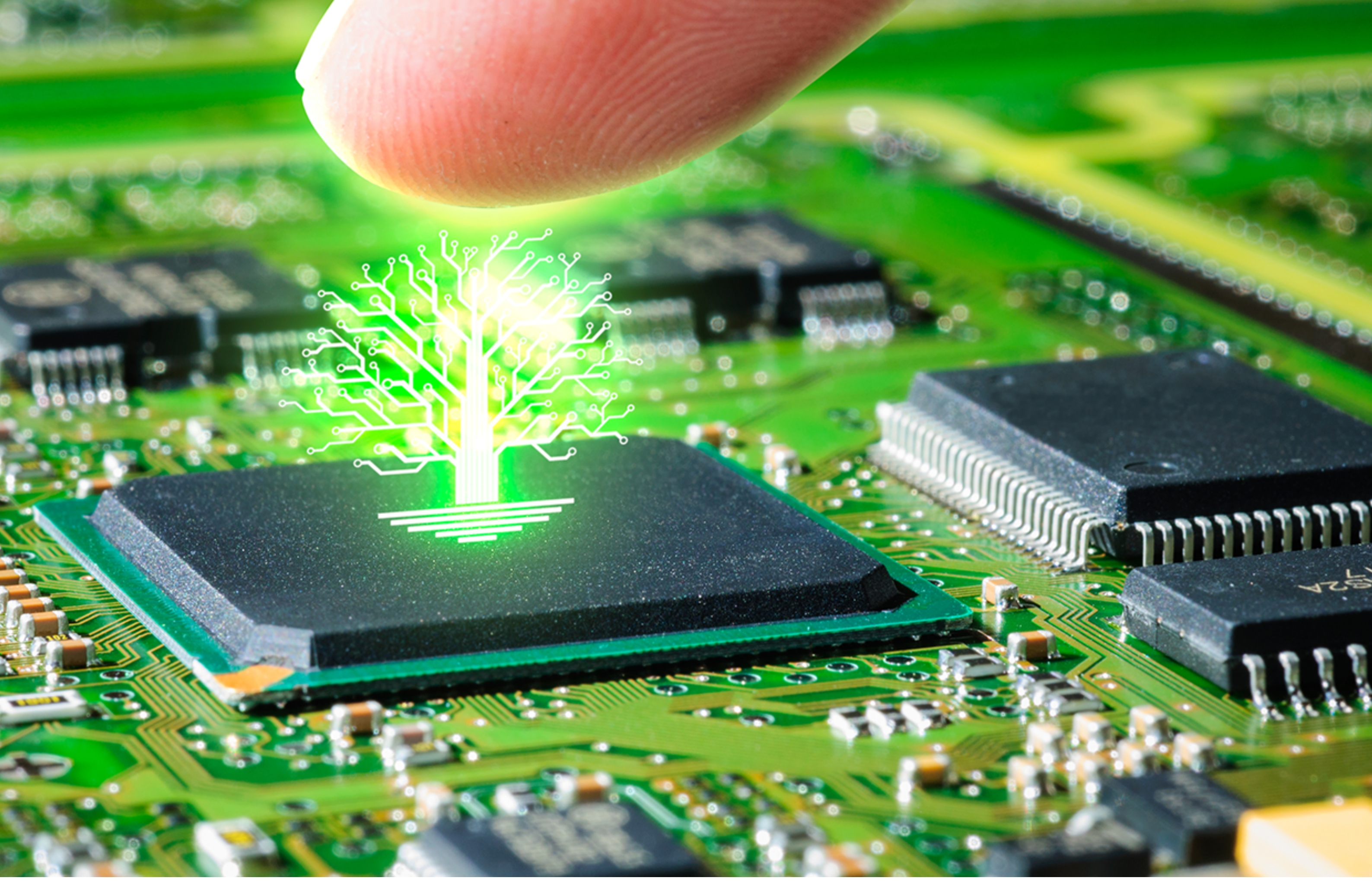

Sustainability for and by Information Communications Technology (ICT)

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Executive summary

The power consumption of digital services is dramatically growing and is under increasing focus of ICT OEMs (Original Equipment Manufacturer), industry, external environmental organizations and governments working to reduce carbon emissions to meet high national and international targets. Increasing energy effectiveness is countered by an exponential increase in data generation, for some time being far in excess of the efficiency gains in ICT hardware capacity that the OEMs have made and will continue to make.

