

Just measure IT! – Electricity consumption measurements of electronic devices and estimates of datacenter and network services for one household

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Abstract—Nearly all appliances and electronic devices were measured for a whole year in 40 Swedish households 15 years ago by the Swedish Energy Agency. New measurements are discussed, in the meantime, with the help of smart plugs and a professional meter, nearly all electronic devices have been measured in one Swedish 4-person household. Long term measurements started 1st Nov 2022, and this paper is based on the first two months of measurements. All long- and short-term measurements are scaled to a full year (2022).

The desktop gaming PC and primary TV with peripherals stand out with 353 and 304 kWh respectively. Their 23 kWh in off/sleep mode was significantly lower than for PCs/TVs 15 years ago. The fiber modem, home Wi-Fi router, and extension Wi-Fi router consume 191 kWh. All other about 40 devices consume about 360 kWh (e.g., 3 laptops, 2 displays, 4 smartphones, 3 Wi-Fi speakers, 2 more TVs, 8 “IoT” devices).

Many recent studies have claimed that streaming video, or “downloading” digital media, or having videoconferences, consumes a lot of electricity. Real measurements in this study show that a laptop’s power consumption increases about +5 W when videoconferencing. The fiber modem and router power vary typically only $\pm 1\%$ with use, including streaming. Downloading at >400 Mbps (>180 GB/h) over a LAN-port increases power +0.3 W and over 5 GHz Wi-Fi the increase is +2.5 W to +5.5 W depending on signal quality. The impact of video streaming and *downloading* is marginal in the household.

Unique for this study is that also the household’s *use or share of network and datacenter services* have been estimated to 295 and 266 kWh respectively. For example, Netflix/AWS report about 1.5 kWh per subscription and the household’s total streaming can be estimated to about 6 kWh per year, and all Microsoft and Google services to about 50 kWh.

Keywords—*electricity consumption measurements, power consumption measurements, electronic devices, user devices, datacenter services, network services*

I. INTRODUCTION

“The science is clear. The global warming debate is over. We simply must do everything we can in our power to slow down global warming before it is too late.”, said by the Governor of California back in 2006 [1]. To avoid the worst effects of global warming, greenhouse gas (GHG) emissions must be halved *now* (2030), and then reach zero in 2050. “The evidence is clear: the time for action is now. We can halve emissions by 2030” [2]. Otherwise, humanity will face increasing heat waves, droughts, storms, rains, floods, and rising sea levels, resulting in eco-system collapse and the destruction of people’s lives and our societies. There is one cause above all for the global warming crisis: Fossil fuels [2].

Significant shares of fossil coal and gas are used to produce electricity globally. Since 2015, the average GHG

emissions per produced kWh has been around 0.5 kg CO₂-equivalents (CO₂e) [3]. If coal and gas supply, transport and distribution (T&D) losses, power plant and grid construction, and waste treatment are also included, GHG emissions per consumed kWh goes up to around 0.6 kg CO₂e [4].

There is also an ongoing energy crisis in Europe that started in winter 2021/2022 when gas prices soared, and electricity prices followed. All citizens are encouraged to save energy. To reduce the indoor temperature and reduce the need for heating, and to reduce hot water consumption saves energy and reduces costs. But what about all appliances and electronic devices in a household? How significant are they and what can be done to reduce their electricity consumption?

New measurements are key to better understand a household’s electricity consumption, so proper actions can be taken to reduce it, reduce costs, and as a bonus, reduce GHG emissions. Motives to measure are strong for household owners, industry, the research community, and for authorities and governments. But to measure all electronic devices in people’s homes on a larger scale is not an easy task. Grouped devices in about 40 households were measured for a whole year in Sweden 2007–2008 [5]. Not as extensive and partly questionnaire based investigations were made in other EU countries at the same time, e.g., Norway [6] and UK [7], as part of an EU initiative [8]. No new long-term real household measurements have been made since. There is a growing knowledge gap especially concerning new individual devices.

Many recent news articles have claimed that streaming video, or *downloading* digital media, or having video conferences, consumes a lot of electricity. A key component is missing in the background studies, real measurements, empirical evidence. It is relatively easy to measure e.g., your own home router, which is one of the new key measurements in this study. As similar components are found in the operator’s street cabinet, this measurement can also be used to better understand the network outside the house.

As William “Kelvin” Thomson (1824–1907), puts it [9]: “*When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the stage of science.*”

The common denominator in the claims of high electricity consumption for downloading, is the use of *kWh/GB* figures that imply “more data = more electricity”. What happens with the power consumption when a large PC game is downloaded or when streaming video to the TV? And of interest to employers and employees, when working from home and having a video conference? The first part in the answer to all these questions is simple: – Just measure IT!

What happens in and between a datacenter and your house is typically unknown to most people. Even if access to such sites and measurement of equipment in them is out of reach, specifications and measurements by manufacturers and operators are publicly available. Unique for this study is that the household's *use or share of network and datacenter services* have also been estimated. The research questions and goals of the study can be summarized as:

- Explore pros and cons of smart plug measurements and compare to measurements with a professional multimeter and manufacturers specifications
- Focus on long term measurements of key consumers: fiber modem, home Wi-Fi router, home workplace (laptop PC, display), TVs, gaming PC
- Investigate how power varies with use and data
- Measure all electronic devices in a household, and estimate the annual electricity consumption (AEC) by extrapolating to a full year (full annual study planned)
- Compare to the older Swedish study [5]
- Show how the home network can be used to better understand the network outside the house and how publicly available data and studies from manufacturers and operators can be used to estimate the *use or share of network and datacenter services*

This study has one obvious limitation - only one household is measured. However, it is the same type of devices based on similar components that behave in similar ways in households around the world. What can be a better place to start if not with yourself and your own household? This is the household:

- Parents (53 and 50 years old), two children (20, 17)
- Fiber broadband, 500 Mbps, 400–1000 GB/month
- 4 mobile 4G/5G subscriptions, < 10 GB/month each, 100 Mbps in the house (<2 km to tower), average smartphone screen time is about 2.5h per day
- Daily use (4 persons total): music streaming 9h, video streaming 8h, working from home and online education 8h (video conferencing 3h), gaming 7h, others 4h, total 36h (9h/person, overlapping exist)
- A map of the home network and all connected key devices (19) can be found in Fig. 4.

II. METHODOLOGY

Long term measurements started Nov 1st 2022, and this paper is based on the first two months of measurements. All devices in this study have been measured with a professional multimeter [10] designed to do accurate power/energy measurements together with six so called smart plugs [11]. All smart plugs measurements have been checked with the professional meter. The Customer Premises Equipment (CPE, home modems/switches/routers), primary TV, and the home workplace was measured over the whole period from the start for 61 days. The desktop gaming PC was measured for 47 days (Nov 15 – Dec 31), and the secondary TV for 31 days (Dec). The sixth smart plug has been used to measure various other devices over the same period. The CPE site is used here as the key measurement example. The measurement setup for the CPE site and smart plug app interface is shown in Figure 1.

The smart plugs have been used to be able to measure many devices simultaneously for a long time, while the professional meter is used to check all measurements and also do additional measurements at any time. Bluetooth smart plugs were used to not impact any of the Wi-Fi measurements.



