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On Thin-Clients and the Cloud; Can Smartphones and Tablets Really Reduce Electricity Consumption?

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***Abstract*-- Cloud computing suggests that we can move many computational and data storage services from the desktop onto the network. New thin clients provide an excellent user interface for cloud services and also reduce both manufacturing electricity and lifetime electricity use by an order of magnitude. But do they really reduce overall electricity consumption? In this paper we examine how the total electricity consumption due to consumer computing devices is evolving. We attempt to estimate its growth in terms of global electricity consumption and determine longer term trends due to the rapid growth in thin-clients and the broad adoption of cloud computing.**

I. Introduction

Sales of ICT devices - laptops, home computers, their associated peripherals (networking, storage and display) dominate market share and recent growth in the consumer electronics industry [1]. ICT markets have been driven by the consumer sector for some time now. With recent explosive growth in markets for new ICT devices - smartphones and tablets in particular - and the ongoing transition of the television to a connected network device these 'digital' consumer devices now dominate global sales of consumer electronics. Throughout the remainder of this paper we refer to this broad category of devices as as CE-ICT 'appliances'.

Since 2008, several emerging technologies have initiated broad and disruptive impact across the ICT sector: (i) cloud computing promises efficiency of scale both in terms of capital and operational costs [2], [3], [4], [5]; (ii) high-speed wireless networks promise near-ubiquitous network access [6], [7], [8], [9] and (iii) thin-client solutions such as smart-phones and tablet devices provide appropriate, low power user-interfaces to take advantage of this emerging next-generation ICT infrastructure [10]. There are strong improvements in energy efficiency promised both in terms of computational efficiencies [2], [11], [12] and data storage [13], [14], [15].

The main question we seek to answer in this paper is whether this new consumer ICT infrastructure can reduce the overall energy costs of society's new digital lifestyle, or is it catalyzing a substantial rebound effect that could skyrocket ICT-related energy costs over the next decade?

II. Layout

Throughout this article we employ the term *energy usage* as interchangeable with *electricity consumption* - practically all energy utilized by manufacturing industry, communications networks, data centers and CE-ICT devices is taken from the electricity network. It is also useful to estimate the percentage of total global electricity consumption dedicated to CE-ICT devices and the associated infrastructure.

A. Overview of this Work

To reach this answer we start by estimating how much global electricity usage that can be ascribed to CE-ICT. Based on the work of previous researchers [16], [17] we present a methodology where electricity consumption is divided into 4 principle categories - (i) client devices: PCs, laptops, TV and home entertainment systems; (ii) network infrastructure; (iii) data center computation and storage; and lastly, (iv) device manufacturing energy costs. We then evaluate current and projected energy consumption in each of these categories using, where practical, more than one methodological approach. Note that the work presented in this paper is a summary of a more detailed report available online [18].

III. Electricity Consumption Baseline for 2012

Detailed information on the installed base of devices in a range of different categories is available from various government & industry sources. It is also possible to apply a detailed usage analysis model such as those developed by [19] to each category of devices.

A. Usage Model for Installed base of CE-ICT

In *Table 1* a summary of results from our model is presented, extrapolating the usage models of [19] to the installed base of global CE-ICT devices. More details in [18].

Table 1: Electricity consumption (TWh/yr) for CE-ICT devices and peripherals 2011-2013; estimates based on methodology of [19].

Installed Devices ($x10^6$)	**2011**	**2012**	**2013**	**kWh/yr**
Desktops	579	588	598	*220*
Monitors	608	617	628	*97*
Laptops	729	832	946	*80*
Smartphones	700	1000	1350	*5*
Tablets	50	150	250	*15*
TV	1900	2000	2100	*200*
TV STB	722	760	798	*100*
TV GC	380	400	420	*135*
A/V Receiver	570	600	630	*65*
DVD/Blueray	665	700	735	*28*
TWh/yr				
Desktops	127	129	132	
Monitors	59	60	61	
Laptops	58	67	76	
Smartphone	4	5	7	
Tablets	1	2	4	
TV	380	400	420	
TV STB	72	76	80	
TV GC	51	54	57	
A/V Receiver	37	39	41	
DVD/Blueray	19	20	21	
Total (TWh/yr)	**808**	**852**	**897**	

