# Does Not Compute: Facts and Fiction about Computing and the Environment

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This talk is an expansion of ideas presented in Koomey, Jonathan, and Eric Masanet. 2021. "Does not compute: Avoiding pitfalls in assessing the energy use and carbon dioxide emissions of information technology." *Joule*. In press.

Blog post at http://www.koomey.com will have a link to download a PDF of the talk by tomorrow, June 2, 2021

People routinely overestimate the energy use and environmental effects of information and communication technologies

# Some examples of high-profile misconceptions

**Misconception # 1:** The internet doubles every 100 days (Huber and Mills 1999 and Coffman and Odlyzko 2001)

**Reality check:** Internet data flows doubled every 100 days for only a short period circa 1995-1996, fiber optic network 97% unused in 2002 (per Dreazen, *WSJ*).

**Misconception # 2:** Information technology (IT) will use 50% of US electricity in 10 years (Huber and Mills 1999)

**Reality check:** IT uses no more than 5% of electricity use in total, and total isn't growing much if at all (Malmodin and Lundén 2018)

Investors thinking electricity sector stocks would do well because of growth in IT electricity use got burned when tech bubble burst (at least six major investment reports repeated incorrect claims uncritically, as per Koomey 2017)

**Misconception # 3:** California's electricity crisis was caused by IT's electricity use (Mills and Huber 2000)

**Reality check:** CA electricity crisis was caused by market manipulation and structural flaws in market design, not IT electricity use or growth in electricity demand more generally (Weare 2003)

**Misconception # 4:** A wireless Palm Pilot's (or iPhone's) "behind the wall" network electricity use is as much as one (two) refrigerator(s) (Mills and Huber 2000 and Mills 2013, respectively)

**Reality check:** Wireless Palm pilot network electricity overestimated by a factor of two thousand (!), iPhone network electricity overestimated by a factor of 18 (Koomey et al. 2004 and Koomey 2013a)

**Misconception # 5:** One Google search emits as much $CO_2$ as boiling water for half a cup of tea (Leake and Woods 2009).

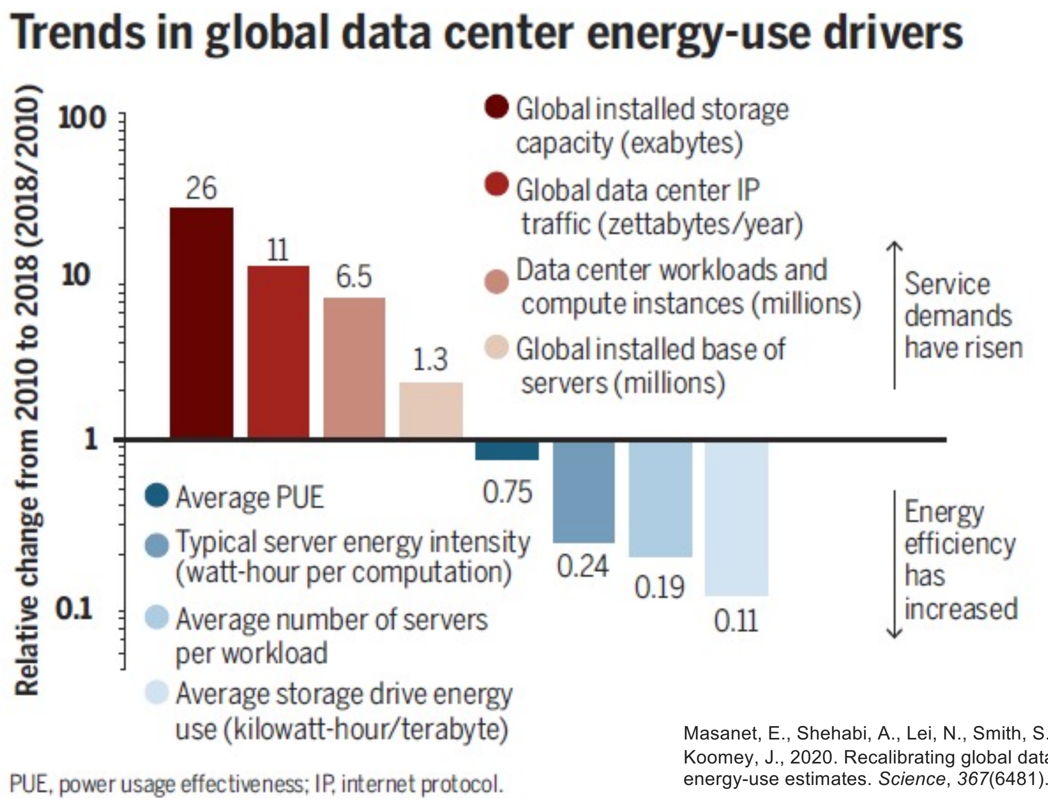
**Reality check:** One Google search's emissions circa 2009 overestimated by a factor of 35 (E. Mills and Koomey 2009)

**Misconception # 6:** Data center electricity use will grow 2.7-fold from 2010 to 2018 and 15-fold to 2030 (Andrae and Edler 2015)

**Reality check:** Global data center electricity use grew a scant 6% from 2010 to 2018 as computing output, IP traffic, and storage capacity increased to 6.5, 11, and 26 times their 2010 values, respectively (Masanet et al. 2020).

# Global data center energy

From 2010 to 2018 power demands rose just **six percent** in the time it took for compute instances to jump **550 percent**.




Masanet, E., Shehabi, A., Lei, N., Smith, S. and Koomey, J., 2020. Recalibrating global data center energy-use estimates. *Science*, *367*(6481).

