Cloud Computing and Consumer Electronics: A Perfect Match or a Hidden Storm?

By Peter M. Corcoran

One of the potential benefits of cloud computing is the commoditization of information technology (IT), which through economies of scale should offer the potential for significant energy savings. In this article, we consider how the network connectivity demands of next-generation consumer electronics (CE) products, coupled with growth in cloud-based services, are more likely to lead to significant increases in IT-related energy consumption. Current market growth figures are used to extrapolate the likely near-term growth in energy consumption. Even when viewed conservatively, the resulting estimates of growth in power consumption during the period 2010–2016 are twice those of previous researchers.

CE has become more efficient in the past few decades. If we think back to early desktop computers with power-hungry motherboards and cathode-ray tubes of early monitors and TV sets and contrast these with today's smart phone or tablet devices, it seems as if we have made large strides in terms of technology and computing efficiency. After all, today's smart phone or tablet delivers all this computing power for a handful of watts of power consumption in a neat and highly ergonomic package.

Of course, with all these new smart phones and tablets mixed in with our legacy laptops and desktop computers, it has become challenging to keep everything synchronized. It is an all-too-familiar problem to leave some important files that you needed for that important presentation on your office computer. Fortunately, just as all these new networked CE devices have begun to appear, we also have the emerging silver bullet of cloud computing, making it easy to keep your important data—both personal and work related—in secure locations in the cloud.

Granted not everyone is comfortable, just yet, with the cloud, but given the number of new start-ups in this field of technology, it seems certain that a large number of consumers will quickly become accustomed to the benefits of cloud services and storage, especially as they find more and more devices hooked onto their home WiFi zone. In fact, many consumers have already moved their family photograph and video collections, at least, partly into the cloud, using services such as youtube, Flickr, and Picassa Web Albums.

So it would seem likely that the growing success of new CE product categories, notably smart phones and tablets, will continue unabated, driven and supported by a growing number of new cloud services. In practical terms, the cloud offers a perfectly matched back end for these new client devices. It is almost infinitely scalable and addresses the problem of limited storage capabilities for these new devices. (In fact, it is not that their storage is limited but rather that these devices are such powerful generators and consumers of digital content. And, the digital content they generate and consume needs to be stored somewhere.)

On first glance, this is an almost perfect match between the needs of new, networked CE devices and the service and storage infrastructure offered by modern cloud computing. It is easy to see how continued growth in the market for these devices will drive further demand for cloud infrastructure. Also, as the services and capabilities offered by this infrastructure are developed and enhanced, this will, in turn, drive further waves of growth in the market for these new devices. In many ways, new CE and the cloud are a perfect match for each other.

But if we consider this emerging new order carefully, it starts to become clear that there are dark clouds ahead. Also, a clue to those dark clouds can be found in a report from Greenpeace [13] that examines the energy sources used to power cloud computing. Yes, surprising as it may seem, it is the impact on energy consumption of this synergy of cloud computing and new CE technologies that needs to be considered in detail.

In 2011, data centers in the United States were expected to consume about 120 billion kWh or 4 kWh per person [1]. Now, this is a relatively small amount of energy compared with HVac or vehicular transport, but it is growing

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at much faster rates than other modes of energy consumption. Network traffic has also increased annually by 50% for the last five years.

This brings us to the core theme of this article in which we make a back-of-envelope analysis of recent developments in CE markets and extrapolate energy consumption rates up to 2016. We apply methodologies from the recent literature but introduce current market projections and growth analysis. As has just been noted, there are several major technology shifts that are driving the new patterns of growth within the CE sector. We begin by analyzing each of these trends independently.

CURRENT GROWTH IN IT-RELATED INFRASTRUCTURE

In this section, we try to deduce some estimates of current growth in computing infrastructure, extrapolating this onto the likely growth in energy demands placed on IT as cloud computing continues to expand.

GROWTH IN THE BASE OF CLIENT COMPUTERS

In Figure 1, we show projections taken from an IDC forecast for growth in PC sales from 2010 to 2015 [4]. As might be expected, growth in PCs and laptops is stagnant or in a slight decline in developed economies but continues to grow in developing nations. Overall, we see growth from 350 million units in 2010 to 535 million in 2015 [1] or a compound annual growth rate (CAGR) of 9%.

