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The energy and carbon footprint of the global ICT and E&M sectors 2010-2015

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Abstract

This paper estimates the energy and carbon footprint of the Information and Communication Technology (ICT) and Entertainment & Media (E&M) sectors globally for 2010-2015 as well as a forecast to 2020. It builds on two previous global studies (2007 and 2011) and a Swedish study (2015) by the same authors. The study is based on a extensive dataset which combines primary and secondary data for operational (use stage) energy consumption and life cycle greenhouse gas emissions (CO_2e) for the included sub-sectors, including energy and carbon footprint data from about 100 of the major global manufacturers, operators and ICT and E&M service providers. The data set also includes sale statistics and forecasts for equipment to estimate product volumes in addition to published LCA studies and primary manufacturing data to estimate the embodied carbon footprint of products. The result shows that the ICT and E&M sectors have turned their previous growing footprints into shrinking ones despite a continuous increase in subscriptions and data traffic. Furthermore the results of this study is also indicating significantly lower levels than previous forecasts.

Keywords— ICT, ICT sector, Media, TV and Media sector, E&M sector, energy footprint, carbon footprint

I. Introduction

The term *carbon footprint* is a well-established concept commonly understood as the life cycle carbon equivalent emissions and effects related to a product or service. To understand the carbon footprint, its relative magnitude and the development trends are important matters to investigate for any sector due to the growing concern for the global warming. In 2016 experts associated to the World Economic Forum ranked global warming as the no.1 threat to society and the economy [1]. For the ICT (Information and Communication Technology) and E&M (Entertainment and Media) sectors, there is a strong connection between carbon footprint, the energy consumption and the supply of energy, which makes it important to also study the energy consumption.

This study is the third global study by Malmodin and Lundén following a study that estimated the global carbon footprints of the ICT and E&M sectors in 2007, published in 2010 [2], and a similar study estimating the footprints in 2011 including forecasts to 2020, published in 2013 [3].

The magnitude of the ICT sector´s carbon footprint has been discussed for some year, both among scientists and in society. This discussion has concerned both the footprint itself and ICT´s impacts in comparison to impacts from other sectors. A recent example is [4], an earlier but persistent one is the comparison between ICT and the aviation sector [5]. In several cases the assumed growth of the ICT footprint is stated to be a concerning one, based on the assumption that the ICT sector's footprint is growing fast in line with the data traffic increase. Estimates like these are usually based on limited and/or uncertain data, often of a certain age, which, based on the earlier research by the authors [6], overstates the ICT footprint. In addition, the modelling may be deficient and may not consider the complexity of the sector, as further discussed in Section VI. Thus, to more reasonably estimate the ICT footprint, continued wide data collection efforts and studies are needed to maintain a well-founded and up-to-date view on the development of the ICT energy and carbon footprints related to the products, services and the whole sector.

Until recently most studies have estimated a growing energy and carbon footprint for the ICT sector, see references [7-12]. But last year, a study for Sweden [13] revealed that the energy and carbon footprints of the ICT and E&M sectors had peaked around 2010 and then started to decrease, despite growing number of usage (data traffic), see figure 1.

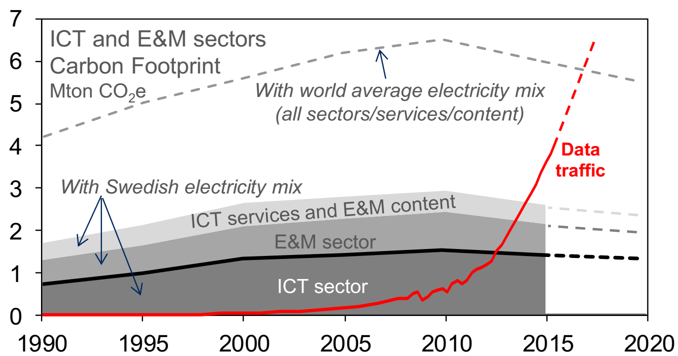

Figure 1: Total carbon footprint results for the ICT and E&M sectors in Sweden in 2015 [13]. The dotted line shows the emissions if world average electricity mix would have been used instead of the low-carbon Swedish mix (Mainly based on hydro and nuclear).

Similar decreasing energy consumption trends as in Sweden have also been reported for Germany and the US. Figure 2 shows the results of two recent studies estimating the electricity consumption of the ICT sector in Germany [14] and data centers in the US [15] combined with a study on the electricity consumption of consumer electronics in the US [16].

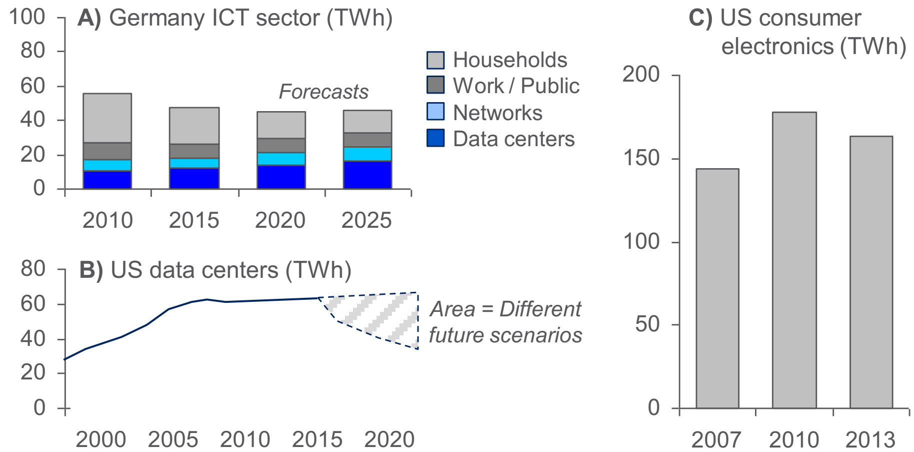

Figure 2: A) Total electricity consumption of the ICT sector in Germany including also TVs and other consumer electronics [14]. Total electricity consumption of B) data centers [15] and C) consumer electronics [16] in the US. Note that the scale is the same in all graphs.

One of the remaining questions for this study is if the aggregated energy and carbon footprints of the ICT and E&M sectors per year have peaked and started to decrease also on a global scale. This is the reason in-depth studies are needed to fully understand the energy and carbon footprint related to any product, service or whole sector. This is best achieved if the studies are based on as large samples of measured data as possible.

II. Scope

The scope of this study is the full life cycle carbon equivalent emissions and effects from all products and services related to the global ICT and the E&M sectors, according to the boundaries defined by Figure 3 and further outlined in chapter III-V. For the E&M sector cinemas, theatres, and other arena (or physical site) events (e.g. sports) that require physical human presence have been excluded.