**Misconception # 7:** $CO_2$ emissions from Bitcoin ALONE will push global temperatures beyond 2C in the next few decades (Mora et al. 2018)

**Reality check:** Bitcoin emissions overestimated by at least a factor of four in that analysis (Masanet et al. 2019)

**Misconception # 8:** $CO_2$ emissions from watching half an hour of Netflix equal those from driving four miles (Shift Project 2020)

**Reality check:** Streaming video emissions overestimated by a factor of eighty (Kamiya 2020)

**Misconception # 9a:** Watching video in 4K or Ultra High definition emits eight times more than watching in Standard Definition (The Royal Society 2020).

**Misconception # 9b:** Leaving the camera off during a web call can reduce CO2 footprint by 96% (Obringer et al. 2021)

**Reality check:** Majority of video-related electricity use occurs at end-user devices independently of data transmission rates. Network equipment is not generally energy proportional, so electricity use doesn't vary when data flows change.

# Brandolini's law highlights an asymmetry

- "Brandolini's Law" states (paraphrased for a family audience): "the amount of energy needed to *refute* misinformation is ten times greater than the amount of energy needed to *create* misinformation".
- The implication is that rigorous research to produce accurate data will always trail misinformation, because it's harder and takes longer to get the numbers right.
- Social media exacerbate this asymmetry

# Four common pitfalls

- Wrongly assessing changes over time
- Assuming that short-term changes in computing services must result in increasing electricity use
- Making long-term projections more than 3-5 years into the future
- Drawing broad conclusions based on trends in only one part of the IT system

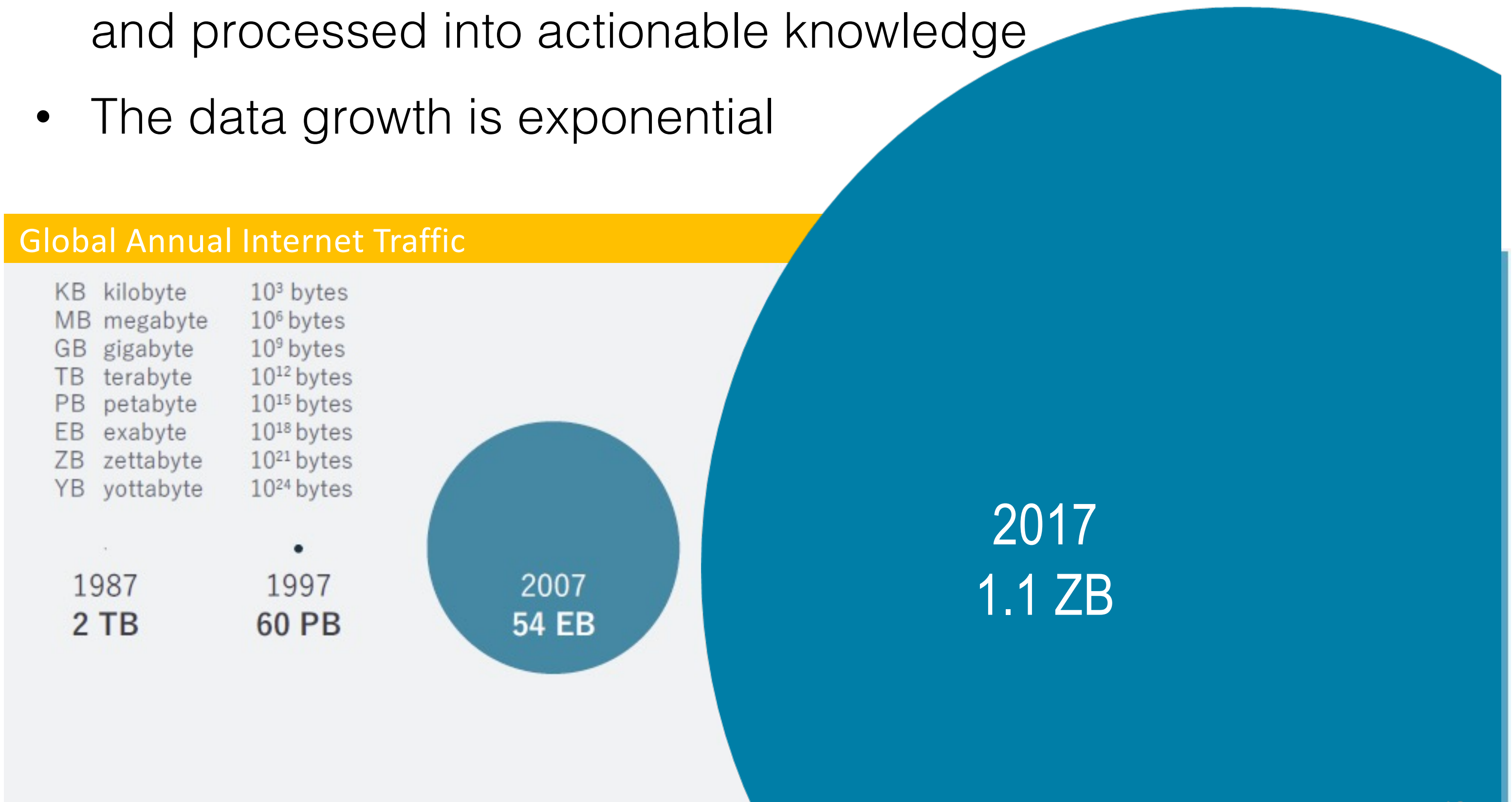
- **Pitfall #1**: Analysts ignore, misunderstand, or mischaracterize changes in key parameters over time.

- **Key lessons**:
  - Rapid changes and pervasive data gaps make accurate, up-to-date assessments difficult or impossible.
  - Analytical errors, failure to fact check cited statistics, and inadequate documentation make accurate assessments less common than they ought to be, and
  - Analysts and the media may recycle published data long after they are no longer valid.