This growth rate assumes that an older device is retired for every new device introduced. However, if we look at another source of statistics (i.e., for network growth [7]), we see that fixed network traffic is projected to grow at an annual rate of 32%. We will see some explanation for portions of this growth shortly, but we conclude that a CAGR of 9% for PC devices may be a somewhat conservative estimate.

SMART PHONES AND TABLETS

Our estimates of PC and laptop growth are complicated by the emerging smart phone and tablet markets. Apple has already sold 50 million iPads, and 130 million units of its iPhone and CAGRs for both these products are still more than 100%. Also, these products are having an increasing competition from other smart phone brands and a range of tablet manufacturers, particularly, those running the Android operating system (OS) from Google. Android devices have the potential to at least match the numbers given here for the iPhone and iPad over a five-year period. The bottom line is that the volume of new smart phone and tablet devices will probably dwarf the 500 million unit PC market by 2015.

So what is a reasonable estimate for growth in client devices? If we are conservative, we might expect to see twice the estimate for PC devices, but I feel that a figure of three to four times is more likely for a number of reasons. First, many people in developed countries will own one of each device: laptop, tablet, and smart phone. In developing countries, a smart phone is likely to become a less-expensive alternative to a laptop. It is also likely that reduced pricing will lead to families owning both a PC (for home use) and a smart phone for work. Thus, a ballpark figure of more than 1 billion units for these new devices by 2015 is probably not unreasonable.

NETWORK-CONNECTED TV

But that's not all. What about flat-screen TVs? Connectivity is a premium feature in today's flat screens, but market competition and the marginal cost of adding a WiFi chipset is likely to make this a standard element for every flat screen by 2015. Figure 2 shows some recent projections on connected TVs from two well-known consultancy firms.

Now, this analysis omits another important category of a connected-TV device: connected Blue-ray players. These will soon appear on the market and form an important element of a recent strategy by content providers to provide faster online access to new movies. Most such devices are intended to securely download large (>4 GB) high-quality movie files. While it is not yet clear how readily consumers will adopt such devices, current predictions [9] see this market developing along similar lines to that of connected TVs, but with a two- to three-year lag.

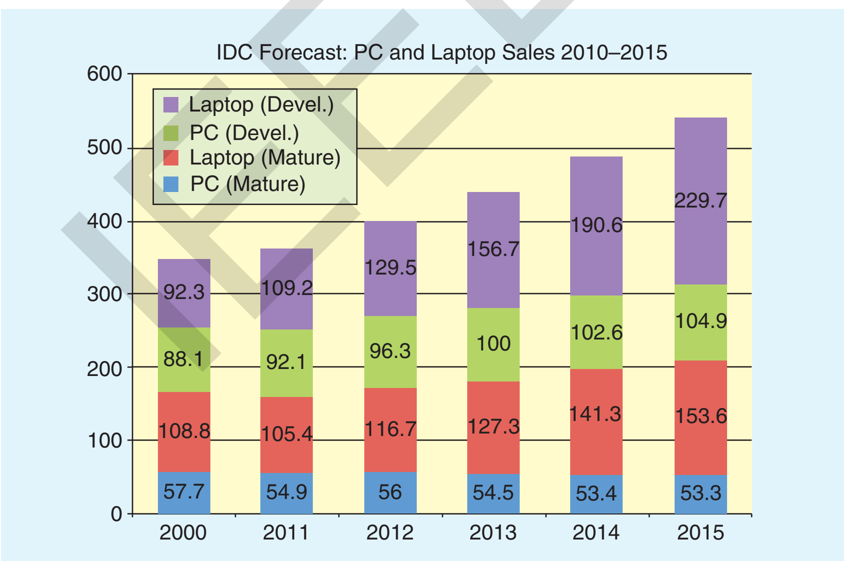


FIGURE 1. Growth in PC sales 2010 (year 1) to 2015 (year 6): blue, desktop sales in OECD **<AU: Kindly spell out OECD.>**; red, laptop sales in OECD; yellow, desktop sales in developing countries; green, laptop sales in developing countries; graph recreated based on figures from [4].