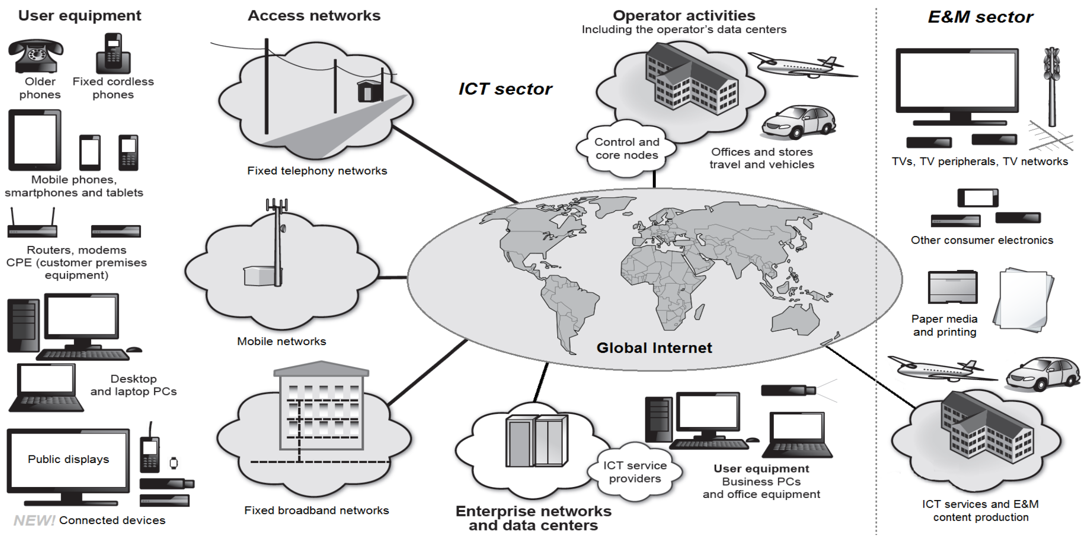

Figure 3: The scope of the study: The ICT and E&M sectors globally. New connected devices added to the ICT sector have been considered

The applied sector boundaries are the same as for other studies by the authors [2, 3] with one difference: The category "*New connected devices"* has been added. This category *of* user devices consists of public displays, surveillance cameras, payment terminals, smart meters connectivity and wearables representing a growing range of IoT (Internet of Things) devices.

The *energy footprint* is defined as the *operational electricity consumption* or *use stage electricity* consumption. This means that the energy footprint has a more narrow scope than the carbon footprint which considers the full life cycle. The reason is partially that a full life cycle primary energy footprint is hard to estimate due to data gaps for total primary energy in the production stage which are common in LCAs, but also that the mix of primary and secondary energy data (e.g. electricity) converted to primary energy including conversion losses makes it hard to understand and interpret.

This study estimates the footprints for 2015, as well as a forecast for 2020 including a comparison with previous studies.

III. Methodology, definitions and data sources

The methodology and definitions used in this study have been reused from previous studies [2, 3, 6] by the authors. In all these studies, both top-down and bottom-up data collection approaches have been used. The major difference compared to the previous global studies is that more primary data have been collected directly from ICT and E&M companies.

In total, data from about 100 of the world's largest manufacturers, operators and ICT and E&M services companies have been collected, a large part of that as primary data. Table 1 summarizes the ICT and E&M sectors, and the main data sources for the products including data for embodied emissions. It also lists the allocations performed to avoid double-accounting.

ICT sector scope and key data sources	
Data centers (DCs) All use of servers from "in closets" to "hyper scale" DCs	This study relies to a large extent on studies by Koomey [17] and others in the US [15] plus the new IEA report *Digitalization & Energy* [18].
ICT networks PSTN (telephony), Mobile networks, Fixed networks	Detailed data from a new report [19] that covers about 40% of mobile and about 15% of fixed subscriptions globally. High-level data for about 70% of all subscriptions have also been collected in this study.
Enterprise networks (reported with data centers)	Enterprise networks estimated based on average network ports [15] and the authors own experience of operating large "Intranets".
ICT user devices	See user devices below and table IV on next page for details.
E&M sector scope and key data sources	
Cable-TV and broadcasting (including radio)	These networks have been estimated based on the study in Sweden [13] together with new Swedish data confirmed by similar studies in Germany.
Paper media and printing	Pulp and Paper Industry Intelligence (RISI) estimates of the global paper consumption and its carbon emissions [20].
E&M user devices	See user devices below and table IV on next page for details.
	Double accounting adjustments
Data centers	To avoid double accounting, ICT network operators and ICT and E&M manufacturer's data centers have been fully allocated to "Data centers".
Enterprise networks and office devices	Network operators and equipment manufacturers own networks and devices included in their reported totals except for personal user devices.
Cable-TV networks	A share for fixed broadband over Cable-TV have been allocated to ICT network operations.
User devices (see details in Table 3) and server key data sources	
Gartner: Smartphones, Other mobile phones, Tablets, Laptop PCs, Desktop PCs	Gartner, Worldwide Quarterly Device Shipments, https://www.gartner.com/newsroom/id/3187134
IDC: Smartphones, Other mobile phones, Tablets, Laptop PCs, Desktop PCs, Wearables, *Servers*, Hardcopy devices	Worldwide Quarterly Mobile Phone Tracker (prod id=37), https://www.idc.com/tracker/showproductinfo.jsp?prod_id=37 Worldwide Quarterly Personal Computing Device Tracker (1541), Worldwide Quarterly Wearable Device Tracker (962), *Worldwide Quarterly Server Tracker (7)*, Worldwide Quarterly Hardcopy Peripherals Tracker (3)
IHS: Computer displays, Public displays, Surveillance cameras, Automotive (all display products)	Desktop Monitor Market Tracker, https://technology.ihs.com/572224/desktop-monitor-market-tracker-q1-2016P , Public Display Market Tracker, https://technology.ihs.com/572984/public-display-market-tracker-q1-2016 , Security Market Tracker, https://technology.ihs.com/Research-by-Market/551540/security-technology , Small and Medium Display Market Tracker, https://technology.ihs.com/572824/small-medium-display-market-tracker-q1-2016
Future Source: CPE (modems, gateways), Computer peripherals, STBs (Set-top boxes), DVD/BD players, Media players, Home audio systems, Portable media players, Headphones, Cameras	Future Source, https://www.futuresource-consulting.com/ One of the leading analyst for audio and camera products but also for CPEs (gateways, modems etc.), STBs and projectors, and also for optical and electronic media (discs, memory sticks/cards, printer consumables), See also: CES 2016, Global Tech Spending Update, Presentation at CES 2016 January 6-9 Las Vegas (media copy)
Jon Peddie Research (JPR): Camcorders, Game consoles, Portable game consoles, Arcade game machines	Jon Peddie Research, https://www.jonpeddie.com/press-releases/millions-of-android-gaming-consoles-on-the-horizon/ http://www.jonpeddie.com/publications/console-gaming-hardware-market-study/

Table 1: Scope and key data sources
Note that the number of unique data sources are very high in this study and only examples of the latest market reports have been referenced above. In most cases the market reports come out on a quarterly basis.