The growth in social networking, often characterized by HD-image generation, transmission and storage is fuelling a great deal of the growth in power demand, even though this is only available to less than 40 per cent of the global population. As internet access expands to the remaining >60 per cent the growth in power consumption will accelerate at a higher rate.

This White Paper describes the problem of energy growth and, to offset that growth, considers the carbon-reducing solutions that some ICT applications make possible. This paper considers uses, such as social networking, to the rather more noble ambitions of low-carbon enablement, information, education, medical, security and governmental services. It raises the question of the future traffic of the internet and possible regulation, access, pricing, taxation or even bandwidth limitation. We hope that it stimulates debate surrounding the value of the digital services that the internet could provide.

In the commercial sector ICT is predominantly used for business efficiency and is, in itself, an efficiency enabler providing indirect gains via improvement of productivity or directly via improved planning, material reduction or dematerialization and substitution. It is also the case that inefficient use of ICT (mobile applications for example) can be justified since the overall benefit is still a net positive on productivity grounds.

There is clearly a difference between ICT applied to commercial use versus that used for consumer and entertainment and one dramatic conclusion could be that some applications that feed the power growth curve are not globally sustainable without price intervention or a paradigm shift in ICT hardware and network infrastructure effectiveness, or, more simply put: is social networking sustainable?

The definition of sustainability

The route to true sustainability, according to the classical definition, has three distinct steps, each having to be taken in strict order:

1. Reduction in consumption of the end-product
2. Improvement in 'efficiency' of the process
3. Draw the power required from renewable sources

For ICT in particular we have a problem with the first step, 'reduction in consumption'. We shall see that the demand for digital services continues on an exponential growth curve, both from existing internet users in the established first-world regions and new internet users in the developing third-world. Additionally, the power demand emanating from digital services growth has consistently out-stripped the advances in technology. With the present technology paradigm power consumption is only set to grow despite any efforts to slow the growth through technical interventions.

For the second step, 'improvement in efficiency', we have made substantial progress, e.g. low power microprocessors, higher efficiency power-supplies in ICT hardware, decreasing power requirement per packet of data transmitted over the internet, virtualization of hardware to increase hardware utilization, data centres with low infrastructure power overheads (low Power Usage Effectiveness (PUE)). However, hardware utilization (and the idle power of that hardware) is a key factor in both the first and the second steps to sustainability and we shall return to this problem.

For the third step, 'power from renewable sources', the problem is the same as that for every other consumer of energy in the world; for the foreseeable future, energy available from renewable sources will only be a proportion of the total power available and needed. Hence, in a world dominated by carbon based energy and nuclear electricity generations the target of achieving true sustainability for ICT in isolation is more than ambitious. The question 'why should ICT be powered only by renewable power?' should be asked, because there is no obvious or logical answer. Environmental campaigns against data centre services, such as Greenpeace targeting data centres (under the headline 'How dirty is your data?'), only serve to confuse issues since each national fuel mix dictates the carbon content of the power delivered by the grid, e.g. 0,45 kg/kWh in the UK compared to 0,06 kg/kWh in France, reflecting the 85 per cent difference between a high proportion of natural gas based generation in the UK and predominance of nuclear generation in France. But are we interested in 'low carbon' or 'sustainable', since (as the theory goes) it is carbon emissions that are causing climate change? The business entity or end-user can purchase renewable energy certificates, or generate a proportion of their demand from renewables on site, but the availability of renewable energy in the grid network is entirely dependent upon the national power policy and is a finite resource; for every 'clean' Watt that an ICT application burns involves some other application burning a 'dirty' Watt – a zero-sum game for the planet albeit distorted between countries.

Can a conclusion be reached about the definition of sustainability of ICT? Is one such conclusion 'Feeding an underutilized and inefficient process/facility, that is not enabling a low-carbon solution with 100 per cent renewable energy, is a waste of that valuable resource'?

The definition of energy efficiency

The classical definition of energy efficiency is the ratio of 'work output' to 'energy input'. A machine for lifting will therefore compare the ratio of power to lift to power 'in', expressed as a simple percentage, e.g. 85 per cent – with 15 per cent of the input power being 'wasted' in the process and usually manifesting itself as waste heat.

