].

Table 2. Differences between [3] and the present prediction for 5G mobile networks.

		2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Best Case	5G Traffic EB	41	164	324	677	1248	2656	4316	6685	9928	14403
	TWh	0	0	0	1	1	3	4	7	9	13
Expected case	5G Traffic EB	44	189	399	892	1762	3881	6996	11609	18473	28714
	TWh	0	1	2	4	7	15	26	41	61	91
Best case	5G Traffic EB	41	164	324	677	1248	2565	4316	6685	9928	14403
	TWh	0	5	8	15	23	41	62	87	120	166
Expected case	5G Traffic EB	44	189	399	892	1762	3881	6996	11609	18473	28714
	TWh	2	7	12	23	38	74	120	181	268	396

Table 3. Differences between [3] expected case and the present prediction for mobile networks.

	Electricity use TWh	
	\cite{10}	Present
2020	98	98
2021	92	94
2022	100	92
2023	114	95
2024	127	102
2025	144	116
2026	145	142
2027	149	181
2028	157	237
2029	172	320
2030	196	446

3.2. Fixed access wired

One of the major weaknesses of the predictions done in [3] is likely the overestimation of fixed wired (core) networks. To improve this, a faster improvement of the TWh/EB is assumed between 2010 and 2022, 20% per year is used instead of 10%. However, a gradually waning Moore's law is introduced from 2022 so that the improvement factors run from 19% in 2022 to 5% in 2030, instead of 5% from 2022 to 2030. Overall however, this results in a dramatically lower electricity use of these networks in 2030 compared to [3] (Table 4).

Table 4. Differences between [3] expected case and the present prediction for fixed access wired networks.

	Electricity use (TWh)		
	\cite{10}	Present best case	Present expected case
2020	439	134	171
2021	494	129	171
2022	588	126	174
2023	703	125	179
2024	843	126	188
2025	1014	129	200
2026	1222	138	223
2027	1477	152	255
2028	1789	169	296
2029	2171	192	352
2030	2641	224	428

3.3. Alternate assumptions for Devices power use including Wi-Fi modems

From 2020 the improvement of kWh/unit/year for devices is assumed 3% as in [10]. The difference is that Wi-Fi is added to the consumer devices section. Wi-Fi is overestimated in [3] as the Wi-Fi modems electric power use is actually rather independent of handled traffic. The action taken is to increase the electricity intensity improvement from 10% to 20% per year from 2010 to 2022 for the expected case scenario. The resulting electricity use is shown in Table 5. As a sensitivity check, 2 billion homes globally - each with one 3 Watt Wi-Fi modem - would use on average around 52 TWh per year. This shows that the new assumption is more reasonable than previous [3]. Table 5 shows that adding Wi-Fi (moving Wi-Fi from the Networks) to consumer devices, both in [3] and here, suggest increasing and flattening TWh, respectively.

Table 5. Differences between [3] expected case and the present prediction for devices use stage electric power use.

	Electricity use (TWh)		
	\cite{10}Consumer devices + Wi-Fi modems	Present Consumer devices + Wi-Fi modems	Wi-Fi modems
2020	1132	1039	72
2021	1153	1051	75
2022	1171	1054	79
2023	1186	1049	84
2024	1200	1037	91
2025	1217	1017	99
2026	1250	1008	113
2027	1298	1008	133
2028	1365	1017	157
2029	1451	1038	190
2030	1559	1073	234

This prediction is to be considered highly uncertain as the devices will of course also be affected by the power issues related to the slow-down of Mooret's law. This slow-down is included for Wi-Fi devices. Anyway, the order of magnitude for the TWh is most likely correct. Still, a reduction of consumer devices power use seems quite optimistic. It can happen though, thanks to a firm focus on power saving and updated energy labeling requirements for end-user devices.

In the future the use stage electric power of USB dongles, smart home devices, wearables, AR & VR devices, and Wi-Fi modems should be added systematically. Moreover, due to a strong push for longer lifetimes for consumer devices, lifetimes may increase compared to [3].