Fig. 1. The professional multimeter measures a fiber modem and home router to 12.86 W (via a branch outlet) while a connected smart plug measures 12.27 W, indicating the smart plug's internal power consumption is around 0.6 W. When measured by the professional meter, the smart plug's internal power consumption was 0.46 W, indicating the smart plug error is in the order of -0.1 W and it should have measured 12.4 W.

There's a bit of learning to be made and then planning, *methodology development*, before starting long term measurements. New ideas come up to measure certain behavior and answer specific research questions as you measure. In the end, it's important to describe how the measurements were done and if any special circumstances existed that could impact the results.

The professional multimeter can measure the power consumption of a smartphone charger in stand-by mode (no smartphone connected) accurately to 30 mW. This low power cannot be measured by a smart plug, it shows "0.000 W". The smart plug uncertainty is specified as: <1 W: ± 0.23 W, 1-5 W: $\pm 10\%$, 5-10 W: $\pm 2\%$, >10 W: $\pm 1\%$ [11]

The measurement error of the smart plugs was below 1% for measurements above 50 W. Apart from measurement uncertainty, the smart plugs also do a *truncation error* and records only e.g., 12 Wh over an hour even as 12.7 Wh has been measured on average. The CPE site smart plug recorded 12 Wh for 1455 hours during the 61-day measurements, and 13 Wh for only 9 hours, 17.6 kWh in total. This measurement was clearly a bit low and needed to be corrected. The fiber modem was measured to 3.55 ± 0.05 W (3.4–3.7 W) and the home Wi-Fi router to 9.15 ± 0.15 W (8.8–10.5 W) by the professional meter. The low end is for no connected devices (LAN-ports or Wi-Fi), but Wi-Fi is on (2.4 and 5 GHz).

For nearly one additional week, the router and the whole CPE site was also measured by individual smart plugs. The CPE smart plug also measured the internal consumption

(+0.46 W) of the router smart plug and measured 13 Wh for 147 hours and 12 Wh for 3 hours, which indicate the CPE site likely consume around 12.75 W. Another way to get more accurate smart plug meter readings is to check the exact time when the meter adds another Wh. This has been done in the end of many hours to improve the accuracy to about ± 0.1 W.

Fig. 2. shows two screenshots of the smart plug app with callouts explaining key measurements. To the left is the main screen with a list of all active smart plug measurements and to the right is the energy screen with daily/hourly electricity measurements of the workplace laptop PC and extra display. The power measurement screen has been shown in Fig. 1.

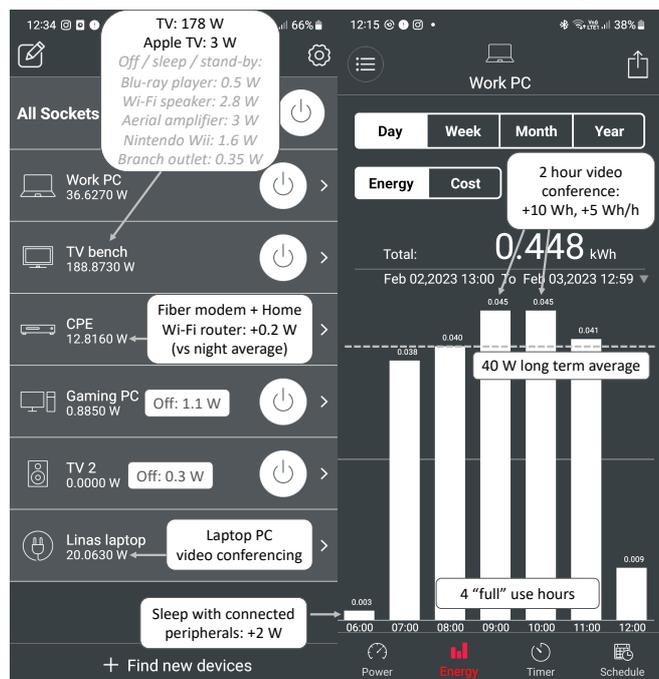


Fig. 2. Two screenshots of the smart plug app during measurements.

Most devices are not on 24/7 as the CPE, and then the average use power has been determined by adding up many “full” use hours (see example above in Fig.2.) and calculate an average per hour. Based on average use power and more exact low power measurements, average time in use and time in “off” or “sleep” modes could be determined based on the total electricity consumption of the device.

All long- and short-term measurements have been scaled to a full year (2022). Extrapolations to a full year (2022) is done by dividing a full year (365.25 days) with days measured (e.g., $365.25/61 = 5.99$).

III. MEASUREMENTS OF ELECTRONIC DEVICES

The annual electricity consumption levels, based on measurements and extrapolations, for the different devices are shown in Fig. 3. Also shown separate in Fig. 3. are devices that was disconnected as a result of the measurements and corrections added due to truncation and measurement errors. Measured and corrected electricity consumptions are accurate but the average use power and time in use is a bit uncertain. For example, the 4.5 h/day average use and 210 W average power for the gaming PC could also be 4.25 h/day and 222 W, or 4.75 h and 199 W, as the total is 945 Wh/day. However, the 210 W figure is based on 100+ hourly averages and is believed to be quite accurate. The five key measurements are described in more detail in section A-E.

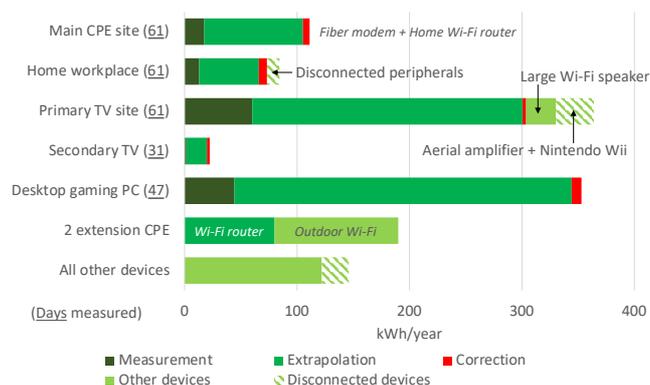


Fig. 3. Measurements, extrapolations, and corrections.

A. CPE and M2M/IoT

The CPE site and smart plug measurements have already been described to a large degree in the previous *Methodology* section that used the CPE site as the key example. An extension Wi-Fi router and an outdoor Wi-Fi access point is connected to the home router via LAN-cables, and they have also been measured, but not continuously as they show the same behavior as the CPE site (confirmed by measurements).

The Wi-Fi extensions of the smart utility meter and the photovoltaic (PV) inverter and the six smart plugs that have been used in this study, are listed here as *M2M/IoT* devices as they share the same *always on* behavior as the CPE. The smart meters com-module has been estimated based on [12], but as it is owned by the electric grid company, it is not included in any later household totals. See all results and data in Table I.

