THE CLOUD BEGINS WITH COAL

BIG DATA, BIG NETWORKS, BIG INFRASTRUCTURE, AND BIG POWER

AN OVERVIEW OF THE ELECTRICITY USED BY THE GLOBAL DIGITAL ECOSYSTEM

Mark P. Mills
CEO, Digital Power Group
www.tech-pundit.com

Sponsored by:
National Mining Association
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Contents

This report provides an independent assessment of the technical literature and the nature of existing estimates and surveys of electric demand in the global and U.S. ICT ecosystems. This analysis was supported in part by the National Mining Association and American Coalition for Clean Coal Electricity. DPG is responsible for the contents of this report and the analyses contained herein. The analysis and the graphics developed during the course of this research represent the independent work and views of DPG and are intended to contribute to the dialogue on the present and future energy requirements of the ICT ecosystem.

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Report graphics drawn by Bankesh Thakur

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EXECUTIVE SUMMARY

The information economy is a blue-whale economy with its energy uses mostly out of sight. Based on a mid-range estimate, the world's Information-Communications-Technologies (ICT) ecosystem uses about 1,500 TWh of electricity annually, equal to all the electric generation of Japan and Germany combined -- as much electricity as was used for global illumination in 1985. The ICT ecosystem now approaches 10% of world electricity generation. Or in other energy terms – the zettabyte era already uses about 50% more energy than global aviation.

Reduced to personal terms, although charging up a single tablet or smart phone requires a negligible amount of electricity, using either to watch an hour of video weekly consumes annually more electricity in the remote networks than two new refrigerators use in a year.[1] And as the world continues to electrify, migrating towards one refrigerator per *household*, it also evolves towards several smartphones and equivalent per *person*.

The growth in ICT energy demand will continue to be moderated by efficiency gains. But the historic rate of improvement in the efficiency of underlying ICT technologies started slowing around 2005, followed almost immediately by a new era of rapid growth in global data traffic, and in particular the emergence of wireless broadband for smartphones and tablets. The inherent nature of the mobile Internet, a key feature of the emergent Cloud architecture, requires far more energy than do wired networks. The remarkable and recent changes in technology mean that current estimates of global ICT energy use, most of which use pre-iPhone era data, understate reality. Trends now promise faster, not slower, growth in ICT energy use.

Future growth in electricity to power the global ICT ecosystem is anchored in just two variables, demand (how fast traffic grows), and supply (how fast technology efficiency improves):

- As costs keep plummeting, how fast do another billion people buy smartphones and join wireless broadband networks where they will use 1,000 times more data per person than they do today; how fast do another billion, or more, join the Internet at all; how fast do a trillion machines and devices join the Internet to fuel the information appetite of Big Data?
- Can engineers invent, and companies deploy, more efficient ICT hardware faster than data traffic grows?

To *estimate* the amount of electricity used to fuel everything that produces, stores, transports, processes and displays zettabytes of data, one must account for the energy used by:

- Data centers that have become warehouse-scale supercomputers unlike anything in history;
- Ubiquitous broadband wired and wireless communications networks;
- The myriad of end-use devices from PCs to tablets and smart phones to digital TV, and,
- The manufacturing facilities producing all the ICT hardware.

Hourly Internet traffic will soon exceed the *annual* traffic of the year 2000. And demand for data and bandwidth and the associated infrastructure are growing rapidly not just to enable new consumer products and video, but also to drive revolutions in everything from healthcare to cars, and from factories to farms. Historically, demand for bits has grown faster than the energy efficiency of using them. In order for worldwide ICT electric demand to merely double in a decade, unprecedented improvements in efficiency will be needed now.

Electricity fuels the infrastructure of the world's ICT ecosystem -- the Internet, Big Data and the Cloud. Coal is the world's largest single current and future source of electricity. Hence the title of this paper.

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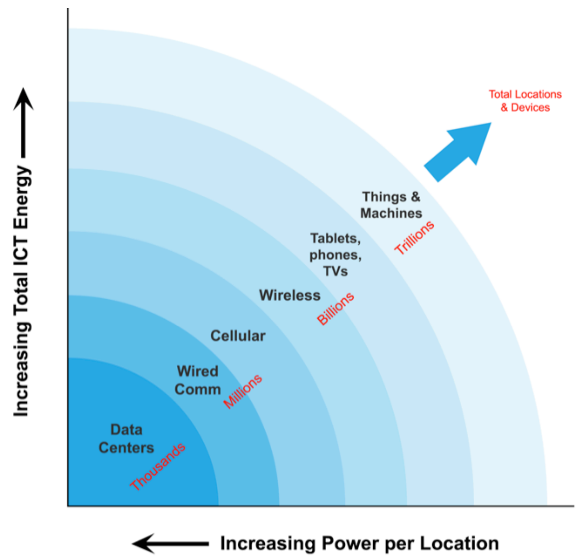
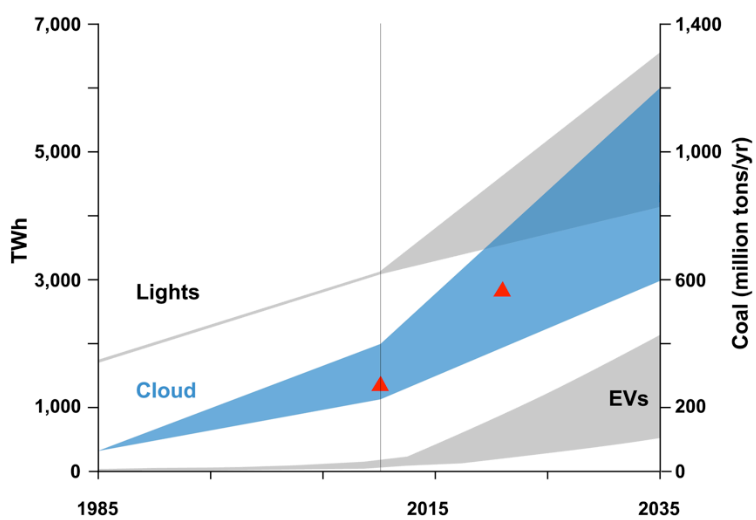
AN OVERVIEW OF THE ELECTRICITY USED BY THE GLOBAL DIGITAL ECOSYSTEM

Where Electricity Is Consumed in the Digital Universe



Global Electricity Demand: The Cloud, Illumination, and EVs



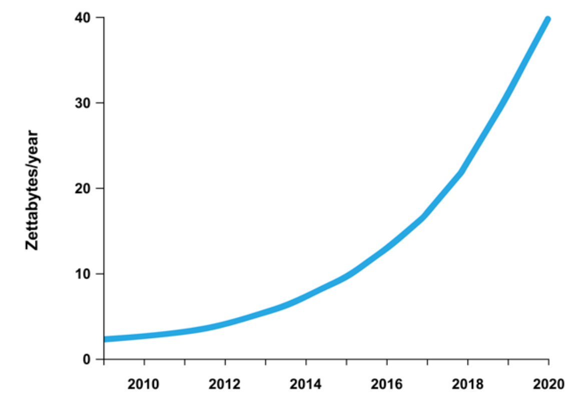
The global ICT ecosystem uses as much electricity as global lighting did circa 1985, and in two decades will likely use triple the energy of all EVs in the world by then, assuming an optimistic 200 million EV forecast.

["Cloud" is used here to refer to the entire global ICT ecosystem, and not to a more narrow definition of Cloud business services.]
[Red triangles indicate global ICT estimates from Greenpeace. Coal use is based on current global 40% share of electricity generation.]

1. PREFACE – WE'VE ENTERED A NEW ELECTRICITY-CENTRIC DIGITAL ERA

Shortly, ***hourly*** Internet traffic will exceed the Internet's ***annual*** traffic of the year 2000. And data created, used and transported annually – the "digital universe" – is now growing at a faster pace than at any time in history. The world is in what Cisco has coined, the zettabyte era.[2] (The unit zetta is a tera times one billion; a zetta-stack of dollar bills would reach the sun and back –- one million times.)

Size of the Digital Universe – Annual Data Created & Consumed

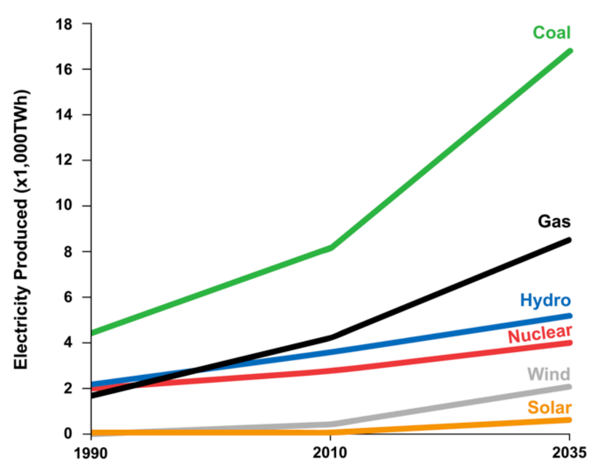


Data Source: IDC Digital Universe 2013

"The digital universe is made up of images and videos on mobile phones uploaded to YouTube, digital movies populating the pixels of our high-definition TVs, banking data swiped in an ATM, security footage at airports and major events such as the Olympic Games, subatomic collisions recorded by the Large Hadron Collider at CERN, transponders recording highway tolls…"

All of this digital traffic requires a huge distributed physical infrastructure of equipment that specifically and almost exclusively consumes electricity. Since coal is the world's largest and fastest growing source of electricity – 68% of additional supply over the past decade and forecast to supply at least 50% for the next decade[3] -- the reality is that **the digital universe and Cloud begins with coal**.

Annual Global Electricity Generated

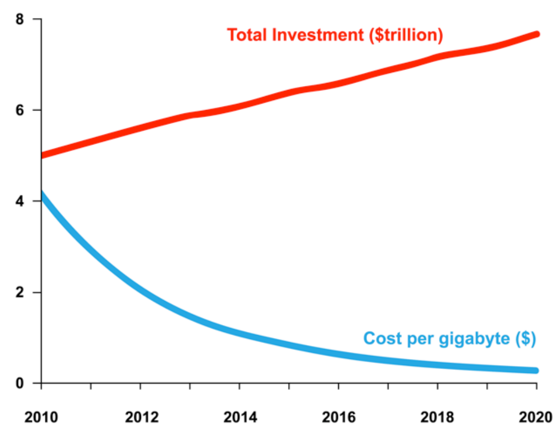


Data Source: IEA

Coal is 40% of global electricity and is forecast, by the IEA, to supply 50% of the growth in world demand over the next 20 years.

Global investment in the infrastructure of the digital economy is already over $5 trillion, and will grow another $3 trillion within a decade. Global Big Data capital spending is now in the same league as Big Oil.[4] But while Big Oil produces energy, Big Data consumes energy, specifically electricity.

Infrastructure Investment in the Digital Universe

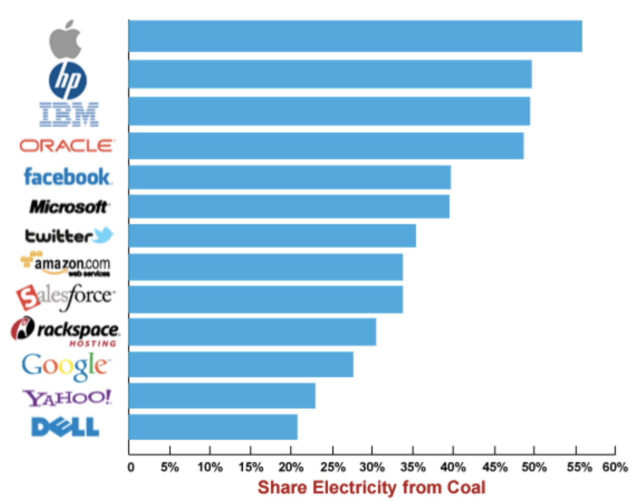


Data Source: IDC Digital Universe 2013

Even as the cost (measured in $ per gigabyte) of IT equipment keeps falling, annual IT enterprise investment keeps climbing.

Information-Communications-Technologies (ICT) -- the Internet, Big Data and the Cloud -- use electricity across every niche of the digital ecosystem, from handheld devices and IT embedded in machines, to data centers, networks and factories. Since all digital bits are electrons -- or optical and RF photons which are quantum cousins to electrons -- astronomical quantities of data eventually add up to real power in the real world. This reality has been noted by Greenpeace, for example, which has ranked the coal dependence of major cloud data center companies.

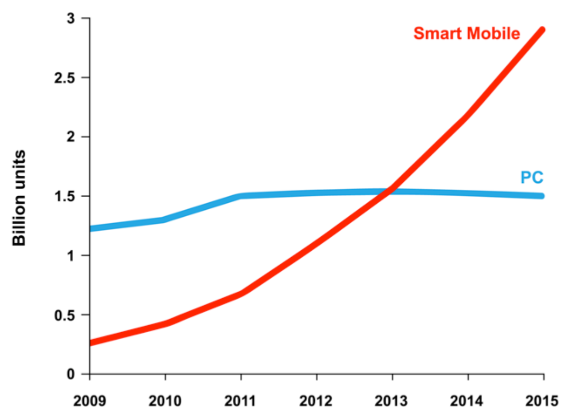
Dependence on Coal for Data Centers



Source: Greenpeace International, How Clean is Your Cloud, April 2012

Now, the scale and the character of the ICT ecosystem are changing. Not only will there be more and bigger data centers coming, but the evolution of computing towards mobile platforms, smart phones and tablets creating the "Mobile Internet" is radically altering where and how data are produced and used, collaterally changing the nature and scale of the network infrastructure.

Global Installed Based of Computing - - The Rise of the Mobile Internet

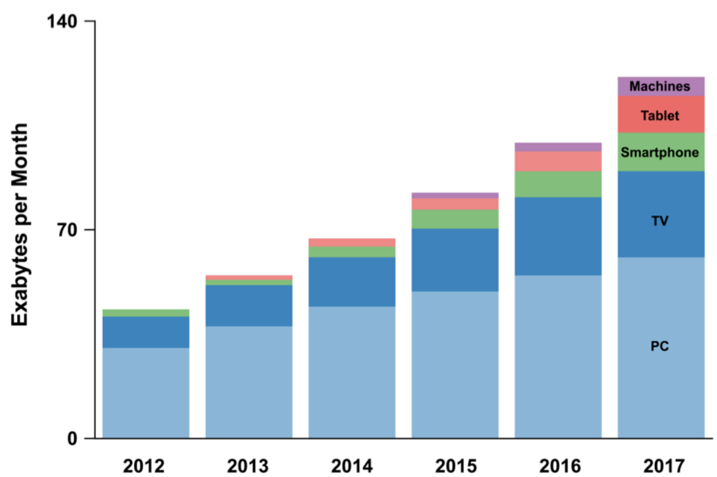


Data Source: *Internet Trends*, Mary Meeker, Kleiner Perkins, 2012 & 2013
PCs (including notebooks) vs. smart mobile (tablets + smartphones)

The Mobile Internet, the Cloud and Big Data revolutions create economic opportunity and generate enormous efficiencies. But just how big is the global ICT ecosystem now, and how big will it become? How much electricity is consumed, and will be consumed in the future, by the entire ICT ecosystem?

The new and emerging digital devices and services for consumer and businesses have created opportunities unimagined in scale or character by any visionary during the heyday of "irrational exuberance" of the 1990s when the Internet began. Soon more data will be associated with non-PC devices than PCs – even as PC-centric traffic itself doubles.

Where Global Data Traffic Originates

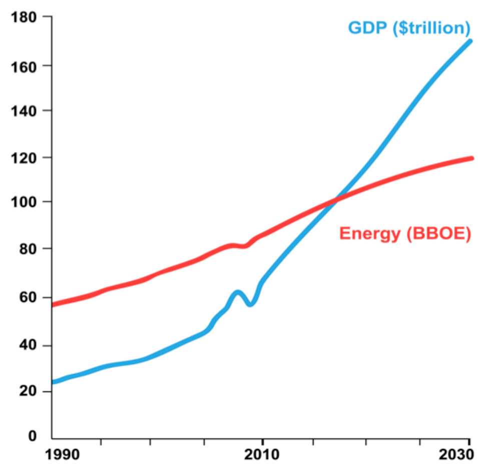


Data Source: Cisco, The Zettabyte Era
At 80 exabytes monthly, the world enters the zettabyte per year era.