# Delivery of IT services is increasing rapidly

# We are in the Zetabyte Era

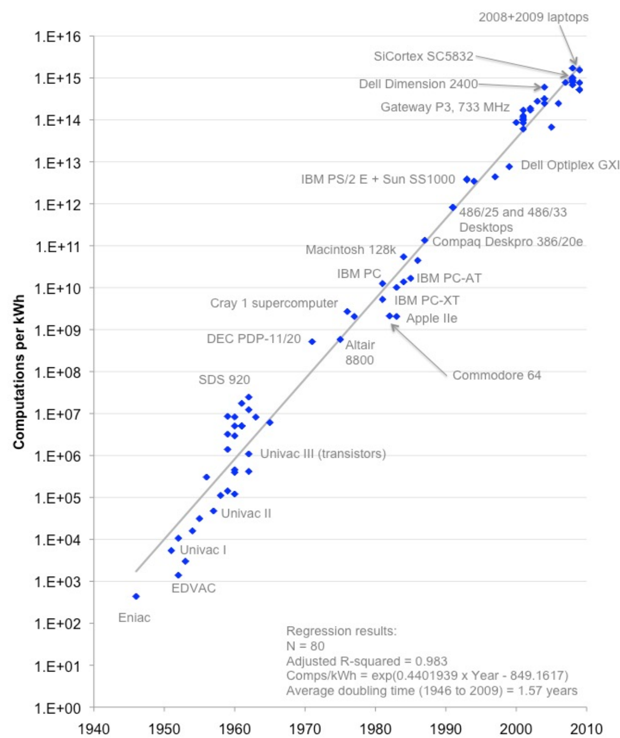
- More and more data is being generated, transported, stored, and processed into actionable knowledge
- The data growth is exponential




Source: International Energy Agency, *Digitalization & Energy* (2017)

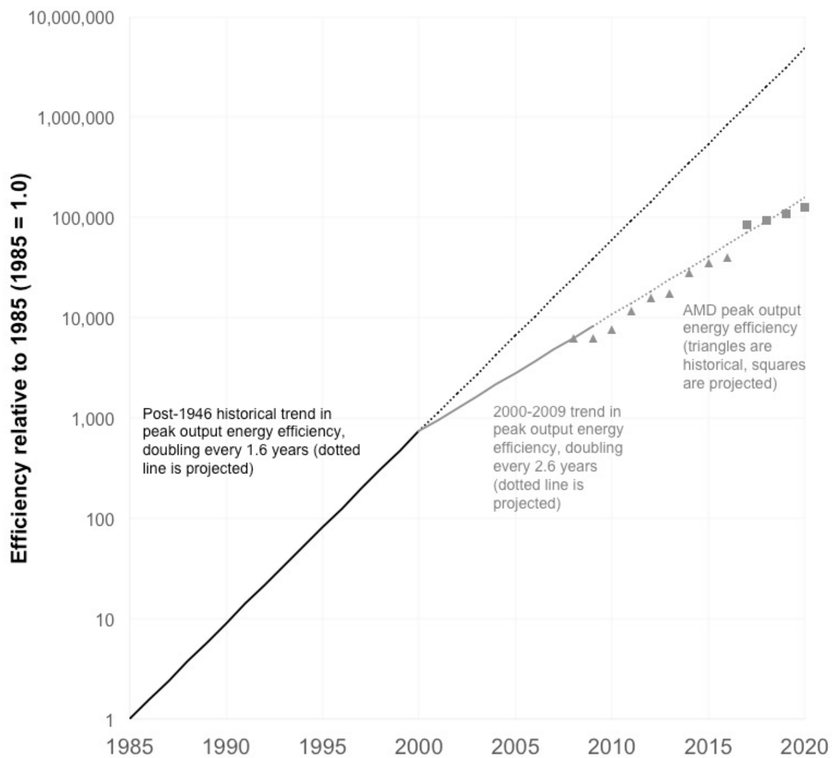
At the same time, information technology is becoming more energy efficient at a furious pace