For digital services we can measure the input energy accurately – usually electrical energy in kWh – but it is impossible to measure, or estimate without some form of proxy, the 'work output'. In this respect the terminology 'effectiveness' rather than 'efficiency' is more useful and PUE – the globally accepted data centre infrastructure energy metric – reflects the correct view.

Consider that a data centre takes in energy and outputs both digital services and 100 per cent of the input energy as waste heat (plus any solar-gain from the building fabric itself). The re-use of that waste heat is a topic for much discussion and consideration but we should bear in mind that we have rarely considered the waste heat from the 'old' industries such as iron/steel/aluminium production – or indeed from electrical power generation itself, although district heating schemes are an established, if not common, solution.

The re-use of waste heat from the production of digital services, particularly from data centres, is the target of new international standards.

So, we can improve (reduce) our PUE and be 'more effective', or even 'greener' (if you allow the confusing terminology), but we need to consider additional metrics surrounding the data centre infrastructure and role before we can claim any sort of 'energy efficiency' or 'green' credential.

The internet and network connectivity growth

The internet originated in 1969 with the Advanced Research Projects Agency connecting four major US universities, intending to be a communications network with the ability to survive a military attack on the traditional infrastructure. The development of the network that we take for granted today is far more recent:

- Email was innovated in 1972, using the @ symbol
- Designed in 1973, TCP/IP became the standard communication between computers by 1983
- The word 'internet' was used for the first time in 1982
- In 1984 the Domain Name System (.com, .org, etc.) was established
- The origins of America Online offered email, bulletin boards and news from 1985

- In 1989 the term 'World Wide Web' was coined
- By 1993 only 1 per cent of internet traffic was between 'www' connections
- In 1996 only 45 million people were using the internet, 30 million of them in North America and 9 million in Europe. In that year 43 million USA households owned a PC but only 14 million of them were online
- 1998 saw Google open its first office
- By the beginning of 1999 internet users worldwide reaches 150 million, more than 50 per cent being in the USA
- In 2002 c10 billion electronic messages were sent daily by the 544 million users worldwide and Wikipedia was created. In the USA 164 million people (59 per cent of the population) were using the internet
- 2003 saw c2,6 billion illegal music downloads, SPAM accounted for 50 per cent of all traffic and Apple introduced iTunes. The 'Controlling the Assault of Non-Solicited Pornography and Marketing Act' was signed by President George Bush
- During 2004 viruses MyDoom and Novarg spread through internet servers and infected 1 in 12 of all messages whilst internet based shopping increased by 26 per cent in one year to US$117 billion
- In 2005 YouTube.com was launched and there were more than 90 million websites online
- In 2013 an interruption to Google services was reported to reduce the global internet traffic volume by 40 per cent

In September 2013 the exponential acceleration of internet connections continues with over 1,7 billion connections and 2,7 billion users worldwide (37 per cent of the global population). Billions of other sensors and devices are connected, via intranets, to form the 'internet of things' whilst hardware sales contributing to the connectivity growth include 560 000 computers and, probably more importantly, 2,8 million mobile phones delivered every day. The pervasive mobile phone has, with its camera and internet connectivity, become one of the largest growth generators in digital data and the developments from 3G to 4G has only served to accelerate mobile data generation.