2. The Global Context – Energy Demand Grows, But Electricity Grows Faster

Energy forecasting has entered a new era driven by radical changes on both the demand and supply sides of the equation. Population and economic growth are the driving forces in the world's need for energy in general and electricity in particular. Even with substantial gains in efficiency, overall global energy use will rise by an amount equivalent to adding two United States' worth demand by 2030.

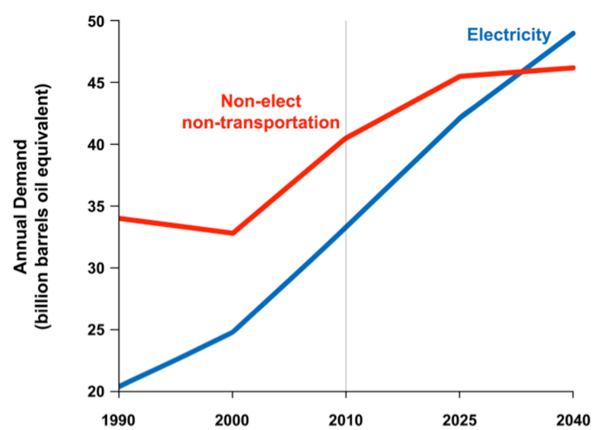
World Energy Use and GDP



Data Source[5]: DOE/EIA; IEA, BP, Exxon. (constant $2010)

Meanwhile, the electrification of everything continues. The world is on track by 2035 to cross a threshold the U.S. crossed in 1995, wherein energy used for electricity exceeds that used for everything else – everything, that is, excluding transportation, which will remain largely non-electrified for decades, even in the most optimistic scenarios. How much of the growth in electricity comes from information technologies and the Cloud?

Global Electric v. Non-Electric Energy Consumption
(Excluding energy used in transportation)

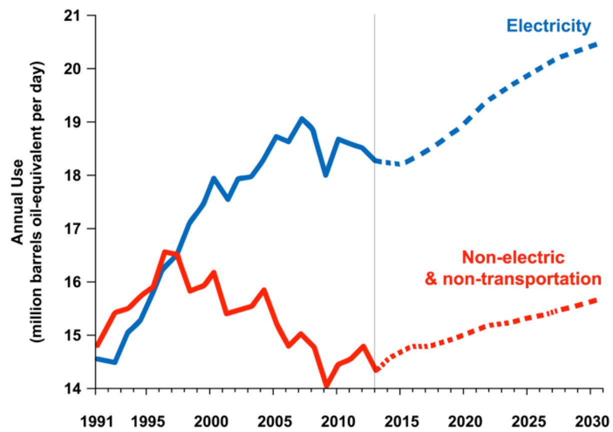


Data Source: Exxon

3. The U.S. Context – Demand For Electricity Grows

U.S. electric demand grew 30% over the past two decades and is forecast by the EIA to grow another 15% over the coming two.[6] Meanwhile, non-electric non-transportation energy use started declining in 1995 – marking a turning point in the continued electrification of the economy. That point in history is contemporaneous with the emergence and growth of the ubiquitous Internet.

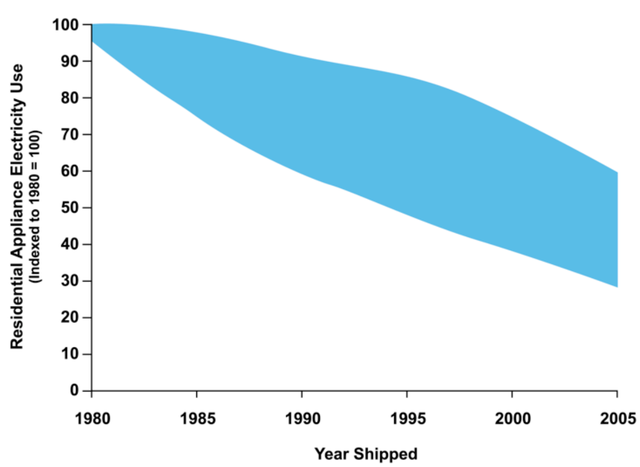
U.S. Electric v. Non-Electric Energy Consumption
(Excluding energy used in transportation)



Data Source: DOE/EIA
A 15% growth by 2030 on top of America's enormous electric system requires additional generation equal to the power system of Germany. Transportation remains largely un-electrified; electric vehicle (EV) penetration remains under 0.1% even by 2035 in EIA forecasts.)

About 80% of electricity is used by three classes of equipment: illumination, cooling and heating, and electric motors. Remarkable efficiency gains in these legacy uses have taken place over the past two decades, a period long enough to see significant turnover to new more efficient equipment thereby moderating demand growth as the economy expanded.[7]

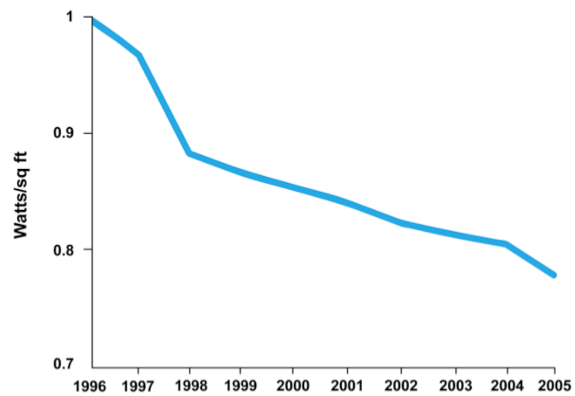
Average Efficiency of Five Major Appliances



Data Source: The Impact of Consumer Electronics on Home Electricity Use, NRDC

Off-setting the gains in average efficiency of conventional equipment are the macro-economic features that drive more demand. Over the past two decades: population and commercial building space both grew 25%, total residential space grew 50%, and GDP and industrial output grew 60% and 50% respectively. Future demand growth will depend on how fast more efficient conventional equipment is installed, and whether there are new uses for electricity.

Average Power Density to Illuminate Commercial Office Space
(Average power per square foot of building space)

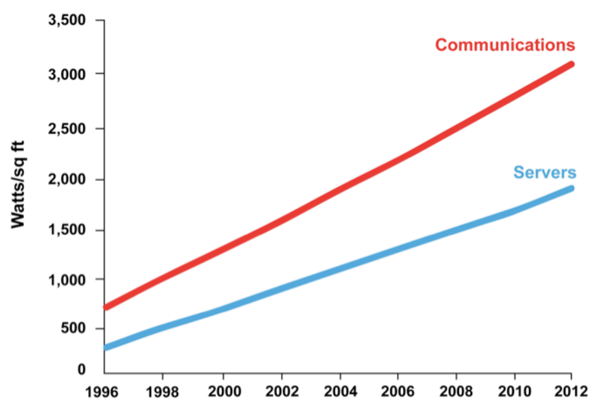


Data Source: Energy Efficiency Trends in Residential and Commercial Buildings, USDOE

A key feature driving the recent and future growth in electric demand is largely buried in the statistics -- the rise of ICT hardware everywhere from the wireless networks, to the gargantuan data centers, to the proliferation of devices in homes and offices, and the factories where microprocessors are made.

Compare the power density trends for illumination (above) with ICT equipment (below), the latter now common in commercial buildings and the only 'occupant' that fills thousands of warehouse-scale data centers. The average square foot of a data center uses 100 to 200 times more electricity than does a square foot of a modern office building. Put another way, a tiny few thousand square foot data room uses more electricity than lighting up a one hundred thousand square foot shopping mall.

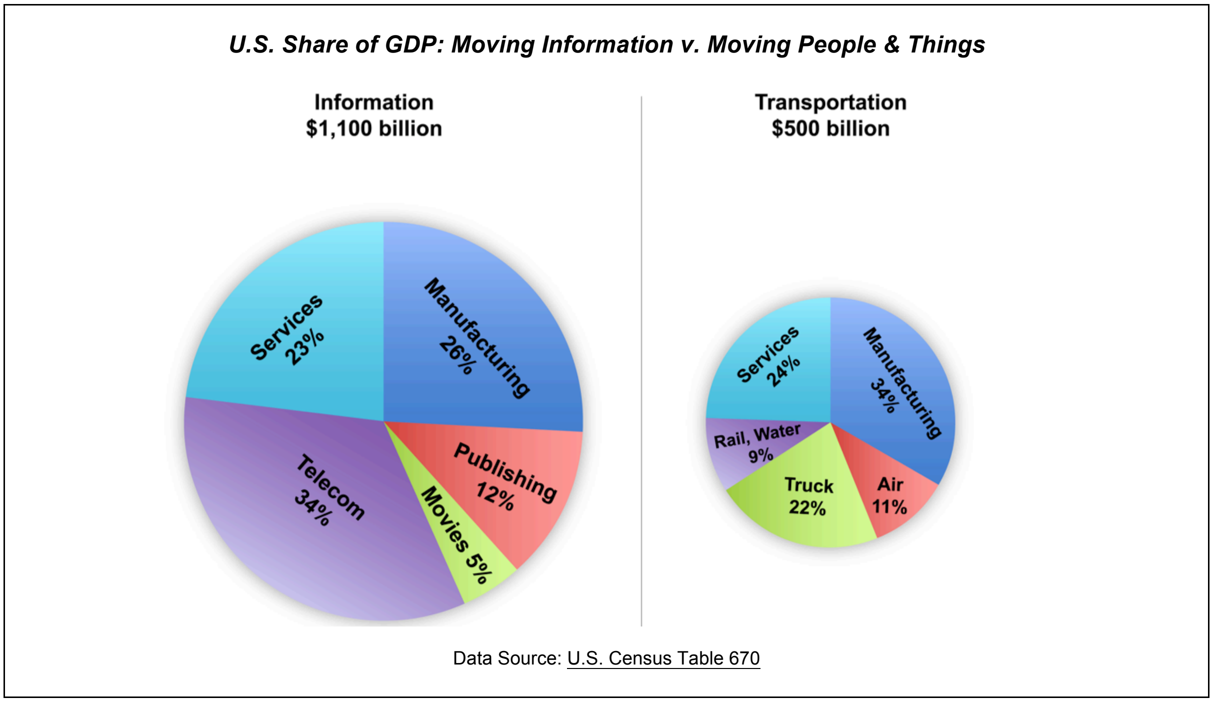
Power Density of Equipment to Process and Communicate Data
(Power density of typical datacenter equipment)



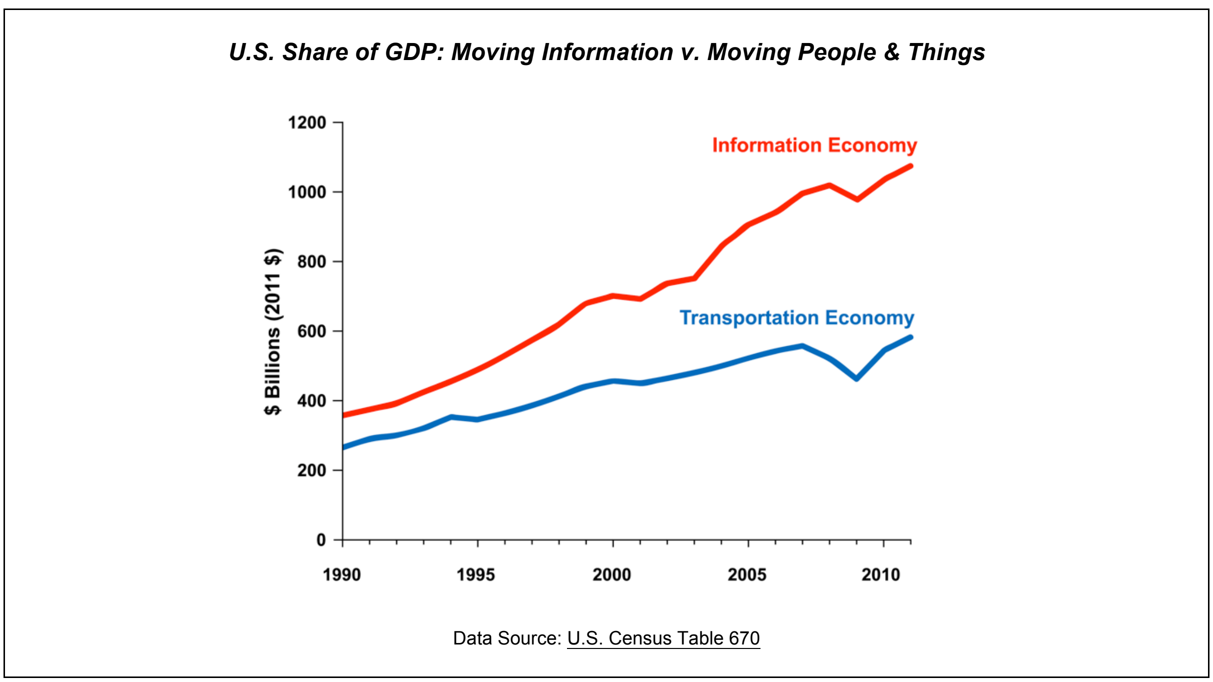
Data Source: ASHRAE Datacom Equipment Power Trends

4. The Rise of the Information Economy – Big and Getting Bigger, Fast

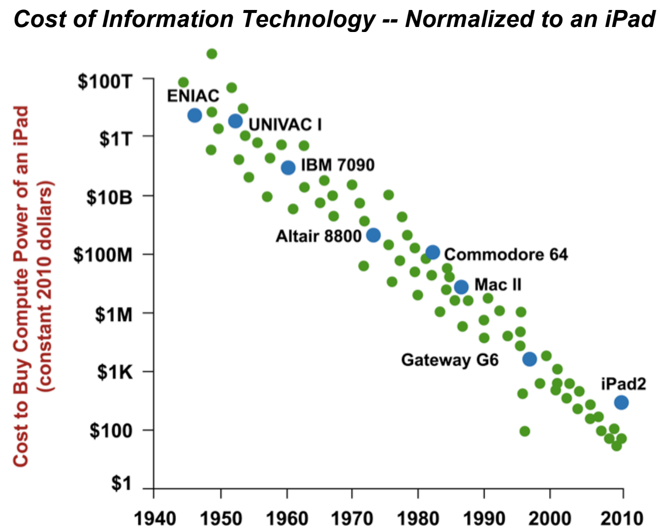
Over $1 trillion of the U.S. economy is associated with the ecosystem of information and data -- *moving bits* – everything from the manufacturing of ICT equipment, to services products and infrastructure. This is more than twice the share of the GDP associated with *transporting people and stuff* – similarly counting everything from vehicle manufacturing to FedEx and all forms of transportation services.



The information sector is now the fastest growing part of the economy. In the last decade, the transportation share grew 15% while the information economy grew 45%.

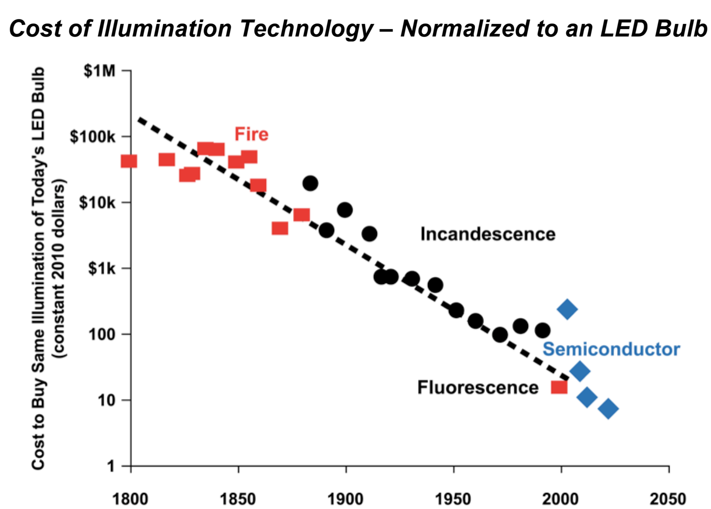


Before exploring information's energy appetite, consider the core driving force for ICT growth: Computing and the networks to connect people and things to computing have become stunningly cheap. Consequently, computing is increasingly showing up everywhere, not just in phones and tablets but embedded in toys, tools and medicine.