# Computing efficiency at peak output doubled every 1.6 years to 2000



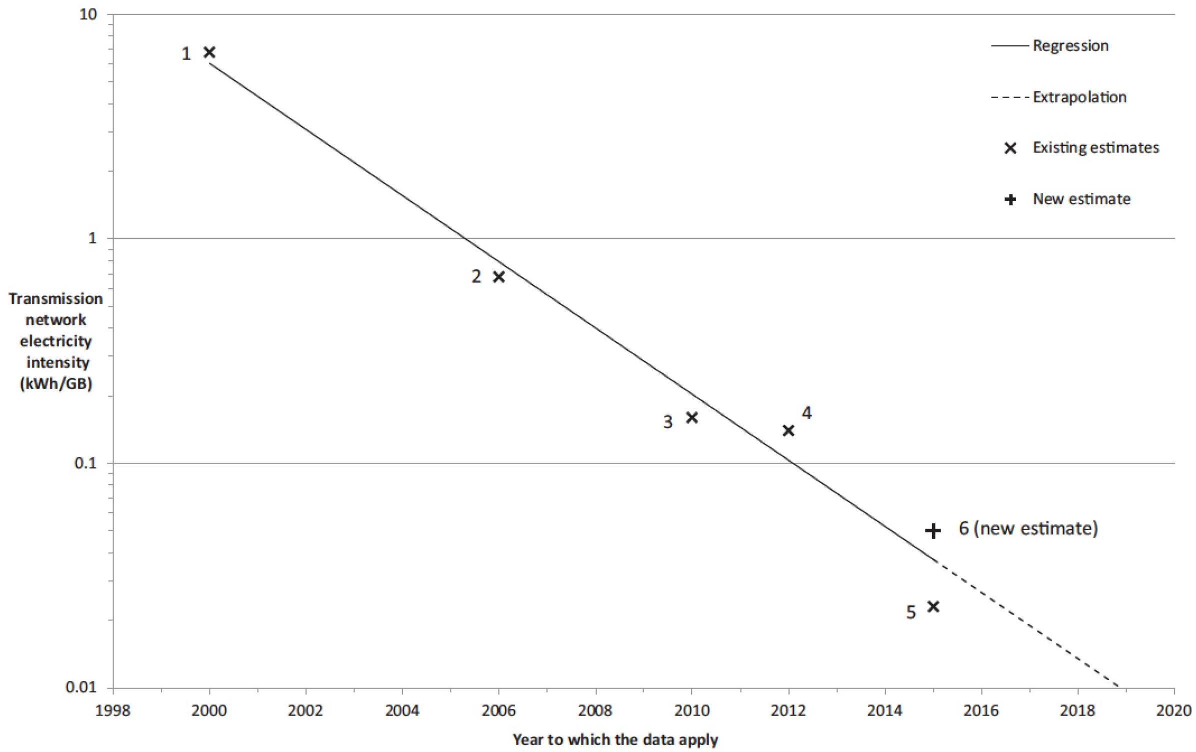

Source: Koomey et al. 2011

# Computing efficiency trend slowed after 2000 (peak output efficiency doubling every 2.6 yrs)




Source: Koomey and Naffziger 2016

# Network electricity intensity/GB halving every 2 years after 2000 for broadband downloads




Source: Aslan et al. 2017. Boundary: Core + land line access networks.

Growth in data use, data transfers, or computations don’t necessarily imply growth in computing electricity use

# Two opposing factors

- Energy use per year is a function of computations per year and electricity use per computation

$$\frac{\text{Total Energy (kWh)}}{\text{Year}} = \frac{\text{Computations}}{\text{Year}} \times \frac{\text{kWh}}{\text{Computation}}$$

- Equivalently

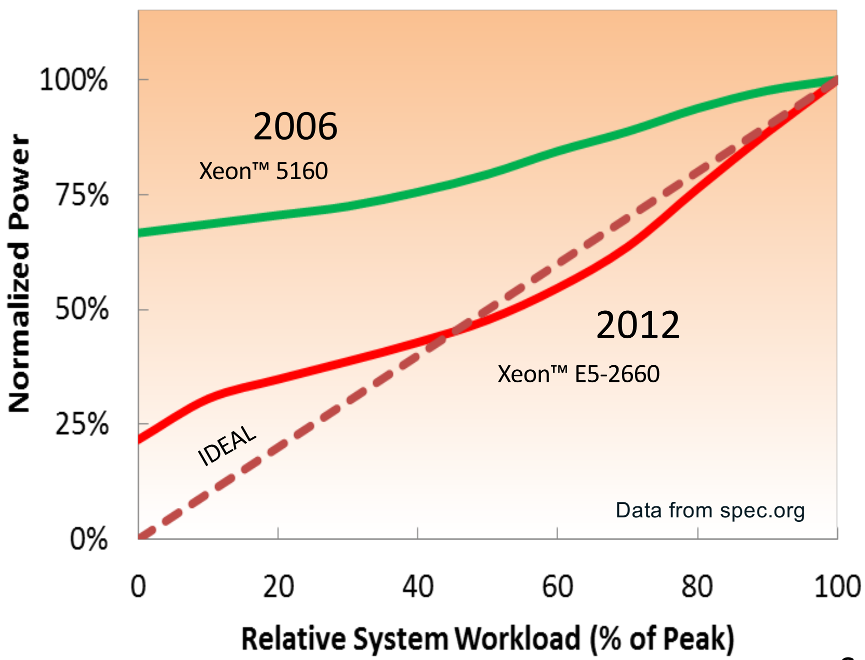
$$\frac{\text{Total Energy (kWh)}}{\text{Year}} = \frac{\frac{\text{Computations}}{\text{Year}}}{\frac{\text{Computations}}{\text{kWh}}}$$

- **Implication**: If Computations/Year goes up faster than Computations/kWh, then total kWh goes up! (and people often underestimate improvements in computations/kWh)

**Pitfall #2**: Assuming that *short-term* changes in computing services must lead to proportional and immediate changes in electricity use.

**Key lesson**: Most IT devices are not perfectly energy proportional, and network equipment is the least sensitive to changes in changes in load levels.

# Energy proportionality: Computer servers




- Usage Driven
- Variable Utilization
- Proportional Energy Use
- Optimized Efficiency