Exponential data growth

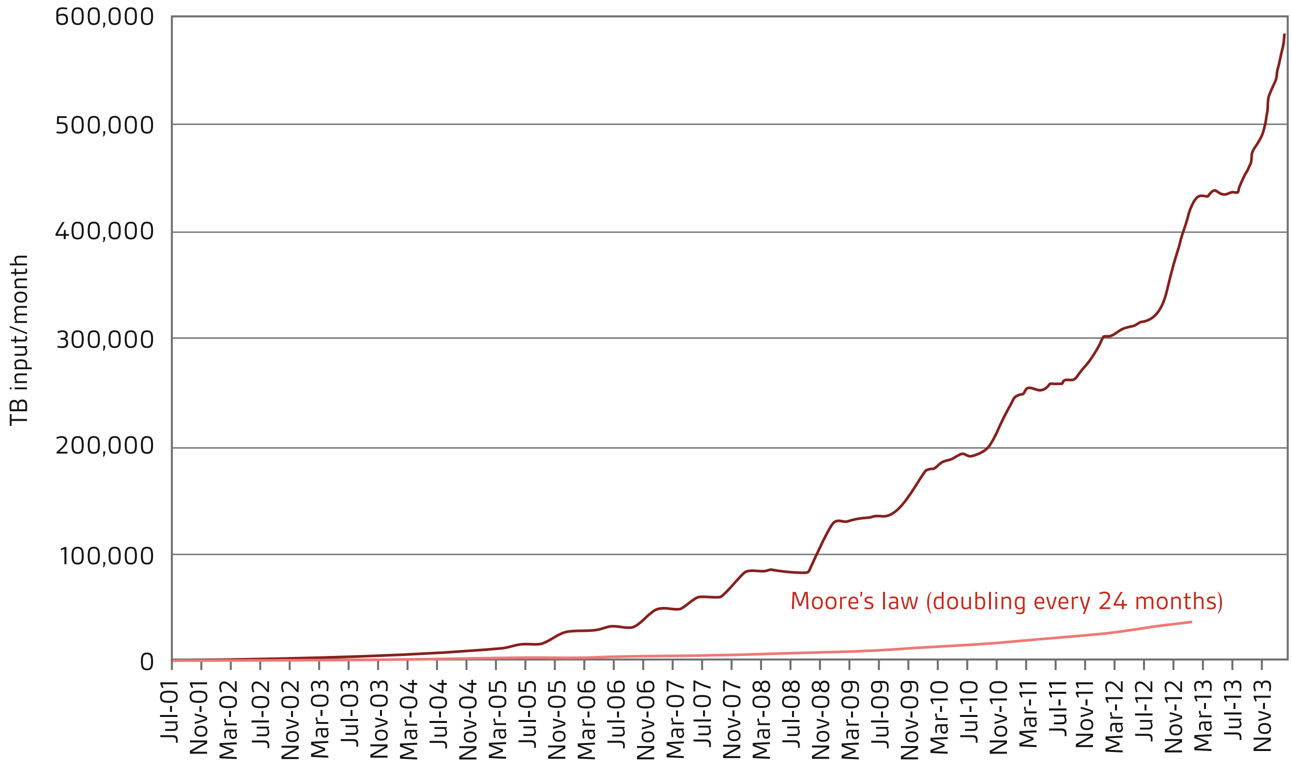
The growth in data generates a growth in power consumption to drive the transfer, storage and processing and re-transmission devices. Whilst we are now witnessing more than 100 million emails being sent per day it is the attachments to those emails that represent >98 per cent of the traffic by file size volume but even this is dwarfed by the 2,3 billion Google searches per day – each most often resulting in downloading large quantities of digital items; text, data, still and video image files (predominately high definition), music, etc. and there are numerous published examples of the resultant growth.

In a 2009 paper sponsored by the Japanese government and authored by S. Namiki, T. Hasama and H. Ishikawa[1] it was shown that Japanese internet traffic was growing exponentially. Broadband subscribers between March 2000 to July 2007, rose from 0,22 million to 27,76 million and the result was a 40 per cent Compound Annual Growth Rate (CAGR) in daily average JPIX traffic (Japanese Internet Exchange). Fibre-to-the-Home (FTTH) was the biggest driver with the traffic growing from 324 Gbps in November 2004 to 722 Gbps by May 2007. By September 2007 there were 10,52 million FTTH subscribers which reached c25 million subscribers by the end of 2010, with a download volume per user per day of 225 MB. The 2013 figures indicate that the Japanese download rate per household (widely regarded as amongst the most highly connected in the world) has exceeded 350 MB and will continue to accelerate with the advent of 4K ultra-high definition 3D TV. The paper links data growth to power consumption and the conclusion was dramatic in that the current technologies can't scale to the future traffic and that Japan needs a new technology paradigm with 3–4 times the energy reduction on today's technology to avoid the internet routers consuming 100 per cent of the 2005 grid capacity by 2030. With the 2011 Fukushima Daiichi nuclear disaster dramatically changing the future energy policy of Japan, the papers conclusions are even more striking.

- At the Photonics West 2009 Conference in San Jose, L. Paraschis of Cisco correctly predicted that '20 US homes with FTTH will generate more traffic than the entire internet backbone carried in 1995'. In 2013 Cisco commented that 'networks were going to be pushed to the edge' by the whole of traffic forecast in the very near future.