TABLE I. CPE AND M2M/IoT MEASUREMENTS

Device	Annual electricity consumption (kWh/year)		
	Typical (range) Watt	Max W	kWh
Fiber modem	3.55 (3.4–3.7)	~5	31
Home Wi-Fi router	9.15 (8.8–10.5, 14.7)	~20	80
Ext. Wi-Fi router	9.1	~20	80
Outdoor Wi-Fi	12.5	~25	110
TOTAL:	34.3	~70	301
Smart meter	(~2)		(~18)
Smart meter Wi-Fi	0.175 (specification)	?	1.5
PV inverter Wi-Fi	~0.175 (as above)	?	1.5
6 smart plugs	2.8	~5	24
TOTAL:	3.15		27
Fiber modem and home Wi-Fi router	Basepower about 12.2 W, nothing connected Nighttime average power: 12.6 W (12.5–12.8) Daytime typical power: 12.7 W (12.5–13.8)		
Home Wi-Fi router, Max test: >400 Mbps (>180 GB/h)	LAN-port: +0.3 W (from idle, lower when on) (495 Mbps, >400 Mbps sustained over time) Wi-Fi (good signal): +2.5 W (485 Mbps) Wi-Fi (low signal): +5.5 W (420 Mbps)		
Home Wi-Fi router	Same high power increase (+5 W) when several persons use Wi-Fi with high data rates		
Extension Wi-Fi router	Very similar behavior seen in measurements and observations as the home Wi-Fi router		

Also listed in Table I are several key observations made during specific measurements. A simple way of testing a fixed or mobile broadband is to use an independent Internet test site. *Bredbandskollen.se* [13] help people test their Internet connections in Sweden. This test was used to do power consumption measurements at maximum data rates and to test the Wi-Fi at different signal strengths.

The key observation for the CPE site is the near constant power consumption. The power increase for connecting LAN-cables, starting to use a device, and other normal use including video streaming is in the order of +0.1 to +0.2 W, but short bursts of higher power around +1 W can be seen related to use over Wi-Fi.

A large download of a PC game over a LAN-cable at >400 Mbps (>180 GB/h) with the desktop gaming PC add only +0.3 W. The same download at a similar data rate over Wi-Fi consume +2.5 W with a high signal strength, and as much as +5.5 W with a low signal strength, and then the data rate drops as well. Key measurements and observations for the CPE site are shown together with the power for a typical day in use in Fig. 4. Also shown is a map over the whole home network and how all key devices are connected.

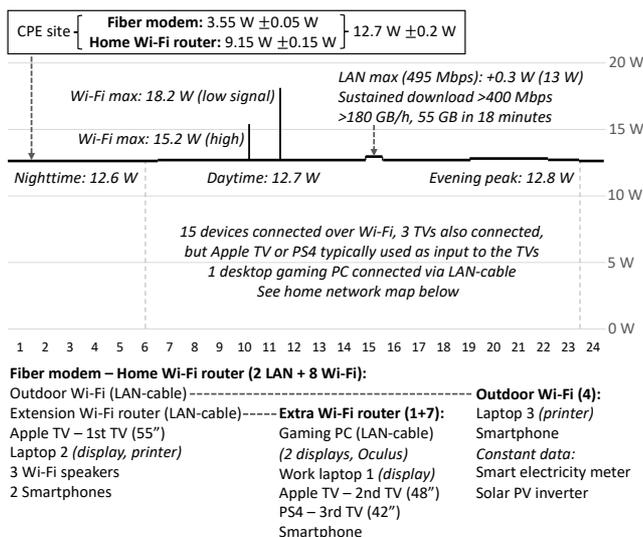


Fig. 4. Key measurements and observations for the CPE site a typical day.

The measurements of the CPE site verify the power-model proposed in [14]. As the power is near constant, power over time in use divided by number of users fits the behavior of the CPE site. The power can also be further split on components: LAN-port(s), Wi-Fi, IPTV, and VoIP. The LAN-port used in the >400 Mbps download described previously consumes about 0.5 W when on and +0.3 W was measured for the whole CPE site during the download. The Wi-Fi module stand-by is about 4.5 W and then +2.5 to +5.5 W for the same download. The power split is based on [15].

B. Home workplace and other laptop PCs

The 61-day measurement period included 43 working days and the laptop was disconnected 11 days when it was used during commuting, in the office or at external sites. No business trips took place during the period and the number of vacation days or sick leave was close to the average. Most laptop use on battery is included in the measurement as most charging was done at home. The average time spent working from home can be estimated to about 75%.

The average use power was quite stable around 40 W, and the only longer periods of increased power draw are related to video conferencing, about +5 W on average, see Fig. 2. To turn off the camera saves about 2 W. The average YouTube video adds about +1 W and for 4K video it is about +2 W.

The smart plug measured the 32" display that via USB power the laptop and two always connected Bluetooth

transceivers (mouse/keyboard and headphones). There is a Connection sleep mode (+1.1 W) which is higher than the individual sleep mode of the laptop and display, see Table II.

TABLE II. HOME WORKPLACE AND OTHER LAPTOP PCs

Device	Annual electricity consumption (kWh/year)			
	Mode	Watt	h/day	kWh
Laptop PC 1 (61 days)	Sleep	0.2	18	1.3
	Average use	6 (3–15)	4	8.8
32" display (61 days)	Sleep	0.3	20	2.2
	Average use	33	4	48.2
Connection	Added 24/7	+1.1	20	8
Teams video conferences	Added	+3	1.5	1.6
	Camera add.	+2	1.5	1.1
Peripherals	Added	+2 (1–5)	1	0.7
TOTAL:				72
Laptop PC 2 (14 days)	Sleep	0.5	19	3.5
	Average use	12 (6–25)	3	13
27" display	Sleep	0.3	20	2.2
	Average use	25	2	18
Laptop PC 3	Sleep	0.2	21.5	1.6
	Average use	~8 (5–10)	2.5	7
2 Printers	Sleep	0.2	23.9	1.8
	Average use	~7.5 (5–15)	0.1	< 0.5
TOTAL:				48
2 more laptops are used occasionally in the household, both belong to schools where they are normally used (charged). They are not included in the study. Electricity cons. in the house can be assumed to <5 kWh.				
The list of other peripherals is long but they are all powered by the laptop PCs or displays (USB), so included in measurements when used (e.g., 4K webcam, headphones, USB-hubs, external storage, etc.)				

There is an added sleep power when more devices are connected to the USB-hub and the average sleep power can increase to >3 W if a 4K webcam, a second USB-hub, and an external storage are connected. This led to the practice to always disconnect peripherals when they are not needed and the 4K webcam has not been used at all after that. The savings can be estimated to nearly 2 W or about 15 kWh/year.

The second most used laptop is used for online education and personal use, and it was measured for 14 days. It consumes about 6–12 W when nothing else is connected, and about +3 W when the external display is connected, and then +3 to +5 W for videoconferencing with camera off/on. The third laptop and the printers are not used much at all. Measurements confirmed the specified low off/sleep power.

C. TVs and TV peripherals

One smart plug measured the primary TV and 5 other devices connected via a branch outlet. The electricity consumption for each device was sorted out by knowing that the primary TV and Apple TV were on at the same time, the aerial amplifier was on all the time, and the other devices was hardly ever on. A large Wi-Fi speaker was included in the measurements but is reported in section E. As a result of the measurements, the Nintendo Wii and the aerial amplifier was disconnected as they were simply not used. The secondary TV was measured for one month only. The 3rd TV and connected PlayStation 4 (PS4) are rarely used and has been estimated based on just one measurement session. All TVs and TV peripherals are listed in Table III.