Source: A Dozen Economic Facts About Innovation, Hamilton Project
It would have cost $10,000 in 2000, $100 million in 1980, and $10 billion in 1960 to buy an iPad's computing capability

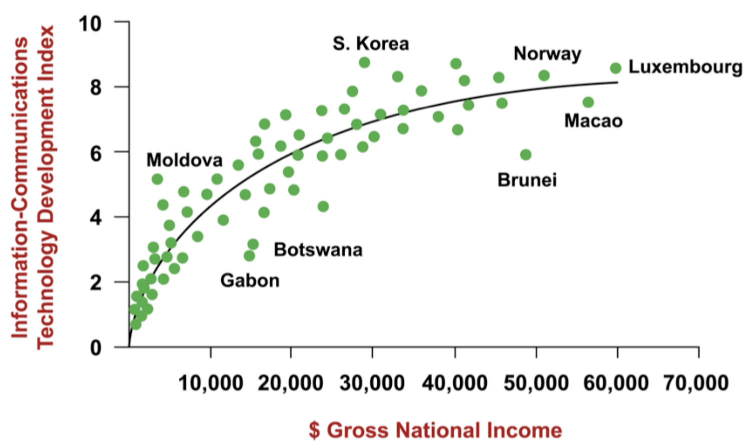
Information technology has declined in real costs in a way that is unprecedented in the history of any product or service. Only lighting technology has had a similar kind of exponential decline in costs. But even there, in 50 years computing costs have dropped a 100 million fold more than illumination technology cost declined in over 200 years. Just as the collapse in the cost of illumination over history has lead to the now ubiquitous use of lumens, so too is the even greater decline in computing costs propelling an even broader diffusion of data.



Data Source: Optoelectronics Industry Development Association Technology Roadmap
It would have cost $5,000 in 1900 and $50,000 in 1800 to buy as much illumination as one $10 semiconductor LED bulb can deliver today.

People can use only so many lumens per square foot, eat so much, or spend so much time in a car, setting limits on total lighting, food and fuel consumption. But the appetite for bits shows no bounds. Even prosperity for emerging economies is no longer measured just by the penetration of electricity and light bulbs (though that is still vital), but by bits-per-capita. This is a radical shift from the 1980s when economists puzzled over ICT's 'hidden' productivity gains. Nobel economist Robert Solow famously asked in 1987: *"You can see the computer age everywhere but in the productivity statistics."*[8]

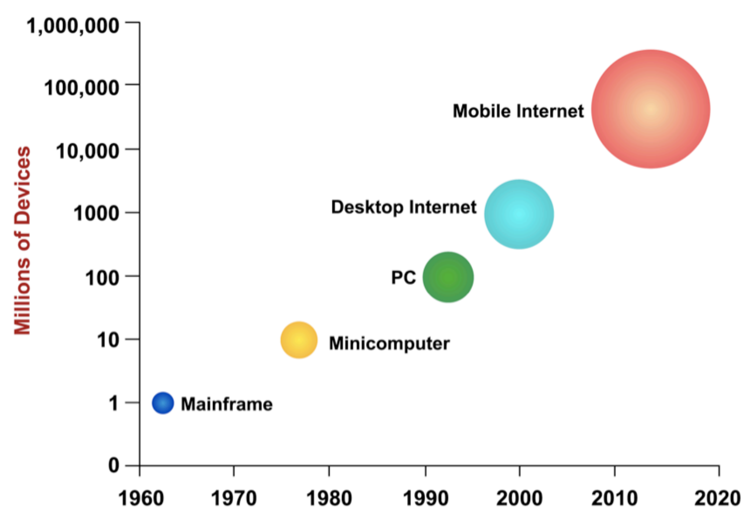
Global Wealth Correlates With ICT Penetration



Source: Telecommunications Union ICT Development Index
ICT penetration is measured as a composite of 11 deployment and availability indicators.

These broad ICT trends – declining costs, rising global demands -- are now being amplified by the emerging transformation of the Internet into what is being popularly if loosely termed the Cloud, and the Mobile Internet. The scale of this next transformation is more significant than that from mainframes to PCs and the wired Internet. In 2013, the world will spend $3.8 trillion on ICT, on everything from servers and network gear, to software and telecom services.[9] How much electricity is associated with that much hardware and economic activity?

The Transformation of the Information Economy Continues



Source: Morgan Stanley

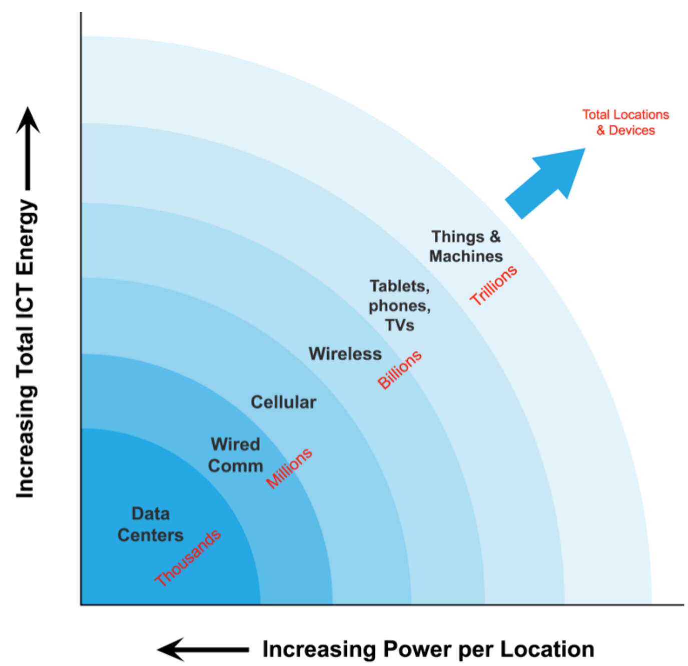
5. The Information Economy – How Much Electricity Does It Use & Where is it Used?

Manufacturers now produce each year "far more transistors than the world's farmers grow *grains* of wheat or rice."[10] How much electricity is used by all those transistors?

The idea that ICT devices could be counted in terms of their aggregate contribution to electricity consumption did not come into general discussion until 1999, when we published *The Internet Begins with Coal: A Preliminary Exploration of the Impact of the Internet on Electricity Consumption*.[11]

Data centers are the largest and most easily identified feature of the infrastructure of the Internet and the Cloud, but comprise just one part of the ICT ecosystem. Still, there are tens of thousands of these massive warehouse-scale buildings, each consuming as much electricity as an entire town. Many communities solicit data centers for tech jobs, and electric and tax revenues, while environmental groups target them to challenge tech companies' green bona fides.

Where Electricity Is Consumed in the Digital Universe



Source: Digital Power Group

Does reading an e-book, or watching a streaming video, use more energy than reading it on paper, or buying a DVD – counting everything from mine-mouth and forest to consumer? Does playing a video game use more energy than playing Monopoly? Does a doctor using an iPad for diagnostic advice from artificial intelligence in the Cloud use more energy than, what? Traveling for a second opinion? The answer involves more than knowing how much electricity one iPad, PC or smartphone uses. It requires accounting for all the electricity used in the entire ICT ecosystem needed to make any of that possible.

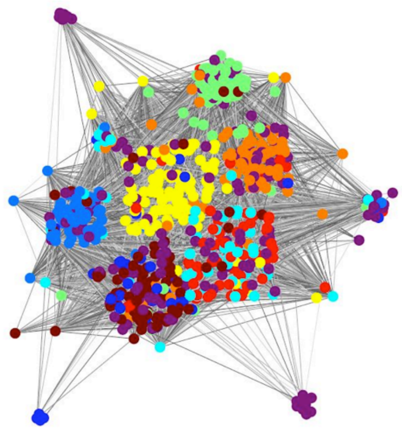
Many analyses of ICT energy use are colored by motivations that can either narrow or distort the analytic framework. One major study starts with:

- *"Why is ICT so critical? It provides intelligence to manage, even lessen the impact of the most imminent threat to our existence: climate change."*[12]

But none of the factors that gave rise to today's digital economy were anchored in, or were motivated by either saving energy or carbon.

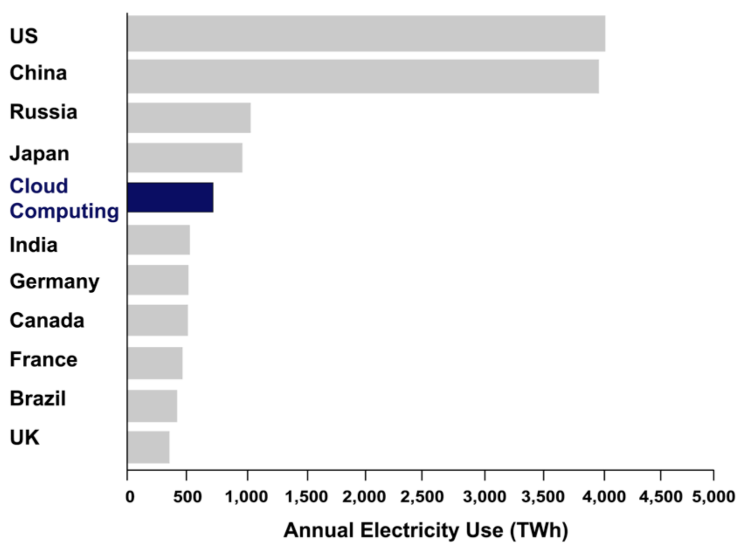
The energy characteristics of the ICT ecosystem are quite unlike anything else built to date. Turning on a light does *not* require dozens of lights to turn on elsewhere. However, turn on an iPad to watch a video and iPad-like devices all over the country, even all over the world, simultaneously light up throughout a vast network. Nothing else in society operates that way. Starting a car doesn't cause dozens of cars elsewhere to fire up.

The Cloud is a Global Network of Interconnected Always-On Electricity-Consuming Devices



Amongst the extensive technical literature on various specific aspects of ICT energy use, two recent studies stand for their attempt at a comprehensive overview, one by the Boston Consulting Group[13] and another by Greenpeace, where the latter organization noted that: "Data centers are the factories of the 21st century information age … many of which can be seen from space, consume a tremendous amount of electricity." *And* "If the Cloud were a country, it would have the fifth largest electricity demand in the world."[14]

Global Cloud Electric Consumption

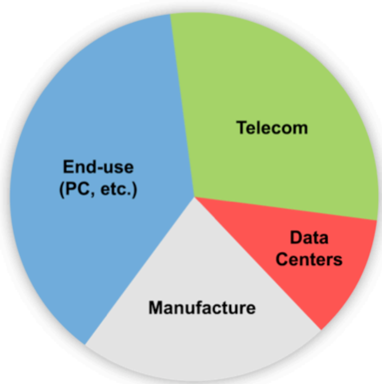


Source: Greenpeace International, How Clean is Your Cloud, April 2012
Note: Cloud consumption here includes telecommunications infrastructure, but not the entire ICT ecosystem.

There are four main energy-consuming features of the ICT ecosystem:

- Public and private data centers which store, route and process information;
- Wired and wireless private and public networks, including cellular, WiFi and fiber;
- End-user equipment in homes, offices, factories and farms;
- Factories that manufacture all the ICT equipment.

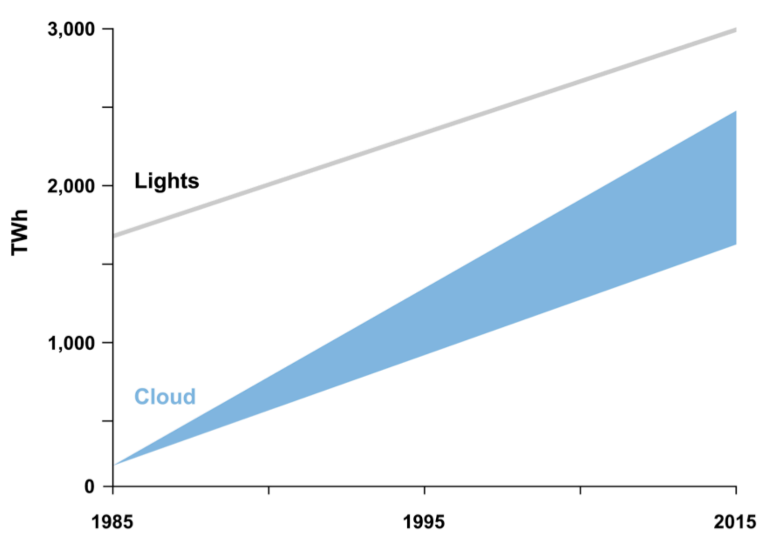
Where Electricity is Used in the ICT Ecosystem



Data Source: Directions Towards Future Green Internet, 12th Int. Symposium on Wireless Personal Multimedia Communications

A number of analysts have estimated that current electricity consumption in the global ICT ecosystem ranges from 1,100 to 1,800 TWh annually.[15],[16],[17] This puts global electricity used by ICT today in the same league as global lighting energy demand circa 1985. Thus lighting up silicon and lasers has moved into the big leagues as an electricity-consuming sector. However, as we will explore herein, these estimates are either incomplete, use old data, or use debatable assumptions.

Electricity for Global ICT v. Illumination – The Current Wisdom

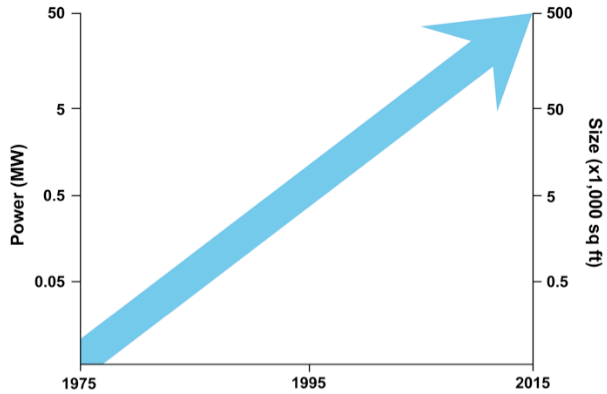


Data Source: current ICT/Cloud data per citations above; lighting data from IEA

6. Electric Demand in the ICT Ecosystem – Data Centers *[250 – 350 TWh]*

The tens of thousands of data centers around the world comprise a high-profile feature of the ICT architecture, from Iowa and South Carolina[18], to Texas[19] and California, and from Ireland to Iceland, and from China to India. A 300,000 sq.ft. 40 megawatt (MW) Facebook data center opened in 2012 in North Carolina where electric rates are 10-30% below the U.S. national average (the local grid is 56% coal, 32% nuclear). There, the Facebook facility will save $100 million in operating costs compared to national average rates,[20] and use one million tons of coal over the next decade.[21]

The Size & Power Of Leading-Edge Data Centers Keeps Rising

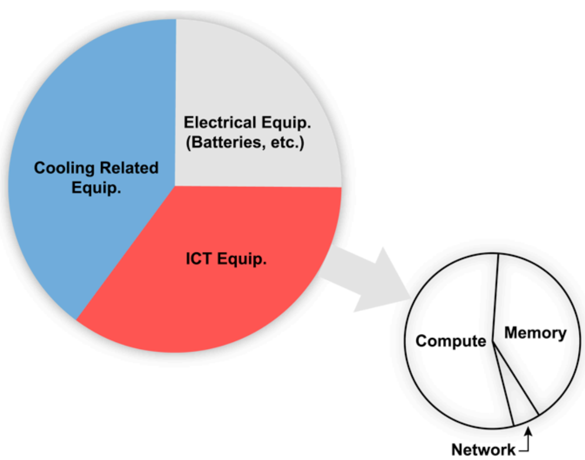


Source: Sun Microsystems

One of the world's biggest commercial data centers, in Nevada, at 400,000 square feet now (seven football fields) is slated to expand to two million sq. ft.[22] Meanwhile, the owners of a $1.6 billion, 200 MW one million-square-foot data center under construction in Chongqing, China, advertises there cheap power (from China's 80 percent coal-fired electric grid), not cheap labor, as their competitive advantage in pursuing global Cloud services.[23]