1 From the Network Photonics Research Center of the National Institute of Advanced Industrial Science and Technology. http://www.researchgate.net/institution/National_Institute_of_Advanced_Industrial_Science_and_Technology/department/Network_Photonics_Research_Center

Figure 1 — Amsterdam International Internet Exchange – monthly input traffic (TB) July 2001–January 2013



- Vodafone reported in their 2011 Annual Report a 79 per cent data growth in one year in their 3G mobile network. 4G will enable increased capacity and growth.
- YouTube started to describe their website traffic in terms of hours of conventional TV broadcast compared to the monthly upload that their users generate. Only two years ago it was 120 years, then 170 years and now, in 2014, more than 300 years' worth of TV network broadcast is uploaded every month.
- The Amsterdam International Internet Exchange (one of the major European hubs) publishes the traffic volume handled every month and the trend from July 2001 to January 2014 is characterized by consistent exponential growth. The data growth, graphically shown in Figure 1, is 'data input' and the curve for 'data output' is very nearly identical on a monthly basis. The 'input' growth has increased from 690 TB to 578 000 TB per month in the last 13 years and the continuous exponential growth pattern is clear. The development in ICT hardware capacity (characterized by Moore's Law with a doubling of effectiveness every 24 months) has clearly always lagged behind demand.

To characterize the impact upon traffic during an outage in digital services there is the recent Google example where it was reported that there was a 40 per cent reduction in global internet traffic during a service outage.

However, the clear evidence for exponential increase in data production and transmission growth is matched, if not exceeded, by the growth in online data storage and the present consumer and business demands for 'instantaneous and always-on access' to stored data also results in continuous power consumption – which is an important area that may require close review in the future if energy reduction is needed to contribute to the sustainability of digital services.

The use of the internet

The internet has become, for the <40 per cent of the world population that benefits from it, a pervasive and essential infrastructure as important as energy, water, sewage treatment and food distribution.

Applications are diverse and not always 'essential' in the true context of a sustainable future for the planet. However it is undeniable that such digital services as social networking (which may not be regarded as a sustainable service) present huge employment opportunities, GDP generation and advertisement revenues, etc. Some services will enable rapid and worthy development of emerging economies and third-world social development – such as education and medical services. That said it is clear that for the 70 per cent of the world's population that do not benefit from what the internet can offer there is a huge untapped reserve of future data generation and associated power consumption. Many uses overlap, for example 'search' and 'education', and some uses enable low carbon enablement of other infrastructure services, such as smart logistics. The following list is not exhaustive, nor is it in any order of importance, value, social-worth or power consumption:

- Reduction in travel, home working and video conferencing, etc.
- Entertainment such as video for home cinema and digital TV services, books, music, electronic online games, ticketing
- Mapping, routing, GPS, travel and vacation
- Medical, health records, online diagnosis
- Education, resources, online courses
- Enablement for smart grids, smart manufacturing and smart logistics – the 'internet of things', with billions of sensors online

In many of the developed countries of the world (and especially the UK) digital services (or the businesses enabled by those services) have replaced manufacturing as the primary generator (or enabler) of GDP growth and employment. Such businesses as call centres (enabled entirely by ICT and web-based information) now employ more than 1 million in the UK and, along with all of the other applications, rely on connectivity via the internet to the heart of the ICT system; data centres – the digital 'factories of the future'.

We can see that data growth is generated by increasing levels of digital-based businesses and, very importantly, at ever lower costs. Bandwidth, for businesses and private consumers alike, is dramatically competitive and as the price comes down the capacity becomes 'unlimited', at least in the advertisements. This increasing 'efficiency' (more capacity for less cost) is in itself exacerbating the problem of power consumption, just as forecast and described by William Stanley Jevons in his book *The Coal Question*, published in 1865. In response to a dramatic shortage of coal in the cotton mills of Manchester in the mid–1860s many commentators heralded the replacement of Newcomen steam engines (2 per cent fuel efficient) with those of James Watt (6 per cent fuel efficient) as a solution to the problem. However, Jevons wrote 'It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth', which quickly became known as 'Jevons Paradox'. Proven correct at the time (coal consumption escalated as more steam engines were installed as businesses could now afford the reduced fuel costs per unit of work) and for the past 150 years it is now often referred to as the 'Rebound Effect' and is used extensively today in energy planning. Today's low cost of internet access and ability to generate and disseminate data only serves to increase the usage – probably demonstrated best by the use of smart phones in taking HD digital images and posting them in proliferation to the internet for all to see.