Furthermore, market statistics and forecasts 2010-2020 have been collected from leading market analysts [Se Table 2] and added to the already existing large dataset from previous studies. Table 3 shows the key user devices data and individual energy and carbon footprint results. Annual shipments of devices were used together with emissions data for the different devices to derive the embodied footprint related to the raw materials acquisition and production.

For the emissions data, this study uses a combination of life cycle assessment (LCA) results and production data from leading ICT component and equipment manufacturers. Combining these sources for data validation and filling gaps enables a more accurate estimate of the embodied emissions and prevent that outdated LCA data leads to overestimations of the embodied footprint. As example, for key contributors like IC and displays, the data set covers about 50% of all IC manufacturers in terms of revenue, and the coverage of display manufacturer data corresponds to about 85%.

Despite this approach, the embodied footprints of user devices represent the most uncertain part of the footprints as they cannot be measured in an accurate way. In addition, the following reporting coverage related to network operations can be revealed (before extrapolation to global level): Global Data center operations: 10%, Network operator data: 70%, IT manufacturing production: Data from 35 of the largest IT producers globally (nearly 50% of global production) and a global material study submitted to the ICT4S conference 2018 [21]).

ICT and TV subscription data and other key data fundamental for the study are listed in Table 3.

ICT subscriptions (subs) [million subscriptions]	**2010**[1]	**2015**[1]	**Data sources**
Fixed telephony (voice)	**1 240**	**1 070**	**ITU [22]**
…additional VoIP subscriptions	~150	~250	ITU [22]
Mobile subscriptions	**4 970**	**7 110**	**ITU [22]**
…of which is mobile broadband	710	2 950	ITU [22]
Additional M2M subscriptions	70	350	GSMA [23]
Fixed broadband (lines)	**500**	**775**	**ITU [22]**
…of which is FTTH/FTTB	65	160	ITU [22]
…of which is Cable-TV	100	150	DTVR [24]
ICT total subscriptions (not including M2M subs)	**6 710**	**8 955**	
E&M subscriptions (subs) [million subscriptions]	**2010**[1]	**2015**[1]	**Data sources**
Pay-TV subscriptions	715	893	DTVR [24]
…of which is Cable-TV	525	561	DTVR [24]
…of which is IPTV	30	113	DTVR [24]
Free TV (estimates)	**725**	**660**	DTVR [24]
TV total subscriptions	**1 440**	**1 553**	
ICT and E&M total subs	**8 150**	**10 508**	
Other Global Key Data	**2010**	**2015**	
Data traffic [million TB]	240	910	Cisco [25]
Smartphone share of data traffic	<1%	~10%	Cisco [25]
Electricity consumption [TWh]	19 000	21 000	Enerdata [26]

Energy and industry related CO_2 emissions [Mt CO_2]	32 000	35 000	IEA [27]
Carbon footprint [Mt CO_2e]	49 000	52 000	PBL [28]

Table 2: ICT and TV subscriptions globally and other key data 2010 and 2015
[1]Subscription numbers are per mid-year, not end-of-year

Further details regarding each sector and subsectors are given in Section IV. with regards to how key parameters such as annual production, number of devices in use and their usage profiles changes over time and how that impact the results.

A world average electricity mix and electricity production emission factor have been used. This factor includes the full life cycle emissions and effects related to electricity production and is set to 0.6 kg CO_2e/kWh [2, 3], a value that has not changed much over the last 10 years.

ICT sector	**Shipments 2015 [million]**	**Est. total shipped weight [kt]**	**Est. total embodied CF [Mt CO_2e]**	**Est. total units in operation[1] [million]**	**Est. total OEC[2] [TWh]**	**Est. total OEC[2] CF[3] [Mt CO_2e]**	**Data source(s)** See Table 1
Fixed phones (PSTN + VoIP)	200	40	4	**1 650**	28	16.8	ITU
Smartphones	**1 433**	215	**64.5**	**3 700**	11.1	6.7	Gartner, IDC
Other mobile phones	**537**	54	13.4	**3 400**	5.1	3.1	Gartner
CPE (modems, gateways)	184	77	7.7	775+150	**83.5**	**50.1**	Future Source / IHS
Tablets	**208**	156	15.6	700	4.9	3	IDC
Laptop PCs	163	**285**	**32.6**	970	**34**	**20.4**	IDC
Desktop PCs	114	**855**	**28.5**	730	**109.5**	**65.7**	IDC
Computer displays	130	**650**	13	1 000	30	18	IHS
Computer peripherals	(114)	114	5.7	na.	na.	na.	Future Source
Projectors	8	60	1.6	50	7.5	4.5	IHS
Public displays	3.5	175	1.8	25	7.5	4.5	IHS
Surveillance cameras	28	80	2.8	140	8.4	5	IHS
Payment terminals	35	35	1.8	150	4.5	2.7	BI Intelligence
Wearables	46	7	0.9	100	0.1	0.06	IDC
Smart meter connectivity	*40*	*6**	*0.8**	*400*	*8**	*4.8**	Pike Research
ICT sector total:	**3 213.5**	**2 749**	**196**	**14 170**	**342**	**205**	
E&M sector	**Shipments 2015 [million]**	**Est. total shipped weight [kt]**	**Est. total embodied CF [Mt CO_2e]**	**Est. total in operation[1] [million]**	**Est. total OEC[2] [TWh]**	**Est. total OEC[2] CF[3] [Mt CO_2e]**	**Data source(s)** See Table 1
TVs	**235**	**3 525**	**70.5**	**1 900**	**266**	**160**	Digital TV Research
STBs (Set-top boxes)	**265**	133	**8**	**890**	**89**	**53.4**	Future Source / IHS
DVD/BD players	57	114	2.9	400	20	12	Future Source
Media players	50	50	1.5	200	4	2.4	Future Source
Home audio systems	79	**395**	4	**800**	**40**	**24**	Future Source

Portable media players	35	5	0.7	130	0.13	0.08	Future Source
Headphones	**320**	160	3.2	na.	na.	na.	Future Source
Cameras	35	9	1.8	500	0.5	0.3	Future Source
Camcorders	23	6	1.2	200	0.2	0.12	Jon Peddie Research (JPR)
Game consoles	37	65	**5.6**	250	25	15	Jon Peddie Research (JPR)
Portable game consoles	18	9	1.4	100	1.5	0.9	Jon Peddie Research (JPR)
Arcade game machines	2.4	**480**	4.8	25	18.8	11.3	Jon Peddie Research (JPR)
Automotive (displays)	75	56	3.8	400	na.	2	IHS
E&M sector total:	**1 231**	**5 006**	**109**	**5 795**	**467**	**280**	
Paper media (E&M)							
Hardcopy devices	103	1 030	10.3	500	75	45	IDC
GRAND TOTAL:	**4 548**	**8 785**	**295**	**20 465**	**884**	**430**	

Table 3: User equipment: shipments, total number of units in operation, OEC and resulting CF's
[1]Estimated total number of devices in operation are per mid-year, not end-of-year.
[2]OEC = Operational Electricity Consumption.
[3]CF = Carbon Footprint.