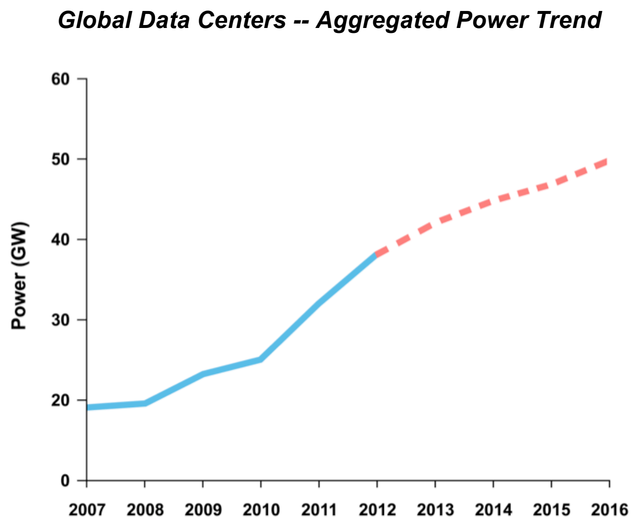
Globally, data centers are estimated to consume (as of 2010) from 250 to 350 TWh annually.[24,25,26]

Where Data Centers Use Energy



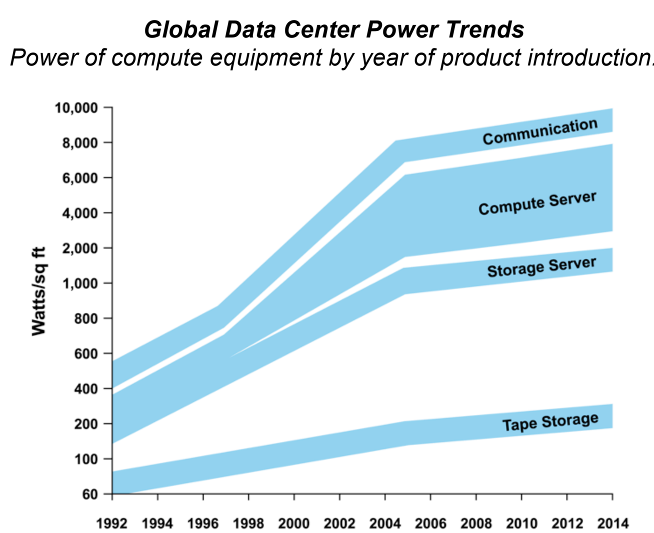
Data Source: The Datacenter as a Computer: An Introduction to the Design of Warehouse-Scale Machines, Google.
Allocations vary with age, purpose, location. Cooling incl. chillers, fans, pumps; electrical incl. UPS, batteries, distribution & switch-gear.

Even as the efficiency of computing equipment improves, and radical gains have been achieved in overall data center operational efficiency in recent years, total global power needs to light up the world's data centers keeps rising, nearly doubling in the past five years.



Data Source: Powering the Datacenter, DatacenterDynamics, 2013
One-third of global data center energy use is in U.S., but growth rates are fastest in emerging economies.

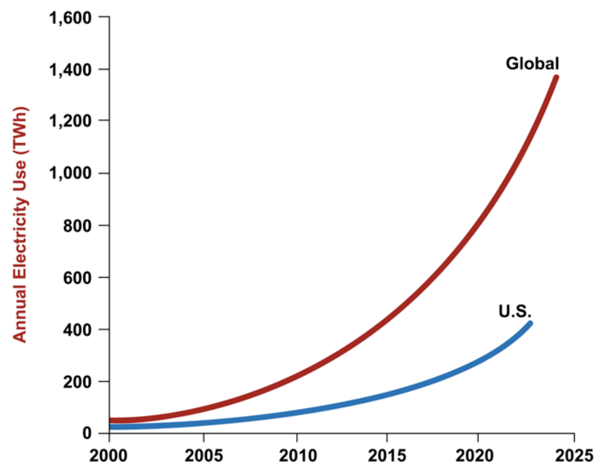
As the next Cloud-dominated era expands, many existing data centers will be gutted and rebuilt, or entirely replaced with new state-of-the-art ICT equipment far more performance per watt and per dollar, but also far more power per square foot of space occupied by the hardware. The average data center in the U.S., for example, is now well past 12 years old – geriatric class tech by ICT standards. Unlike other industrial-classes of electric demand, newer data facilities see higher, not lower, power densities. A single refrigerator-sized rack of servers in a data center already requires more power than an entire home, with the *average* power per rack[27] rising 40% in the past five years to over 5 kW, and the latest state-of-the-art systems hitting 26kW per rack on track to doubling.[28]



Data Source: Datacom Equipment Power Trends and Cooling Applications, ASHRE 2012
Note: ASHRE measures power as heat load.

Progress in data center equipment efficiency will continue[29], but forecasts still show substantial growth in data center energy, and in some estimates comprise the fastest growing part of the ICT energy-using ecosystem in the next decade.[30] (Others see network energy demands growing faster; explored next.)

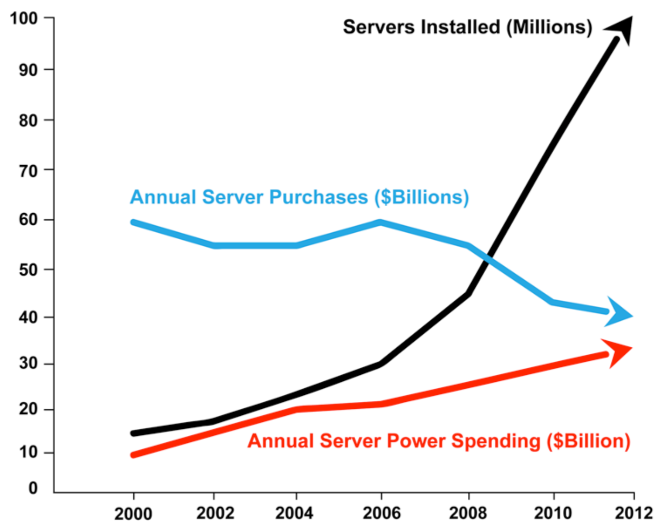
Electricity to Power the Cloud's Data Centers



Source: Microsoft Global Foundation Services

If the above forecast is roughly accurate, then the world's data centers alone will approach 1,000 TWh within a decade – more than the total now used for all purposes by Japan and Germany combined. For many data centers today, the cost of buying computer servers is now less than the cumulative cost of buying electricity to run those servers over their four-year life. As computing hardware costs continue a long-term decline, the share of spending and importance of energy costs increases.

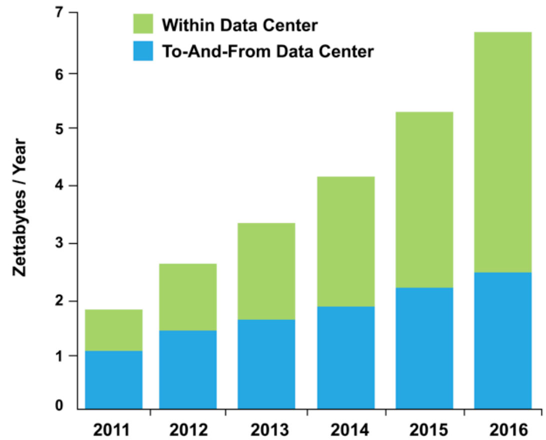
Servers in Global Data Centers



Data Source: IDC
Note the number of servers includes "virtual" machines achieved by maximizing equipment use through virtualization software. Virtual machines also consume energy.

Data centers have entered a new era in terms of the character of traffic. Most data-center traffic until recently was associated with managing data flowing to-and-from users. Intra-data-center traffic is now growing far faster than traffic to-and-from end-users due to the rising use of IT services, remote storage, and the increasing use of real-time processing (enabled by high-speed user connectivity) such as mapping, voice recognition, industrial and medical diagnostics, and big data analytics.

The New Character of Global Data Center Traffic

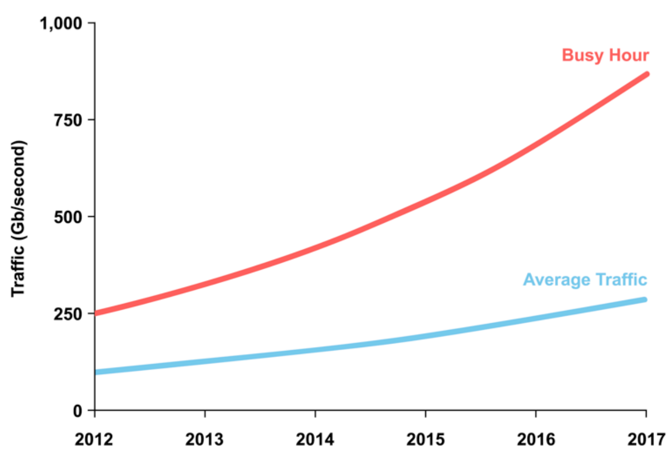


Data Source: Cisco Global Cloud Index

For global data center energy use to remain unchanged, efficiency of all future and existing data centers needs to improve 300% in five years.

Now data centers are increasingly seeing peak demand characteristics akin to that experienced by electric utilities – necessitating similar, costly, "reserve" capacity. Data center peaks necessarily occur contemporaneously with expensive utility grid peaks. One solution is to have data traffic follow cheap power when available at other remote facilities (requiring reserve data capacity at those facilities). Some of the additional facility costs may be offset by using software and hardware to replace expensive back-up power gear (used for local reliability) to enable instead a "graceful" failover to another data center in the event of power failure, and used for smoothly transferring traffic to cheaper power locations when called for.[31]

Utility-Class Peak Demand Challenge Comes to Data Centers

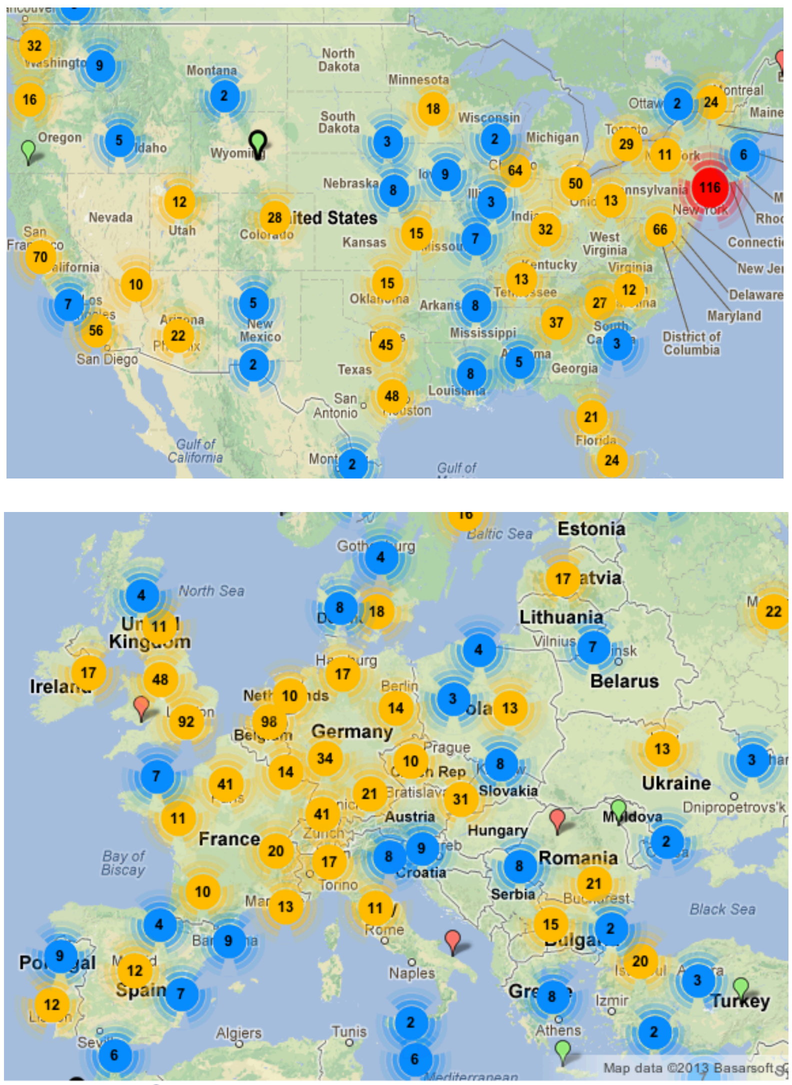


Data Source: Cisco Video Networking Index

The universe of data centers is rapidly expanding and construction outside of the U.S. is growing at twice the pace of North America. Many are located where power is cheap and bandwidth available, others where power is more expensive but proximity to markets is critical. As fast as the speed of light is, computing is so fast that distances to data centers of only a few tens of miles are possible for "real time" exchanges for such things as critical backups, financial transactions, or increasingly common dynamic real-time activities such as navigation. Thus when speed matters proximity matters too, and data center operators can't follow cheaper power but are captive to local power rates.

The criticality of electricity for data centers is evident in the global spending on technology and software to manage data-center power, a $15 billion annual industry now, forecast to triple to $45 billion in five years.[32]

Data Centers Across the U.S. & Europe
(Location & Number at Each Location)

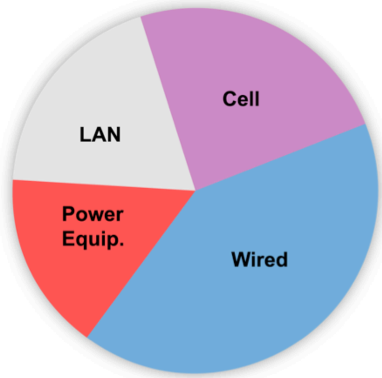


Source: Data Center Map
A global site with a map of over 2,500 enterprise class co-location data centers: i.e., excludes ~ 9,000 other enterprise class data centers such as Apple, Google, and other private enterprises, governments and research, and excludes thousands of communications data centers.

7. Electric Demand in the ICT Ecosystem – Communications Networks *[250 – 600 TWh]*

Networks are comprised of transport hardware in the wired (fiber, coax, and legacy copper) and wireless domains (cellular, WiMax, and WiFi.) Today's high-speed wireless networks enable smartphones and tablets to display streaming video anytime and anywhere.

Where Networks Use Electricity

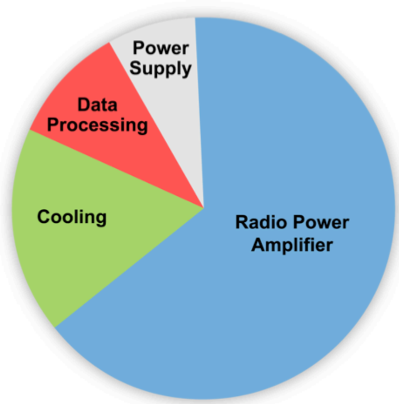


Data Source: A Review of Energy Efficiency in Telecommunication Networks, Koutitas, et al, Telfor Journal.

Estimates of global network electricity use range from 250 to 400 TWh.[33],[34],[35],[36] But the traffic in the communications world has changed dramatically in the few years since all these estimates were made.