3.4. Alternate assumptions for Production of ICT hardware

Andrae and Edler [3] overestimated the electric power used to produce ICT goods used in Networks and Data Centers. This is improved in the present prediction by setting the so called life cycle ratio for Networks and Data Center production to 0.02 instead of 0.15. This assumption brings down the production TWh significantly. Assuming that 2 million base stations with ?3 MWh/unit [14] - used in wireless access networks - and 60 million servers with 1 MWh/unit [15] - used in data centers - will be produced in 2030, the electric power needed would be around 66 TWh. The present study predicts 38 TWh in 2030 - of 289 TWh - for all network and data center equipment. This suggests that a 0.02 life cycle ratio for production is reasonable for traffic dependent calculations of data centers and networks. Table 6 shows that the production estimates are much lower in the present study than in [3].

Table 6. Differences between [3] expected case and the present prediction for production of ICT hardware.

	Electricity use (TWh)	
	\cite{10}	Present
2020	549	381
2021	540	358
2022	547	339
2023	562	324
2024	584	311
2025	614	302
2026	650	295
2027	696	291
2028	752	290
2029	821	292
2030	903	298

With the current twists and turns in the global economy it is almost undoable to predict parameters for production of ICT. Still, the latest understanding [10]is that production of ICT is underestimated.

4. Results

The stability of Andrae and Edler [3] trend analysis - of how much electric power the ICT Sector might use in 2030 - is remarkable considering the number of changed (improved) assumptions made in the present update and others [10–12]. In summary in 2030, all entities are predicted to use much less electricity - except wireless access networks - than the expected scenario in [10]. The total TWhrs - for the current studied Internet scope - are very close to best case scenario in [3].

4.1. Data centers power use

Figure 1 shows some trends for data centers 2020 to 2030.

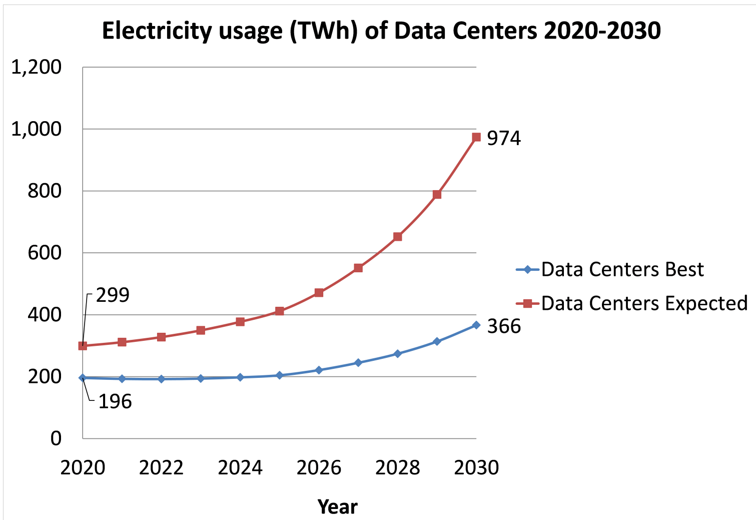

Figure 1. Trends for data centers 2020 to 2030.

Although the electricity intensity improvements are assumed higher than in [3] the consequences caused by data traffic increase compensate, and the electricity use might still rise. 366 TWh in 2030 - for the best case - are due to a very moderate data traffic growth.

4.2. Networks power use

Figures 2 and 3 show some trends for Networks 2020 to 2030.

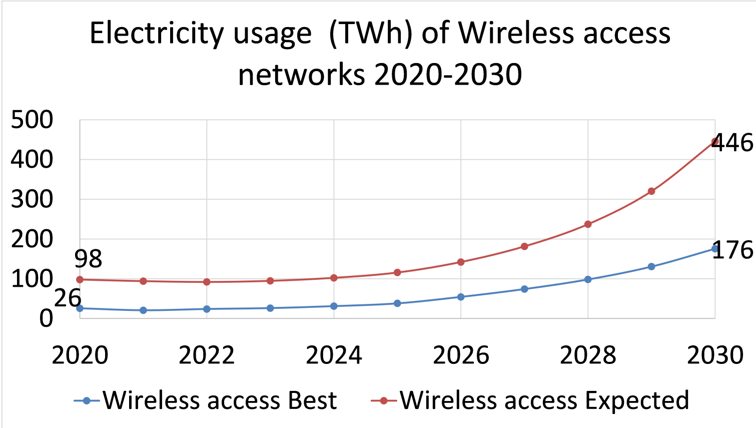

Figure 2. Trends for wireless access networks 2020 to 2030.

