Projecting the chiaroscuro of the electricity use of communication and computing from 2018 to 2030

ANDERS S. G. ANDRAE [1]

[1]Huawei Technologies Sweden AB

Skalholtsgatan 9, 16494 Kista

SWEDEN

[1]anders.andrae@huawei.com

Abstract: - It is not unlikely that we might enter the YottaByte (10^{24} Byte) era in the next decade. If so, how can the effect on power consumption be understood? 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 Moore´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 centres and networks until 2030 is presented. However, the electric power consumption of the present ICT scope will be very 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. Nevertheless, the power use of certain types of blockchain applications could be another driver which cannot be ignored in the context of ICT global power use. Artificial Intelligence could help reduce the power consumption in ICT, but depending on the goal of the optimization, it may also foster more power use overall. Video streaming is a strong driver of data generation and electricity consumption. 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 several times more TWh than today.

Key words: communication, computing, 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 into the next decade. Most schools of thought agree that with the current moderate data traffic the power consumption 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, ICT stands for up to 8% 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. It is desirable for many if the electricity generated by renewable energy could increase. In 2015 the share of hydro, wind, solar and biomass power was 25% on average in China [1] which is of importance as the growth of data traffic 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 so problematic to account for all of the unknown variables. 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 be supplied with renewable electric power. The cost of electricity has to date been rather small for ICT Service providers compared to other expenditures [2], but this might change if the electricity price 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 – a couple of PWh - power consumption of ICT than slowing.

2030 is rather far away. 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, use of data centres, 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 will in itself help optimize the power use of production.

Use stage power of data centres is now around 12%, but is expected to become one of the most important drivers for ICT electricity use.

Use stage power of Networks (wireless, core and Wi-Fi modems) is now at around 20% of ICT, but its share is expected to increase. There is however considerable uncertainty about 5G's power use depending on point of introduction and regional differences. Use stage power of consumer devices is now at more than 50% of ICT 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.

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 centres as well as the production of hardware for all. The 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&Edler in 2015 [3] when adding new assumptions/predictions of data traffic and electricity intensity improvements obtained between 2016 and 2018.

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. The baseline year is 2018 and only one trend curve – for ICT total - will be proposed toward 2030.

2.1 Alternate assumptions for data centres 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 2018 than in [3].
- Due to the explosive growth of mobile data traffic (see Section 2.2.1), a much higher amount of data will eventually be processed in the data centres (see Tables 1 and 2).

Table 1: Differences between [3] and the present prediction for data centres.

	Global Data Centre IP Traffic (ZettaBytes/year)		Zettabits (Computations[1])		Electricity use (TWh)	
	[3]	present	[3]	present	[3]	present
2018	9	9[2]	82	83[3]	539	211
2019	11	11	101	102	596	208
2020	13	13	125	127	660	207
2021	16	16	153	155	731	202
2022	20	20	189	193	854	239
2023	25	26	232	244	998	287
2024	30	33	285	311	1166	347
2025	37	43	351	404	1362	429
2026	46	57	432	535	1592	540
2027	56	78	531	733	1860	702
2028	69	110	653	1039	2173	946
2029	85	162	804	1531	2539	1324
2030	105	249	988	2347	2967	1929

2.2 Alternate assumptions for Networks

2.2.1 Wireless access

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

- Baseline CAGR 2018-2030 79% instead of 58% as there are indications that the mobile traffic is growing faster than expected [4].
- Expected CAGR 2020-2030 is assumed to be 79% instead of 50%.
- Electricity intensity of 5G data traffic (TWh/ExaByte), 0.12 instead of 0.06.

  Table 2 shows the dramatic increase in electricity use of wireless due to explosive data growth.

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

	Mobile + Voice Traffic (ZettaBytes/year)		Electricity use (TWh)	
	[3]	present	[3]	present

---

[1] It is assumed that one bit equals one computation in the data centre.

[2] 8965 ExaByte/2^{10}

[3] 8965 ExaByte/$2^{10}\times 2^{70}\times 8/10^{21}$

2018	0.23	0.25[4]	111	122
2019	0.35	0.44	103	127
2020	0.54	0.77	98	136
2021	0.79	0.94	92	108
2022	1	2	100	130
2023	2	3	114	168
2024	3	5	127	223
2025	4	9	144	306
2026	6	17	145	350
2027	9	30	149	434
2028	14	54	157	584
2029	20	97	172	846
2030	30	174	196	1300

2.2.2 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%. This results in a considerable lower electricity use of these networks in 2030 (Table 3).

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

	Electricity use (TWh)	
	[3]	present
2018	351	173
2019	392	172
2020	439	171
2021	494	171
2022	588	204
2023	703	244
2024	843	292
2025	1014	351
2026	1222	423
2027	1477	512
2028	1789	620
2029	2171	752

---

[4] 259 ExaByte/2^{10}

2030	2641	915

2.2.3 Fixed access Wi-Fi

Also Wi-Fi is overestimated in [3] as the modems electric power use actually is 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 4. 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.

Table 4: Differences between [3] and the present prediction for fixed access Wi-Fi networks.