IV. Key trends and key data

A. Data centers and enterprise networks

The term data center is in this study used for all server installations from "in closets" to "hyper scale" data centers. According to [15], the energy footprint of data centers in the US stopped to grow around 2010 and has been stable since then. The global electricity consumption of data centers was estimated to be between 203-272 TWh in 2010 [17]. But IEA estimated in a recent study the electricity consumption of data centers globally as stable but at a lower level, 200 TWh 2010-2014 and that this electricity consumption level will continue to 2020 [18]. In this study, the data center electricity consumption is estimated to be slightly higher, about 240 TWh for 2015. The differences compared to IEA is that more servers are estimated to be in operation and that electricity (and other energy) consumption in offices is included.

Enterprise networks have been estimated based on estimates for network ports [15], number of work PCs, additional so called small cells / WLAN network equipment, and the authors internal company information for these network components serving 100k+ employees.

Figure 4 show annual server sales, estimated servers in operation and estimated electricity consumption of data centers globally.

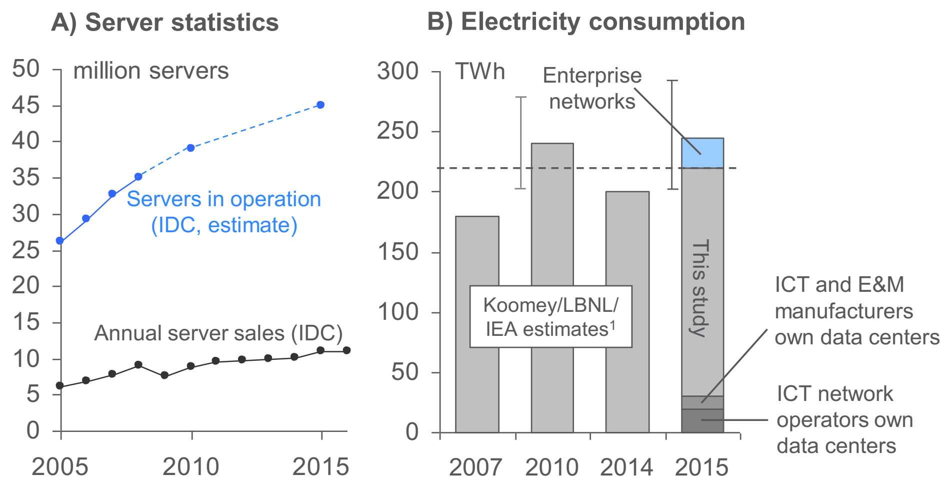

Figure 4: Figure 4 Server statistics and estimated electricity consumption of data centers globally (all server installations, also "in closets"). Based on IDC, Koomey [17] and IEA [18]. ICT network operators own data centers (20 TWh) and ICT and E&M manufacturers own data centers (10+ TWh) reported as *data centers*.

The energy consumption related to offices and travel for the ICT and E&M service organizations that operates the data centers have been included in the footprints, together with the embodied footprint of equipment and infrastructure. These data are based on reports by Google [29] and Facebook [30]. The estimated total carbon footprint for data centers and enterprise networks is about 160 Mt CO_2e.

B. Network operations (operators)

During 2017, the authors made a substantial data collection effort to get a better understanding of the electricity consumption and the carbon footprint of the ICT network operators, which resulted in a large dataset that covers about 40% of mobile and 15% of fixed network operators with regards to subscriptions, see [19]. That dataset is the primary source for ICT network operators in this study.

Figure shows the operational electricity consumption for the global ICT network operations including on-site generated electricity and electricity consumption in the operators own data centers, offices and stores. The network operators own data centers electricity consumption was about 20 TWh in 2015 and is reported as "Data centers" (shown also in Figure 5) and is later subtracted from the total reported figures for ICT network operations in section V. to avoid double counting.

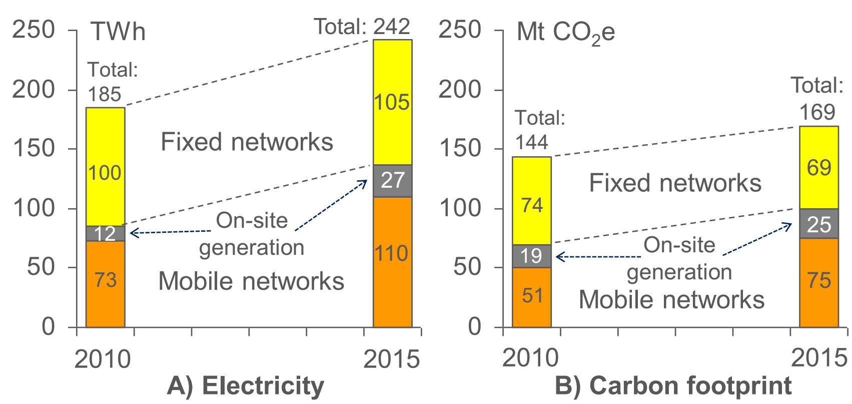

Figure 5: Total operational electricity consumption (A) and carbon footprint (B) of ICT network operations globally in 2010 and 2015, based on [19]. On-site generation is mainly done with diesel generators but solar

(PV) is increasing fast. Note that ICT network operators own data centers is included in the figure above from [19] but in this study all data centers are reported together as *data centers*.

C. PCs, TVs and Tablets

Figure 6 below shows the global PC sales 2007-2016 with a persistent decline in sales since 2011. The figure also shows TV and tablet sales which have also declined but at a slower pace. Figure 6 also shows some historical forecast figures which have by now turned out to be too high. The way smartphones and tablets, at least early on, would change behaviors and the PC and TV markets, was hard to foresee. Previous studies that have used these values to forecast the footprint of those subsectors and of the ICT and E&M sectors have thus made too high estimates.

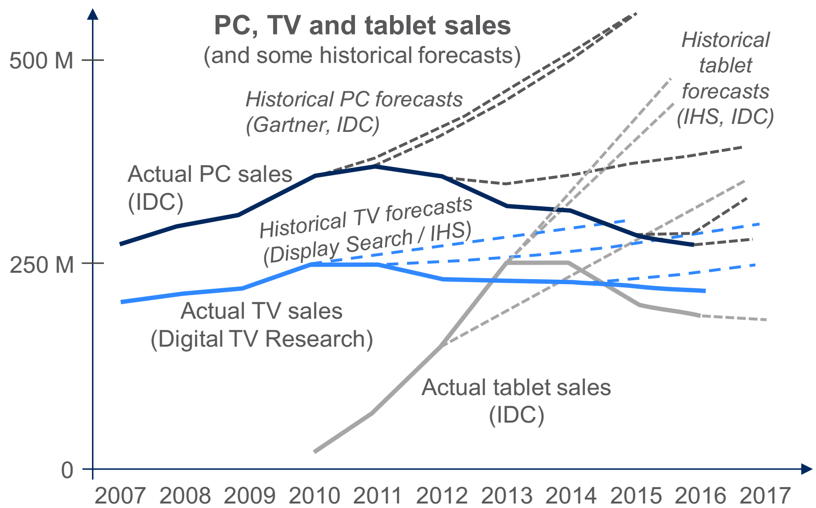

Figure 6: Total global TV, PC and tablet sales 2007-2016 including some historical forecasts later proved to be too high. Sources (see Table 1 for details): IDC, Gartner, IHS and Digital TV Research.