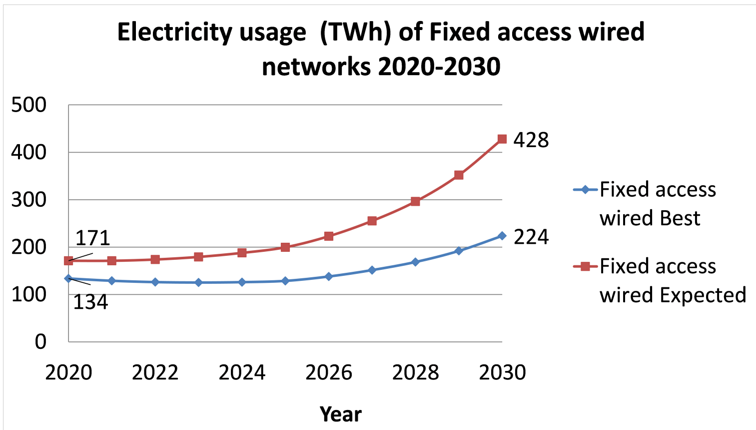

Figure 3. Trends for fixed access wired networks 2020 to 2030.

4.3. Devices power use

Figure 4 shows some trends for end-user consumer ICT goods use stage 2020 to 2030.

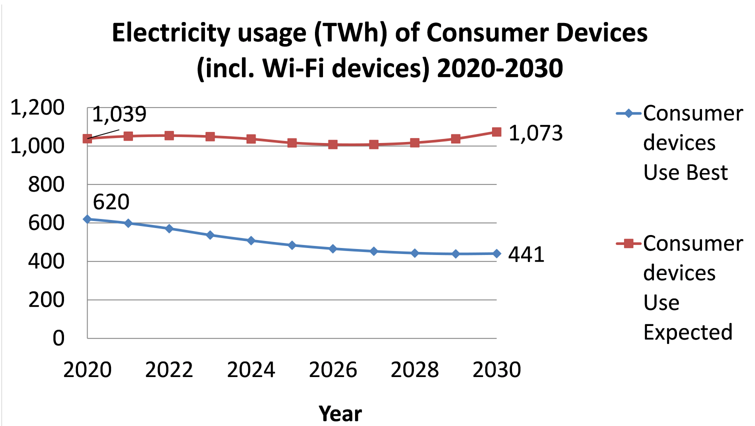

Figure 4. Trends for consumer ICT goods use stage 2020 to 2030.

5. Summary

Figures 5 and 6 show some trends for the synthesis per contributing category in 2020 and 2030, separately. Andrae and Edler [3] is compared to the present update.

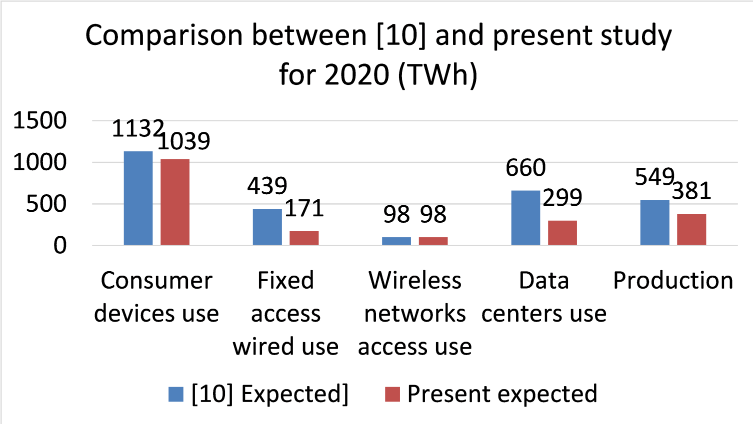

Figure 5. Trends for ICT electric power overall 2020.