There are several adjustments/refinements that are worth noting. Firstly the annual kWhr rating for a typical US TV panel was estimated at 180 kWhr in 2010. Here a 10% higher figure of 200 kWhr has been adopted to reflect two factors: (i) in emerging economies we expect a higher proportion of older high-power TV sets in the installed base, and (ii) there will be a larger proportion of single-TV households in developing economies and these primary TV sets have higher annual usage than 2nd and 3rd TVs in multi-TV households. A similar logic applies to laptop computers.

Based on these estimates we see that annual consumption for all devices is estimated at 808 TWh/yr in 2011, which fits nicely between the estimates of 778 to 830, TWh/yr determined from the work of prior researchers - see *Table 2* below.

For 2012 a figure of 852 TWh/yr is obtained. This is somewhat lower than prior estimates but can be explained in by changes in the both PC and TV markets. PC sales have stagnated in recent years and have been strongly displaced by laptop sales and more recently tablet computers. Thus there is a shift to lower power client devices in the ICT category although a significant installed base of older PCs and laptops remains in 2012. On the TV side we note that the market has stagnated at c. 250M units per annum [20], [21] in contrast to a 7.5% or higher growth rate predicted by past researchers. Again there is much anecdotal evidence of changing use patterns that lead to more viewing of content by consumers on thin client devices.

B. *Electricity Consumption by CE-ICT Devices*

It is helpful to compare our three main sources of recent data to see how each predicts the increased consumption of CE-ICT devices. The IEA estimates [22] begin from 2010 and are closely in line with Pickavets estimates [17]. Corcoran is lower which is most likely because that work restricted itself to the major categories of ICT Clients (PC, laptop and other consumer ICT devices) and to TV displays and associated peripherals [16] (*i.e.* Pickavets includes an additional 'other' category that is only partly covered by Corcoran's estimates).

Nevertheless we see a close convergence in 2011 and 2012 from all three of these researchers and this supports our model described in section 4.1.2 above.

Table 2: Electricity consumption (TWh/yr) for all primary CE-ICT devices and peripherals (2008-2012) from previous researchers, compared with the individual device model of this work.

	2008	2009	2010	2011	2012
IEA [22]			**776**	824	873
Pickavet, et al. [17]	648	703	762	826	895
Corcoran [16]	613	625	645	824	870[1]
This Work				**808**	**852**

The main goal of this section is to obtain a consensus estimate for the electricity consumption of devices in 2012. Given the improvements in energy efficiencies for TV sets and, to a lesser extent, for PC and laptop clients it seems reasonable to use the 852 TWh/year estimate from our model as a basis for predicting the future trends in electricity by CE-ICT devices in section 5.

C. *Manufacturing Electricity*

Several sources present annual numbers of shipped devices that can be used for 2008-2012 [20], [21], [23], [24], [25] [26], [27], [28]. The present set top box and game console shipments can be regarded as low estimates [29], [30]. Monitor sales follow the desktops shipments [30]. These are used to calculate manufacturing electricity and the growth of installed base, using replacement rate data where available. More details can be found in [18].

Table 3: Manufacturing Electricity (TWh/yr) by Device Category

	2008	2009	2010	2011	2012
Desktops	27	26	25	24	23
Monitors	42	40	39	38	37
Laptops	19	22	24	25	27
Smartphones	5	6	13	16	23
Tablets	0,04	0,07	4	8	11
TV	96	93	91	87	84
TV STB	4	4	4	4	4
TV GC	7	7	7	7	6
A/V Receiver	7	7	7	7	6
DVD/Blueray	17	16	16	15	15
Networks equipment					51
Data center equipment					40
Total	277	309	322	327	327

D. *Electricity Consumption by Networks*

Table 4 shows a comparison of the total electricity consumption of global networks from a number of previous researchers. Note that the network growth figures for Corcoran [16] have been adjusted to take account of the delayed deployment of LTE networks and significant changes in user behaviors such as data offloading via Wifi. After this adjustment we can see that all researchers have broadly convergent estimates leading to a consensus figure of the order of 350 TWh/yr for 2012.