The measurements show a large variability in power consumption, about 80–200 W for the primary TV, and about

40–85 W for the other TVs. The variation is mainly related to the *brightness* of the material shown on the TVs, and then on the TV’s brightness settings. A dark Apple TV *screen saver* can be under 100 W at times, and when watching skiing the power was >200 W occasionally. The average power for the primary 55” TV was measured to about 140 W for 5.5 h/day average use.

TABLE III. TVs AND TV PERIPHERALS

Device	Annual electricity consumption (kWh/year)			
	Mode	Watt	h/day	kWh
1 st TV (55”) (61 days)	Off	0.3	18.5	2
	Average use	140 (117–175)	5.5	281
Apple TV (61)	Sleep	1.3	18.5	8.8
	Average use	3 (2-5)	5.5	6
Blu-ray player (61)	Off	0.5	23.7	4.3
	DVD average	14	0.3	1.6
	Blu-ray av.	16.5		
TOTAL:				304
Amplifier (61)	Average use	3	24	26
Wii (30)	Off	1.6	24	14
TOTAL:	<i>Wii and amplifier have been disconnected</i>			(40)
2 nd TV (48”) (31 days)	Off	0.3	23.3	2.6
	Average use	65 (45–85)	0.67	16
Apple TV	Sleep	1.3	23.3	11
	Average use	3 (2-5)	0.67	0.7
3 rd TV (42”)	Off	0.3	23.75	2.6
	Average use	~60 (40–80)	~0.25	~5.5
PS4	Off	0.4	23.75	3.5
	Average use	~55 (44–110)	~0.25	~5
TOTAL:				47

D. Desktop gaming PC

A *high-end* gaming PC when it was new in 2018 (Nvidia GTX 1080 Ti, Intel core i7) and two connected 24” displays was measured together via a branch outlet. The power consumption was in the range 100–150 W for standard desktop apps, 130–200 W for standard games, and >200 W for more advanced games. The two 24” displays are of the same model and were measured to about 22.5 W each, their consumption is quite constant and is included in above figures.

The average use power based on 100+ hourly averages were about 210 W (118–360 W). The average use time was about 4.5 h/day. Included in this use is also stand-by when not gaming but the PC is left turned on with a game loaded and possibly also logged-in to a game service.

TABLE IV. DESKTOP GAMING PC AND PERIPHERALS

Device	Annual electricity consumption (kWh/year)			
	Mode	Watt	h/day	kWh
Desktop gaming PC (47 days)	Off	0.5	19.5	3.6
	Average use	165 (73–315)	4.5	271.2
2 x 24” displays (47)	Sleep	0.6 (0.3 each)	19.5	4.3
	Average use	45 (22.5 each)	4.5	74
TOTAL:				353
Headset Steering wheel Oculus VR set	<i>Powered by the desktop gaming PC, included in measurements when used (same for mouse/keyboard)</i>			

Sometimes special peripherals are connected, and the maximum power measurement over an hour was 360 W when

a steering wheel with force feedback was connected. The driving simulator also put a high demand on the CPU/GPU.

E. Other devices

Charging of smartphones is estimated to about 3 kWh/year and phone including AC/DC losses (8 Wh/day and phone, typical battery size 12 Wh). The average smartphone display on-time is about 2.5h according to phone statistics, which suggests 4 Wh/day. Music streaming with screen off, sleep, and charging losses can be estimated to another 4 Wh/day. Charging of headphones consumes <0.3 kWh stand-by and <0.1 kWh for the charging (USB). Of greater concern is the 3 Wi-Fi speakers that proved to have a relatively high sleep power, about 7 W and 58 kWh/year all together, see Table V, nearly as much as all TV/PC stand-by (63 kWh).

TABLE V. OTHER DEVICES

Device	Annual electricity consumption (kWh/year)			
	Mode	Watt	h/day	kWh
4 smartphones	Charging	See text above		12
4 headphones	Charging	See text above		< 1.6
Large Wi-Fi speaker	Sleep	2.8	23	23.5
	Average use	~8	~1	~2.9
2 Medium Wi-Fi speakers	Sleep	4.2 (2.1 each)	22.5	34.5
	Average use	~10 (~5 each)	~1.5	~5.5
TOTAL:				80
Portable radio	Average use	5	2.5	4.5
4 Branch outlets w. switch	Average use	1.4	24	12.3
6 LED lights	Average use	18	4	26.3
TOTAL:				48
<i>Disconnected devices: Desktop gaming PC, Xbox 360, iPad, “a number of old mobile phones and peripherals in drawers”</i>				

It was also discovered that branch outlets with a switch and an indicator LED consumes about 0.35 W when turned on, and they are typically always turned on. They are reported here and not together with the devices they connect. The six LED lights are related to the 4 workplaces used by the persons in the household. They are estimated to about 26 kWh, but it can be argued if branch outlets and lighting should be included as part of *electronic devices*.

IV. ESTIMATES OF NETWORK AND DATACENTER SERVICES

Based on what the three largest Swedish network operators report for year 2021 (770 GWh) [16–18], about 870 GWh electricity can be estimated for Swedish networks including all operators, which is close to the 900 GWh estimated for operation in 2015 [19]. Operator figures up to 2020 can also be found in the ETNO/Europe study [20]. The total electricity consumption can be split into 540 GWh for 2G-5G mobile subscriptions (subs) including a core network share, and 210 GWh for fixed broadband (BB) subscriptions, also including a core share. The remaining about 120 GWh is not considered in the study or out of scope as it is related to fixed telephony (scrapped and not available to the household), B2B communication plus its core share, own datacenters, and offices and stores.

The electricity consumption figures above can be divided with subscriptions based on statistics for Sweden [21]. The result is about 37 kWh/sub for all mobile subs (14.7 M, excluding M2M/IoT), about 40 kWh/sub for mobile data subs (13.5 M), and about 49 kWh/sub for fixed BB subs (4.26 M). An estimate for the household’s four mobile data subs is then

160 kWh/year. Note that the mobile data use per sub in the household (<10 GB/month) is lower than the Swedish average (16 GB/Month), as all household members switch to Wi-Fi automatically when inside the house. The Swedish average of 49 kWh/year for fixed broadband is a bit higher than the 35 kWh/year estimated for the household’s new fiber broadband deployed in 2022, see section A that follow for more details.

The use of enterprise networks (LANs/WLANs), including open Wi-Fi at e.g., restaurants, can be estimated to about 60 kWh/year. This estimate is based on [14] for a typical enterprise network user, and the assumption the other family members is about 1/3 of that as they typically use dense school networks which result in lower electricity per user.

The Swedish terrestrial broadcast network consume about 100 GWh/year for public TV/radio, see [19]. This whole network can be split on all Swedish citizens as all can use it, and it also works as a *safety network* the government can use to alert and inform citizens. The consumption is about 10 kWh/capita resulting in 40 kWh/year for the household.

The simplest way to estimate datacenter services is to divide datacenters electricity consumption [22] with number of Internet users globally [23], 205 TWh / 5 billion = 41 kWh. This is a global estimate, and it can be motivated by the global nature of datacenter services. A rough estimate of datacenter services for the household is then 164 kWh/year. A similar figure for Sweden is problematic as Sweden is one of the most datacenter dense countries in the world, and Swedish datacenters serve a much larger population/region. A more detailed estimate of datacenter services is described in section B that follow.