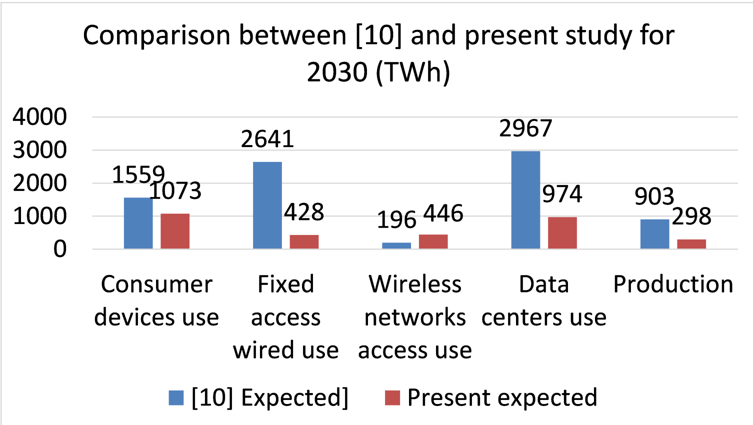

Figure 6. Trends for ICT electric power overall 2030.

Generally the values for 2020 are lower for most entities. For 2030 too except for wireless access networks which will use more electricity. In total the electric power predictions for the ICT Sector have been reduced by 31% in 2020 and 61% 2030 in the present study compared to expected case scenario in [3]. Potential further reductions are discussed in Section 8.1.

6. Discussion

The ideal framework for ICT electric power footprint would be based on annual shipments of each ICT good, each lifetime and each measured annual and lifetime electric power consumption. However, it may not be practicable to make that journey yet. Connectivity and smart metering is probably the road ahead for collecting power data. Still, the electricity predictions need to be checked against bottom-up and national top-down assessments too. It is crucial to find out how such national assessments are done and to which degree ICT electric power consumption estimates are included.

The implications for researchers regarding the path to sustainable computing practices are at least four:

1. Produce research results which help reduce the electricity use and environmental impact of computing
2. Sourcing of the power
3. Power saving strategies
4. Recycling strategies for the used computers, screens etc

Knowing the high degree of variability, here follows some suggestions for future research approach of this topic. Nissen *et al.* [16] suggested that process flow modelling would be the best for improving the precision of wireless access networks energy use modeling. As for the future forecasting of ICTs electricity use, Artificial Neural Networks seems a very useful modeling tool [17].

7. Bottom-up considerations for research

The electricity cost of individual computing in particular might be difficult to isolate. Still, there are ways with which we can implement green computing. For example, somehow mimicking the green software coding idea "Proof of stake" - by which the cryptocurrency ethereum plan to slash its power use [18] seems like a good idea. Nevertheless it does not seem useful for individuals to calculate their personal ICT electricity consumption, but some measures probably can be taken. One easy measure is to turn off the video image in communication when voice+video is possible but visual communication is not really required. Still, in Section 4.3 the overall individual and global electricity cost of video streaming is estimated.

8. Testing of the order of magnitude of worldwide ICT and data center electric power use

8.1. What if the 20% per year electricity intensity improvements continue after 2022

Figure 7 shows the summary of the present predictions. At the moment Wi-Fi based - or fixed optic fibre broadband - computing is preferable to wireless 4G based computing from an overall electricity consumption point of view.