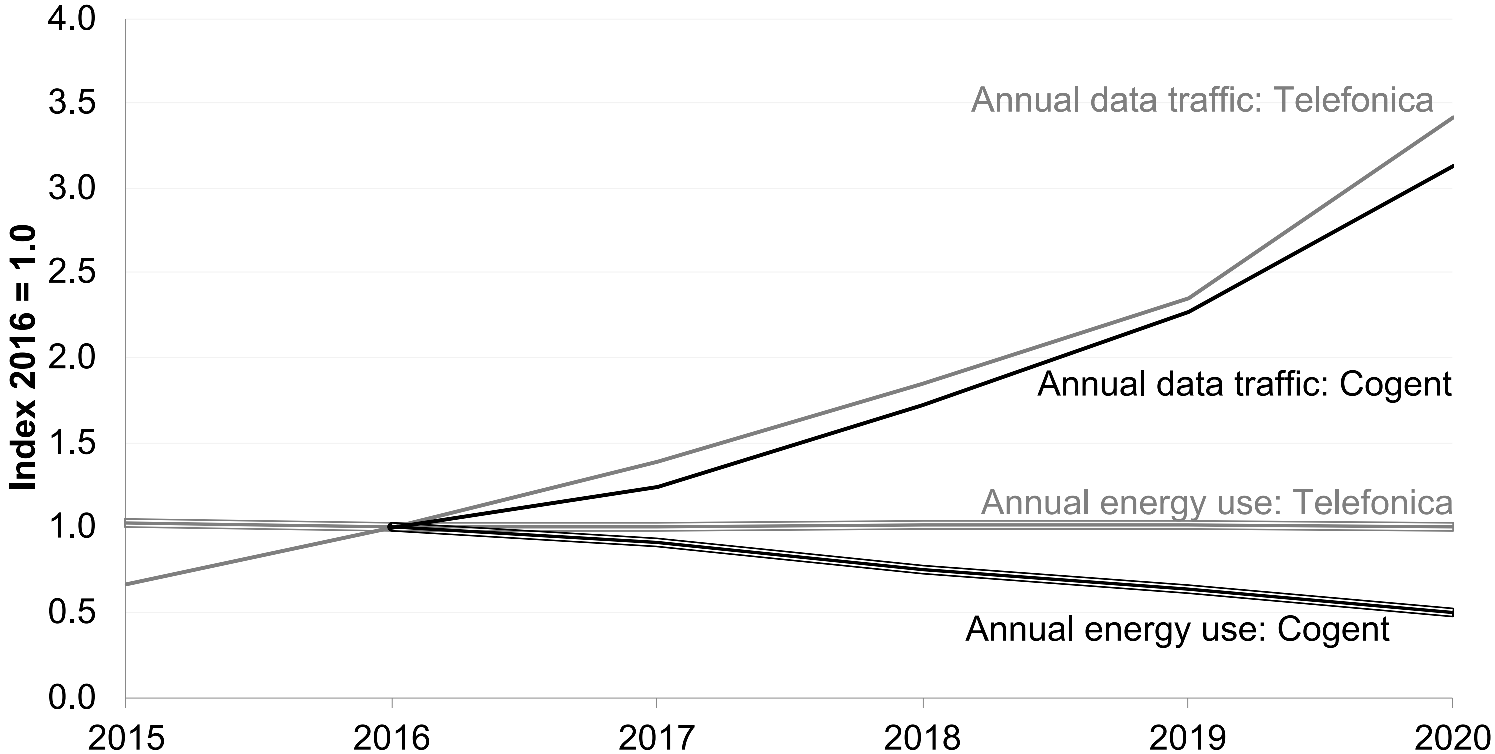
- Technology Scope:
- CPU and Memory
- Power Delivery, Fans, etc.
- Instrumentation

Source: Winston Saunders, Intel

**Approaching "Ideal" Server Behavior IN THEORY**

Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark* and MobileMark*, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. Configurations: Dual Socket Server. For full configuration information, please see backup. For more information go to http://www.intel.com/performance

# Data flows up from 2019 to 2020, electricity use flat or declining

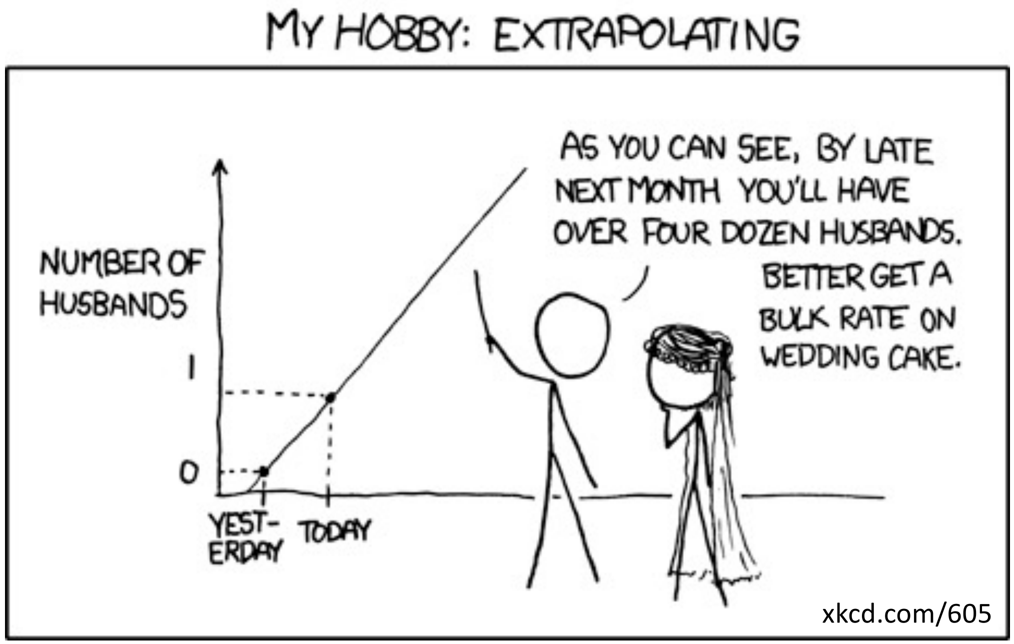


**Pitfall #3**: Making long-term projections more than 3-5 years into the future

**Key lesson**: Don't make projections for IT beyond the period of manufacturer product roadmaps, except in very rare special cases