The share of sales for the more energy consuming desktops is declining, and there are also energy efficiency improvements across all types of PCs. The only PC segment that is expected to increase its total electricity consumption is the high-end gaming PCs, but their market share is quite limited.

Though the sales of TVs has declined since 2010, the effect of the fast-paced display technology development and its energy efficiency improvements plays a larger role for the footprint. Figure shows the estimated annual electricity consumption of all TVs in an average EU household 1990-2020 [31]. New TV sets obviously consume less electricity despite the larger displays.

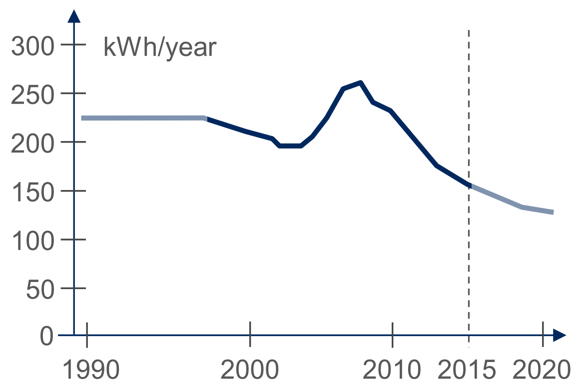

Figure 7: Electricity consumption of TVs in EU households 1990-2020 [31].

The PC and TV trends have also been captured by the excellent and extensive research performed by the Fraunhofer Institute in Germany [14] and the US [16]. Their combined results are the foundation for the PC and TV subsector's total electricity consumption in this study.

D. Smartphones

The annual global sales of smartphones have increased from about 300 million in 2010 to more than 1.43 billion in 2015 which is about twice the sales of PCs, tablets and TVs combined. During the same period the total value of smartphones has increased from about 100 B$ to about 400 B$ and the smartphone market in 2015 had a higher value than the PC, tablet and TV market combined. In this study, a high number of smartphones have been estimated to be in active use in 2015, about 3.7 billion. This is equal to sales 2013-2015, and can be compared to the total sales 2010-2015, about 5.3 billion.

Last year, Ericsson and Sony published a detailed smartphone LCA [32] which has been used as a main data source for the smartphones. In addition, a large part of the component data could be reused to estimate the embodied footprints for similar products, like tablets and laptops.

The impact of smartphones is fundamental and goes beyond their own footprint by impacting the usage of all other devices in this paper. Smartphones are replacing PCs and TVs resulting in large energy savings, consumer electronics are replaced by smartphone apps, and paper consumption decreases when paper media moves online. Cisco [25] estimate that the data traffic (mobile and WiFi) from smartphones has grown fast from <1% in 2010 to about 10% in 2015 and will continue to grow fast to about 30%-40% in 2020.

E. Telephones, home network equipment and set-top boxes.

Cordless telephone base stations, CPEs (modems/gateways) and STBs are constantly drawing power in households and because of that they have a significant energy footprint, about 200 TWh (see table III). Energy efficiency per device is improving, but more can be done in the future.

F. Other consumer electronics, peripherals and IoT

The sales of many consumer electronic categories decrease fast due to the impact of smartphones, e.g. portable media players and gaming consoles, cameras and radio and audio products. The same trends are seen for various storage media.

All ICT devices, and most E&M devices, have built in connectivity. Other connected devices considered in this study are public displays, surveillance cameras, payment terminals and wearables and smart meters with regards to their control units and communication modules. The total number of these devices were still low in 2015, which also the number of M2M subscriptions (350 million) indicate, but the numbers increase fast. IoT s further addressed in Section VI.

G. Paper media and hardcopy devices

This subsector includes traditional paper media as well as office and home printers and similar equipment and their energy consumption.

The global paper consumption has decreased by about 20% 2007-2015, from about 160 Mton to about 126 Mton. The total carbon footprint of paper media was estimated to about 300 Mton CO2e in 2007, see [2]. For 2015 the carbon footprint was estimated to have decreased to about 220 Mton with paper production representing about half, or 110 Mton.

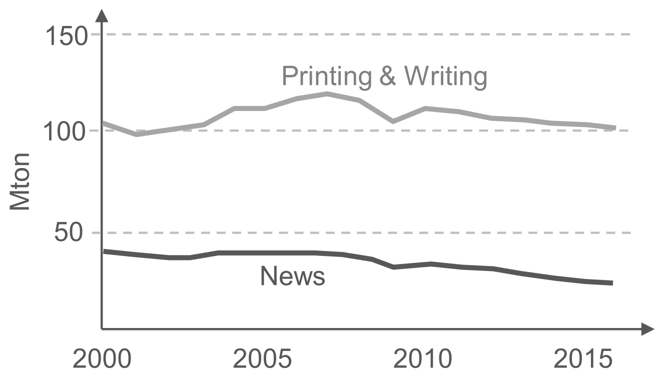

Figure 8: Global production of graphical paper for news and printing & writing 2000-2016 [27]

Global sales of hardcopy devices (i.e. printers, copiers, faxes and combo-devices) have declined in recent years and are expected to further decline until 2020. The manufacturing of these devices has a small embodied footprint but their operation contributes more significantly. Hardcopy devices have also decreased their operational electricity consumption by about 50%, from about 150 TWh to about 75 TWh due to decreased paper use, less new device shipments, fewer devices in operation and improved energy efficiency. It can also be assumed that the results for 2010 were an overestimated due to outdated input data. Note that this is an estimate made in this study based on the authors own companies experience.

H. ICT and E&M services

In addition to the network and device related subsectors, also service oriented activities have been estimated. As the use of network and devices are already accounted for in other sub-sectors, this part includes the additional offices and travels by employees in the sectors. The estimates of impacts per employee are based on the study of the ICT and E&M sectors in Sweden [13] and are thus they are considered quite uncertain due to the limited sample. The impact per employee is scaled by an estimated number of employees in the sectors globally which is also a very uncertain estimate.

V. Results, analysis and observations

See section VII (Conclusions) for a summary of absolute figures and share of global energy and carbon footprints.

A. Total carbon footprint results

The result of this study shows that the trend of increasing ICT and E&M footprints has not only flattened but changed into decreasing footprints, which is in contrast to previous global studies, as illustrated by Figure 9. At the same time the growth in number of users (subscriptions) and usage (data traffic) has continued, as shown in Table 2.

The footprint of the ICT sector itself is flat, but ICT´s impact on the E&M sector is strong, and this sector has decreased its footprint significantly. This is mainly due to the use of smartphones, but also to the tablets, leading to decreased sales and usage of new TVs, PCs and other consumer electronics. The energy efficiency improvement of new display technologies is another important reason for the reduction in the footprint of the E&M sector. The consumption of graphical paper for news, printing and writing shows a steady decrease since the economic downturn in 2008, as shown in Figure 9. The reason is considered to be that traditional paper media increasingly "moves" online.

