Data centres, energy efficiency, and energy transitions

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2000		2019
6.1 billion	**Population**	7.7 billion
68 trillion	**GDP**	130 trillion
14 PWh	**Electricity use**	23 PWh
0.4 billion	**Internet users**	4.1 billion
0.9 EB	**Internet traffic**	2000 EB

Sources: UN (2019), World Population Prospects 2019; World Bank (2020), Data Bank: GDP, PPP (Constant 2017 International $); IEA (2020), Data and statistics; ITU (2020), Statistics; Cisco (2015), The History and Future of Internet Traffic; Cisco (2018), Cisco Visual Networking Index: Forecast and Trends, 2017–2022

Forbes

May 30, 1999

Dig more coal -- the PCs are coming

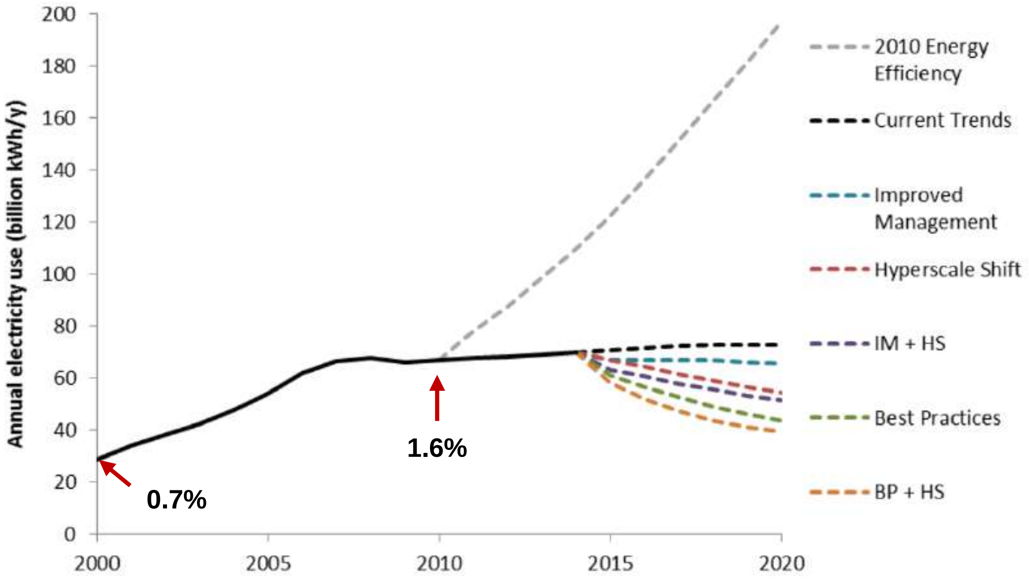
This article is more than 10 years old.

"It's now reasonable to project that half of the electric grid will be powering the digital-Internet economy within the next decade."

Forbes (1999). https://www.forbes.com/forbes/1999/0531/6311070a.html#21a128aa2580.

US data centre energy use trends

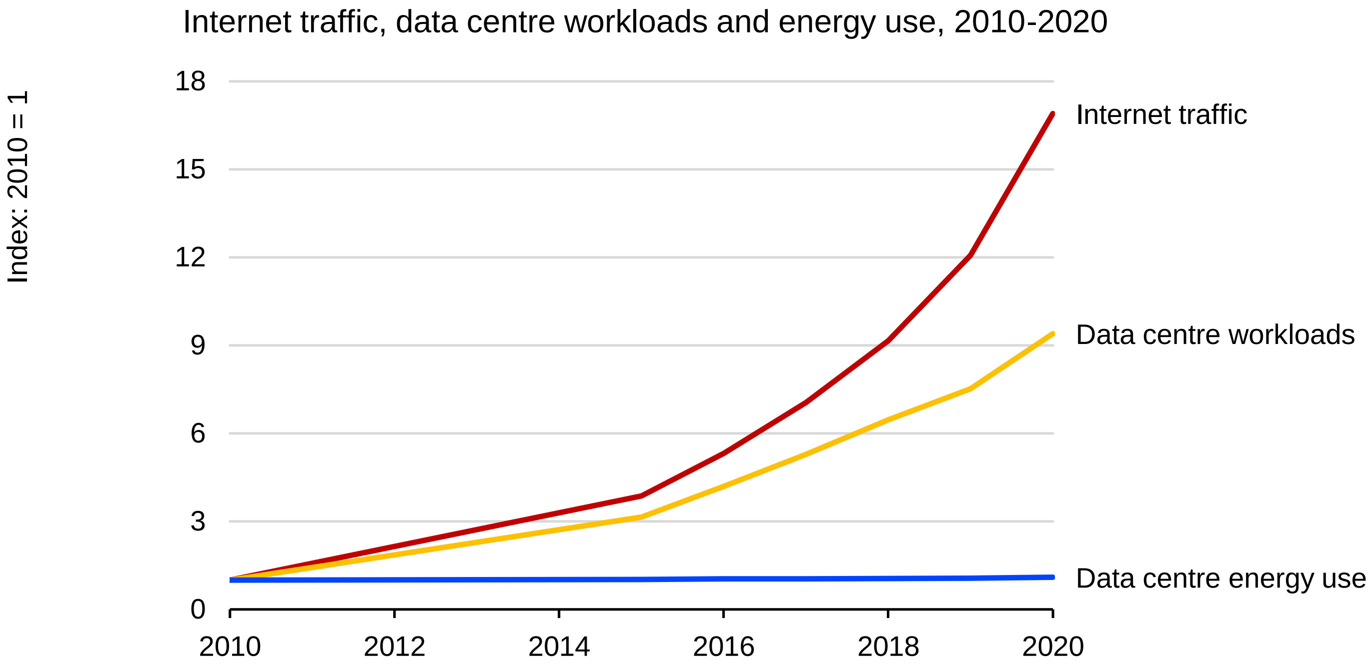
Data centre energy use in the United States