As the goal here is to be as conservative as possible, these devices will not be included in the present analysis, but we remark that they could increase the ballpark figures presented in Figure 2 by up to 50%. But combined with tablets and smart phones, we still have 1.2 billion active client devices added in 2015.

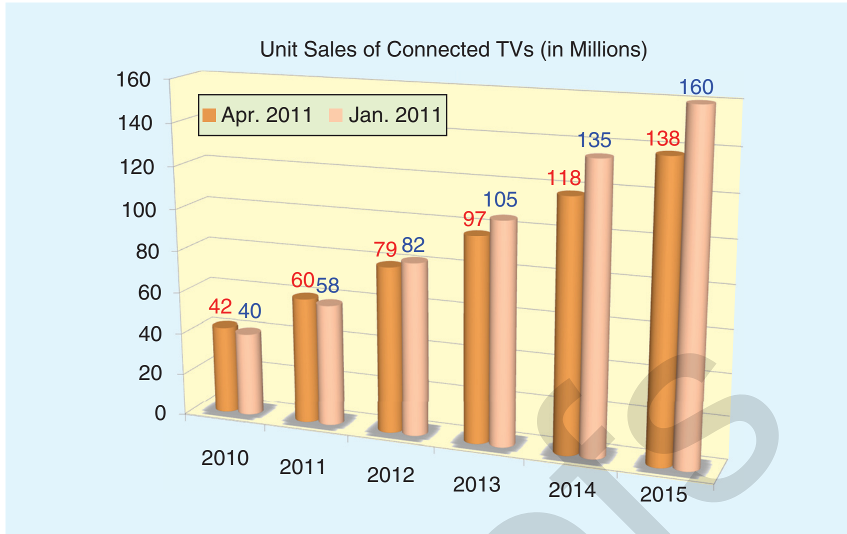


FIGURE 2. Growth in connected TVs by 2015; taken from market reports by two different consulting firms [9], [10].

GROWTH IN NETWORK TRAFFIC

In Figure 3, we show the CAGR of all network traffic with a breakdown by device category. Even though this survey was taken in 2011, it seems to rely on growth projections from 2010. A large growth in traffic due to smart phones was anticipated but was less due to tablet devices, as traffic growth in the living room TV set was not considered. **<AU: Edit OK?>** In any event, we see a 92% annual growth rate, which we could say is in line with our estimated growth rates in conventional IT clients such as laptop and desktop PCs combined with smart phone growth. However, it does not adequately account for tablet devices and even consider the impact of Internet-connected TVs. If we regard this 90% growth rate as a conventional scenario, then in a disruptive scenario, with strong tablet and Internet-TV growth, the true CAGR figure could easily rise above 100%.

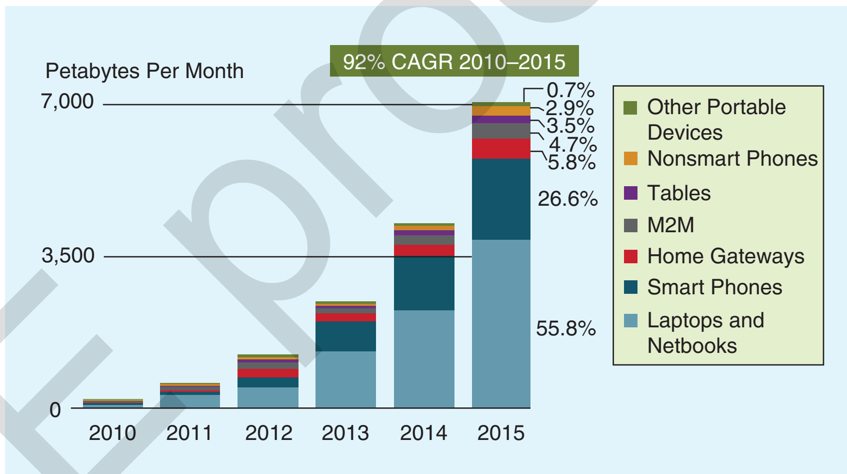


FIGURE 3. Growth in network traffic with breakdown by client device [7].