Current published estimates of the energy used by networks are based on data typically predating 2010, and much of that is anchored in measurements and analyses performed earlier, wherein a common reference in many reports is a 2007 Ericsson analysis. The iPhone was introduced in 2007 and networks have experienced unprecedented increases in traffic since the introduction of smartphones and tablets. U.S. mobile traffic, for example, rose 400% since 2010.[37]

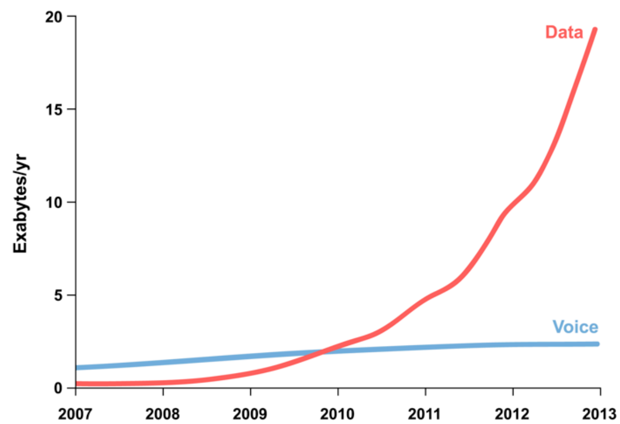
How Wireless Networks Use Electricity



Data Source: Cellular Networks with Embodied Energy, IEEE Network
Data transmission is inherently more energy efficient on wires and fiber than radio, where the RF amplifier is the biggest energy-user.

At the end of 2012 there were 3.2 billion cellular subscribers, of which 1.2 billion were broadband subscribers – the latter is twice as many as the total land-line broadband subscriptions.[38] Not only are there a lot more people on wireless networks, but the traffic on those networks has grown faster. Consequently, total mobile traffic is up some 400-fold since 2007, and that growth came almost entirely from broadband data not voice use.

Growth in Global Mobile Traffic

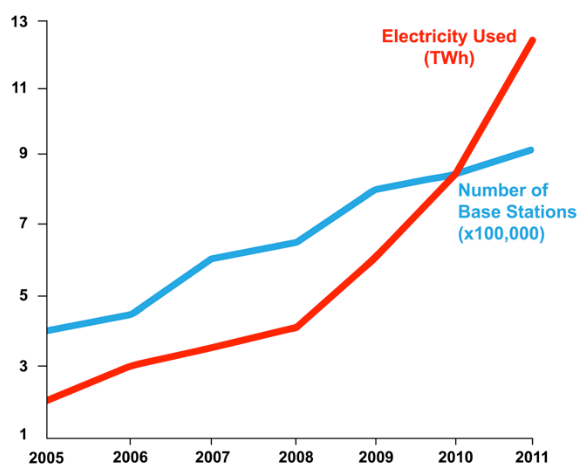


Data Source: Ericsson Mobility Report: June 2013
Data is based on global field measurements of traffic on over 1,000 mobile networks (excludes M2M, WiFi)

Could improvements in cellular network energy efficiency over the past half-dozen years have offset a 400-fold rise in traffic? Nothing in the literature suggests anything close to such gains.[39]

One major cellular network operator recently published data on the impact of these traffic trends. China Mobile claims a 50% improvement in their system energy efficiency over the past half-dozen years, but overall electricity use grew far more rapidly than the rise in the number of subscribers and base stations – a phenomenon that began contemporaneous with broadband wireless.

China Mobile's Energy Consumption & Wireless Base Station Growth

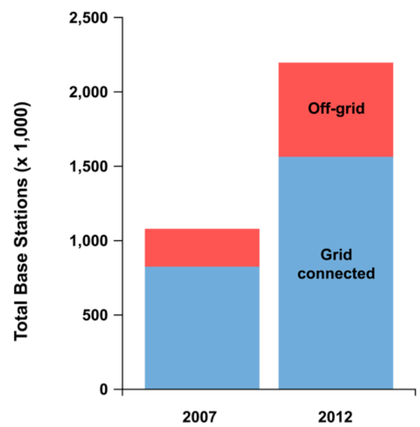


Data Source: China Mobile Research Institute

China Mobile's experience suggests that current estimates of global network energy use are low. Extrapolating China Mobile's experience, where pre-broadband trends would have yielded a 6 TWh system by 2011 rather than the 12 TWh realized, today's global network energy number is also likely far greater than the prevailing estimates of 250 - 400 TWh – perhaps it is more like 500 – 800 TWh. Even assuming lower broadband penetration and greater efficiency gains than in China, the upper bound estimate for global network energy use is likely closer to 600 TWh.

Even more grid demand will emerge in due course as many diesel-powered cell towers convert to grid power. Of the world's four million base stations, one million were added since 2007 of which one-third are currently off-grid using diesel generators.[40] With diesel-electric power as much as 10 times more costly than for grid-connected towers, wireless operators will convert as fast as feasible.

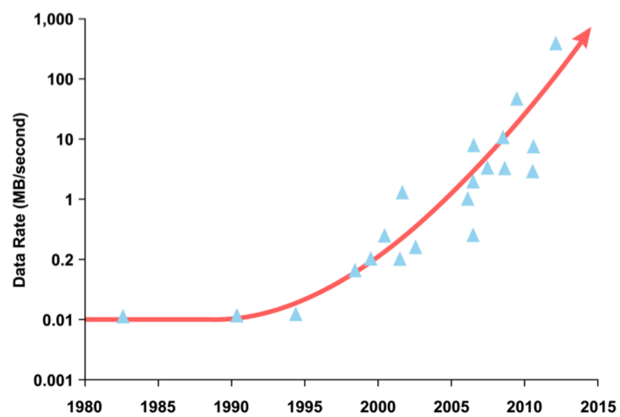
Growth in Mobile Base Stations in Emerging Nations



Data Source: Green Cellular Networks: A Survey, Some Research Issues and Challenges, IEEE

The migration to mobile broadband is driven by the advent of high-speed wireless data; up 100-fold in a decade and rising another 10-fold over the next five years.[41] Carriers are finding that smartphone and tablet users consume surprising amounts of data when fast broadband networks are offered.[42]

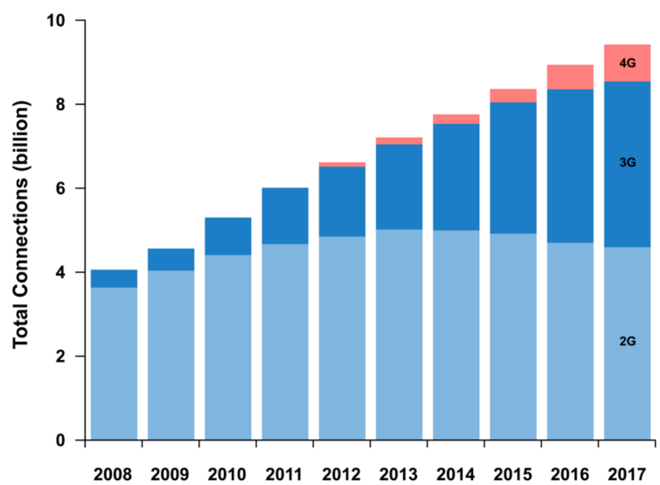
The Growth in Maximum Wireless Data Rates



Data Source: IEEE Solid-State Circuits Magazine

The new high-speed LTE networks that accelerate the mobile Internet require up to three times more data per hour per task compared to the previous slower 3G networks, and thus more energy.[43] And compared to 2G networks, LTE energy consumption is 60 times greater to offer the same coverage.[44]

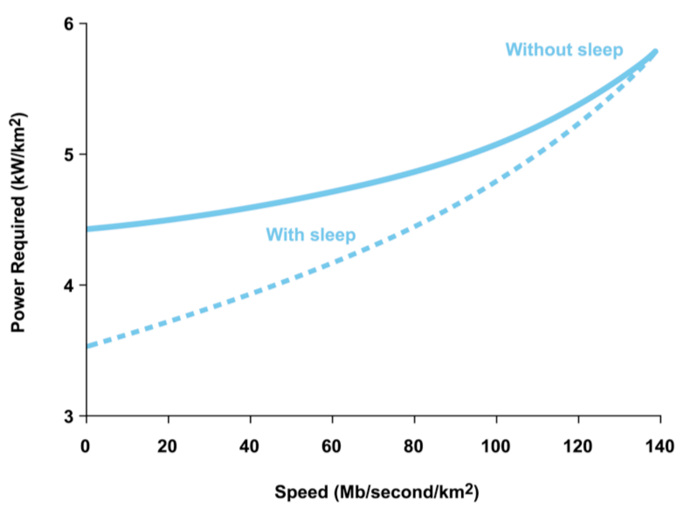
The Rising Share of Higher-Speed More Energy-Intensive Wireless Broadband



Data Source: The Mobile Economy 2013, GSMA and ATKearney
The world's wireless networks are transitioning to high-speed broadband hardware.

Base station power requirements increase as wireless broadband speed increases.

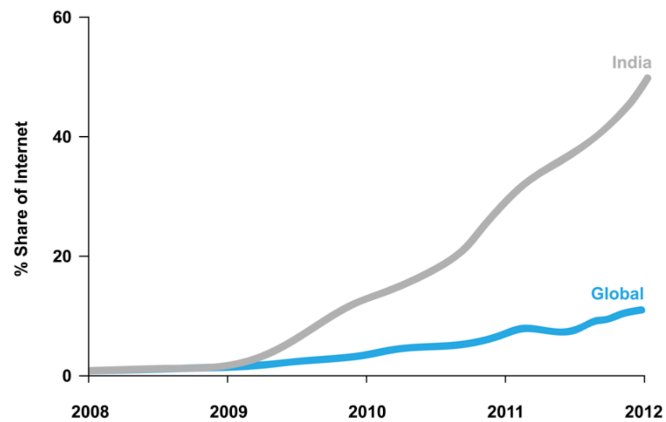
The Power Cost of Cellular Speed on High-Speed LTE Networks



Data Source: Energy Aware Radio and neTwork tecHnologies
Engineers are proposing implementing "sleep" mode software to reduce base-station energy use when traffic use is lower.

Global Internet traffic is going mobile. Migration to the wireless Internet is happening fastest in emerging markets, but is occurring everywhere.[45] The same amount of data carried on wireless networks consumes far more energy than when transported on 'wires' (fiber optics). Mobile data traffic doubled in the past year and is forecast to rise 10-fold in five years. [46] (At the same time, wired network traffic also grows to transport the data from wireless nodes back to the Cloud's data centers).

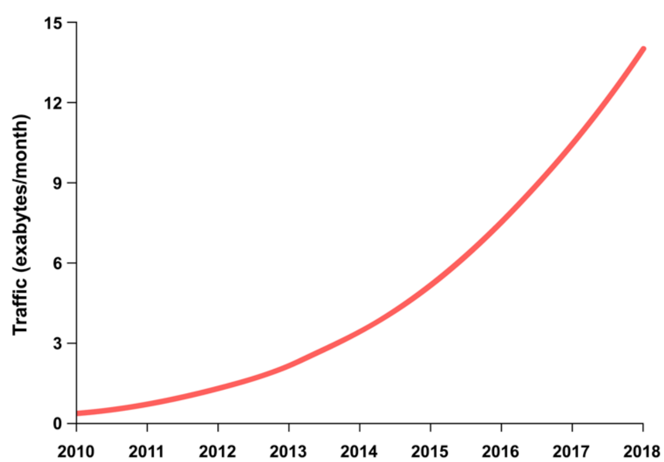
Share of Internet Traffic on Wireless Networks For the Last Mile



Data Source: Meeker, KPCB

Global traffic on mobile networks is expanding at historically unprecedented rates, rising from today's 20 to over 150 exabytes a year within a half decade. While today's networks energy use ranges from 1.5 to over 15 kWh/GB of traffic,[47] overall network energy efficiency will need to improve nearly 10-fold in five years to keep total system energy use from rising substantially.

Global Mobile Network Traffic



Data Source: CTIA Semi-Annual Wireless Industry Survey, 2013

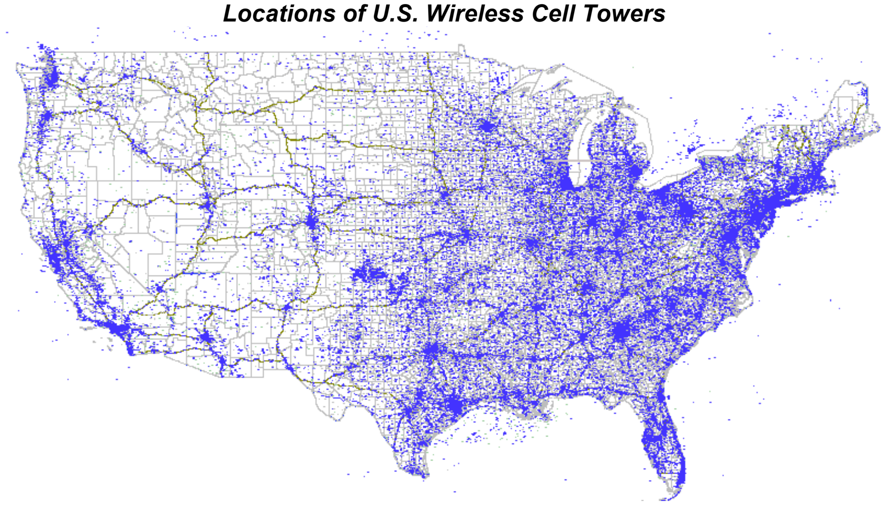
The underlying architecture of all communications networks have become both digital and migrated increasingly onto the Internet. There has thus been a blurring of the line between data centers and telecommunications facilities for which there are thousands of the latter located across the United States and around the world. The cost to power such facilities is necessarily dictated by local rates.

Locations of U.S. Telecommunications Central Offices – Communications Data Centers

Source: Marigold Technologies

The "last mile" of the world's phone infrastructure is morphing from the century-old wired standard to wireless; common in emerging nations and 30% of U.S. homes have only a wireless phone. The wired last-mile system used less energy and was easy to power since all electricity came from central offices. Wireless energy-per-customer is much greater, requiring power in three locations, central office, cell towers, and at the customer, multiplying the energy and the challenge of keeping everything lit 24x7.

Locations of U.S. Wireless Cell Towers



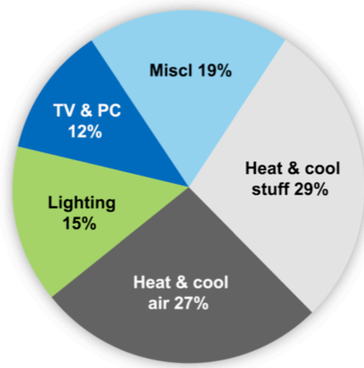
Source: Tower Maps

Note: none of the energy associated with the radio and TV broadcast networks has been included here or elsewhere even though that infrastructure is merging into the Cloud. ESPN's broadcast operation is functionally the same as a major data center or communications central office.[48]

8. ELECTRIC DEMAND IN THE ICT ECOSYSTEM -- END-USE DEVICES *[460 – 1,200 TWH]*

Tracking the energy-use of thousands of types of end-use devices in homes, business and factories requires making assumptions rather than measurements, in particular about how devices are used and how often. And assumptions are made about whether and how much to count the increasingly common ICT features in old dumb appliances. Now TV is the biggest variable in digital energy accounting as all forms of video increasingly become part of the digital ecosystem.