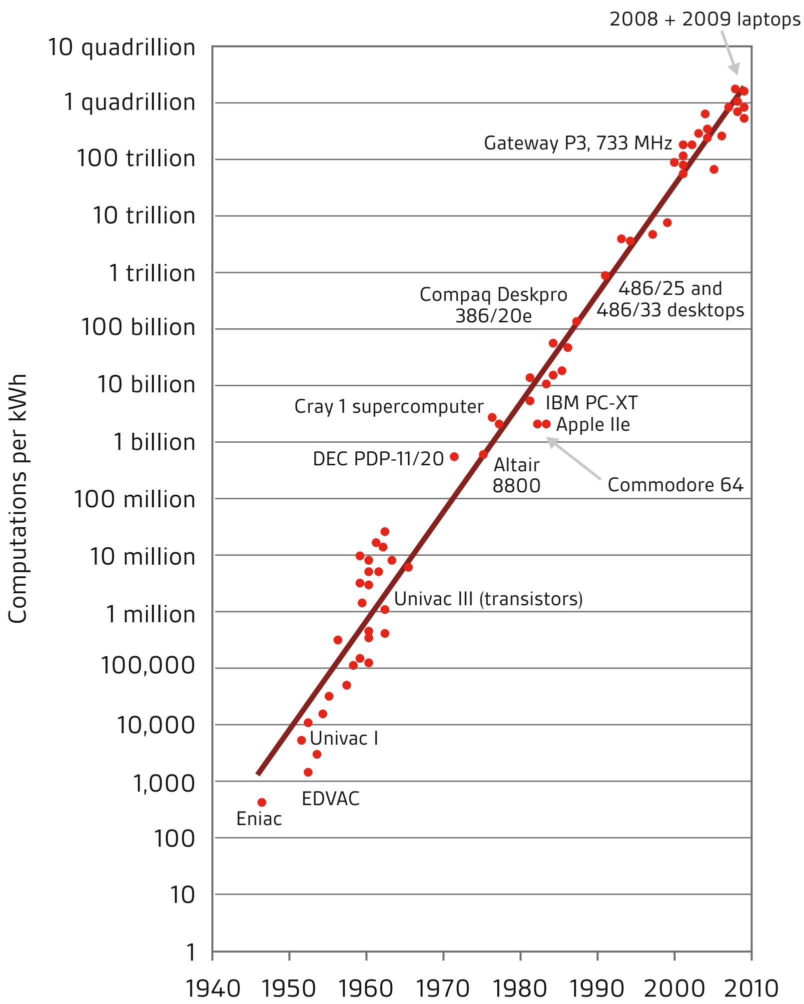
Power consumption

The power consumption of ICT hardware has improved in line with Moore's Law, essentially on an exponential 40 per cent CAGR. Gordon Moore was a founder of Intel and c40 years ago he predicted the doubling of the number of transistors on a single microprocessor every two years. His Law has held true ever since and also applies to a doubling of the compute capacity, a halving of the Watts/FLOP and a halving of the energy used (kWh) per unit of computations every two years. Figure 2[2] shows how accurately Moore's Law has been followed for 'Computations per kWh' from 1945 to 2010.

Within the date range that Moore was directly interested in, transistors on a single photo-etched chip grew from 2 300 in 1971 to over 2,6 billion by 2010, an 11x106 increase. In the Amsterdam Internet Exchange traffic growth curve shown in Figure 1, the reader can see the technology capacity growth curve represented by Moore's Law and, staggering though the technological advances have been, it is totally eclipsed by the exponential growth in data.

2 Copyright Koomey, Jonathan, 2014. Reproduced with permission. Source of data: Koomey, Jonathan G., Stephen Berard, Marla Sanchez and Henry Wong. 2011. "Implications of Historical Trends in The Electrical Efficiency of Computing." *IEEE Annals of the History of Computing*. vol. 33, no. 3. July–September. pp. 46–54. http://doi.ieeecomputersociety.org/10.1109/MAHC.2010.28

Figure 2 — Historical trends in the electrical efficiency of computing



Source: http://doi.ieeecomputersociety.org/10.1109/MAHC.2010.28.