DATA CENTERS

Koomey [2] estimated energy usage of data centers worldwide. He noted an annual growth rate lying 15–20% over that period with a faster growth rate in Asia/Pacific. Total electricity usage for computing, HVac, and auxiliary infrastructure was 17 GW, equivalent to about 1% of worldwide electricity generation. A more recent study by Pickavet et al. [3] provides data for 2008, as shown in Figure 4.

DOING THE MATH

So far, I have put a number of different parts of the puzzle into place. We can see that previous estimates of the growth of electricity usage by ICT **<AU: Kindly spell out ICT.>** did not take account 1) explosive growth in tablets and to a lesser extent smart phones, 2) Internet-connected flatscreen TVs, and resulting in 3) exponential growth in network traffic. As a consequence, the authors of [8] estimate annual growth rates of 7.5% for electricity use by client devices, 12% for energy due to networks, and similar 12% growth rates for data centers.

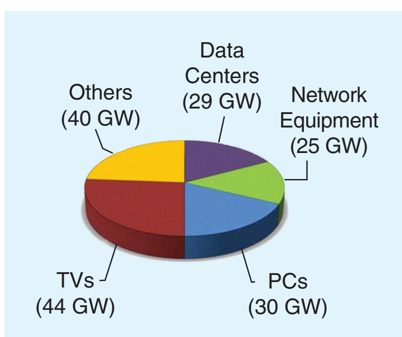
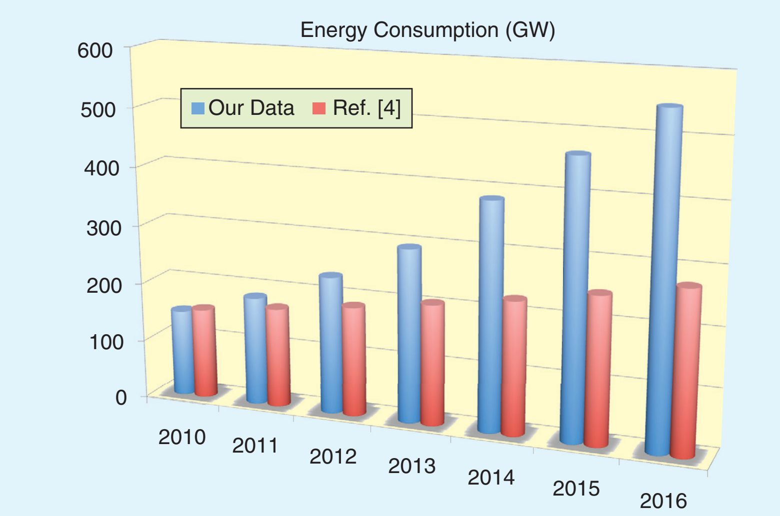


FIGURE 4. Electricity consumption of ICT equipment by category [3].

However, when we consider our 2010–2015 figures gathered from various sources, we have a growth rate closer to 9% for PC clients. Network traffic over the same period is likely to grow at annual rates between 60 and 90%. To meet increased numbers of client devices, particularly, the demand for new Cloud-based services, we expect data center capacities to grow at rates between 40 and 50%



	2010	2011	2012	2013	2014	2015	2016
Our Data	148.41	185.21	234.46	295.01	385.68	466.37	547.84
Ref. [4]	154.68	170.12	187.14	205.93	226.68	249.58	274.88

FIGURE 5. Energy consumption of ICT based on our projections (blue) and those of the authors of [7]; year 1 is 2009 and year 8 is 2016.

rather than the 12% estimate given in [2]. **<AU: Edit OK?>**

Now it is clear that energy efficiencies will be achieved over the same period, both on the networking side through increased use of optical networks and on the data center side through a variety of measures, to reduce cooling requirements and using more energy-efficient hardware. Let's be generous and anticipate a 50% increase in networking efficiencies based on a wider adoption of high-capacity, high-efficiency optical networks and a 40% improvement in data center efficiency. Thus, we assume a conservative 30% growth rate, in terms of net energy consumption, for network data traffic and a 25% growth rate in energy consumption for data centers. Using these assumptions and comparing with the authors of [3], we find the results shown in Figure 5.