	Electricity use (TWh)	
	[3]	present
2018	135	67
2019	158	69
2020	185	72
2021	216	75
2022	253	93
2023	296	114
2024	346	141
2025	405	174
2026	474	215
2027	555	266
2028	649	328
2029	759	405
2030	889	501

2.3 Alternate assumptions for Devices power use

In this section the use stage electric power of USB dongles, smarthome devices, wearables and AR and VR devices is added. Moreover, due to a strong trend of longer lifetimes for consumer devices, a 3-year lifetime is assumed instead of 2 years in the present prediction [3]. Table 5 shows that the newly added devices do not change the use stage predictions much.

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

	Electricity use (TWh)	
	[3]	present
2018	944	957
2019	944	958
2020	947	962
2021	937	953
2022	918	934
2023	890	906
2024	854	871
2025	812	829
2026	775	793
2027	744	763
2028	716	736
2029	692	714
2030	670	696

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 Moore´s law. Anyway, the order of magnitude for the TWh is correct but a reduction seems quite optimistic. It can happen though, thanks to a hard focus on power saving and updated energy labeling requirements for end-user devices.

2.4 Alternate assumptions for Production of ICT hardware

Andrae&Edler [3] overestimated the electric power used to produce ICT goods used in Networks and Data Centres. This is improved in the present prediction.

In this section the production of USB dongles, smarthome devices, wearables and AR VR devices is added. Moreover, the so called life cycle ratio for Networks and Data Centre production is set to 0.02 instead of 0.15, bringing down the manufacturing TWh significantly. Assuming that 0.7 million *macro base stations* - used in wireless access networks - and 20 million *blade servers* – used in data centres - will be produced in 2030, the electric power needed would be around 28 TWh. The present study predicts 95 TWh in 2030 – of 382 TWh - for *all* network and data centre equipment. This suggests that a 0.02 life cycle ratio for production is reasonable for traffic dependent calculations of data centres and networks. Table 6 shows that the production estimates are much lower in the present study than in [3].

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

	Electricity use (TWh)	
	[3]	present
2018	509	366

2019	530	376
2020	549	384
2021	540	360
2022	547	344
2023	562	332
2024	584	324
2025	614	319
2026	650	318
2027	696	322
2028	752	332
2029	821	351
2030	903	382

3. Results

The stability of Andrae&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. In summary in 2030, production of hardware and fixed access networks use stage are predicted to use much less - and wireless access networks much more than predicted - than the expected scenario in [3].

3.1 Data centres power use

Fig. 1 shows some trends for data centres 2018 to 2030.

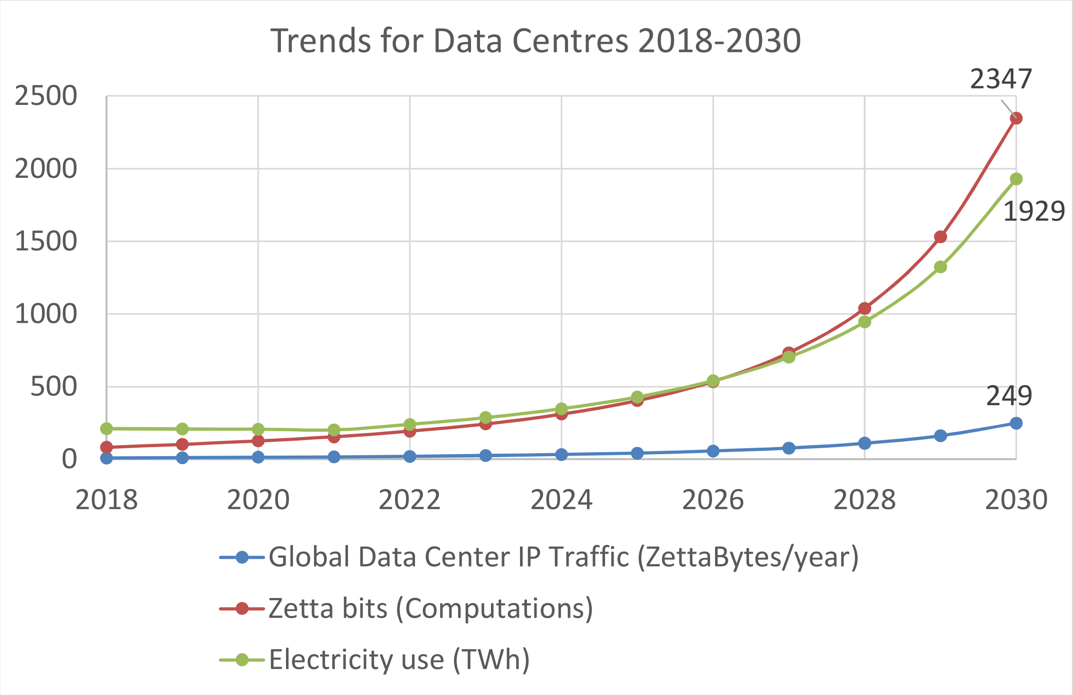

Fig. 1: Trends for data centres 2018 to 2030.