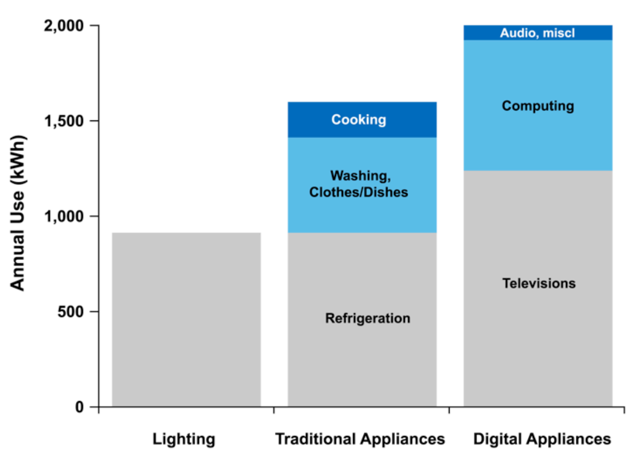
Global Consumer Electricity Uses



Data Source: Overview of World-Wide Energy Consumption of Consumer Electronics and Energy Savings Opportunities, NRDC

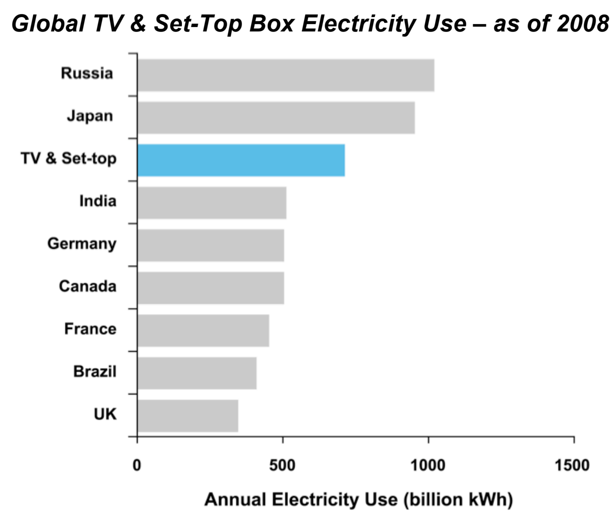
Current estimates of global electricity used by digital devices in the global residential and commercial sector ranges from 460 to 550 TWh annually.[49] This puts home computing in the same range as electricity used for residential lighting, or refrigeration.[50] But that range doesn't account for all current ICT end-uses and new trends. Aside from ignoring the increasingly common, but relatively small loads from ICT embedded in old 'dumb' appliances, the current ICT end-use estimates have little or no accounting for digital TVs.[51] Also typically omitted, or under-counted, is the TV set-top box which can alone use as much electricity annually as a refrigerator.[52]

Typical Electricity Use Per Residence
(excluding heating/cooling of air and water)



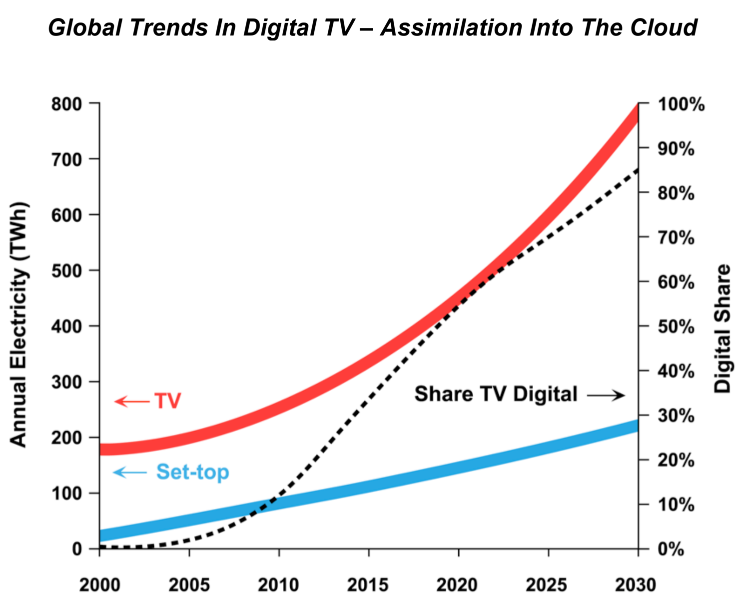
Data Source: EIA & IEA Gadgets and Gigawatts, Policies for Energy Efficient Electronics

Studies focused on TVs and set-top boxes estimate U.S. consumption at 90 - 100 TWh.[53,54] Globally, TVs are estimated to use 400 - 700 TWh,[55,56,57] a total that is comparable to prevailing estimates for all end-use ICT loads. Digital TV is often (erroneously) allocated a minimal share of the ICT ecosystem's energy use. Allocating only 20% of TVs to the Internet would add about 80 to 140 TWh to the previous cited ICT end-use energy, increasing the maximum estimated global total to 690 TWh.



Data Source: IEA, Ericsson
Netflix began streaming to TVs in 2008, now serves 25 million U.S. consumers, illustrating the rapid recent changes.[58]
[Note: Above illustrates high range from Ericsson]

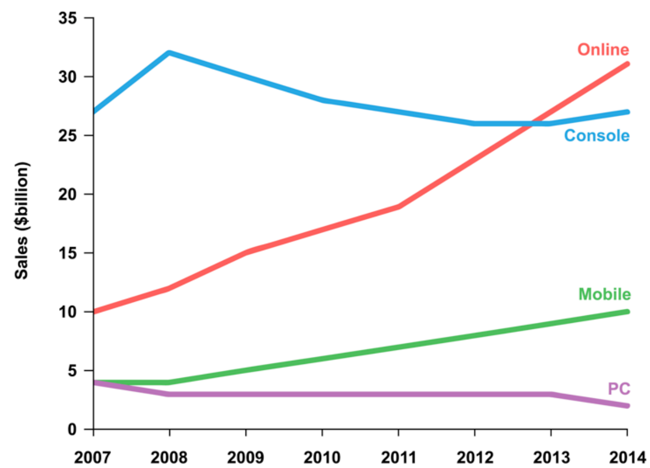
The migration of TV to the Internet will dominate ICT end-use energy for years (and for networks and data centers as well). The share of TVs that will be digital is forecast to reach 50% by 2020.[59] And before long, another video growth cycle begins as the next era of displays emerges with glasses-free 3D, and also wall-scale displays. DisplayWalls will shortly move from the rarified worlds of research and military domains, and Hollywood imaginations, to ubiquity.[60]



Data Source: IEA, Gadgets and Gigawatts, Policies for Energy Efficient Electronics

Video game consoles, inherently computing-centric and increasingly Internet-connected, are another variable in the end-use accounting also often omitted or under-counted. Global electric use from game consoles is estimated to be 30 to 60 TWh.[61] Each generation of game console has exhibited rising power requirements (on average doubling in the past decade) and the games are increasingly played online, thus adding a network traffic (and power) load.

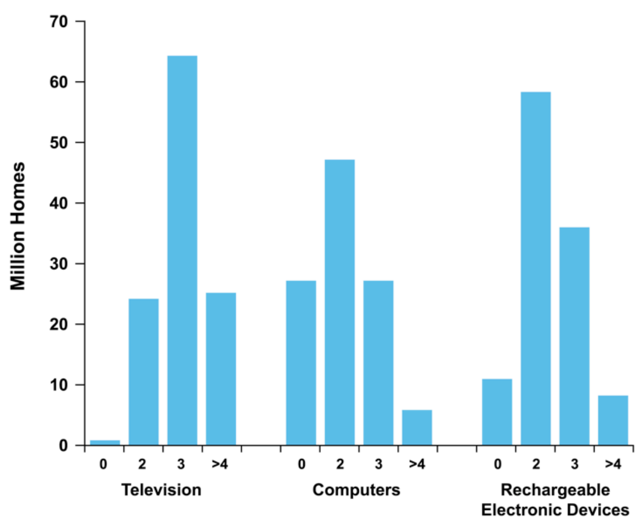
Video Game Trends – Power-Hungry Consoles & The Rise of Online Gaming



Data Source: Wedbush, PriceWaterhouseCoopers, Wall Street Journal

And then there is the multi-device per user phenomenon. When a family has more cars than registered drivers, the extra cars cannot be used simultaneously. That is not the case for ICT devices that can, and often are operating simultaneously.

Proliferation of Multiple Digital Devices Per U.S. Household

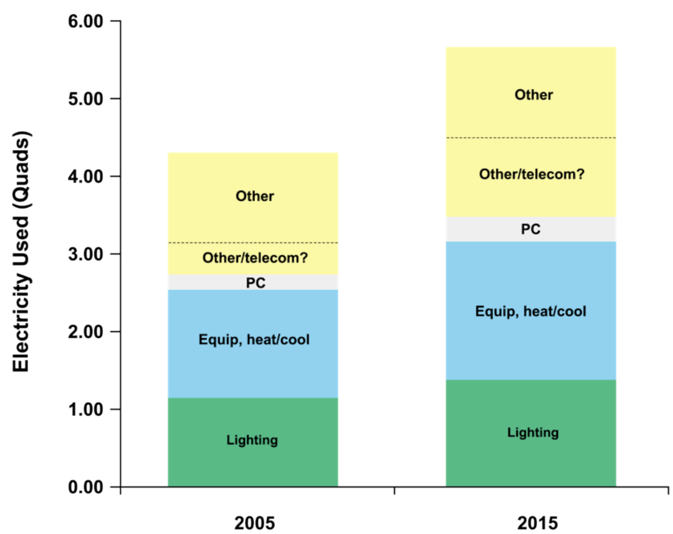


Data Source: EIA, How Americans are Using Energy in Homes Today

Yet further under-counting of ICT energy use arises from the legacy approach to data collection. EIA's estimate for office PCs and monitors does not include all the energy used by equipment in the IT 'closets' of commercial buildings. We can find the rest of commercial ICT hardware in a catch-all category labeled "other" by EIA, a 'bucket' created in the pre-Internet era to aggregate myriad devices which collectively used to use very little electricity -- coffee makers, water pumps, service station gasoline station pumps, CAT and MRI and x-ray machines, ATMs, elevators, and escalators, and "telecommunication equipment."[62]

"Other" has grown to become the largest single electricity-using category in the commercial sector, accounting for 30% more energy than lighting.[63,64]

Electricity In The U.S. Commercial Sector– 'Hidden' ICT Loads Swept Up In "Other" Uses



Data Source: *EIA*, *ICF*, How Small Devices are Having a Big Impact on U.S. Utility Bills

Increased use of such things as escalators and gasoline pumps is extraordinarily unlikely to account for the size and growth of "other" electricity uses. In fact, recent analysis found that of the 500 TWh in "other" only 150 TWh can be allocated to coffee makers, distribution transformers, EVs used indoors, medical gear (MRI, CT, X-ray), elevators, escalators, water pumping and treatment.[65] This leaves 350 TWh unaccounted for in the "other" where we find, as noted, "telecommunications equipment."

Allocating only half of that 350 TWh to ICT equipment (specifying here that there remains no explanation for what hardware uses the rest), increases the estimate of total U.S. commercial sector ICT end-use to nearly 250 TWh. Extrapolating the U.S. figure globally, this implies as much as 600 TWh of electricity may be omitted in current world-wide commercial sector ICT accounting, increasing the upper range for all ICT end-use to roughly 1,200 TWh.[66]

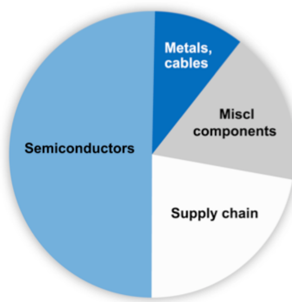
There is yet more uncounted ICT end-use in all the devices operating and embedded in industrial equipment. While the ICT portion of such equipment is a small share of the inherent energy use of the hardware in which it is embedded, that does not obviate the fact that the ICT piece is a new electric-using feature. (For example, a smart digital motor will use less electricity overall, but the embedded logic devices are new ICT loads, and as that device increasingly connects to the Cloud, it will drive collateral ICT electric use there too.) Finally, in due course, we will see the emergence of – all-electric – 3D printing migrating manufacturing into a new more digital and electrified era.

9. Electric Demand in the ICT Ecosystem – Manufacturing *[560 – 800 TWh]*

It takes energy, dominantly electricity, to manufacture ICT hardware. Building one PC uses about the same amount of energy as making a refrigerator, for example.[67] Annualized, the energy to fabricate a PC is three to four times that of a refrigerator because the latter is used three to four times longer.[68] Even enterprise hardware is replaced frequently. Data center operators rank rapid adoption of new tech as a higher priority than product lifespan by a 71% to 26% margin.[69] The faster ICT products are obsoleted, the greater the manufacturing energy. The obsolescence rate is, if anything, accelerating.

Semiconductors dominate energy in ICT manufacturing. It takes 1 - 2 kWh to make a square centimeter of microprocessor.[70] The world's $300 billion/year semiconductor industry produces hundreds of billions of square centimeters.[71] At the end of useful life the silicon device has no inherent material or energy value – it's trash. The embodied energy can't be recycled; it has been consumed.

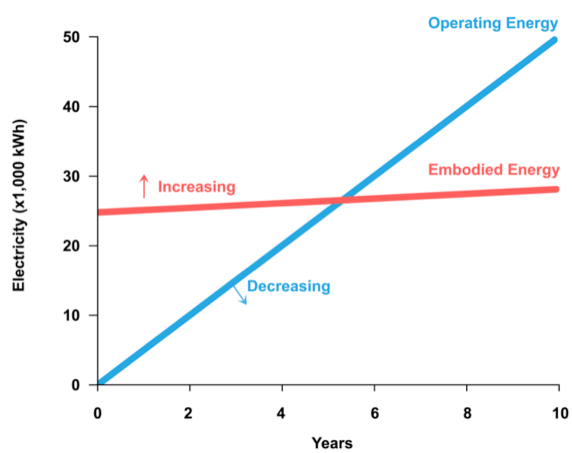
Energy Embodied in Manufacturing a Cellular Base Station



Data Source: IEEE
Cumulative capital investment in the hardware of the U.S. cellular network alone now approaches $400 billion.[72]

As new more complex ICT technologies are adopted, embodied energy increasingly dominates the total life-cycle energy picture. It takes years before the electricity to operate a cellular base station equals the energy embodied in manufacturing it. As system operators accelerate equipment upgrades and expansion, to bring new features and to reduce electricity costs, those expenditure not only increase manufacturing energy use, but have the effect of shifting future operational energy savings to immediate, possibly greater, energy used in manufacturing.

Embodied v. Operating Energy For A Cellular Base Station

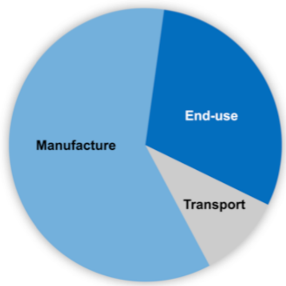


Data Source: IEEE
Embodied energy accounted for 25% of a cellular network's total life-cycle energy use in 2005 and grew to 43% by 2007.[73]

For a smartphone, the embodied energy ranges from 70 to 90% of the electricity the phone will use over its life, counting recharging its battery.[74,75,76] Thus, the energy use of smartphone itself (i.e., excluding networks and data centers) is totally dominated by manufacturing, not by the efficiency of say the phone's wall-charger or battery. This is quite unlike other consumer products.

For a refrigerator, embodied energy is just 4% of total life-cycle energy; power to run the fridge dominates.[77] For a car, only 20% of life-cycle energy is in manufacturing; burning gasoline over the car's life accounts for 80% – the inverse of the smartphone. (There are 'hidden' network energy costs associated with cars, for example – highways, refineries, etc. – but pro rata allocation is *de minimis*, unlike ICT networks where network energy costs are enormous and can dominate, as covered herein.).

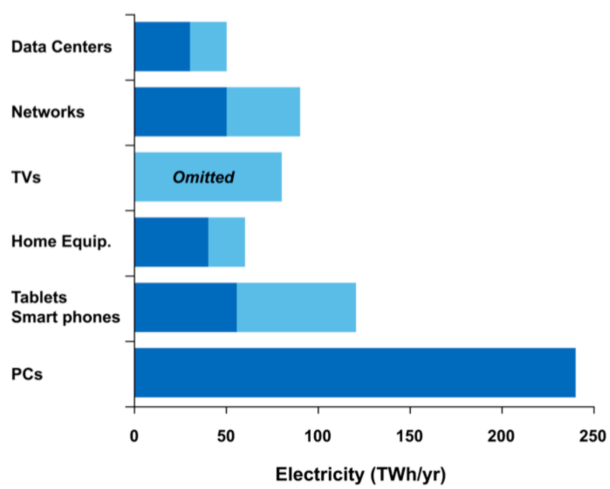
Energy Associated With Manufacturing And Charging a Cell Phone
(excludes wireless networks, data centers, etc.)



Data Source: Nokia
Steel & aluminum comprise 60% of the embodied energy of a car,[78] offering easy energy-saving recycling. Under 10% of cell phone embodied energy is associated with bulk materials; semiconductors dominate.[79] "Transport" is moving materials to factories, product to consumers.