The authors of [3] estimated that the total electricity usage by ICT- and IT-related consumer products in 2008 was about 8% and would grow to 430 GW or 14% by 2020. Our estimates suggest a much faster rise in electricity consumption rates, approaching the 400-GW level in 2014 and the 550-GW level in 2016. This implies that 18% of total electricity would be generated in 2014 and as much as 24% by 2016. **<AU: Edit OK?>**

These figures may appear a little surreal but remember that we have used recent market trends for our estimates and also made ambitious estimates regarding improvements in energy efficiency, both within data centers and at the network level. Much of the research literature uses pre-2010 data and does not take into account recent trends in CE.

In reality, the underlying network backbone is already mostly optical and has a high energy efficiency per bit; much of the additional energy cost will be at the consumer end where less-efficient wireless or cable infrastructure is employed. It is true that there will also be a redundancy factor as many new devices will connect over the existing network infrastructure but increased data traffic will force downstream upgrading of network infrastructure. Ultimately, the overall accuracy of our estimates will depend on the rate at which network infrastructure is added in the developing world.

To emphasize this point, Figure 6 shows mobile network connection

	2009	2010	2011	2012	2013	2014	2015	CAGR 2010–2015 (%)
Global								
Global Speed: All Handsets	101	215	359	584	934	1,465	2,220	60
Global Speed: Smart Phones	614	1,038	1,443	1,953	2,608	3,424	4,404	34
By Region								
Asia Pacific	37	74	115	188	328	584	984	68
Latin America	13	50	103	206	402	744	1,260	91
North America	376	707	1,071	1,556	2,198	2,996	3,994	41
Western Europe	151	444	932	1,696	2,708	3,919	5,336	64
Japan	769	1,394	2,009	2,631	3,353	4,282	5,509	32
Central and Eastern Europe	43	117	246	499	955	1,704	2,786	89
Middle East and Africa	13	59	141	309	620	1,142	1,948	101

FIGURE 6. Growth in mobile network connection speeds by region, from [7].

speeds. Note that the fastest CAGR figures are in regions of the developing world that, in turn, implies significant investment in wireless infrastructure that typically consumes ten times more energy than wired infrastructure.

With regard to data centers, it has been recognized that the widespread adoption of virtual machines within the data center infrastructure has already had a significant effect on improving the energy efficiency [5]. Most data centers now use smart load balancing to operate with most computers either at close to 100% operating load or sleeping. Future efficiencies must come from the improved design of the data center infrastructure to reduce cooling costs, from the use of more efficient, low-power server hardware, or, alternatively, from commercial reuse of the waste heat. Again, a 50% improvement in efficiency is probably challenging over a short three- to four-year time frame, but it could be achieved.

In the end, these assumptions could end up being conservative, if consumers in the developing world take to the iPhone and iPad as they have in the United States and Europe.

THE JEVONS PARADOX

There is another fly in the ointment of energy efficiency and IT, known as the Jevons paradox [6], [11]. Simply stated, the paradox is that technological progresses when the increase in efficiency associated with resource utilization tends to increase (rather than decrease) the rate of consumption of that resource. In our case, the increasing availability of networked IT services and data via smart phones, tablets, and now networked TV sets will lead to increased demand for the underlying IT resources.

To take a simple example that is familiar to many of our readers, consider your use of a smart phone to read and access your e-mail. This is a more empowering resource because you can handle your e-mail almost immediately. How many of us send a quick text response when we are on coffee break, on the bus, in the doctor's waiting room, or even walking down the corridor between meetings. Later, when we get to our desk, we'll give a more detailed answer. So where we would have sent one response, we often send two. And the recipient may acknowledge our short texts, even if it is not strictly necessary. So instead of one message and one response, we suddenly have two.