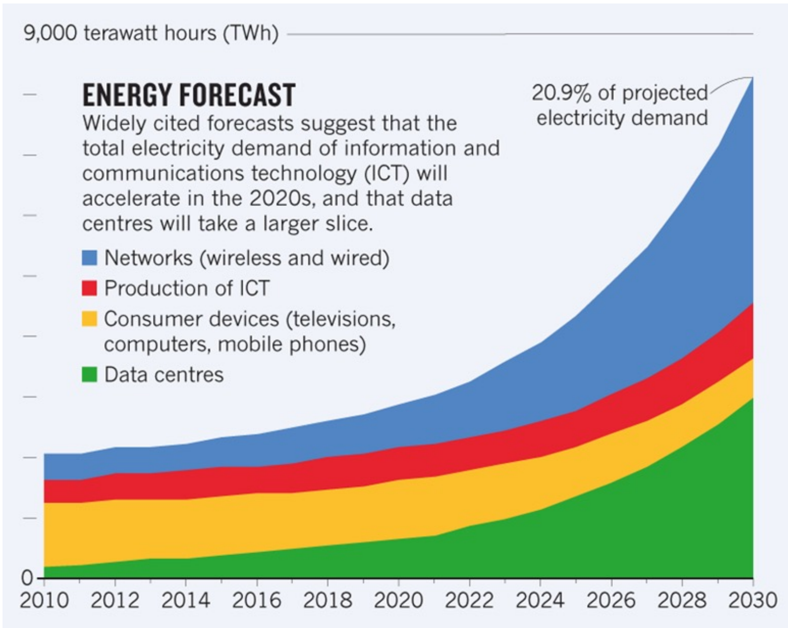
# Watch out for simple-minded extrapolations

Data Limitations




xkcd.com/605

# Extrapolations = nonsense projections




**Source: Jones, Nicola. "How to stop data centres from gobbling up the world's electricity."** ***Nature*** **561.7722 (2018): 163.**

A Facebook data centre in Luleå, Sweden.

JONATHAN NACKSTRAND/AFP/GETTY

# THE INFORMATION FACTORIES

*Data centres are chewing up vast amounts of energy — so researchers are trying to make them more efficient.*

BY NICOLA JONES

Upload your latest holiday photos to Facebook, and there's a chance they'll end up stored in Prineville, Oregon, a small town where the firm has built three giant data centres and is planning two more. Inside these vast factories, bigger than aircraft carriers, tens of thousands of circuit boards are racked row upon row, stretching down windowless halls so long that staff ride through the corridors on scooters.

These huge buildings are the treasuries of the new industrial kings: the information traders. The five biggest global companies by market capitalization this year are currently Apple, Amazon, Alphabet, Microsoft and Facebook, replacing titans such as Shell and ExxonMobil. Although information factories might not spew out black smoke or grind greasy cogs, they are not bereft of environmental impact. As demand for Internet and mobile-phone traffic skyrockets, the information industry could lead to an explosion in energy use (see 'Energy forecast').

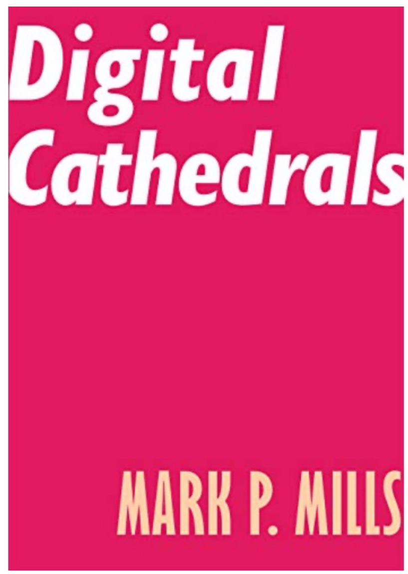
Already, data centres use an estimated 200 terawatt hours (TWh) each year. That is more than the national energy consumption of some countries, including Iran, but half of the electricity used for transport worldwide, and just 1% of global electricity demand (see 'Energy scale'). Data centres contribute around

**Pitfall #4**: Drawing broad conclusions based on trends in only one part of the IT system.

**Key lesson**: Analytical rigor comes from analyzing a whole system, which is often difficult due to pervasive data gaps.

# Hyperscale data centers aren't everything

- **The mistake**: examining the fastest growing part of IT (hyperscale data centers) and assuming the whole IT sector grows at comparable rates.



# How can we do better?

# Industry should improve data sharing

- Technology changes fast
- Companies understandably reluctant to share proprietary data
- Need consistent cross-industry protocols for data/measurements
- Develop indices over time for improvements in technology and computing services (with help from researchers)

# Analysts must report results more precisely and transparently

- Report electricity use, computing service demand, emissions factors, and absolute emissions explicitly
- Report exact dates and locations to which data/estimates apply
- Avoid averaging parameters over long periods
- Release complete documentation to enable others to replicate results

# Analysts should exercise restraint

- Resist the temptation to make assumptions (better to collect data instead)
- When data are not available, better not to publish estimates at all, or to couch results in an appropriately cautious way
- Avoid simple extrapolations and never project more than a few years into the future
- Avoid using estimates from even a few years ago without adjusting for underlying trends in efficiency and service demand
- Use caution when citing factoids about IT electricity use and encourage the media to exercise similar restraint