Although the electricity intensity improvements are assumed higher than in [3] the data traffic increase compensate, and the electric power might still rise. The ZettaBytes/year data will be used in section 4.2.2 to extrapolate the instructions per second in 2030.

3.2 Networks power use

Figs. 2a to 2c show some trends for Networks 2018 to 2030.

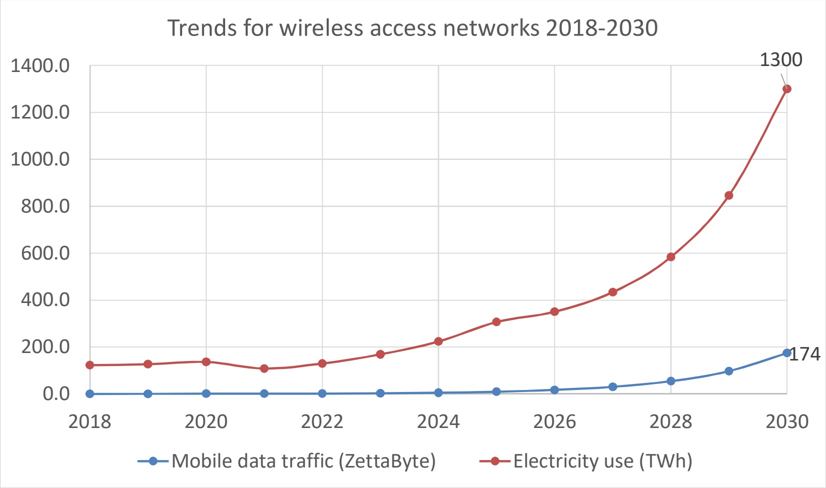

Fig. 2a: Trends for wireless access networks 2018 to 2030.

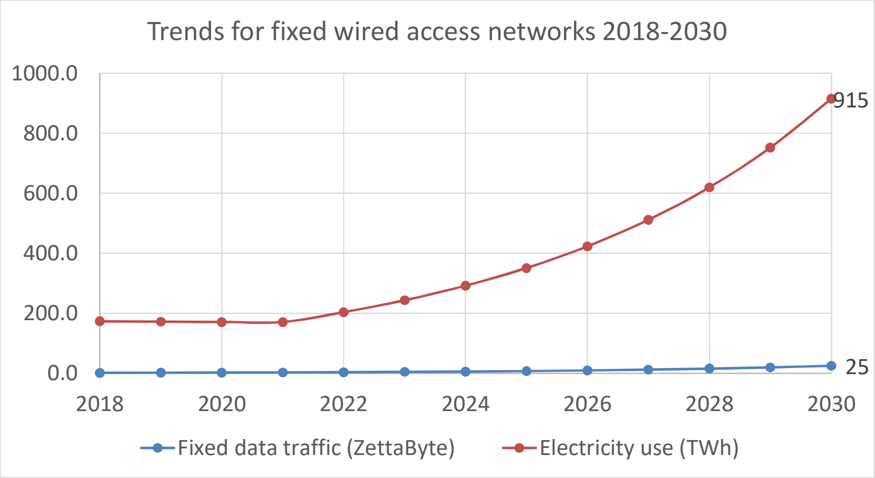

Fig. 2b: Trends for fixed access wired networks 2018 to 2030.

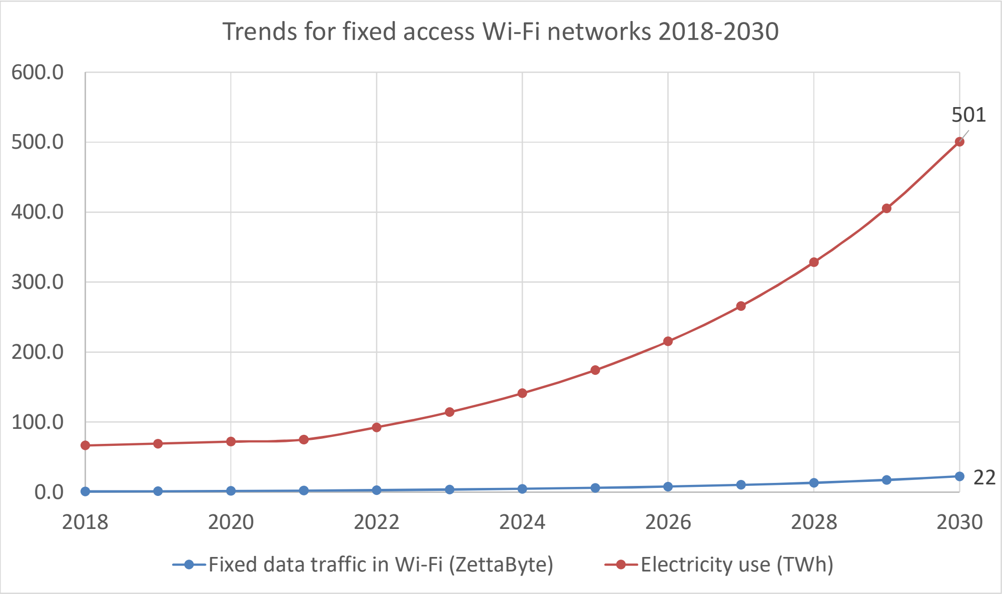

Fig. 2c: Trends for fixed access Wi-Fi networks 2018 to 2030.