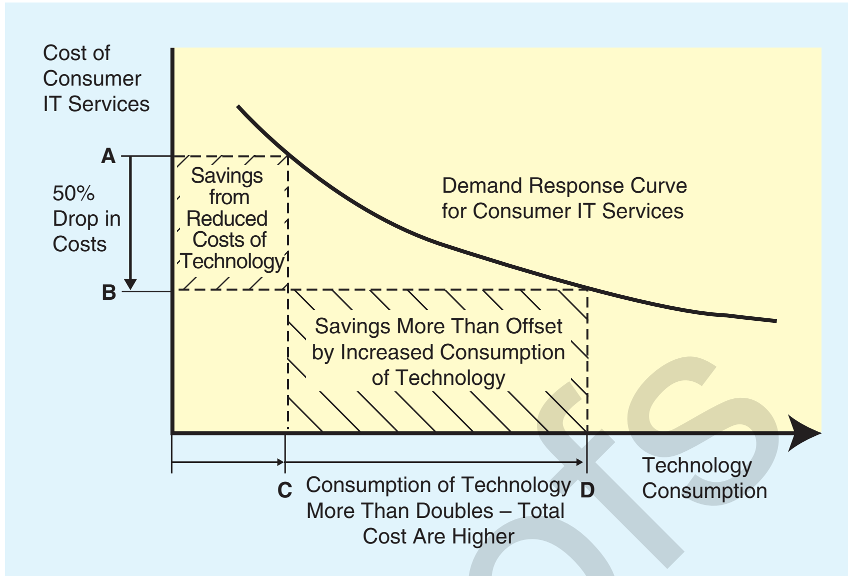


FIGURE 7. Jevons paradox. Although the energy costs of IT services may fall with cloud computing, the overall usage and energy consumption of networked IT is likely to increase and that increase leads to a greater net demand for services.

The more available the Web and e-mail are and the more we use them in our everyday lives, the greater is the demand for network services. Also consider the increasing bandwidth and storage demands of digital photography and video. As we use multiple devices, we are driven to centralized cloud-based storage and services to manage everything. A further catalyst here is the rapid and widespread adoption of smart phones and tablets by consumers, that in turn, has had a disruptive effect, further accelerating the growth of Internet services. This, combined with the increasing availability of a wireless infrastructure and the capacity of that infrastructure to carry more data has led to the commoditization of the Internet and its associated IT infrastructures. Also, commoditization leads to a drop in the access costs and increasing availability of such services.

The Jevons hypothesis was originally applied to the consumption of coal in the United Kingdom during the 19th century [11]. It has also been applied to explain the phenomenon of the paperless office and a range of nonintuitive economic and social outcomes arising from technology-driven improvements (Figure 7). **<AU: Kindly check whether Figure 7 is cited correctly.>**

In the matter under consideration here, we are interested in the reduced cost and increased ease of access to networked IT services. The consequences, in terms of overall IT usage and energy consumption, would appear to be equally counterintuitive as in the original Jevons paradox. After all, who wants to use the computer more? When we see our kids, they are always on their phone, but now it is to browse, text, and e-mail rather than to talk.

Also, tablets have suddenly begun to replace the morning newspaper and after-school TV. In fact, many schools are using them to replace heavy and unwieldy bags of books. I've also noticed that YouTube and a tablet are an endlessly compelling combination for my own kids. As I've said else-