Table 4: Electricity consumption (TWh/yr) for data comms networks (2008-2012) from previous researchers.

Citation	Devices	2008	2009	2010	2011	2012
Pickavet, et al. [17]	Datacom & Teleco Networks; excludes Data Center networks	219	245.3	274.7	307.7	**344.6**
Corcoran [16]	Datacom & Teleco Networks; excludes Data Center networks	219	251.9	276	318[2]	**365**[2]
Lambert, et al. [31]	All networks - based on subscriber numbers		240	265	320	**354**
Kilper, et al. [32]	Mobile Network					**812**

Note that the figure provided for Kilper, et al. [32] is derived from table 5 of Lambert, et al. [31] and illustrates the potential effects of LTE access networks if these were introduced across the entire communications infrastructure.

E. *Baseline Estimates - Data Centers*

The work of Pickavet et al [17] and that of Corcoran [16] were based on the original estimates of Koomey [33], [34] and

[1] The estimate in [16] assumed growth in TV sales driven by adoption of 3D technologies and the introduction of Smart-TV; this figure is modified to reflect the actual market condition of 2012.

[2] The estimate in [16] assumed significant LTE deployments in 2011; major roll-outs were rescheduled by most ISPs to a 2013/14 timeframe; estimates in *Table 4* take account of this change.

as a consequence they significantly overestimate the actual power consumption of data centers. This is illustrated in *Table 5* where Koomey's original work [33], [34] and his later revisions [35] are included.

As Koomey has only provided an estimate for 2010 an estimate of consumption for 2011 and 2012 is extrapolated to provide a reference baseline value for 2012. An annual growth rate of 12% is used in line with the growth rates identified by Pickavet, et al. [17]. Koomey [35] has indicated a lower rate of growth from 2005-2010 of 8%. However there was a significant jump in global electricity consumption of 6.5% in 2010 following a 1.8% decline in 2009 [36]. Given this and other economic factors it seems reasonable to revert to a 12% growth rate for data centers for 2011 and 2012 [18].

Table 5: Electricity use (TWh/yr) of data centers from previous researchers.

Citation	Devices	2005	2008	2009	2010	2011	2012
Pickavet, et al. [17]	Severs & Data Center		254.0 (1)	284.5	318.7	356.9	399.7
Corcoran [16]	Severs & Data Center		254.0 (1)	285.6	343.0	411.5	514.4
Koomey [33], [34]	Severs & Data Center	152.5	**268.7**				
Koomey [35]	Severs & Data Center				**237.4**	**265.9 (2)**	**297.8 (2)**

Notes to table 5: (1) [16] and [17] show lower estimates for 2008 than Koomey because network energy (c. 6%) within the data center is not included; (2) These are extrapolated from Koomey's revised 2010 estimate at an annual growth rate of 12%; these values include c. 6% network energy.

F. *Baseline Estimates - All Categories*

For direct consumption by devices we have compared the estimates of previous researchers and matched this with our own model - *Section III-A*. The value from our model is lower than some of these estimates, but given recent global economic conditions this makes sense. The contribution of networks requires some adjustment of the projections of [16] to correct for delays in the roll-out of LTE/G4 networks.

Table 6: Best Estimate Values for 2012 in each category.

2012 Baseline	
Device Consumption	852 TWhr/yr
Manufacturing (LCA)	330 TWhr/yr
Networks	352 TWhr/yr
Data Centers	281 TWhr/yr
Total	**1,815 TWhr/yr**

After this we find the estimates of network energy usage are within 20 TWh/yr of each other and the recent work of Lambert et al [31] offers a median estimate. We remark that the core network component of datacenters is included in this estimate and thus energy consumption in datacenters must be reduced accordingly - by approximately 6%.