3.3 Devices power use

Fig. 3 shows some trends for end-user consumer ICT goods use stage 2018 to 2030.

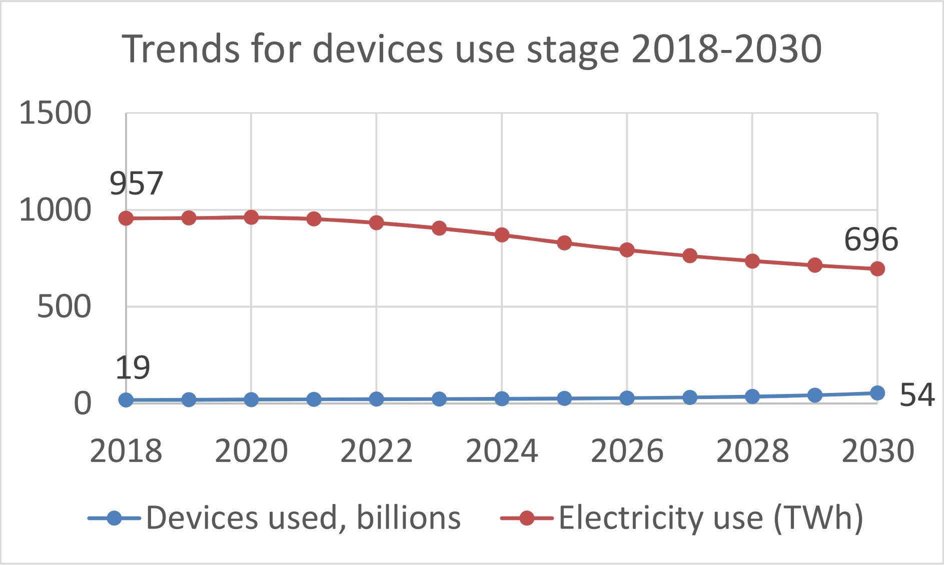

Fig. 3: Trends for consumer ICT goods use stage 2018 to 2030.

3.4 Production of ICT hardware

Fig. 4 shows some trends for production of ICT hardware 2018 to 2030.

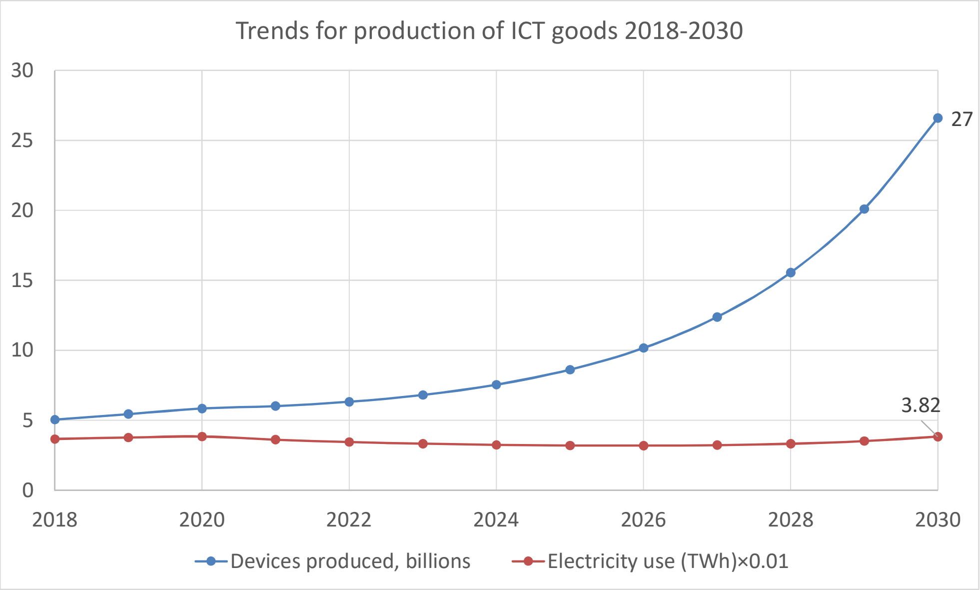

Fig. 4: Trends for production of ICT goods 2018 to 2030.

As shown in Fig. 4, the consumption is to be interpreted as Table 6, e.g. 382 TWh for 2030.

3.5 Summary

Fig. 5 shows some trends for the synthesis per contributing category 2018 to 2030. [3] is compared to the present update.