Current estimates put global ICT equipment manufacturing between 400 and 750 TWh annually, counting PCs, peripherals, network gear and data centers.[80,81] There is considerable variability in the literature on manufacturing energy intensity, in part because much information is proprietary.[82] And most estimates under-count or don't include TVs. Incorporating only 20% of the 700 million TVs made a year adds about 80 TWh, bringing the ICT manufacturing total upper bound to over 800 TWh. Finally, completely unaccounted – electricity used by the $300 billion industry that produces software.

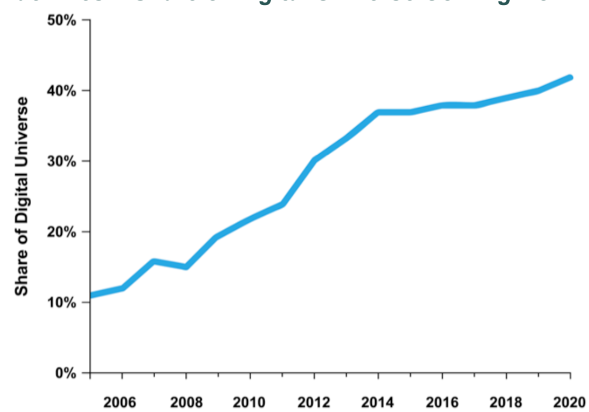
Energy Associated With Manufacturing All The Hardware In the ICT Ecosystem



Data Source: As cited in text above
Current analyses omit or under-count TVs & also use 2011 data for smartphones and tablets– both of which have doubled since then.[83]

Prevailing estimates of ICT manufacturing energy under-count today's reality given recent growth in both end-use devices and infrastructure. The number of cell towers globally (and in the U.S.) has grown 50% in the past five years[84] – a period that post-dates data used in most analyses. And now the global ICT ecosystem is expanding into every segment of the economy from industrial machines to health care to transportation, where machine data accounts for a rising share of the Internet.[85] Engineers talk of "planetary-scale RFID" where sensors will track not just high-value assets, but everything from flowers to individual pills.[86]

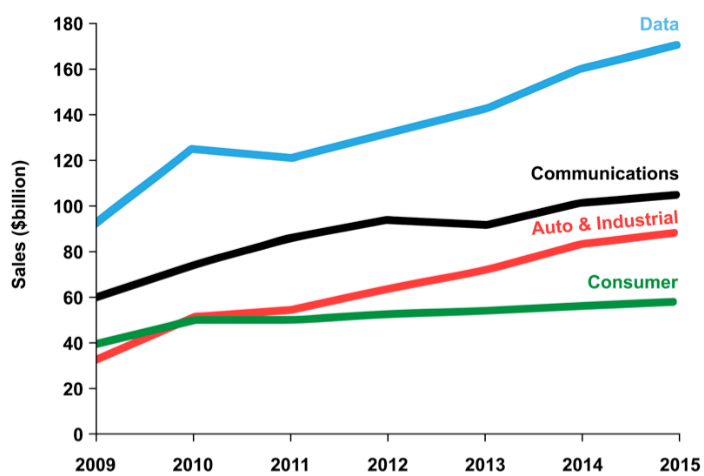
Rise of the Machines – Share of Digital Universe Coming from Machine Data



Data Source: EMC and IDC Digital Universe 2013
As sensors and wireless network costs collapse, the quantity of machine data rises as does its share of the Internet ecosystem.

This all implies more growth in semiconductor manufacturing for the Cloud's ecosystem. The industrial and automotive use of semiconductors is forecast to grow as much as that in the data market by 2015[87] -- the average car will have $500 of semiconductors by 2015, compared to $340 today. (This will collaterally increase digital network traffic too, as everything in cars increasingly connects to the Internet.) A 10% share of just residential "things" becoming smart will lead to a 30% rise in total semiconductor demand.[88] Notably, China has about 50% global market share in semiconductor manufacturing, where 80% of the electricity is supplied by coal.[89]

Global Sales of Semiconductors — Growing Fast For The Machine-to-Machine Internet

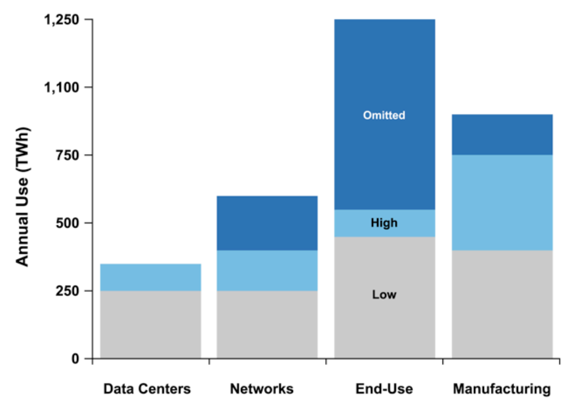


Data Source: PwC, 2012
Growth in sales undercounts the growth in devices shipped due to declining average unit prices.

10. Electric Demand in the ICT Ecosystem – Putting It All Together *[1,100 – 2,800 TWh]*

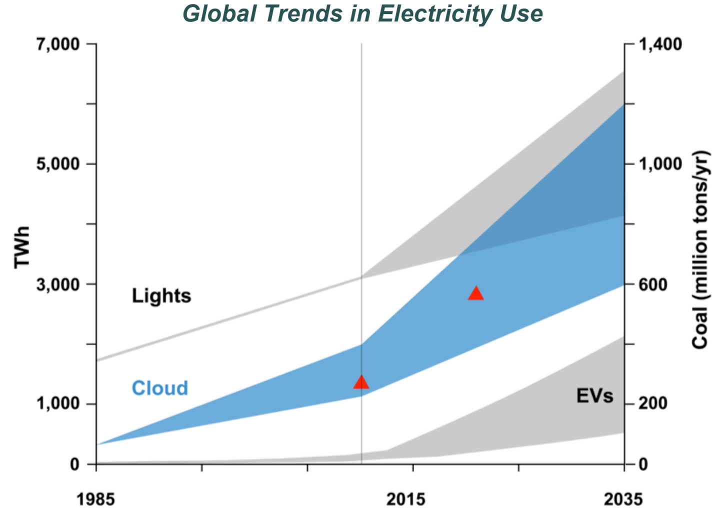
Estimates of ICT energy use are based on many assumptions, notably for example what share of TV to allocate. Most estimates originate in data from the pre-tablet and pre-smartphone era, pre-dating growth in traffic and energy use from wireless broadband.[90] And even the precision of estimates for data centers masks the fact that much is inferred and not based on actual (proprietary) consumption.

Estimated Global Electricity Used in the ICT Ecosystem



Most current estimates likely understate global ICT energy use by as much as 1,000 TWh since up-to-date data are unavoidably "omitted". At the mid-point of the likely range of energy use, the total ICT ecosystem now consumes about 10% of world electricity supplied for all purposes. For ICT energy use to 'only' double over the next decade (as illustrated below), huge gains in efficiency will be needed – at a time when efficiency gains in ICT have slowed.[91] ICT will likely consume triple the energy of all EVs in the world by 2030 (assuming an optimistic 200 million EV goal).[92] Or, in other terms, transporting bits now uses 50% more energy than world aviation, and will likely use twice as much by 2030.[93]

Global Trends in Electricity Use



Data Source: For EVs, Polk & calculation; lights from IEA; Cloud from this report.
One industry analysis forecasts 2020 ICT energy use at 140% of today's level.[94] Greenpeace estimates it will triple in a decade.

11. Electric Demand in the ICT Ecosystem – Where Does & Where Will the Power Come From?

The ICT ecosystem has joined the ranks of major energy-consuming features of the global economy.

One recent global survey found: "Energy cost and availability is the #1 worry of data center operators."[95] The result is unsurprising. A typical data centers costs roughly $7 million per megawatt to build, and another $9 million per megawatt for the cost of electricity over the facility's 10-year operating life, assuming low-cost power.[96] Thus, for example, a single 50 MW enterprise data center sited in Iowa (70% coal, 25% wind) instead of higher cost California (no coal), saves $350 million in electricity expenses over the life of that single data center.

But 80% of global ICT electricity use is highly dispersed and not consumed at the visible warehouse-scale data centers. Thus the cost and availability of electricity for the Cloud is dominated by the same realities as for society at large – obtaining electricity at the highest availability and the lowest possible cost.

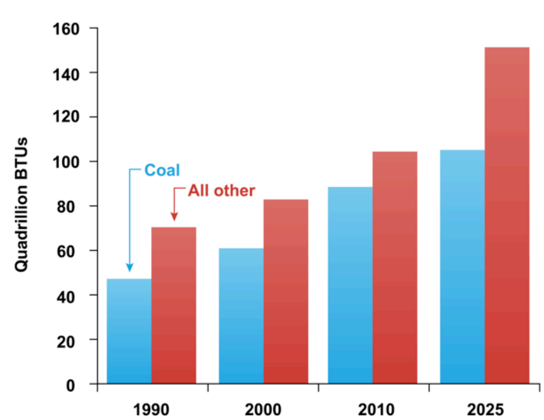
In all scenarios, global ICT electric use is growing, perhaps much more dramatically than most analysts realize. The implications of the trends summarized herein have not gone unnoticed in scientific circles.

> "As the use of the Internet continues to grow and massive computing facilities are demanding that performance keep doubling, devoting corresponding increases in the nation's electrical energy capacity to computing may become too expensive."
> *The Future of Computing Performance: Game Over or Next Level?* National Academy of Sciences

In every credible forecast -- including from the EIA, IEA, BP, Exxon -- coal continues to be the largest single source of electricity for the world. Coal's dominance arises from the importance of keeping costs down while providing ever-greater quantities of electricity to the growing economies, and as the IEA recently noted, the absence of cost-effective alternatives at the scales the world needs.[97] The IEA also forecasts that the second largest source of new electricity will come from renewables – perhaps for some there is irony in the digital ecosystem being fueled by the combination of coal and renewables in partnership, wherein the former provides the essential low-cost and high-availability base.

In an ever-more digital economy, the demand for reliability rises even faster. However, a global survey of utilities in 43 countries found 46% of executives in the mature markets expect current utility trends to increase the risks of blackouts by 2030, only 18% see a decreased risk.[98]

Global Electricity Supply – Everything Grows & Coal Dominates

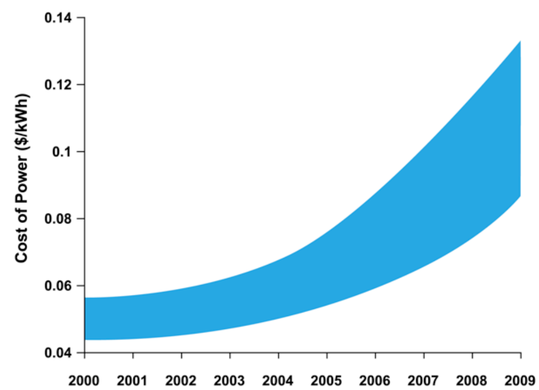


Data Source: 2013 Outlook for Energy ExxonMobil

Coal is the largest single source of new global electric supply over the past two decades, and continues to be so for the next two, and remains at or near today's 40% for global supply even in 2025.[99]

The growth in the energy-intensive wireless Internet in emerging markets is occurring contemporaneously with rising electricity costs. Rising ICT loads add additional pressure to local utility decisions relating to the pursuit of reliable low-cost electricity.

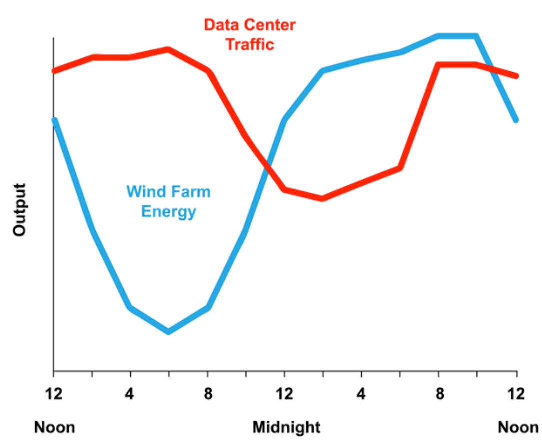
Cost of Power for Wireless Networks in Latin America



Data Source: Telefonica
Average cost trends for power-to-the-tower in six Latin-American countries.

In the ICT ecosystem power has to be available at the *same time* that information flows. This reality means that decision to use, for example, increasing amounts of energy from wind turbines creates a challenge -- while the overall availability of wind power is in the 20 to 30% range, when the wind is available it is on average out of phase with data traffic demand. Conventional power plants operate 24x7 and have 80 to 90% availability. For wind farms to be a viable supplement to info-centric power needs, other power plants are needed to anchor the network. In most of the world, the power networks are anchored by power plants fueled with coal, uranium or natural gas.

Typical Daily Cycles:
Data Center Traffic & Power Demand v. Wind Power Output



Data Source: Akamai, RISO National Laboratory

APPENDIX A -- DOES USING THE CLOUD SAVE ENERGY?

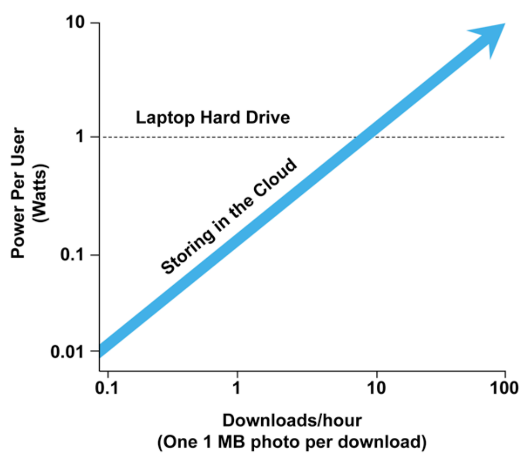
A cloud architecture enables services to be accessible from multiple end-use devices, any time and anywhere. By "Cloud" here we're not referring to the entire Internet's infrastructure (as we have loosely done so in the preceding paper), but to the business of using remote centralized data centers to replace local on-site computing. Cloud services offer convenience and cost savings that come from sharing hardware and software in warehouse-scale computing, whether storing movies, photos and personal data, or scientific and industrial data-crunching and research, and much more yet.

Doing the <u>same</u> compute-store tasks in the Cloud instead of on a local PC can also reduce total ICT energy use because of the efficiency of using remote shared resources. Recent studies have calculated these energy savings.[100] Sharing in the Cloud is, in energy efficiency terms, equivalent to taking the train instead of driving.

But looking more expansively at such analyses one finds that "…under ***some circumstances*** cloud computing can consume ***more energy*** than computing on a local PC."[101] Those circumstance are when a user accesses the Cloud frequently.

Energy Used For Storing Data -- Local PC v. Cloud Storage

The Impact of Instagram, DropBox, Carbonite



Data Source: <u>Green Cloud Computing</u>

A laptop hard drive operates at ~1 watt whether accessing a photo twice a day (~ 0.1 downloads/hr) or accessing 100 photos. As download frequency rises the Cloud can consume over 10 times more energy to store and access information than storing on a laptop.

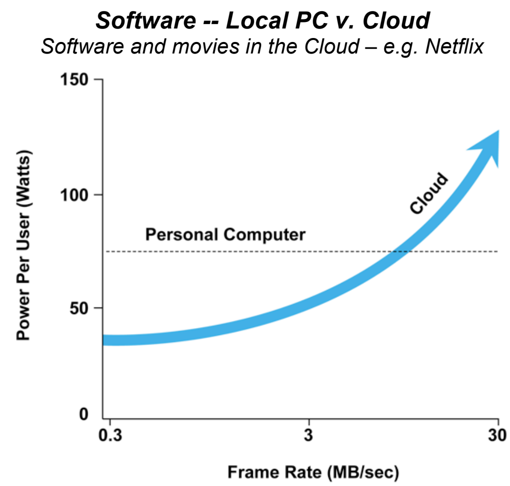
The key energy variable in Cloud analyses is the feature that enables the Cloud in the first place – high-speed, often wireless, connections. Wireless energy consumption is now on track to become a significant factor. Energy use in the networks is often ignored or under-counted, and when included may assume only the use of highly efficient land-line connections that are frequently used in business applications, but ever less frequently used by consumers – or even by businesses in emerging markets where (energy-intensive) wireless broadband is becoming the standard form of connection.[102,103]

- Wireless networks use the energy in 1 pound of coal to transport 1 GB.[104]

If lower costs and greater convenience of using Cloud services leads to significantly more data use – and collaterally greater use of networks -- overall energy consumption will rise. In (simplistic) energy terms, this would be the equivalent of taking a cross-country train ride, and using the financial savings to take long car trips at each stop.