Shortly after Moore published his forecast it was revised to 18 months by Intel to accommodate the increase in clock-rate of the microprocessor and, more recently, Raymond Kurzweil (the American futurologist responsible for many patents and the book, *The Singularity is Near*) now suggests that the doubling in capacity is less than every 1,2 years. This continuous technology effectiveness improvement encourages ever shorter hardware refresh rates. Organizations such as Facebook refresh server hardware every 9–12 months to slow down the rate of increase of data centre space and power so as to cope with the data growth experienced by their service. It is generally accepted that any refresh rate longer than three years will penalize the user on the cost of power. However, for multi-service ICT platforms found in general business and governmental digital service provision (unlike monolithic 'search' or social networking applications) the question of server utilization offers a far greater opportunity for energy reduction. At the heart of the utilization battle is server virtualization software that can lift the traditional utilization from 10 per cent to 40 per cent and higher. High Performance Computing (HPC) platforms can raise the server utilization to higher than 85 per cent but are generally only applicable for large number crunching routines such as weather forecasting, climate change modelling, avionics and military/security, etc.

An area of much research in 2014 is the idea of characterization of 'productivity' of data services compared to energy consumption. This is relatively easy for large single-task systems and has been led by eBay who have published their productivity data as 'sales transactions per kWh', but it is almost impossible where transactions are not related to revenue, e.g. social services or health record keeping. As an example for consideration; how much 'sustainability' value can be placed on a metric that describes the kWh consumption per photo uploaded to a social networking site? Certainly the metric is useful, if not essential, for business planning and costing of advertising rates but has little meaning outside of the individual digital services organization.

As in most system analysis it is worthwhile considering the performance near the extremes in order to put into context the problem, the way we currently use the internet provides many such extreme examples. One such example involves a small part of the equivalent of 300 years of TV broadcast that is uploaded to YouTube every month:

> On July 15th 2012 the Korean pop star Psy uploaded his latest video, called Gangnam Style, to YouTube. This HD-video file was 17 MB and streams for just over 4 minutes. As it passed its first anniversary it had been streamed 1,7 billion times, equal to the global number of internet connections. Taking some published data for the power used in streaming, transmitting and viewing image data we can estimate the order of the power consumption for just this one pop-video:
>
> - TIME Magazine recently reported that it takes 0,0002 kWh of energy to stream 1 minute of video from the YouTube data centre
> - Jay S Walker – American inventor, entrepreneur, Chairman of Walker Digital and patron of Technology, Entertainment, Design (TED) at their annual conference in Monterey CA – postulated that 0,01 kWh is used to download 1 MB over the internet
> - The average internet terminal device consumes 0,001 kWh in streaming 1 minute of video
>
> These relatively small amounts of energy transform into 312 GWh when 1,7 billion downloads in a year are taken into the calculation – equivalent to 36 MW of continuous diesel generation, 100 million litres of fuel oil, 250 000 tonnes of CO_2 or the equivalent emissions of 80 000 UK average car-years. However, and more sobering, this is also more energy than the sub-Saharan country of Burundi uses (273 GWh, 2008) for their entire 9 million population for the same period. Just one, albeit exceptionally popular, pop-video and 0,0000025 per cent of the monthly YouTube upload statistic that challenges the whole concept of sustainability in ICT.

Although it is very hard to determine with accuracy how much energy ICT consumes in the UK it is generally accepted that it is in the 6–8 per cent range, with one third of that (2 per cent) being consumed in data-centres. However with exponential data growth only being tempered by technology improvements (derivatives of Moore's Law) and virtualization software it is clear that, unfettered by regulation or taxation, the power demand would grow as a percentage quite rapidly, e.g. if 6 per cent was taken as the 2012 baseline then it will grow to an unsustainable 15 per cent by 2021 and, similar to the Japanese prediction, to a ludicrous 100 per cent before 2028. There is no doubt that a paradigm change in technology (probably graphene replacing silicon) will rescue us from the possibility but, to date, the timing of such change is not clearly forecast.

The only conclusion that can be made regarding the difference between data-generation and power consumption is that an absolute reduction in power consumption is not possible without market intervention (restriction of access to certain services, price or tax) or a technology paradigm shift as concluded by the Japanese Photonics Institute paper.

Normal supply and demand economics will act to increase both cost and supply of energy in these scenarios, making these end scenarios unlikely (if not impossible) to reach. If anything the case could be made for unblocking the response to market forces, i.e. less market intervention.