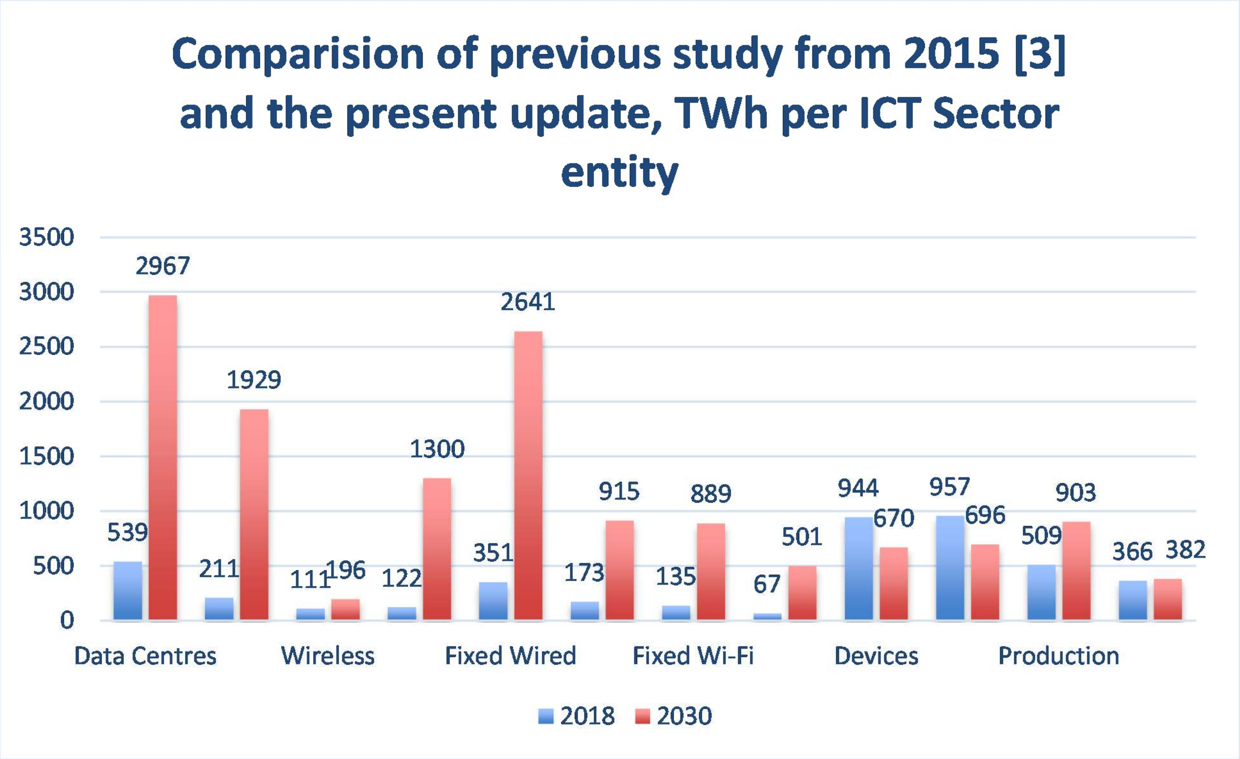

Fig. 5: Trends for ICT electric power overall 2018 to 2030.

Generally the values for 2018 are lower for most entities. For 2030 too except for wireless access networks which will use more electricity. In total the electric power predictions of the ICT Sector have been reduced by 27% and 30% in the present study compared to expected case scenario in [3].

4. 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. It is almost not 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.* [5] 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 [6].

4.1 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 [7] – 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. Still, in section 4.5 the individual electricity cost of video streaming is estimated.

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.

4.2 Testing of the order of magnitude of worldwide data centre electric power use

4.2.1 What if the 20% per year electricity intensity improvements continue after 2022?

Fig. 6 shows the summary of the present predictions.

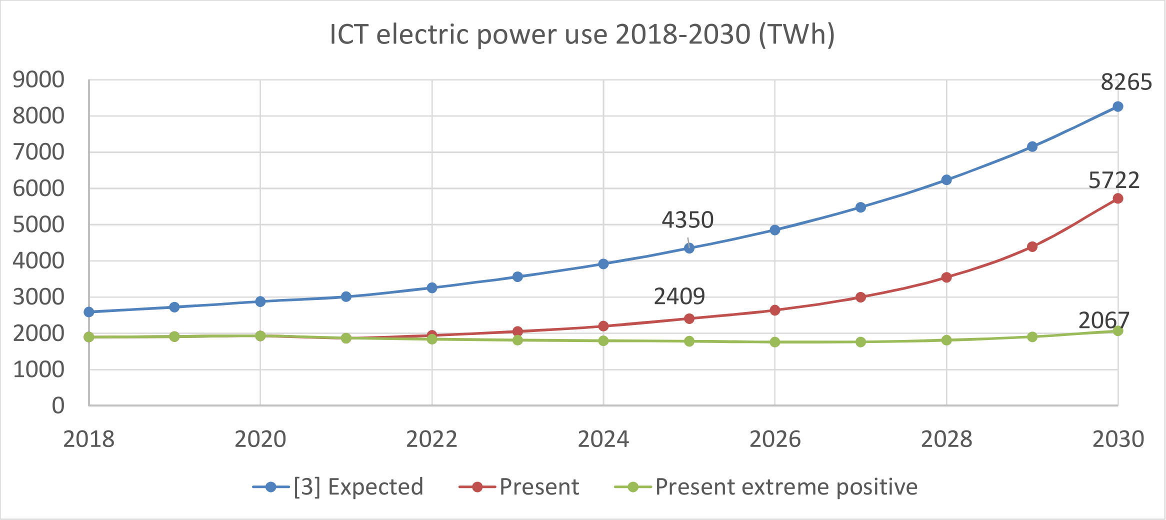

Fig. 6: Trends for ICT electric power use 2018 to 2030.