Listening just once to a song stored in the Cloud uses less energy than purchasing and shipping a CD, taking into account manufacturing and transport energy. Listening to the song a couple of dozen times leads to more overall energy used, largely because of greater use of the networks.[105] The Cloud uses more energy streaming a high-def movie just once than does fabricating and shipping a DVD.[106]

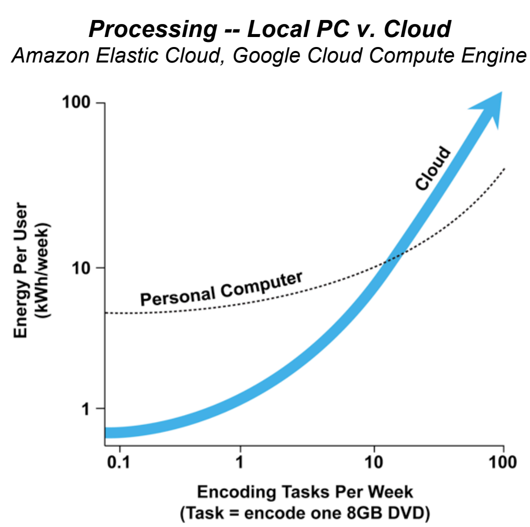
In the case of Cloud-based software-as-a-service, as the speed (frame rate) rises to refresh the local device -- e.g., stream video -- Cloud energy exceeds a local PC as speeds exceed about 5MB/second.



Data Source: Green Cloud Computing

In the case of processing-as-a-service – e.g., for data-intensive tasks such as converting video files to MPEGs, or the equivalent in medical or industrial analytics -- the Cloud uses less energy so long as tasks are performed only occasionally; greater frequency or more data-intense tasks increase overall energy.

Thus future Cloud energy use depends on whether the low-cost and convenience of Cloud services ends up encouraging greater data use (and, as explored previously, whether data traffic grows faster than gains in network efficiency). So far in the history of ICT, lower costs and greater convenience have driven astronomical increase in global data traffic; it is hard to see why that trend will stop now.

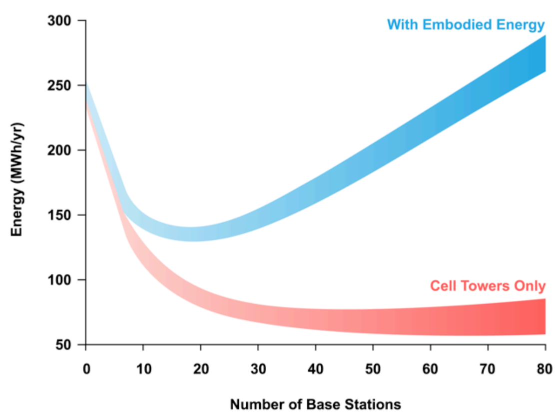


Data Source: Green Cloud Computing

An EU project directed at reducing cellular energy use – because the "networks are increasingly contributing to global energy consumption" -- identified technologies that can yield a 70% reduction in energy per byte transported.[107] But, global mobile traffic is forecast to rise 20-fold in five years.

There are many ideas for improving network efficiency: genetic algorithms that adapt to usage, smart antennas, spectrum sharing, new power supplies, amplifiers, etc.[108] One solution to reduce cell tower congestion and energy use is to move traffic to in-building WiFi and miniature cell 'towers'. Tiny cigar-box sized cell 'towers' are used increasingly; 2 million shipped this year, with 37 million forecast by 2016.[109] Traffic on millions of such picocells or femtocells, and on WiFi, does not eliminate energy, it moves it onto other hardware. Such highly dispersed networks may increase overall energy use when counting both the in-building network energy, and the energy to manufacture millions of picocells.[110]

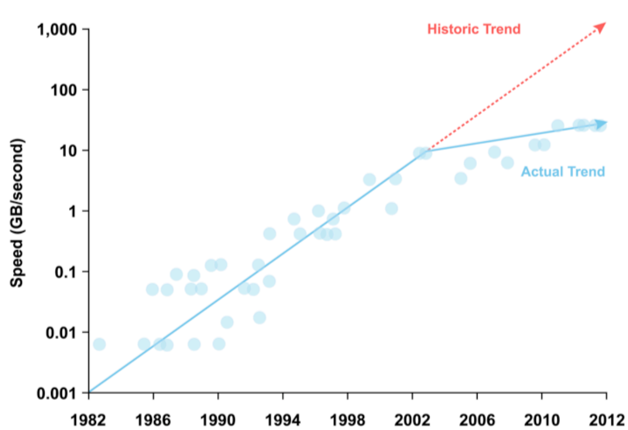
The Impact of Counting The Embodied Energy In Increasing the Number of Cell 'Towers'



Data Source: Cellular Networks with Embodied Energy, IEEE Network
More base stations lowers per-tower energy use & traffic congestion; total energy use rises when including embodied manufacturing energy.

There is a new factor; at the core of the global Internet all of traffic ultimately moves through high-speed fiber-optic Internet exchange points (IXPs). Engineers have achieved a 10,000 fold improvement in IXP speeds since the 1980s.[111] But the rate of improvement hit a physics wall around 2005. Future traffic growth will require new, different and more hardware.

Speed Of Fiber Optic Networks At Global Internet Traffic Exchange Points (IXP)



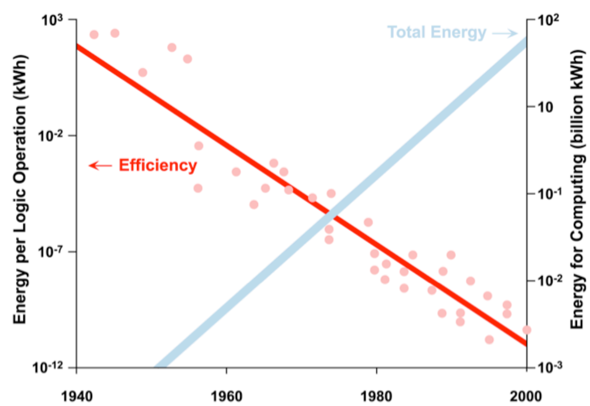
Data Source: OECD Digital Economy Papers

APPENDIX B -- THE IMPACT OF EFFICIENCY ON (ICT) ELECTRICITY DEMAND

Improving the energy efficiency of ICT equipment will not halt growth in ICT electricity use. In fact, improvements in computing efficiency have been core driving force increasing ICT traffic, and thus energy use. Improved computing efficiency made the Internet possible and at least 1,000 times more total energy is used in ICT today compared to when the Internet launched.

Gains in ICT device efficiency have been on-going since the dawn of computing, leading to more overall ICT energy use as the use of more efficient data grows far faster.

Computing Energy Efficiency v. Computing Energy Consumption

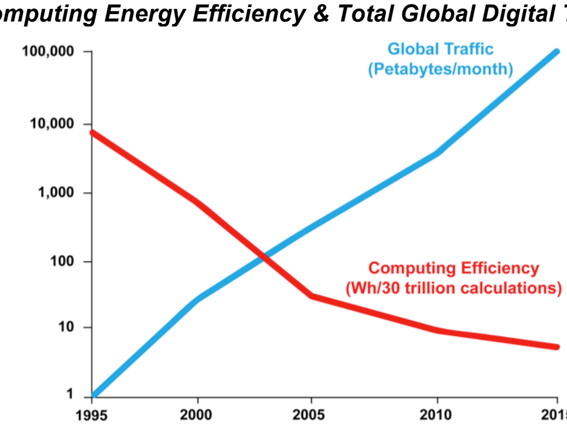


Computing is 10 million times more efficient than at the dawn of computing; total computing energy use increased 100,000 fold. At the energy efficiency of computing in the early 1970s, one iPad would use as much electricity as 12,000 IBM mainframes of that era. [112]

A single 1995 era microprocessor running 24x7 consumes about 40 pounds of coal a year (@40% coal generation). A 2012 CPU is much more efficient; it operates 30 times faster while using only 10 times more power. But the 2012 CPU burns 400 pounds of coal a year, and there are far more energy-efficient 2012 CPUs in the world than there were inefficient ones in 1995.

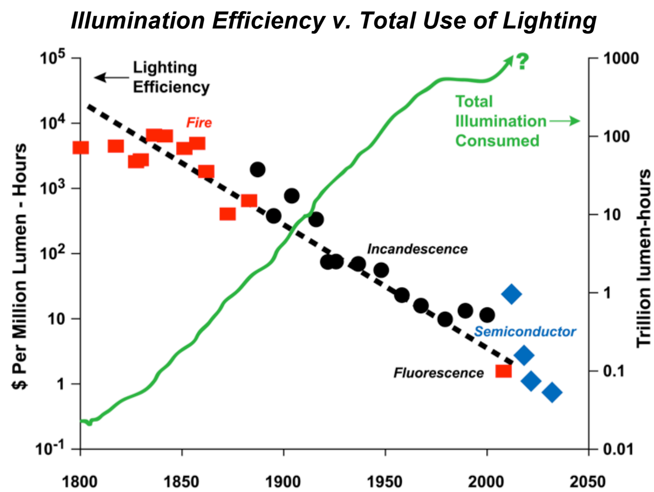
The inexorable exponential decline in energy used per byte has enabled the collateral, now faster exponential increase in global data traffic.

Computing Energy Efficiency & Total Global Digital Traffic



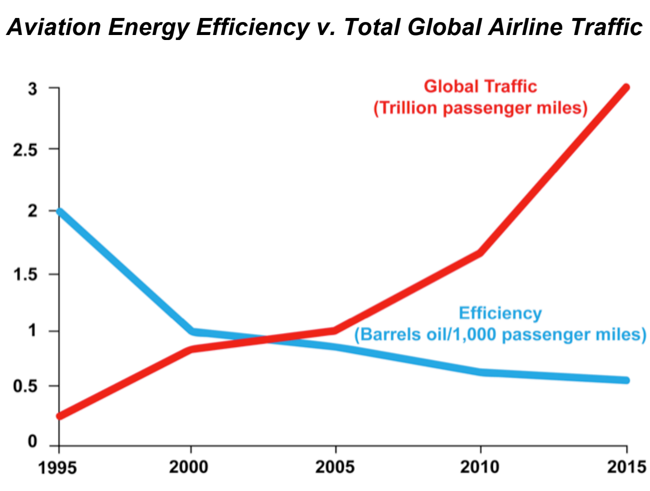
Data Source: IEEE Transactions, Into the Exacloud, Entropy Economics

Efficiency improvements stimulate demand, a well-recognized economic principle and a familiar pattern in history. Illumination has followed a similar trajectory to data. As the costs of illumination (lumen-hours) collapsed 10,000 fold from 1800, illumination use rose exponentially. Growth slowed around 1980 contemporaneous with a leveling off in efficiency gains. Now the advent of super-efficient semiconductor lighting portends historic trends will return and lumen use will rise – but some forecasters believe lumen use will break with the long-run trend and now decline with rising efficiency, even as billions more people in the world acquire lighting.[113]



Data Source: *Heat, Power and Light*, Fouquet *2008: lumen consumption for the U.K.*

The history of efficiency in global aviation tracks the same trajectory as in computing and illumination. More efficiency propels demand. This basic economic rule breaks down only in fully saturated markets, such as with U.S. automobiles where there are more registered cars than registered drivers. Saturation in demand for both air travel and data in particular are far from visible.



Data Source: FAA

GE's new turbine will be 25% more efficient with10% more thrust; lower operating costs will help propel, not slow, trends to more traffic.[114]

Some analysts believe that efficiency gains can now outpace data traffic growth, even though that has not happened in the past.[115]

Meanwhile, the historic rate of improvement in computing energy efficiency – driven largely by Moore's Law – started slowing down around 2005, even as the growth in global traffic on the Internet began accelerating.[116] This combination arithmetically guarantees greater energy use with growth in data traffic.

- "… your wireless, your optical networks, your wire line [networks], your fixed access [technology], your core backbone networks and so forth … [are seeing] a sudden slowdown in the energy efficiency." Thierry Klein, Alcatel-Lucent Bell Labs.

- "[There has been] a sharp reduction in the rate of [computation] energy efficiency improvements over the last several years resulting in the formation of an asymptotic 'wall'." IEEE Transactions on Scaling Very Large Integration Systems.

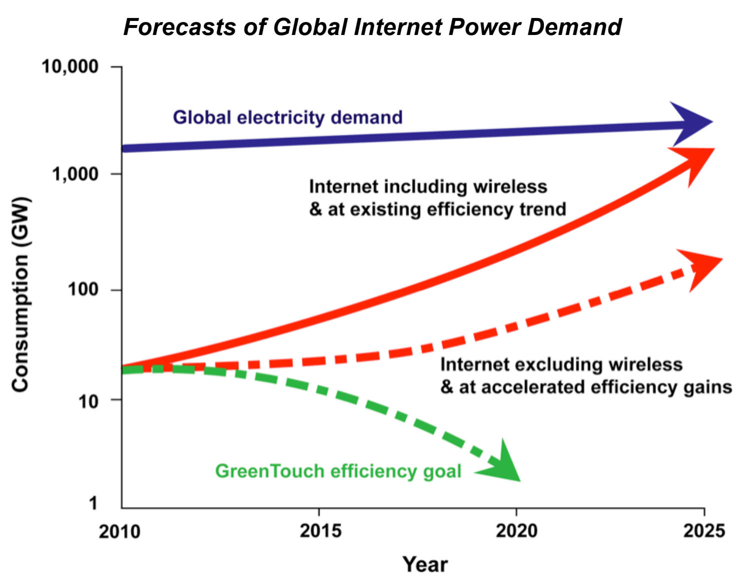
- "We have achieved the ultimate spectral [physics] efficiency. "Marcus Weldon, CTO Alcatel-Lucent.

- "…energy consumption in ICT networks is increasing … [there is] a gap between rapid network growth rates today and historical equipment efficiency improvements -- a gap that promises to increase over the decades ahead. … even considering best-case projected energy efficiency improvements, [they] are not expected to be sufficient to check the rate of energy consumption over the long term." GreenTouch.

Network operators are hoping to radically improve the energy efficiency of their equipment and networks, seeking gains greater than have occurred to date.

- "The consumption of the network starts to approach total global electricity supply in 2025. Clearly something needs to be done about this." Rod Tucker, Director of CEET, April 2012

Clearly neither the above, nor the earlier noted National Academy of Sciences observation about the energy cost of computing becoming "too expensive," will come to pass. Solutions will emerge in semiconductors, software and operating architectures. Global ICT efficiency will improve, but so will global ICT energy consumption – just as both have in the past.



Source: GreenTouch, CEET

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[12] Boston Consulting Group, for GeSI SMARTer2020, "The Role of ICT in Driving a Sustainable Future," 2012: data are presented in terms of CO2 emissions and converted to kWh based on 526.6 gCO2/kWh (per Greenpeace, below, "The emission factors used come from McKinsey and Vanttefall Cost Curve, which are not disclosed in the report. Using a publicly-known global factor for the global carbon intensity of electricity production, WRI's CAITi.") The conversion will slightly overstate total kWh as the GeSI document includes non-electric energy contributions to ICT such as vehicle transport, but the latter are minor
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- GeSI data is in CO2 emissions; converted to kWh @526.6 gCO2/kWh per Greenpeace above: "... [GeSI] emission factors used come from McKinsey and Vanttefall Cost Curve, which are not disclosed in the report. Using a publicly-known global factor for the global carbon intensity of electricity production.") Conversion slightly overstates kWh as GeSI includes some minor non-kWh used in transportation.

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