Given the relatively close agreement between estimates for network consumption we do not provide an alternative model. However future estimates of network contribution are problematic for a number of reasons, not least the projected growth in mobile data [37] and the equivalent growth in electricity consumption by wireless access networks [38].

IV. FUTURE PROJECTIONS?

In [18] the 2012 baseline is matched with market predictions for new client devices, network infrastructures and growth in mobile data to extrapolate values over the next 5 years for each of the four main contributing components of electricity consumption - (i) direct consumption; (ii) manufacturing consumption; (iii) network consumption; (iv) data center consumption. In this short paper we only have space to briefly summarize the findings.

A. *Growth Scenarios for the next 5 years*

The percentage of total global electricity attributable to CE-ICT is shown in *Table 7* - a 3% annual growth is assumed for total electricity consumption, a figure that has been adopted by other authors [31]. The baseline is 23,192 TWh/yr in 2010, the most recent figure available [39]. Three growth scenarios are explored with details for each given in [18]. In the *best case* scenario the consumption of electricity by CE-ICT declines as a proportion of global electricity consumption from 7.4% in 2012 to 6.9% in 2017. For the *expected growth* scenario the increase is to 8.9%, a significant rise but not unexpected given the many disruptive technologies at work in the CE-ICT sector. Note however that global electricity consumption exhibited a jump of 6.5% between 2009 and 2010 [39] so an overall growth rate of 3% may be conservative.

Table 7: Projections of the combined %age of total global electricity consumption in (TWh/yr); based on the best/expected/worst case scenarios as outlined throughout section 5.

TWh/yr	2012	2013	2014	2015	2016	2017
Global Total	24,604	25,343	26,103	26,886	27,692	28,523
Best Case	7.4%	7.2%	7.1%	7.0%	7.0%	6.9%
Expected	7.4%	7.6%	7.9%	8.2%	8.5%	8.9%
Worst Case	7.4%	8.1%	8.9%	9.8%	10.8%	12.0%

The *worst-case* scenario is an outlier, but plausible. Demand for PCs & TV panels is revitalized by the demands of emerging economies and the new middle classes of Brazil, India, Russia and China. LTE/G4 networks create new demands for network services and deploy broadband to large urban population centers in Africa and Asia. In *Figure 1* we show all three scenarios and the comparative growth in electricity consumption from CE-ICT.

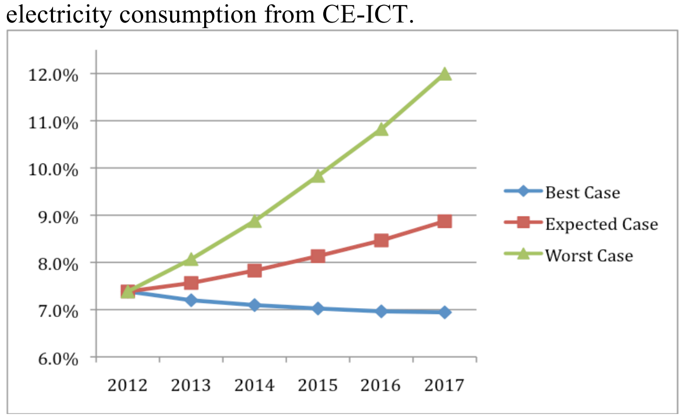

Figure 1: Percentage of global electricity consumption due to CE-ICT for best/expected/worst case scenarios.

V. Conclusions

And so we return to our question - can thin clients help reduce electricity consumption? Well *Figure 1* does seem to suggest that if we manage the emerging support infrastructure property, yes they can. There will be many challenges, both technical and in terms of political and economic policy, but our best-case scenario shows that a significant reduction of 0.5% is indeed feasible.

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