The "present extreme positive" scenario assumes that no slowdown of electricity intensity improvements happen after 2022 – 5% annual improvements from 2022 to 2030 is standard in the present baseline - and that 20% improvements still happen until 2030. In that case ICT power will more or less stay flat while the total data traffic grows 28 times between 2018 and 2030. The electricity use of networks and data centres will be 79% less in such a "present extreme positive" scenario than in the present study.

4.2.2 Alternate way of estimation ICT power use from computations

Andrae&Edler [3] data centre estimations for 2030 can be "tested" quite easily as follows. This approach is based on instructions per second (IPS) [8] and instructions per joule (IPJ) [9].

As shown in Table 7, if Koomey's Law (Eq. 1) [9] for electricity efficiency improvement - 55% per year since 2000 - holds to 2030, and we have 3.0×10^{24} IPS by then - we will have several thousands of TWh needed for computing. This is true even if the Central Processor Unit (CPU) share of the electricity use of the data centres and computers would be 100% (i.e. no extra electric power needed for cooling, fans, uninterruptable power supply etc.) and if no split – regarding energy efficiency - is made between SPC and GPC. Nowadays the CPU share of the electricity use of the data centres might be just 20% for some smaller data centres [10] however much higher - like 70% - for professional hyperscale data centres [11].

Equations 1 to 4 show how the electricity use of computing can be estimated.

$$\left(\frac{Ins}{kWh}\right)_Y = e^{(0.4401939\times Y-849.1617)} \qquad (1)$$

$$\left(\frac{Ins}{J}\right)_Y = \frac{\left(\frac{Ins}{kWh}\right)_Y}{3.6\times10^6} \qquad (2)$$

$$\left(\frac{J}{s}\right)_Y = \frac{\left(\frac{Ins}{s}\right)_{,Y}}{\left(\frac{Ins}{J}\right)_Y} \qquad (3)$$

$$\left(\frac{J}{s}\right)_Y = \frac{\left(\frac{Ins}{s}\right)_{GPC,Y}}{\left(\frac{Ins}{J}\right)_{GPC,Y}} + \frac{\left(\frac{Ins}{s}\right)_{SPC,Y}}{\left(\frac{Ins}{J}\right)_{SPC,Y}} \qquad (4)$$

where

$\left(\frac{J}{s}\right)_Y$ = Electric power use of computing in year Y.

$\left(\frac{Ins}{s}\right)_Y$ = Instructions per second for Computing in year Y.

$\left(\frac{Ins}{s}\right)_{GPC,Y}$ = Instructions per second for General Purpose Computing in year Y [8].

$\left(\frac{Ins}{s}\right)_{SPC,Y}$ = Instructions per second for Special Purpose Computing in year Y [8].

$\left(\frac{Ins}{J}\right)_{GPC,Y}$ = Instructions per Joule for General Purpose Computing in year Y

$\left(\frac{Ins}{J}\right)_{SPC,Y}$ = Instructions per Joule for Special Purpose Computing in year Y

$\left(\frac{Ins}{kWh}\right)_Y$ = Instructions per kWh for Computing in year Y.

The electricity use will be estimated for the year 2030 for SPC and GPC and compared to the values for 2030 in Andrae&Edler [3] and the present prediction for 2030. Table 7 results only refer to computing related electricity in the data centre and computers, which is far from reality. This means that the consumption would be higher if other sources of power than computing would be included.

Table 7: 2030 electricity use of computing based on $\left(\frac{Ins}{kWh}\right)_Y$ and $\left(\frac{Ins}{s}\right)_Y$

	$\left(\frac{Ins}{s}\right)_Y$[5]	$\left(\frac{Ins}{s}\right)_{GPC,Y}$	$\left(\frac{Ins}{s}\right)_{SPC,Y}$	$\left(\frac{Ins}{kWh}\right)_Y$	$\left(\frac{Ins}{J}\right)_{GPC,Y}$	$\left(\frac{Ins}{J}\right)_{GPC,Y}$	$\left(\frac{J}{s}\right)_Y$	TWh
Y = 2030		2.12×10^{22} [8]	3.03×10^{24} [8]	1.98×10^{19}	5.5×10^{10}	5.5×10^{12}	9.42×10^{11}	8253
Y = 2030	1.84×10^{24}					5.5×10^{12}	3.35×10^{11}	2930

---

[5] Extrapolation: Instructions per second 2030 [8]/[Bytes/year] in 2030 [8] × [Bytes/year] present = $3.05 \times 10^{24}/4.86\times10^{23} \times 254498 \times 2^{60}$ = 1.84×10^{24} instructions per second.