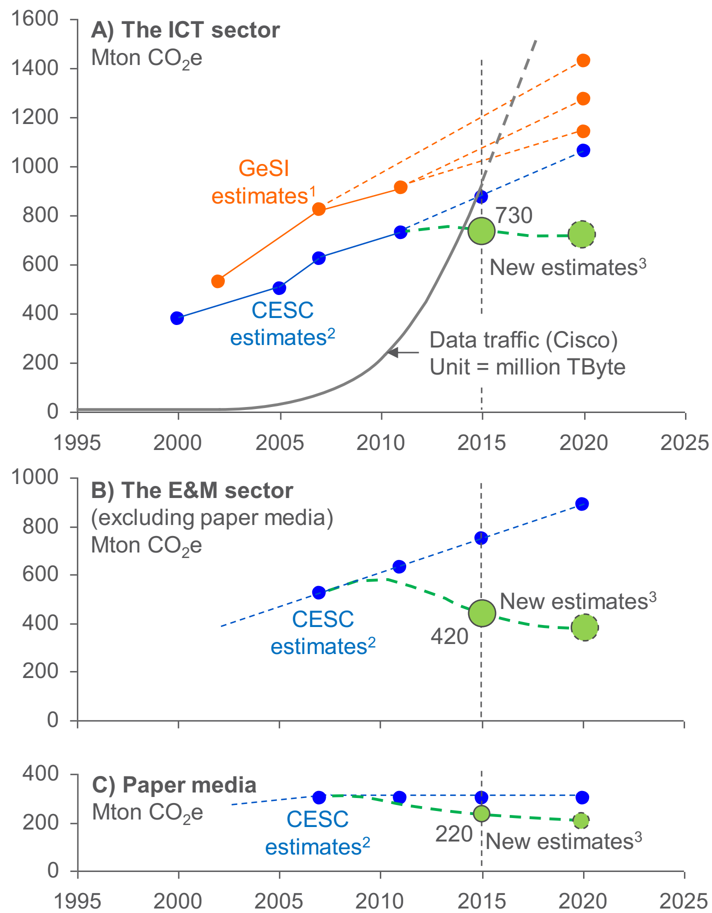

Figure 9: Carbon footprint estimates 2000-2015 and 2020 forecasts for:
A) the ICT sector, B) the E&M sector (excl. paper media) and C) paper media.
1) Previous estimates by GeSI in SMART 2020 [7] and SMARTer 2020 [8].
2) Previous estimates by the authors and Centre for Sustainable Communications (CESC) [2, 3].
3) New estimates in this study.

Figure 10 shows the distributions of the total carbon footprint of each sector for 2015. Most of the carbon footprint is related to user devices, especially their actual use. Still, the manufacturing stage also contributes significantly to the total carbon footprint. Figure 10 also includes a rough estimate for ICT and E&M services and content production.

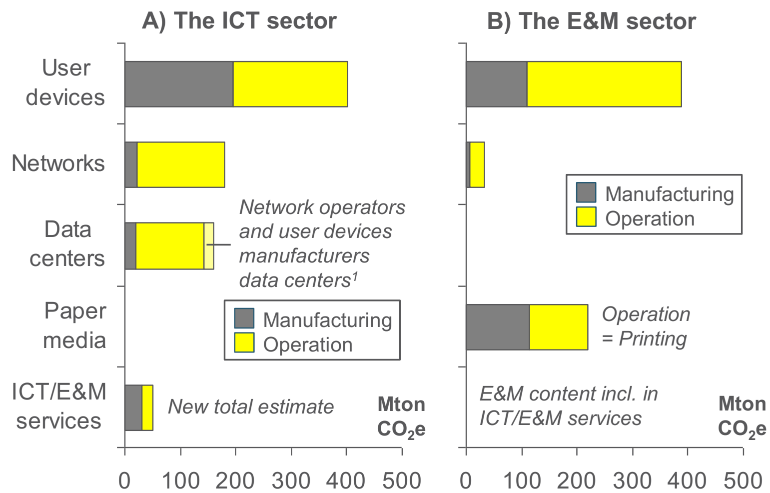

Figure 10: Total carbon footprint results for the ICT and E&M sectors in 2015.

B. *Operational electricity consumption – The energy footprint*

Figure 11 shows that the ICT sector's energy footprint has been flat around 800 TWh in 2010 and 2015, up from about 710 TWh in 2007 [2]. Mobile network operations have increased its share while user equipment have decreased its share.

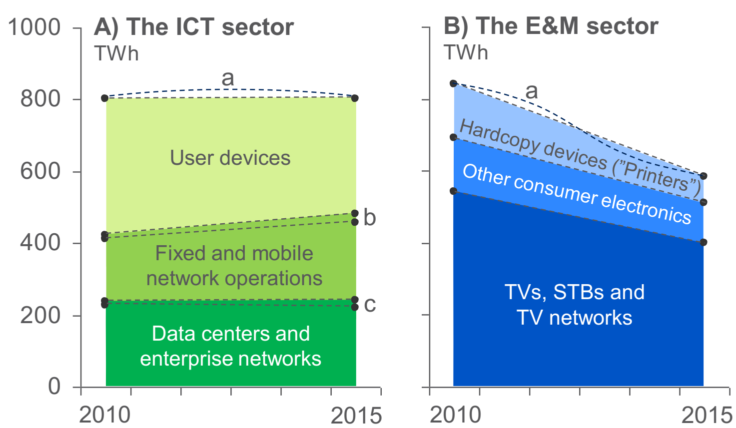

Figure 11: The ICT (A) and E&M (B) sector's total operational electricity consumption. Results have only been estimated for 2010 and 2015, so the trend lines between those years are not showing exact behavior. Thus, the electricity consumption may have reached a possible max and then decreased, as illustrated by (a). Additionally (b) shows on-site generated electricity at mobile base station sites and (c) the network operators own data centers (not reported separately in 2010, estimate shown here).

The E&M sector's energy footprint was estimated to have increased from about 730 TWh in 2007 [2] to about 840 TWh in 2010 [3] but is now estimated to have decreased to about 585 TWh including hardcopy devices ("printers") in 2015 - a decrease by about 30%(!). One reason is the improved energy efficiency of TV displays, another changed user behaviors.

According to the scope of the study, the energy footprint is defined as the operational electricity consumption. The electricity consumption related to the embodied energy consumption can be estimated to about 350 TWh, of which about 150 TWh have been measured by 35 major ICT and E&M manufacturing companies, see Table 4 and Figure 12.