# Journals should improve peer review

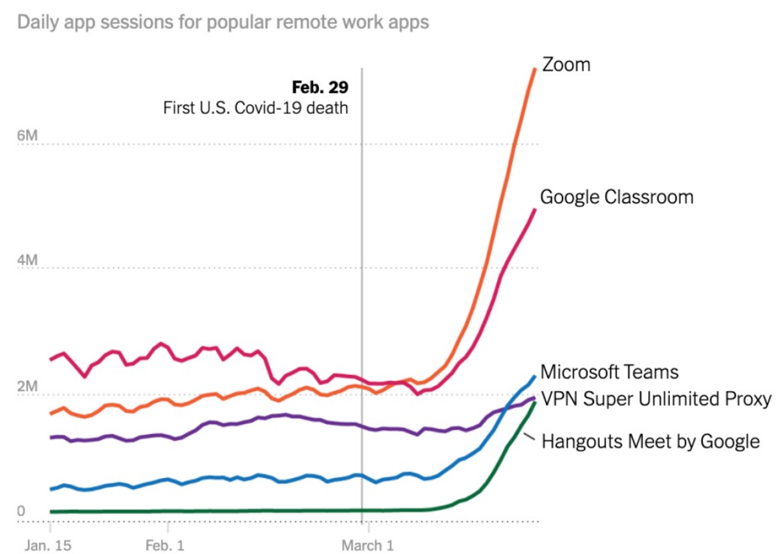
- Research on IT electricity use must be evaluated by people with real subject matter expertise, especially when research is conducted by people from outside this field
- Journals should require full disclosure of underlying assumptions, data, and models, so that others can replicate the results
- Journals should ensure thorough reviews, with full knowledge that this field is rife with exaggerations

Always ask: Compared to what?

# Indirect ICT benefits for the energy transition

ICT is a general-purpose technology that will have broad and deep effects on the economy. Examples:

- Moving bits instead of moving atoms (Telecommuting)
- Replacing parts with smarts (Tesla Model 3 uses phone to unlock car, no traditional key)
- Collecting data (Internet of things)
- Analyzing data for real-time feedback and control (power systems control)
- Blockchain (peer-to-peer energy trading)
- Computer-aided design integrated with emissions analysis (for energy-using and generating products)
- Tech firms sourcing renewable electricity (reduces emissions intensity per kWh)




Koeze and Popper, *The Virus Changed the Way We Internet,* New York Times, April 7, 2020

# Conclusions

- If you hear an amazing factoid about IT electricity use or emissions, assume it is an exaggeration until proven otherwise
  - remember the asymmetry described by Brandolini's law
- Before citing such factoids, make sure they've been checked by credible experts
- Ignore serial disinformers
- Don't project IT electricity use more than a few years into the future
- Focus on the whole system, not just one part
- Remember that efficiency often increases as fast as service demand
- Always ask "Compared to what?"

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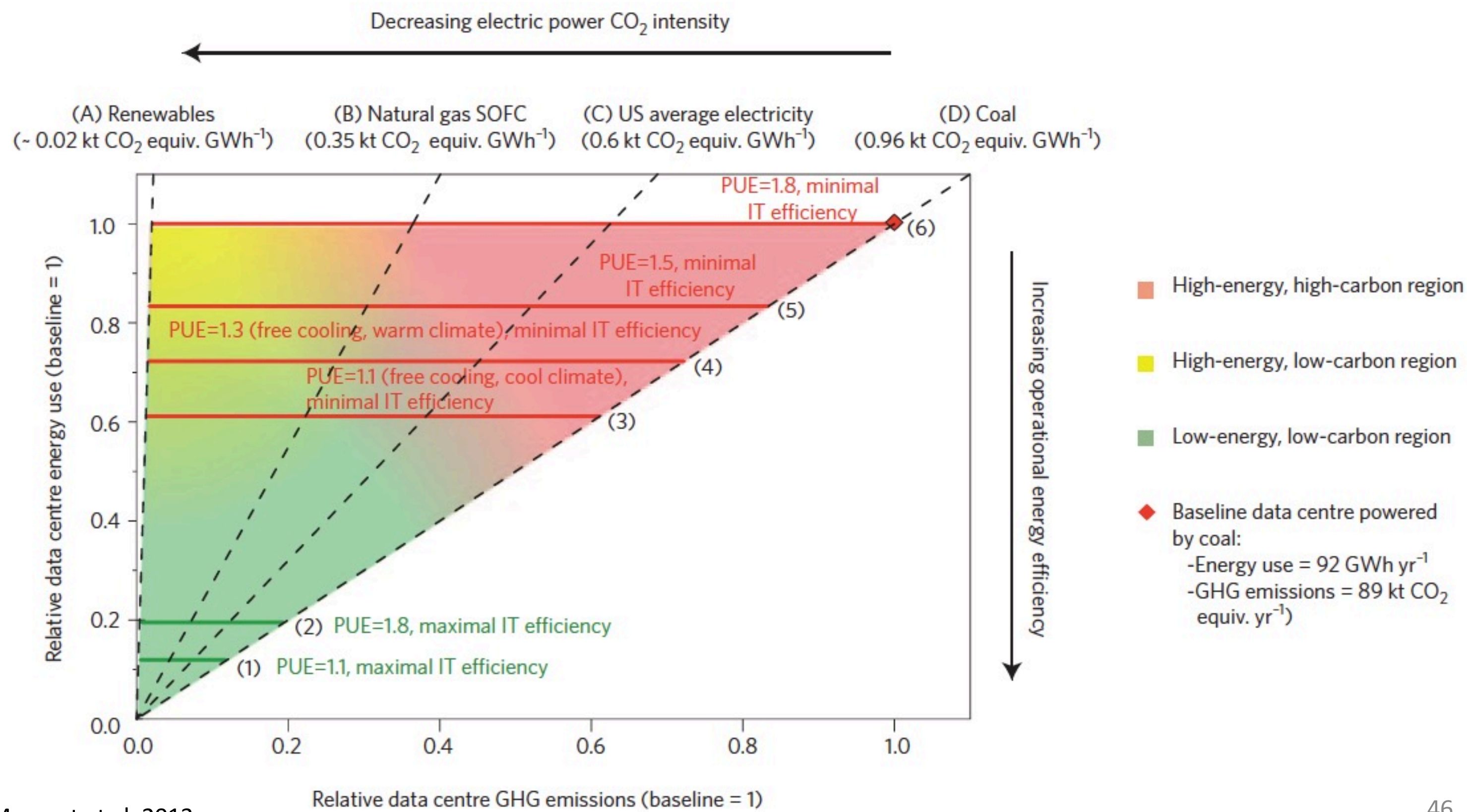
# Supplemental slides