Y = 2030		1×10^{22}	1.83×10^{24}		5.5×10^{10}	5.5×10^{12}	5.15×10^{11}	4509

The instructions per joule (IPJ), also known as million operations per second (MOPS) per milliwatt, for e.g. current silicon on chips (SoC) can be found in many sources such as 193 MOPS/mW [12] and 742.5 MOPS/mW [13]. These translate to $1.93\times10^{11}$and 7.42×10^{11}IPJ showing a much higher energy efficiency than is predicted with Koomey's law for 2015 and 2016.

Alternatively the global IP data traffic generated in 2030 – as predicted by the present study - can be used to extrapolate the IPS[6] in 2030 and thereby the electric power. Table 8 shows some key indicators for data traffic and instructions.

Table 8: 2018 and 2030 key indicators for data traffic and instructions

Year	Global access traffic ("internet traffic"), EB	Global IP data traffic, EB	Global IP data traffic flow, GB/s	Instructions per second, Zetta
2018	1843	8965	305000	2.1 [7], extrapolated from [8]
2030	204244	254498	8670000	1558 [8], extrapolated from [8]

Then, neglecting the different energy efficiency of GPC and SPC, 2930 TWh (Table 7) will be used in 2030. Including the same share of GPC as Xu [8] in 2030 gives 4509 TWh (Table 7). Both predictions are very similar to those shown Figure 5.

This all suggests that the electric power use of ICT will rise considerably in the next decade despite assuming that Koomey's law will continue uninterruptedly with the instructions per joule improving 55% per year from now until 2030. Any slow-down of Koomey's Law will naturally mean much higher electric power consumption.

---

[6] The relation between computations and instructions is not clear.

[7] 2.25×10^{20} IPS/9.38×10^{20}B × 8965 EB × 2^{60} = 2.48×10^{21} instructions per second, 2.48×10^{21} / 2^{70} = 2.1 ZIPS

[8] 3.05×10^{24}IPS/4.86×10^{23}B × 254498 EB × 2^{60} = 1.84×10^{24} instructions per second, 1.84×10^{24} / 2^{70} = 1558 ZIPS

The current traffic flow is 305000 GB/s which could rise to 8460 PB/s in 2030. The access traffic (Internet traffic) is lower.

As a side note, Table 1 for the present study, is consistent with the predictions made in [11] for United States data centres 2018-2020.

4.3 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 [14]. 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.* [14] 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. [7].

4.4 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 has the possibility to be located where the ICT infrastructure will be located.

Using renewable energy to power data centres 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. The relation between renewable energy resources and associated environmental impacts of data centres and networks driven by renewable energy at a global scale should be investigated deeper.

Overall the present prediction suggest that we will go along an average of the Best and Expected Case Scenarios in [3], 1800 TWh in 2018 to 5700 TWh in 2030 (Table 5 and Fig. 6). The greenhouse gas (GHG) emissions might rise from current 1 Gt to 2.2 Gt. The ICT Sector will have a quite high share of the global electricity footprint. However, it might also have a potentially lower increase of the GHG from 2018 to 2030 thanks to much more specific renewable power directed to the ICT Networks and Data Centres, and maybe also to the homes in which the consumer devices are most commonly used.

The GHG emissions from ICT are not predestined to increase sharply as the focus is very strong right now in many parts of the world to solve the renewable power issues. More renewable power is estimated to be produced globally than the ICT demands and will demand in 2030. This is also mentioned in [3].

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

It is relevant to estimate how much data is generated by - and associated electric power used - normal behavior like video streaming several hours every day.

For the present estimations the following key indicators are obtained (Table 9).

Table 9: 2018 and 2030 key indicators electricity intensity relevant for video streaming

Entity used in video streaming	**2018**	**2030**	**Unit**	**Share of total Global access traffic ("internet traffic") 2018**	**Share of total Global access traffic ("internet traffic") 2030**
Wireless access networks	0.47	0.00729	kWh/GB	13%	87%
Fixed access Wi-Fi networks	0.067	0.022	kWh/GB	87%	13%
Fixed access wired networks	0.109	0.035	kWh/GB		
Data centre	0.023	0.008	kWh/GB		

The electricity intensities decrease massively, especially for wireless access networks. However, those networks are used much less extensively for video streaming in 2018 than optic fixed access. Table 9 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 [15]. 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.

4.5.1 Data amounts and TWh from global video streaming

For 2018 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 2018. If all entities are used in Table 9 to deliver the stream, 502 kWh[9] per year per person is needed. Assuming that 2 billion persons have this behavior, 1004 TWh is needed for 5230 ExaBytes[10]. This suggests that video streaming is a big driver for ICT electric power use in 2018.

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.

To provide these hours, 18720 GB per person is generated in 2030. If all entities are used in Table 9 to deliver the stream, 353 kWh[11] per year per person is needed. Assuming that 7 billion persons will have this behavior, 2475 TWh is needed for 122040 ExaBytes[12].

These simple calculations shows that increasing electricity use of the ICT Sector is unquestionably in the cards.