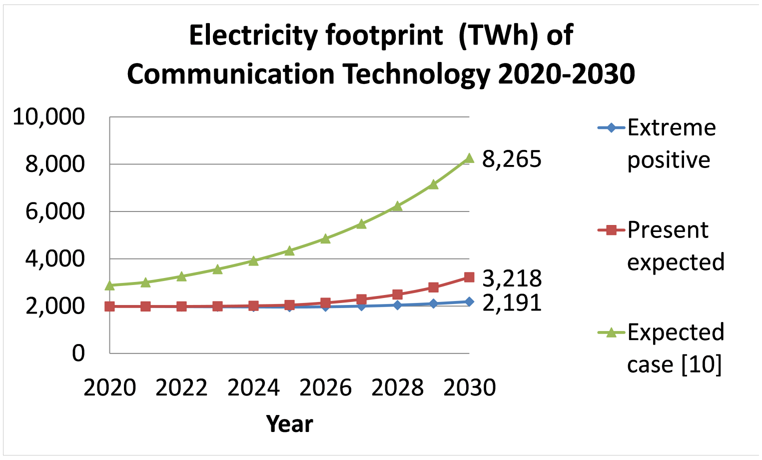

Figure 7. Trends for ICT electric power use 2020 to 2030.

The "extreme positive" scenario assumes that no slowdown of electricity intensity improvements happen after 2022 i.e. no gradually waning annual improvements from 2022 to 2030 as in the present baseline (expected case scenario) - and that 20% improvements still happen in Networks and Data Centers until 2030. In that case ICT power will more or less stay flat while the total data traffic grows 14 times between 2020 and 2030. The electricity use of networks and data centers will be 54% less in such an "extreme positive" scenario than in the present study.

8.2. Blockchain and cryptocurrencies

The blockchain is established on databases that are not consolidated in one server, but in a global network of computers. The information is eternally registered, in sequential order, and in all parts of the computer network. The computing power allocated to the specific blockchain application bitcoin is likely very high [19]. The reason is that with bitcoin every new piece of information added to the chain requires that someone uses computer power to solve an advanced cryptographic problem via Proof of Work. The sooner this cryptographic problem gets resolved, the greater the likelihood that the person who is in charge of the mining of bitcoin cryptocurrencies will be paid in bitcoin cryptocurrency. The demand for bitcoins - as long as it lasts - will therefore increase the demand for electric power. Mora *et al.*, [19] pointed out that any further development of cryptocurrencies should critically aim to reduce electricity demand. Reducing the power use of cryptocurrencies might have a solution in the form of Proof of Stake instead of Proof of Work [18].

Table 7. 2020 and 2030 key electricity intensity indicators relevant for video streaming

Entity used in video streaming	2020	2030	unit	Assumed share of total Global access traffic (internet traffic) 2020	Assumed share of total Global access traffic (internet traffic) 2030
Wireless access network	0.18 (98 TWh/549 ExaByte)	0.0144 (446/30899)	kWh/GB	15%	85%
Fixed access wired networks	0.07 (171/2444)	0.017 (428/25901)	kWh/GB	85%	15%
Data center	0.015 (299/19919)	0.004 (974/274599)	kWh/GB		

8.3. Renewable electric power and ICT

There are discussions ongoing about the possibility that ICT infrastructure can be run entirely on renewable power. One of many challenges is that the renewable power should be located in the vicinity of the ICT infrastructure.

Using renewable energy to power data centers and networks can reduce the environmental impacts. However, the uneven geospatial distribution of renewable energy resources and regions with high ICT use might create uncertainty of supply [20,21]. The relation between renewable energy resources and associated environmental impacts - of data centers and networks driven by renewable energy at a global scale should be investigated thoroughly [10].

Overall the present predictions suggest a trajectory in between the Best and Expected Case Scenarios in [3], ≈1990 TWh in 2020 and 3200 TWh in 2030 (Figure 6). The ICT Sector has and will have a considerable share of the global electricity footprint.

8.4. Bottom-up calculation of the electricity use associated with video streaming

It is relevant to estimate how much data is generated - and associated electric power used - by normal behavior like video streaming several hours every day. For the present estimations the following key indicators are used (Table 7). The electricity intensities are set to decrease massively, especially for wireless access networks. However, those networks are perhaps used much less extensively for video streaming in 2020 than optic fixed access. Table 7 suggests that the electric power use of video streaming is strongly correlated to the way in which the video streaming is obtained. Streaming via a 4G router directly or with Wi-Fi is less efficient at the moment than optical broadband via a mobile phone/tablet using Wi-Fi.