# Moving toward low-carbon data centers

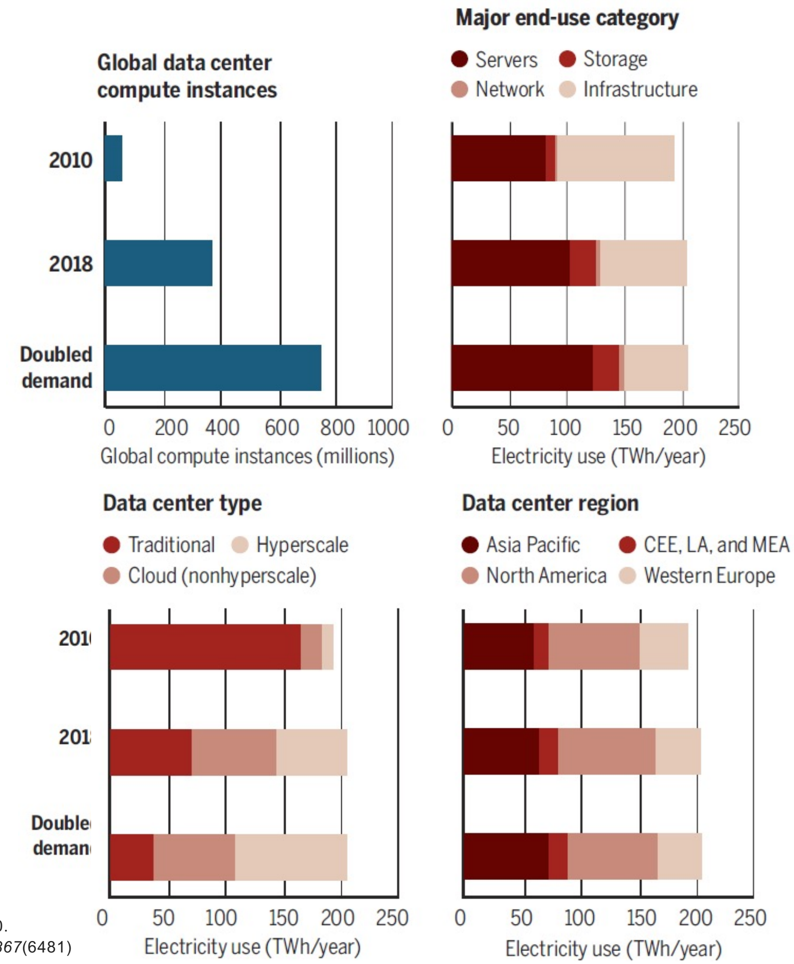
The data center energy-carbon performance map




Masanet et al. 2013.

# Global data center energy modeling

- On-site data center electricity demand currently at 205 TWh (70 TWh U.S.)
- Minimal energy use growth during rapid industry expansion in past decade due to massive energy efficiency gains
- Sufficient energy efficiency resource exists to absorb the next doubling computational demand
- Known stabilization is limited to a few years, after which new measures may be needed
- Doesn't account for newer chips (e.g., ASICs, GPUs)

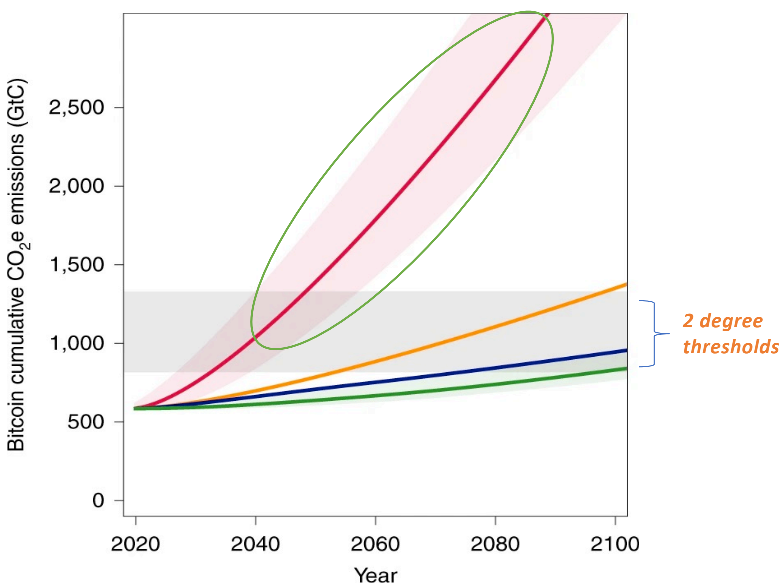



Masanet, E., Shehabi, A., Lei, N., Smith, S. and Koomey, J., 2020. Recalibrating global data center energy-use estimates. *Science*, *367*(6481)

# But what about Bitcoin?

**Mora et al. 2018 :**
***Bitcoin emissions alone could push global warming above 2 ℃ within less than three decades***


**Masanet et al. 2019:**
***Implausible projections overestimate Bitcoin $CO_2$ emissions***




**Over-estimations (Mora)**
**4 main reasons:**

- **overly estimated <u>baseline</u>: old mining rigs (Orange: excluding old rigs)**
- **hold constant carbon intensity (Blue: grid intensity evolution)**
- **error in applying logarithmic model for regression analysis of broadly-used technologies to approximate future bitcoin transactions (Green line)**
- **unwise choice of <u>emission drivers</u>: transactions (should be mining difficulty)**

***Less alarming projections even in the case of inappropriate energy driver choice (following his own approach).***