Low-carbon enablement using the internet and IT

The typical uses to which the internet is put have been listed on page 6 and link together to provide low-carbon solutions, such as internet based shopping reducing collection/delivery carbon-footprint (such as routing algorithms designed to plan truck delivery operations to minimize fuel costs) and some are intertwined for multiple use, such as search-education-business. What did we do before Google et al were available on our smart-phones to reach out for information or check facts in all aspects of our working and leisure life? A good example is the ways businesses (of many diverse kinds) advertise and inform potential and existing customers using YouTube – it is now not uncommon to find 'user-guides' and 'operating instructions' on the web as video downloads, and not just 'tap-dancing dogs'.

Some commentators have questioned if the classic 'video conferencing' and 'home working' carbon-reduction claims have sufficient impact on the overall eco-system but there can be no doubt that such enabled services have transformed our business lives.

Future areas for standards?

Standardization has some significant advantages over regulation as it allows the context of use and overall system requirements to be balanced against use of the standard by those involved.

The areas for consideration include the energy consumption of:

- Terminal devices; cameras, phones, PDAs, pads, notebooks and desktops
- Network components and, importantly, their utilization
  - Servers
  - Storage
  - Transmission
- Energy effectiveness of software (an extremely hard subject to define let alone standardize or benchmark)
- Data centre infrastructure
  - EU Code of Conduct on Data Centre Energy Efficiency
  - PUE when linked to local regulations (for example the maximum target PUE set by Amsterdam city planners) or reduction in carbon taxation
  - Climate Reduction Committment (CRC), now to be replaced by a CCA, Climate Change Agreement, for certain data centres

However, it is worth noting that isolating separate elements for energy optimization in the end-to-end ICT system may be possible and practical but it is the optimization of the overall system that is more important – and that is usually not in the control of a single controlling entity. For example it can be shown when carrying out company-wide ICT footprints that concentration of consumption in data centres can be a factor for the common good.

If we were to consider regulation (by legislation) rather than standardization we have to accept that the record of intervention is not good to date. Unintended consequences are common place in wide-ranging energy efficiency instruments – for example where a data centre gains a higher rating under facility-design due to a higher level of insulation being installed, the consequence being that more mechanical cooling energy has to be expended to remove the heat generated by the ICT hardware housed within the insulated box.

BSI are already very active in these areas via the UK committee IST/46, following and contributing to ISO work within the committee in ISO/IEC JCT1 SC39 WG1 'Resource Efficient Data Centres' and WG2 'Sustainability by ICT'. The metrics currently under development include:

- PUE Power Usage Effectiveness (based on The Green Grid innovation)
- WUE Water Usage Effectiveness (based on The Green Grid innovation)
- REF Renewable Energy Factor
- CUE Carbon content in the energy consumed
- ITEE IT (hardware) Energy Efficiency
- ITEU IT Equipment Utilization

BSI is also very active in the development of EN 50600, *Data centre facilities and infrastructure*, which includes efficiency enablement in infrastructure. Many other organizations are working towards the same goals of reducing the power consumption per unit of demand, including EPRI, The Green Grid, ETSI and ITU.

Conclusions

Data growth results in increased power demand and we have seen that an absolute reduction in ICT power is unlikely to happen as long as the demand for services continues to outstrip technological progress in energy effectiveness. Data growth has been exponential for many years and increasing access at ever lower costs brings the effect of Jevons' Paradox, particularly in social networking applications, that will only serve to exacerbate the growth in data generation and, hence, power demand.

Most governments have digital agendas (improved connectivity via fast and super-fast broadband) for both business and domestic users and, at the same time, have important carbon reduction plans from electricity generation, e.g. to meet Kyoto commitments. However, few legislators appear to realize that the very provision of fast broadband for all (and at an affordable cost) will generate a power demand growth curve that will conflict directly with their plans for a reduction in power generation.

The use of ICT and the internet for education, medicine, social services and business/trade enablement is an essential part of the development of the third-world but, as far as 'non-essential' applications are concerned, it is an unpalatable political and social position to have to consider limitation of access to certain services by cost (taxation) or by regulation.

In the future internet access will become a privilege not a right.

Vint Cerf, 2011. Inventor of the IP address and father of the internet.

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