Category (no. of companies)	Revenue share (%)	Electricity (GWh)	Carbon Footprint (CF) Mt CO_2e	Est. additional CF Mt CO_2e
IC (6)	~50%	50 500	23.2	53
Display (6)	~85%	54 400	23.6	26
Assembly (21)	(~50%)	47 500	25	25
PCBs (2)	~5%	2 000	1	19

Table 4: Embodied footprints of some key manufacturing processes (PCB = Printed Circuit Board)

C. Carbon footprint results in further details

More detailed results for the user devices with the largest carbon footprints are shown in Table 4 and Figure 13. TVs and the various PC types together with the monitors have the largest footprints, but smartphones have also a significant footprint due to their large sales volumes. CPE (modems/gateways) and STBs have, due to their always on operational behavior, a high operational carbon footprint.

The carbon footprint of the user devices, distributed into use stage and embodied emissions, are shown in Figure 12. The embodied emissions can be split into materials acquisition, parts production, component production, and assembly. For the embodied emissions two data collection approaches were applied. Firstly, the energy and carbon footprints of the major ICT and E&M manufacturing companies were collected (35 in total), and scaled to a global level based on revenue, see results for the collected data in Table 4.

Secondly, the embodied carbon footprint of ICT and E&M user devices have been modelled in a bottom-up approach based on the estimated footprint per device and number of shipped devices in 2015, see Table 3. These results were used as gap fillers for the top-down data.

The contribution from materials extraction was also derived top-down in accordance with [21], which estimates the material carbon footprint of the ICT and E&M sector to about 45 Mt CO_2e. Note that this is just the footprint of the raw material itself and further processing and manufacturing into composites and components is included in the other stages in Figure 12.

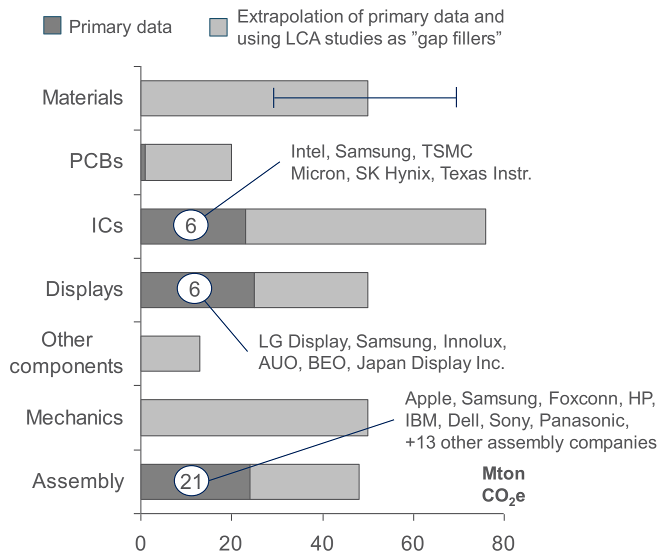

Figure 12: Total carbon footprint of the materials acquisition and production stages of the user devices (often referred to as the "embodied" carbon footprint).

As seen in Figure 12, Integrated circuits (ICs) represents the largest embodied footprint. Materials, mechanics, displays and assembly also have significant footprints. The range indicated for materials shows the impact of recycling as discussed in [21].

The divide of carbon footprint per type of user device is shown in Figure 13.

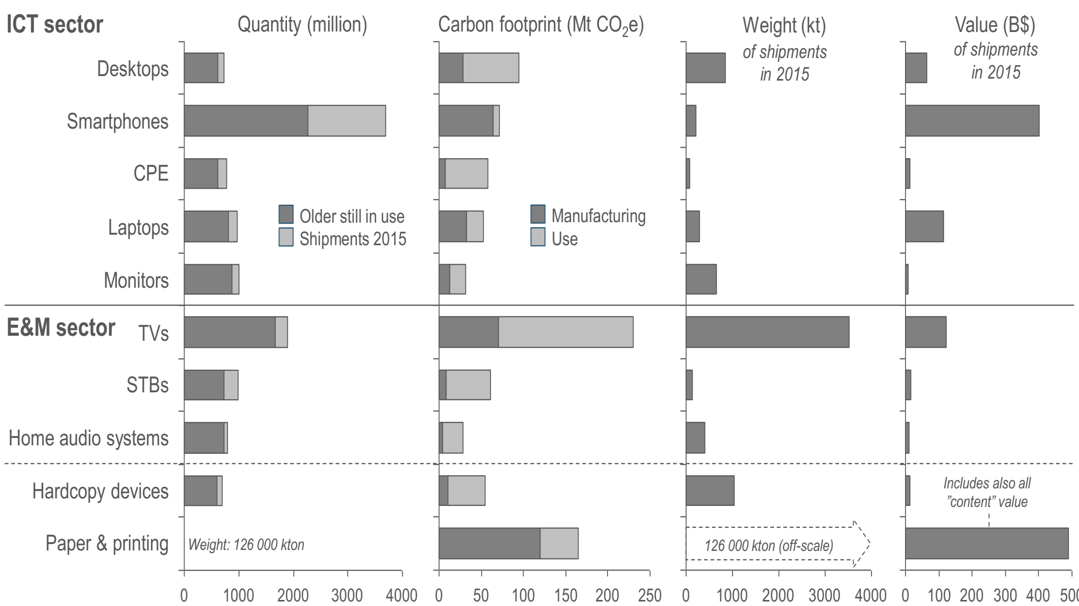

Figure 13: The quantity (volume), carbon footprint, weight and value for the ICT and E&M user devices with the largest carbon footprints. Paper and hardcopy devices are also included. The estimated total weight for each device category is also shown (note that the total weight of all papers used is out-of-scale

VI. Discussion

The outcome of this study shows that the ICT sectors energy footprint is increasing, but not as often assumed, in line with the increased data volumes, but rather in correlation with the increased volumes of subscriptions. Previous studies show that in some IT mature countries, such as for instance Sweden, the energy consumption as well as the carbon fotprint is decreasing. However, when interpreting the results,there are a number of other aspects to consider since they may inflict the results both in a positive and a negative direction.

One of the main questions is whether it is even possible to assess the ICT and E&M sectors, to define "internet", when there is no clear definition. In this study the same boundaries have been applied as in previous studies by the authors [2, 3].The ambition has been to collect the best data available to get a good basis for esimations and extrapolations, which resulted in an extensive collection of primary and published data.

The global IT maturity differs between countries as well as among the ICT and E&M providers, manufacturers and producers. That's why indata is based on several and different sources. By this the collected data and the results will be less biased by the data just a few sources.

Operational data for networks are in many cases seen as sensitive business data which has been kept confidential and communicated only at an aggregated level. In this respect, the data set collected for this paper, in particular with regards to networks, are considered to substantially increase the data availability [19]. To ensure a sufficient and detailed data coverage the operators that provided primary data were promised anonymity. In addition to this extensive primary data set, complementary data have been collected from the annual reports of other major network operators. Take together, these sources corresponds to a large share of the overall global subscriptions representing a wide range of sources which gives a good input for extrapolations.