Typically standard definition video use 1 GB per hour and high definition (HD) video use 3 GB per hour. Other video formats with higher resolution (e.g. 8K 3D) might use even higher amounts. It is assumed 20 GB per hour for the most typical video technology used in 2030.

By this information it is possible to predict the current and future data generation and electricity consumption associated with video streaming and relate it to the total for ICT.

8.5. Data amounts and TWh from global video streaming

For 2020 it is assumed that one person watches video streaming in HD 2 hours/day in weekdays and 4 hour/day on weekends, i.e. 18 hours per week and 936 hours per year.

To provide these hours, 2808 GB per person is generated in 2020. If all entities are used in Table 7 to deliver the stream, 285 kWh per year per person is required. Assuming that 2 billion persons have this behavior, 570 TWh is needed for 5230 ExaBytes. This suggests that video streaming is a noticeable driver for ICT electric power use in 2020. For 2030 it is assumed that one person watches video streaming in HD 2 hours/day in weekdays and 4 hour/day on weekends, i.e. 18 hours per week and 936 hours per year.

However, due to higher GB/hour, 18720 GB per person is generated in 2030. If all entities are used in Table 7 to deliver the stream, 352 kWh per year per person is needed. Assuming that 7 billion persons will have this behavior, 2464 TWh is required for 122040 ExaBytes. These simple hypotheses shows that increasing electricity use of the ICT Sector is unquestionably in the cards.

9. Conclusions

It is very difficult to fathom the circumstances under which the electric power use of communication and computing (the ICT infrastructure) cannot rise considerably until 2030. The total TWh will develop along an average of the best and expected scenario in [3] with a strong leaning to the best case.

10. Next steps

New advances in large-scale fiber-optic communication systems [22–25] should be translated to J/bit and used for predictions of the fixed core network. Advances in heat recovery and lowering temperature of microchips [26] may have big implications for the global ICT power use. The reason is that the energy consumption per transistor is strongly correlated to the temperature at which the transistor is working [11]. The overall effect of solving the Internet of Things, edge devices high computation, memory requirements and power dilemma is not well understood [27]. Moreover, it is plausible that ICT infrastructure can help save electric power in society as a whole, and Ono et al. suggested 1300 TWh in 2030 [28]. These assumptions should be further explored. Also these areas are next steps:

- Find out best way to define an operation or instruction in computing
- Forecast the number of different operations and instructions
- Measure different J/operation or J/instruction.

Andrae [9] put forward these hypotheses for 2015: (i) the "traffic" (instructions/s) was around 1 Zettainstructions/s in total and (ii) the energy efficiency was overall around 7 Gigainstructions/J.

Falsifying in detail the above hypotheses would enable reliable forecasting of the power consumption of computing which involve new technologies. Equation (1) may be the way forward if the data could be collected:

$$ICT_t = \sum_{j,i} 8760 \times \left(\frac{(\frac{Ins}{s})_{j,i,t}}{(\frac{Ins}{j})_{j,i,t}} \right) \tag{1}$$

where,

$ICT_t =$ ICT sector total global average electricity use in Wh related to processing and computing.

$j =$computing type; special purpose, general purpose, machine learning, dark calculations etc.

$i =$ICT good type.

$t =$ year.

$Ins =$computing instructions.

Has data traffic reached the end of the line as proxy for ICT power forecasting? Machine learning training done in a data center may send only a few bits of data to the data center, presumably creating a relatively small amount of IP traffic. That is, on one hand the training process may imply many calculations without necessarily generating a lot of IP traffic. On the other hand the training may use more energy due to the required operations and J/operation [12]. Deep learning may use enormous amounts of electricity [29], however unclear how many Joules per instruction. Then research [30] showed that this electricity use may be reduced 1000 times. These frameworks and speculations need more analysis and put into a global perspective and Equation 1. Another angle to be analyzed further is that as web page sizes increase, the metrics Page Load Time and Page Render Time have larger impact on energy usage on the client side [31].

Conflicts of Interest: "The author declares no conflict of interest."

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