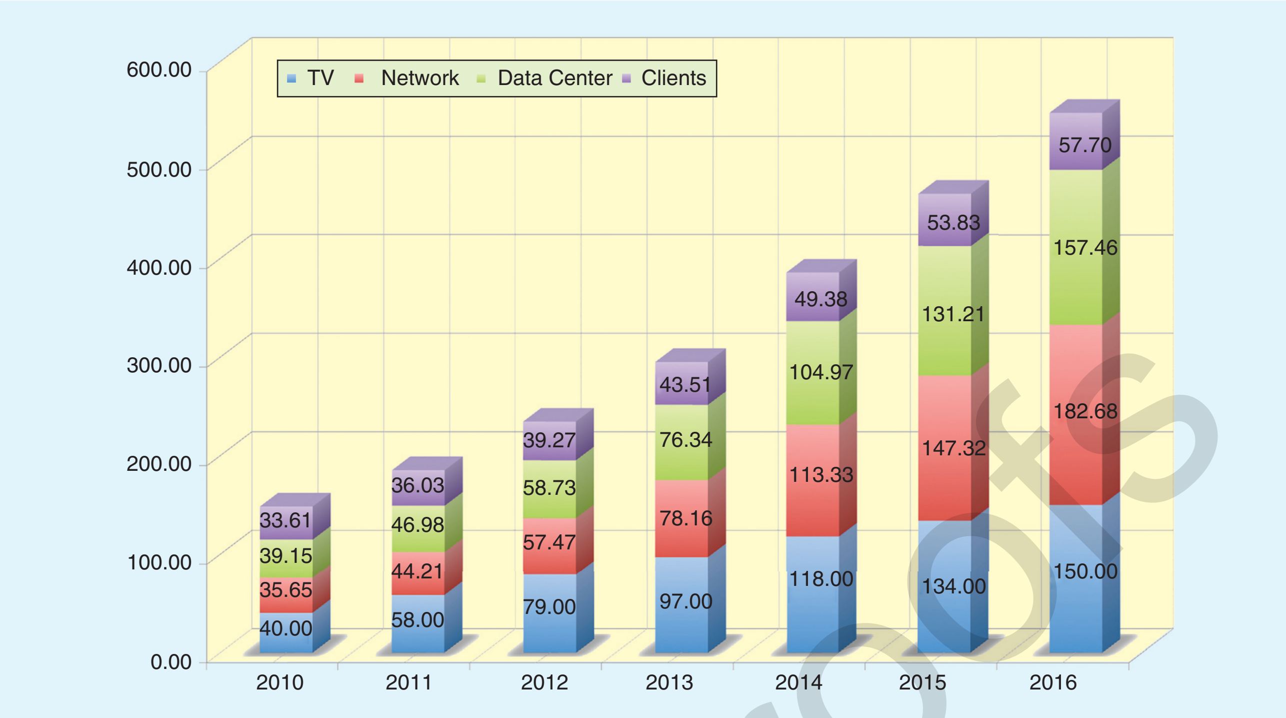


FIGURE 8. Energy consumption by category (in gigawatts).

where, tablets bring the Internet into our living rooms [12]. That also gives us even more time each day to consume Web services and generate multimedia data.

CONCLUSIONS

Clearly, the rapid growth in both the smart phone and tablet device markets were not adequately anticipated by previous researchers and analysts. Even as early as 18 months ago, no one would have thought that the volume sales of tablets would overtake laptops in the market, but this milestone has already passed. Cloud computing has also emerged more strongly into the consumer domain in the last 12 months than had been expected and is touted by industry as the next major driver of growth in the IT sector. When combined with the emergence of connected TV, we have a perfect storm of disruptive CE technologies.

As industry competes to gain market share from the rapidly growing multitudes of cloud-IT users, both network and data center infrastructures will grow more rapidly than anticipated driven by new thin-client CE devices. Consumers, having greater access to data and services, are more likely to move large sections of their personal data to the cloud, driving further demand for both data center and network infrastructures.

The figures presented in the "Doing the Math" section suggest that up to 18% of electricity usage could be IT related by 2014 and as much as 24% by 2016. In fact, these figures might even prove conservative if the Jevons paradox serves to further amplify consumer demand for new IT services. (Figure 8). **<AU: Kindly check whether Figure 8 is cited correctly.>**

What does all this mean? At a time when energy supplies are stressed on a global basis by the demands of the developing world, it appears that an unexpected and significant new demand for energy resources is on the way. This new demand will come from connected consumer devices and be driven by the rapid dissemination of these devices throughout the global community. Indeed, for many in the developing nations, their first Internet access may be via a smart phone or a connected-TV set rather than a computer.

This unanticipated new demand appears likely to manifest in a relatively short period of time, amplifying its potential effects on the electricity infrastructure. However, it is not my role to speculate on what these effects may eventually be; what I can say is that this appears to be a real and new phenomenon and will most likely be impacting a power grid near you sometime in the next two to three years.

ABOUT THE AUTHOR

Peter M. Corcoran. He is the editor-in-chief of *IEEE Consumer Electronics Magazine*.

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In practical terms, the Cloud offers a perfectly matched back end for these new client devices.

The increasing availability of networked IT services and data via smart phones, tablets, and now, networked TV sets, will lead to increased demand for the underlying IT resources.

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