To verify that confidential data from operators are reliable and accurate is a challenge, but since many of the operators also publish externally reviewed annual reports with the same data but presented with lower granularity, the data has to large extent been compared to those sources which are verified through corporate audit reviews. The operators that reported their detailed data were promised anonymity. Through this, data gaps were avoided and access were given to data sets that would otherwise have remained internal. With an assurance of anonymity there is no reason to fake the real data. In the end, in spite of the principal objections against anonymous data, from a quality perspective these data enables more accurate results than a dataset based on theoretical models and one or a few estimated KPI's.

For other indata such as consumer devices, TV's and PC's the results are based on public sales statistics combined with applicable LCA data. Data center operation figures is based on a mix of publicly available annual reports and available information from data center owners, and information received via network operators data collection.

With regards to absolute footrpints and the development of the footrpints over time, it is observed that the trend results are less sensitive to the data quality as biases or uncertainties related to absolute levels, are likely to have similar proportions between different years and thus even out.

When comparing the results and forecasts of this study with others, such as [11], that are using a more limited data sources with unclear data age, it seems reasonable to conclude that the footprint of ICT has sometimes been overstated due to shortcoming in data and models as shown in previous studies [6]. Another parameter which may lead to too high estimates is the neglected energy efficiency improvements that historically have had a considerable impact on network energy performance and footprint.

A challenge still to come is IoT and especially the expected increase of connected devices. Until now, the volumes have been low but they have started to increase. Devices such as Machine to Machine (M2M) are normally easy to track due to their mobile subscriptions, while IoT devices connected via other means, such as Bluetooth and WiFi, are more complicated to trace. Due to the early phase of the technology life cycle, it is highly uncertain to forcast the footprint for the IoT sector after 2020, especially the expected volumes. In 2015 the MaChina forcasted that 27 Billion devices will be connected already in 2024. For 2015, the total number of connected devices can be estimated to approximately 600 million (from Table 3). There seems to be quite a step between the expected future volumes and the current usage.

Another aspect of IoT is the allocation of the connected devises between sectors – if everything is connected, what should be allocated to the ICT and E&M sector, and what should be allocated to other sectors? Should a self driving car be allocated to ICT and E&M sectors footprint since its online? In this study only the electronic hardware of the IoT devices have been included in the report. One may also claim that an IoT device which is primarily intended for communication purposes should be allocated to ICT while one for which the connectivity is a feature should be allocated according to is primary purpose.

ICT and E&M sectors is using a higher share of renewables than other sectors. Approximately 40% of the reporting sectors electricity purchase today is "fossil free" and this is clearly visible among the reporting network operators [19]. This is an important factor to consider when comparing different sectors development.

The development over time indicates that the ICT & E&M sectors have started to decouple the sector expansion from its carbon footprint. This was first seen in ICT mature countries like Sweden, but the results and data of this study implies that this has also started to happen globally. This trend shift has come about quicker than expected based on earlier results. Furthermore, the expansion of ICT has had an effect on other sectors. When studying the development of the paper industry it is reasonable to believe that the paper production decline has a strong correlation to the increased usage of digital media, and especially newspaper media which goes online. Even if the impact on the newspaper industry was expected, the change has been fast and considerable. For other sectors such as transports, building etc. the effect is still to be seen.

How the footprints of the ICT and E&M sectors will continue to evolve remains to be seen, so does the continued development of the impact on other sectors from digitalization. Apparently, this is an area that will require further research, both to follow the development and to deal with the related uncertainties. However, this study has introduced an extensive dataset and results that should reasonably estimate the actual footprints.

VII. Conclusions

This study estimates the footprints of the ICT and E&M sectors as summarized in Table 5.

Study part	**Energy[2] footprint**	**Carbon footprint (CO_2-equivalents)**
ICT sector	**805 TWh (3.6%)**	**730 Mt (1.4%)**
- User devices	*340 TWh*	*395 Mt*
- ICT networks	*220 TWh*	*180 Mt*
- Data centers and enterprise networks	*245 TWh*	*160 Mt*
E&M sector	**585 TWh (2.8%)**	**640 Mt (1.2%)**

- TVs, TV networks, consumer electronics	*510 TWh*	*420 Mt*
- Paper media and hardcopy devices	*75 TWh (150 TWh3)*	*220 Mt*

Table 5: Total energy and carbon footprint results (percentage of global[1] footprints)
[1] Global electricity consumption = 21 000 TWh [26], global carbon footprint = 53 Gt CO_2e [28],
[2] Energy footprint defined as Operational Electricity Consumption (OEC),
[3] If also industrial printing is included (estimate).

The ICT sector have stopped to grow its energy and carbon footprint and the footprint in 2015 are similar to what it was in 2010 (a possible peak in 2012/2013). Networks continue to grow slowly but user devices footprints are now decreasing.

The E&M sector have not only stopped to grow but also decreased its footprint since around 2010. This is a major trend shift despite that ICT subscriptions have grown from 6.7 billion to 9 billion, TV subscriptions have grown by 8% to nearly 1.6 billion and data traffic in the world's networks have increased by a factor of 4 during the same period (2010-2015).

Table 6 show two basic intensity metrics that describe the development for the ICT sector 2007 – 2015. The metrics are constructed from the results in Table 5 and key data in Table 2.

Total results	**2007 [2]**	**2010 [3]**	**2015**
ICT sector total carbon footprint [Mt CO_2e]	620	720	730
ICT sector total operational electricity consumption [TWh]	710	800	805
E&M sector total carbon footprint (excluding paper media and printers) [Mt CO_2e]	520	640	420
E&M sector total operational electricity consumption (including printers) [TWh]	730	840	585
Paper media total carbon footprint (paper media and printers) [Mt CO_2e]	300	~300	220
Intensity metrics	**2007**	**2010**	**2015**
Total carbon footprint per ICT subscription[1] [kg CO_2e / sub]	134	107	81
Total carbon footprint per GB data (in networks) [kg CO_2e / GB]	7	3	0.8
Total operational electricity consumption per ICT subscription[1] [kWh / sub]	153	119	89
Total operational electricity consumption per GB data (in networks) [kWh / GB]	7.6	3.3	0.88

Table 6: Total results of this study compared to [2, 3] and intensity metrics for the ICT sector 2007 – 2015
[1] Not including M2M subscriptions (only 0.35 B in 2015)

The major reasons for the trend shift are believed to be:
- Decreased sales of new TVs and PCs and less use of existing ones in favor of smartphones (and tablets)
- Consumer electronics are replaced by apps that primairly run on smartphones (and tablets)
- Improved material and energy efficiency of display technologies.
- Paper consumption is decreasing as media "moves online"
- Devices that grow in numbers are small and energy efficient, e.g. IoT devices and IoT communication modules.

The study builds on a large and extensive data set compiled over many years with important contributions also from key industries.

Many previous studies have overestimated the negative impacts (the energy and carbon footprints) of the ICT and E&M sectors in the near future. In the light of earlier estimates this study shows a result which is significantly lower than e.g. the carbon footprints projected by the Smart 2020 and Smarter 2020 reports.

The footprints per human, user and subscription is naturally decreasing even more. At least for the ICT and E&M sectors it seems that the age of dematerailization has finally arrived.

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