A. Network services in more detail

For mobile network services the described Swedish average based on operator data is used. Using local base station data would result in about $\pm 20\%$ per subscription (3–5 W), with the higher end based on just the local cell, and the lower end based on 30 base stations covering the small town and nearby small villages.

The fiber modem is connected via a 1.3 km fiber cable to a road-side fiber access cabinet (straight distance only 650 m). About 50 households are connected to the same access switch that consume around 100 W (2 W/household), including back-up battery, fans and site control (10 W). During winter in Sweden heating may be needed, but it is assumed to be limited and not considered. Each household is connected via a SFP (Small Form-factor Pluggable) optical transceiver module that consume about 1 W. These power figures have been checked with the access network technicians while visiting the open cabinet during deployment. The access switch is in turn connected to a central site in the nearest small town about 3 km away straight distance (the fiber takes a longer stretch). About 10 thousand households are connected to this site.

The edge/metro router that connects the household’s fiber access site is shared by hundreds of households and the consumption is about 0.5 W per household (200 W / 400 households), also including overhead, e.g., fans, power, battery back-up, etc. It is assumed 50 households share at least a 10 Gbps optical link and then it is assumed 400 households share at least a 40 Gbps optical link.

Measurements of a typical LAN-switch from 2015 [24] shows the behavior of network access equipment. The typical measured power consumption is 34–37 W depending on first

number of ports connected (1-24), and then marginally on data traffic. The access switch the household connects to has a similar behavior and consumption per port as the outlined typical use case in Fig.5, but it’s a 48-port switch with about twice the consumption and all households SFP modules consume around 50 W instead of around 20 W for standard network ports.

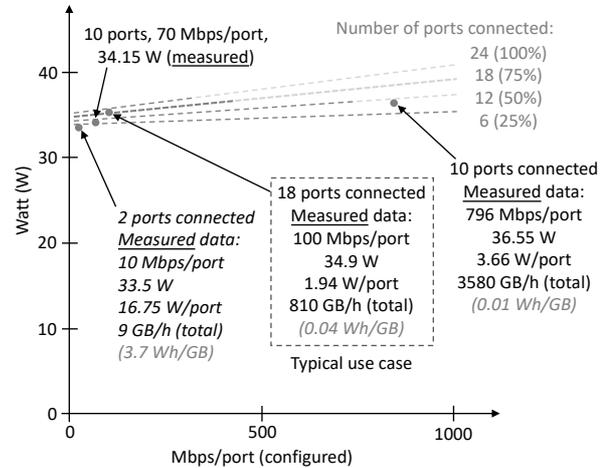


Fig. 5. Power consumption of an access switch based on [23].

Network studies can help us to better understand the edge/metro/core network (short “core”) shared by all access networks. The core part for fixed networks was estimated to about 12 kWh per fixed broadband line and about 2 kWh per mobile subscription based on operators measured electricity consumption in 2018 [21], see Table VI, which also list results from a few other studies used as benchmarks together with the estimates described in this study. As seen in Table VI the core network is a smaller part of the whole network.

TABLE VI. NETWORK SERVICES

Study	Annual electricity consumption (kWh/year)		
	Access kWh	Access + Core kWh	Comments
Fixed networks			
Europe 2018 [20]	51	51 + 12 = 63	33% fiber
Europe 2020 [25]	22	Not studied	Fiber (PtP)
Finland 2021 [26]	69	69 + 12 = 81	50% fiber
Sweden 2015 [19]	41	41 + 12 = 53	33% fiber
Sweden, this study	35	35 + 14 = 49	79% fiber, see text
The household, this study	22	22 + 13 = 35	Fiber (PtP), >1000 GB/month
Mobile networks			
Europe 2018 [20]	21	21 + 2 = 23	2G–4G
Finland 2021 [26]	41	41 + 11 = 52	2G–5G, 39 GB/mon.
Sweden 2015 [19]	33	33 + 3 = 36	2G–4G
Sweden, this study	34	34 + 3 = 37	2G–5G, all subs, see text
The household, this study	37	37 + 3 = 40	2G–5G, mobile data subs, <10 GB/mon.

A simplified power model of the household’s network services is shown and described in Fig. 6. It is based on all the measurements and network services estimates described in this study and some power data in [15]. While the model is tailored to the household it can be used for other purposes and can be tweaked based on other local network data.

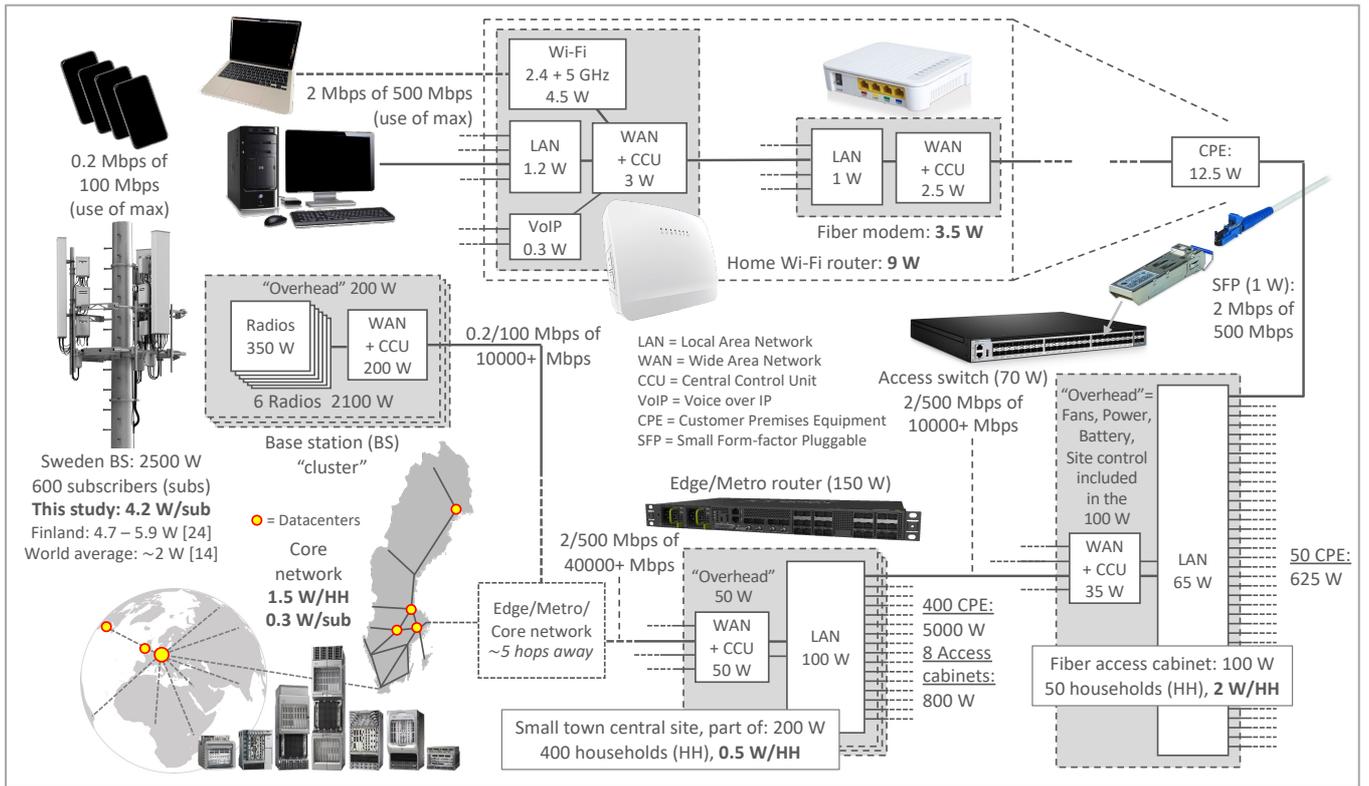


Fig. 6. A simplified power model of the household's network services based on the fiber modem and home Wi-Fi router (CPE) measurements, the household's fiber broadband specifications and network operation data. The operator figures for mobile and core networks in Sweden is described in section A.