5 Conclusions

It is very difficult to see 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].

6 Next steps

New advances in large-scale fiber-optic communication systems [16] should be translated to J/bit and used for predictions of the fixed core network. Moreover, it is plausible that ICT infrastructure can help save electric power in the main sectors of society, and Ono *et al.* suggested 1300 TWh in 2030 [17]. These assumptions should be further explored.

References

---

[9] $52\times(2\times5+4\times2)\times3\times(0.13\times0.47+0.87\times0.109+0.023)=$ 502 kWh/person/year in 2018

[10] $52\times(2\times5+4\times2)\times3\times2^{30}\times2\times10^{9}/2^{60}=$ 5230 ExaBytes/year in 2018

[11] $52\times(2\times5+4\times2)\times20\times(0.87\times0.00729+0.13\times0.035+0.008)=$ 353 kWh/person/year in 2030

[12] $52\times(2\times5+4\times2)\times20\times2^{30}\times7\times10^{9}/2^{60}=$ 122040 ExaBytes/year in 2030

[1] Y. Liang, B. Yu, L. Wang. 2019. Costs and benefits of renewable energy development in China's power industry. *Renewable energy,* Vol. 131, pp. 700-712.

[2] A.S.G Andrae, L. Hu, L. Liu, J. Spear, K. Rubel. 2017. Delivering Tangible Carbon Emission and Cost Reduction through the ICT Supply Chain. *International Journal of Green Technology,* Vol. 3, pp. 1-10.

[3] A.S.G. Andrae, T. Edler. 2015. On global electricity usage of communication technology: trends to 2030. *Challenges,* Vol. 6, No. 1, pp. 117-157.

[4] Ericsson. Mobility Report November. 2018. Available at: https://www.ericsson.com/en/mobility-report/reports/november-2018

[5] N.F. Nissen, L. Stobbe, N. Richter, H. Zedel, K.D Lang. 2019. Between the User and the Cloud: Assessing the Energy Footprint of the Access Network Devices. In *Technologies and Eco-innovation towards Sustainability I*, pp. 49-64. Springer, Singapore.

[6] U. Soni, A. Roy, A. Verma, V. Jain. 2019. Forecasting municipal solid waste generation using artificial intelligence models—a case study in India. *SN Applied Sciences,* Vol. 1, No. 2, p. 162.

[7] P. Fairley. 2019. Ethereum will cut back its absurd energy use. *IEEE Spectrum,* Vol. 56, No. 1, pp. 29-32.

[8] Z.W. Xu. 2014. Cloud-sea computing systems: Towards thousand-fold improvement in performance per watt for the coming zettabyte era. *Journal of Computer Science and Technology,* Vol. 29, No. 2, pp. 177-181.

[9] J. Koomey, S. Berard, M. Sanchez, H. Wong. Implications of historical trends in the electrical efficiency of computing. *IEEE Annals of the History of Computing,* Vol. 33, No. 3, pp. 46-54.

[10] R. Bashroush. 2018. A Comprehensive Reasoning Framework for Hardware Refresh in Data Centres. *IEEE Transactions on Sustainable Computing* (2018).

[11] A. Shehabi, S.J. Smith, E. Masanet, J. Koomey. Data center growth in the United States: decoupling the demand for services from electricity use. *Environmental Research Letters,* Vol. 13, No. 12, p. 124030.

[12] D. Rossi, A. Pullini, I. Loi, M. Gautschi, F. Kagan Gurkaynak, A. Teman, J. Constantin et al. 2016. 193 MOPS/mW@ 162 MOPS, 0.32 V to 1.15 V voltage range multi-core accelerator for

energy efficient parallel and sequential digital processing. In *2016 IEEE Symposium in Low-Power and High-Speed Chips (COOL CHIPS XIX),* pp. 1-3. IEEE.

[13] K. Masuyama, Y. Fujita, H. Okuhara, H. Amano. 2015. A 297mops/0.4 mw ultra low power coarse-grained reconfigurable accelerator CMA-SOTB-2. In *2015 International Conference on ReConFigurable Computing and FPGAs (ReConFig)*, pp. 1-6. IEEE.

[14] C. Mora, R.L. Rollins, K. Taladay, M.B. Kantar, M.K. Chock, M. Shimada, E.C. Franklin. 2018. Bitcoin emissions alone could push global warming above 2° C. *Nature Climate Change*, Vol. 8, No. 11 p. 931.

[15] Netflix. 2019. How can I control how much data Netflix uses? Available at: https://help.netflix.com/en/node/87

[16] X. Zhao, Z. Yu, B. Liu, Y. Li, H. Chen, M. Chen. 2018. An integrated optical neural network chip based on Mach-Zehnder interferometers. In *2018 Asia Communications and Photonics Conference (ACP)*, pp. 1-3. IEEE.

[17] T. Ono, K. Iida, S. Yamazaki. 2017. Achieving sustainable development goals (SDGs) through ICT services. *Fujitsu Scientific & Technical Journal*, Vol. 53, No. 6, pp. 17-22.