B. Datacenter services in more detail

A user's share of a datacenter service can be estimated by dividing the service provider's electricity consumption with number of users, see Table VIII. For example, Netflix report 221 million users and 334 GWh for their datacenters/CDN including their use of Amazon (AWS) services [27], which gives 1.5 kWh/user. This figure may be adjusted based on a specific household, and a factor of 4 is used here as several ways to adjust the Netflix figure result in about 4; 4 persons in the household, about 4 streaming subscriptions on average, and 6h average streaming per day is about 4 times an average Netflix subscription. Netflix US reports 2-3 h [28], UK reports < 1.5 h [29], and 1.5 h is estimated as a global average.

Apple users in Table VII equal iPhone users (no iPad/Mac users added). Users of Meta services equal Facebook (FB) users. Microsoft users is based on number of devices that run Windows or other SW from Microsoft (e.g., Xbox). The 3.5 billion Internet user figure used for Google, Amazon, and *Others*, is estimated from 5 billion Internet users [23] and subtracting countries like China (-1 billion), and Russia, Iran and other similar countries (-0.5 billion) where services are limited. See Table VII which lists all references.

Akamai and Netflix represent about 30% of total Internet data traffic [30] and have similar electricity/bandwidth ratios ($0.34/9.4\% = 0.36$, $0.75/20\% = 0.375$), and the household's download can be estimated to ~6 kWh as streaming and download data are similar in size. Akamai support thousands of other companies including Apple and Microsoft.

The *Others* estimate in Table VIII is based on total datacenter electricity plus *overhead* (e.g., offices) minus all companies in Table VII and China datacenters (-50 TWh),

divided by 3.5 billion Internet users (described earlier). This figure (106 TWh) is a mix of co-location datacenter services and local datacenters/Intranets. It can be argued this estimate is more of a concern for employers and schools, and not for the *employees and students* in the household, but the estimate is included in the total results.

TABLE VII. DATACENTER SERVICES

Service providers % of Internet data [30] (users in the household)	Annual electricity consumption (kWh/year)			
	AEC TWh	Users billion	AEC/user kWh	Total kWh
Netflix 9.4% (4) [27]	0.34	0.22	1.5	6
Apple 4.2% (4) [31]	2.8	1.2	2.3	9.2
Meta/FB 15% (4) [32]	9.4	3	3.2	12.8
Microsoft 3.3% (4) [33]	13	1.7	7.6	30.6
Google 21% (4) [34]	18.3	~3.5	5	20
AWS 3.7% (4) [35]	~20	~3.5	5.7	23.4
Others 23% (4)	106	~3.5	30	120
Akamai 20% (1) [36]	0.75	Download estimate:		~6
Gaming estimate (+5%) (1)	Gaming estimate (see text):			~17.5
Household total:				266

To estimate gaming services is difficult. A game can be played offline, and a *game server* can be hosted locally in a player's computer. A game server in a datacenter can support 1000+ players but in intense action games it is typically <100 players. Gaming in Table VIII is estimated conservative to 50 players per 500 W server, 10 W per player (1/20 of the average gaming PC power in this case). Note also that the gaming data estimate (+5%) is an add-on to the total 100%, so the % sum is 105% Internet data in the first column in Table VII.

V. TOTAL HOUSEHOLD RESULTS AND COMPARISONS

The total extrapolated electricity consumption for all electronic devices in the household is about 1230 kWh/year. In addition, about 560 kWh can be estimated for the *use or share of datacenter and network services* (outside the house). A comparison to the household totals is shown in Fig. 7, and then all details for all devices and services is shown in Fig. 8.

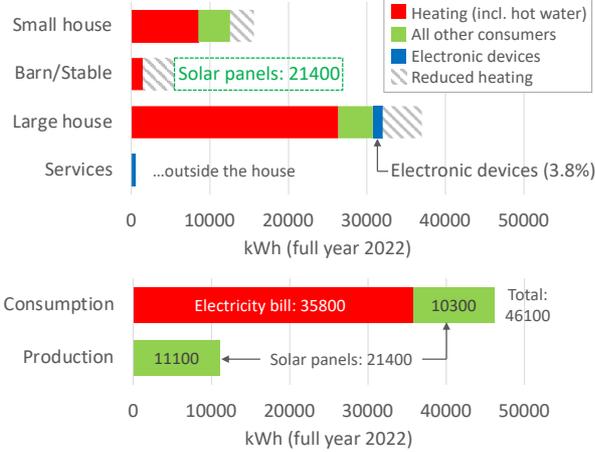


Fig. 7. Total electricity consumption of all electronic devices and services compared to the large house total, the small house, and the barn/stable.

The desktop gaming PC and primary TV with peripherals consume 353 and 304 kWh respectively, more than all other devices together. The other two TVs and three laptop PCs with peripherals consume 167 kWh. The total included stand-by is about 63 kWh, which is about 75% less than in the old household measurements, see Table VIII.

TABLE VIII. COMPARISONS TO EARLIER HOUSEHOLD STUDIES

TVs, PCs and all connected peripherals	4-person families living in a house		
	This study	Sweden [5]	Norway [6]
Number of TVs	2-3	2.1	
TVs electricity (kWh)	351	428	393
TVs total on-time (hours)	6.4	11	
Number of PCs	4-7	1.6	
PCs electricity (kWh)	473	390	340
PCs total on-time (hours)	14	10	
Total stand-by included in TV/PC totals (kWh)	63	267	
Other electronics (kWh)	347 (457)	1371	499

The total PC and TV active electricity consumption and total device on-time is similar to 15 years ago, even as the individual number of PCs/TVs has almost double. But there is a shift in use time from TVs to PCs and other devices.

The fiber modem and home Wi-Fi router (CPE) consume together about 111 kWh (12.7 W) and the extension Wi-Fi router consume 80 kWh (9.1 W). The CPE power is nearly constant and varies only $\pm 1\%$ over time, apart from short power bursts of up to around +1 W for more extensive Wi-Fi use. The fiber line consumes about 35 kWh and has also a near constant power consumption (4 W). About 2 W per household is consumed in the fiber access road-side cabinet, and an equal amount (2 W) in the rest of the edge/metro/core network.

The four smartphones with headphones and network services consume about 174 kWh/year, about 40 kWh/sub for the network, and about 3.5 kWh for charging a smartphone and headphone. Datacenter services are estimated to about 266 kWh/year and *free* network services to about 100 kWh.

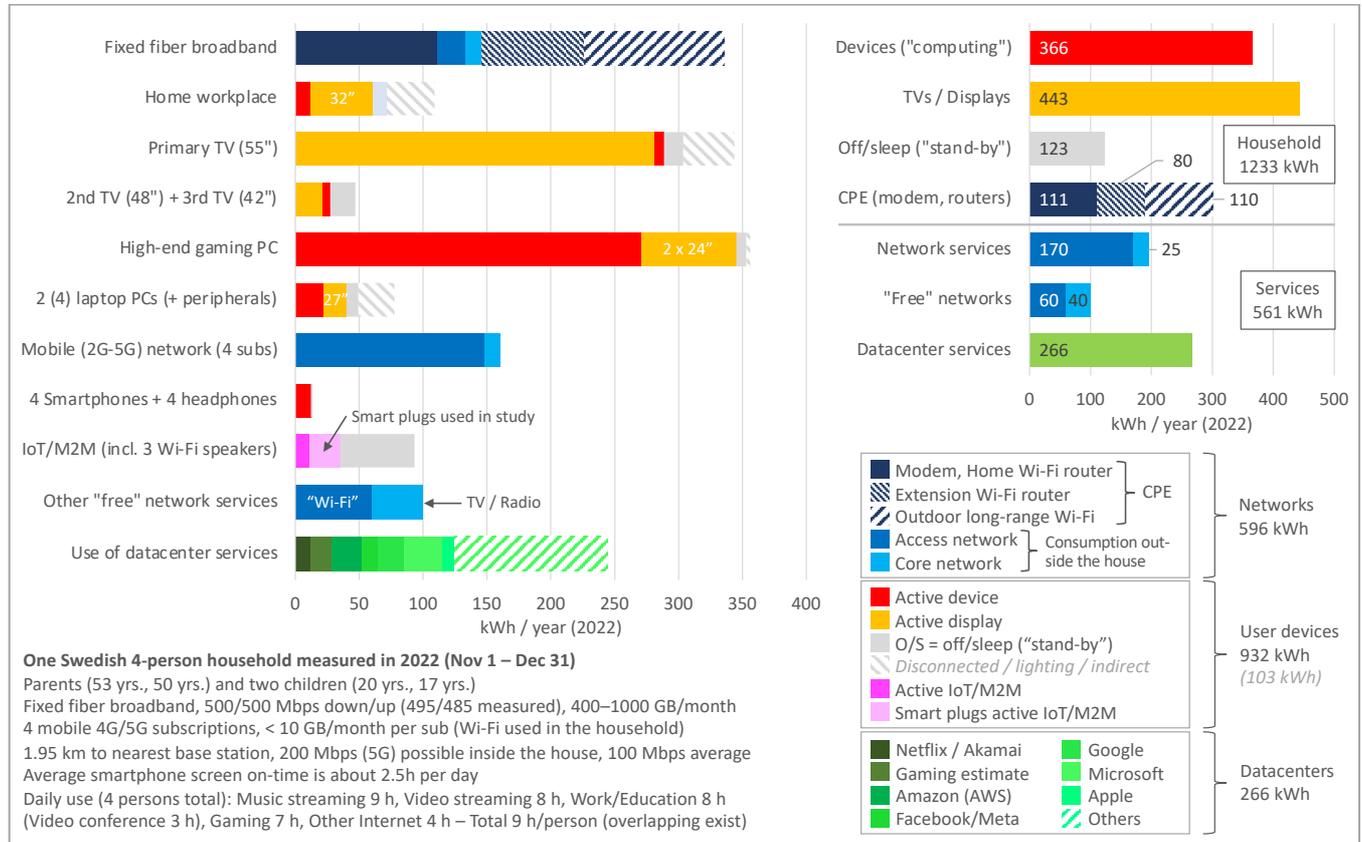


Fig. 8. Electricity consumption measurements of electronic devices and estimates of datacenter and network services for one Swedish household in 2022.

VI. DISCUSSION

First, the measurements will go on for at least a full year and a follow up study will be done next year. Based on the findings so far, what can be done to decrease the total electricity consumption of the electronic devices, and what can lead to an increase? The desktop gaming PC, primary TV and CPE stand out as the three main consumers.

For the gaming PC, apart from simply play less, to make sure the PC is put in sleep mode or turned off when not in use is a good practice. The two 24" displays can be changed to one new larger display that has about 2/3 of the electricity consumption of the two old 24" (both about 7.5 years old). Based on technology development the last 5 years it is possible to buy a new gaming PC with same performance that only need roughly 2/3 of the power. By combining these actions, the gaming PC electricity consumption can be reduced by at least -150 kWh.

A simple solution to lower the electricity consumption of the TVs would be to swap the TVs between rooms and use the 48" instead of the 55". Another solution is to buy a new TV with better energy performance. Both the 48" and 55" TV are 7.5 years old (2015). The new EU TV policy in 2023 recommends up to 84 W for 55" TVs and for example a new 55" can consume < 80 W. An approximation is that the current electricity consumption of the primary TV could be reduced with about 125 kWh.

It can however not be recommended to buy a new device when an older one still works and performs sufficiently. There will be additional environmental impact, including energy use, from producing the new equipment.

The electricity consumption can also go up quite a bit if the primary TV is upgraded to a new larger 65" with new power demanding features like 8K and HDR (High Dynamic Range), and if they are also used. The primary TV electricity consumption can almost double with +250 kWh/year. If a second person in the household start using the old gaming PC or buy a new gaming PC and play a lot, the electricity consumption can also go up with +250 kWh and combined with a new 8K/HDR TV add as much as +500 kWh/year to the current 1230 kWh/year.

A few devices were disconnected because of the measurements. The Nintendo Wii and the aerial amplifier was disconnected as they were hardly ever used. Another result of the measurements was that USB-devices that increase the workplace sleep mode power consumption from 1.6 to >3 W will only be connected when they are needed. The total savings by these actions are about 50 kWh.

Wi-Fi is the primary consumer in a CPE with Wi-Fi, and it can be turned off, but four smartphones and eleven more devices are constantly using it. A solution in theory is to not use Wi-Fi but it would require device replacements. With no Wi-Fi and only a low power LAN-switch or possibly two, the power consumption in the household could be reduced by at least -200 kWh/year. Smartphones just stay connected to the mobile networks and then share the Internet connection or use Bluetooth to transfer data to e.g., wireless speakers. The current high sleep power of the three Wi-Fi speakers could also be reduced by about 50 kWh. The two smart electricity meters that use Wi-Fi constantly need to be connected in some other way if Wi-Fi are not used. But that is not possible as they are currently designed, and they cannot be replaced easily.

If the smartphones stay connected to mobile networks and continue to use as much data as over Wi-Fi, it result in about $4 \times 40 = 160$ GB/month (0.5 Mbps) more mobile data for the household, which is lower than the average for the household's previous so called Fixed Wireless Access (FWA) 4G subscription 2015-2022. It's comparable to the mobile network in Finland in terms of electricity (37 vs 41 kWh/sub for mobile access) and data amount (40 vs 39 GB/month), see Table VI. Based on these figures it can be estimated that a shift from Wi-Fi to mobile networks for the smartphones would have a minimal energy impact. Another argument is that the measured download data rate inside the house is about 100 Mbps with 5G which 3 out of 4 smartphones have. 230 Mbps is possible outside the house. A 0.5 Mbps data rate increase vs 100 Mbps would likely lead to just a small power increase.

The household's impact on the fixed broadband network due to usage and data traffic can be estimated to be minimal due to the near constant power measured for the fiber modem and home Wi-Fi router. The corresponding operator equipment use similar optical transceiver and switching components with similar power/data behavior. The data traffic on the fixed broadband is typically <10 Mbps with around 2 Mbps on average which is <0.5% of the subscription's max allowed data rate. The enterprise switch measurements shown in Fig 5 show also a very small proportionality between data traffic and power consumption.

An average Netflix subscriber consume about 1.5 kWh per year in Netflix and AWS datacenters and this figure was scaled with a factor of 4 to 6 kWh for the household. To stream less video can then be estimated to save up to 6 kWh/year. The TVs would still consume in the order of 300 kWh if other sources provided the 6 h/day video input. For video conferencing, the added electricity consumption for about 1000 hours is about 5 kWh (+5 W on average) and about 2 kWh could be saved by not using the camera at all.

Datacenter services have individual characteristics, see the large differences in Table VII. Netflix (including their use of AWS) and Akamai for represent nearly 30% of Internet data but consume only about 0.5% of global datacenter electricity. The electricity consumption of a datacenter service cannot be quantified by its data traffic. Per user/subscriber is a better approach.

A traditional cable-TV connection, house amplifier and cable-TV STB (Set-top-Box), consume in the order of 20 W all the time, or 175 kWh/year [25]. If the 6 h/day video would come from the Blu-ray player that consumes about 15 W when playing an optical disc, the electricity consumption would be about 33 kWh/year, and then physical discs need to be manufactured and delivered to the house. By disconnecting the aerial amplifier in the house that consumed 3 W all the time, a reduction of 26 kWh was made. Traditional TV broadcast, cable-TV, and DVDs/BDs consume more electricity than streaming video.

The Apple TVs use about 3 W when streaming to the TVs and 1.3 W in sleep mode while connected to the TVs. They are needed as the two TVs are a bit old (7.5 years) and some streaming apps do not work on the TVs and most apps work a lot better using the Apple TVs. With new smart TVs extra streaming STBs like Apple TVs are not needed.

The potential electricity savings related to all electronic devices can be compared to what has been done for the entire household. When the electricity prices soared in winter 21/22,

indoor temperatures were reduced, and some electric heating was turned off. New heat pumps (air/air) was installed after summer 2022, and more electric heating could be left turned off in the winter 22/23. The total reduction including the barn/stable and small house in 2022 vs 2021 added up to 12000 kWh, nearly 10 times as much as what all electronic devices consume in the large house. The reduction in the large house was about 4000 kWh.

This study focus on electricity consumption. However, it is also interesting to do a rough estimate of the *Embodied Carbon Footprint* (ECF) related to manufacturing of all devices. Based on purchases the last 20 years, the lifetime of each device and the number of new devices per year can be estimated. By multiplying number of new devices per year with an ECF factor for each device, as much as 675 kg embodied CO₂e can be related to the household's purchases of devices every year, see Table IX. Three of five laptops are owned by employers/schools and may be excluded in the household's ECF. The ECF/unit figures in Table IX are based on a new study that assesses the ECF of ICT user devices [37].

TABLE IX. EMBODIED CARBON FOOTPRINT

Devices	ECF = Embodied Carbon Footprint (kg CO ₂ e)				
	Units	Life years	New units/year	ECF /unit	ECF /year
Smartphones	4	4	1	60	60
Laptops	2-5	5	1	200	80–200
PC displays	4	8	0.5	100	50
CPE	3	7	0.4	30	12
TVs	3	8	0.375	300	112.5
Desktop PCs	2	8	0.25	600	150
Fiber cable deployment	1	20	0.05	400	20
All other	Estimate incl. cables and peripherals				70
TOTAL:	Annual total ECF for the household				555–675

The carbon footprint of the new fiber cable deployment can be estimated to about 400 kg. This estimate was made during the excavation and deployment work in spring 2022 and will be described more in a coming network study. Note that only 5 households of potentially about 10 in the small village share the 1.3 km long fiber cable. A conservative short lifetime (20 years) result in about 20 kg CO₂e/year for the fiber cable.

The electricity consumption in Sweden result in zero direct carbon emissions as all electricity comes from the household's solar panels or Swedish hydroelectricity (by contract). All indirect carbon emissions for manufacturing solar panels, wind turbines, and the grid itself can be estimated to about 48 kg CO₂e/year based on LCA studies of electricity production [4]. Table X also show what the electricity emissions would be if the household was supplied by a world average mix according to [3] and whole life cycle based on [4].

TABLE X. TOTAL AEC CARBON FOOTPRINT

Electricity consumption (EF = Emission Factor)	Global EF = 0.57 kg CO ₂ e/kWh Sweden EF = 0.03 kg CO ₂ e/kWh		
	Total electricity kWh	Global kg CO ₂ e	Sweden kg CO ₂ e
Household (devices)	1231	702	37
Network services	295	168	6.3
Datacenter services	266	152	4.4
TOTAL:	1792	1022	48

From a carbon emissions perspective, reducing the electricity consumption has a lower priority in Sweden. The 675 kg CO₂e embodied carbon footprint is on the other hand not insignificant. To keep using the current devices for as long as possible is obviously the best way to reduce the ECF. The age of the 1st and 2nd TV is 7.5 years, and the age of the two desktop gaming PCs is 4.5 and 7.5 years. As these devices has a higher ECF, to buy a new TV or gaming PC is a decision that will impact the household's carbon emissions.

VII. CONCLUSIONS

The learnings and results of the study can be summarized in short:

- The workplace laptop PC and extra display consumed on average about 40 W, videoconferencing added about +5 W.
- The fiber modem and home Wi-Fi router (CPE site) has a near constant power consumption, 12.7 W. Normal use including video streaming is in the order of +0.1 to +0.2 W, but short bursts of higher power around +1 W can be seen related to use over Wi-Fi.
- A large download of a PC game over a LAN-cable at >400 Mbps (>180 GB/h) with a desktop gaming PC add only +0.3 W. The same download at a similar data rate over Wi-Fi consume +2.5 W with a high signal strength, and as much as +5.5 W with a low signal strength, and then the data rate drops as well.
- The desktop gaming PC and primary TV including all peripherals consume 353 and 304 kWh respectively, more than all other devices in the household.
- The total included PC and TV stand-by including all peripherals is about 63 kWh, which is about 75% less than in the old household measurements
- The four smartphones with headphones and network services consume about 174 kWh/year, about 40 kWh/sub for the network, and about 3.5 kWh for charging a smartphone and headphone.
- Datacenter services are estimated to about 266 kWh/year, but the most data demanding services, video streaming and gaming including game downloads, is estimated to only about 30 kWh

To measure all electronic devices in a household has been a lot of fun and educational. The professional meter together with smart plugs proved to be a good combination. Based on the data and results in this study, other measurements with only smart plugs can probably be made more accurate. To do measurements is highly recommended.

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