Source: LBNL / Shehabi et al. (2016). United States Data Center Energy Usage Report. https://eta-publications.lbl.gov/sites/default/files/lbnl-1005775_v2.pdf.

Data centre energy use in the US increased rapidly between 2000 and 2010, but only reached 1.6% of total electricity use

Global data centre energy use trends



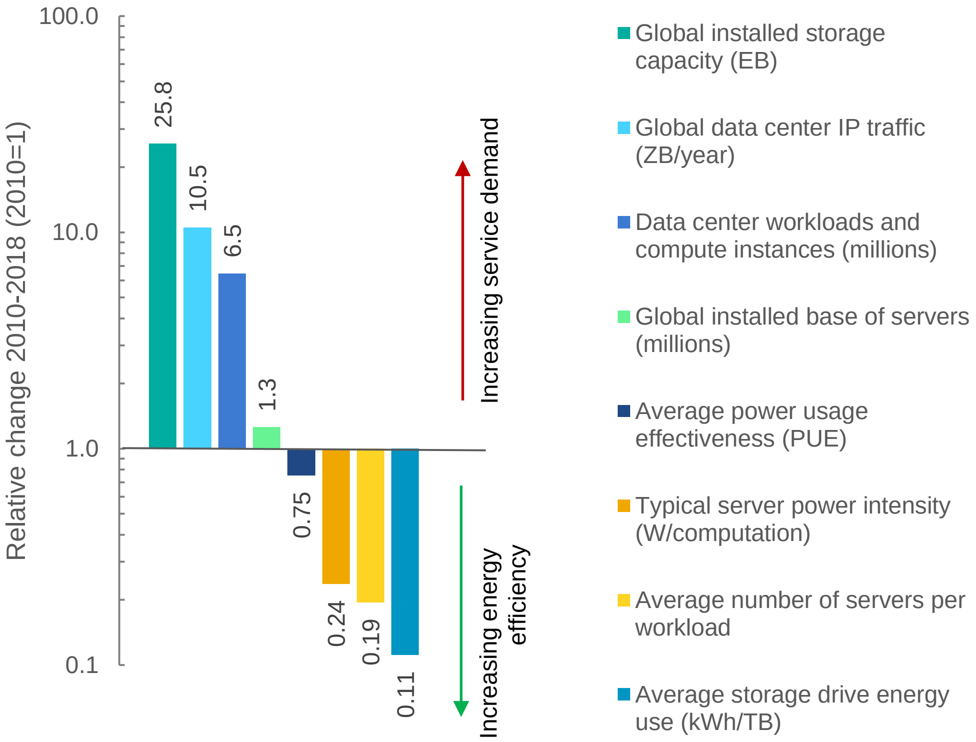
Sources: Masanet et al. (2020). Recalibrating global data center energy-use estimates. IEA (2021). Data centres and data transmission networks; Cisco (2018). Global Cloud Index: Forecast and Methodology, 2016-2021; Cisco (2019). Visual Networking Index: Forecast and Trends, 2017-2022.

Note: Figures exclude cryptocurrency mining

Globally, data centres used an estimated 200-250 TWh in 2020, or around 1% of global electricity use

Efficiency drivers in data centres

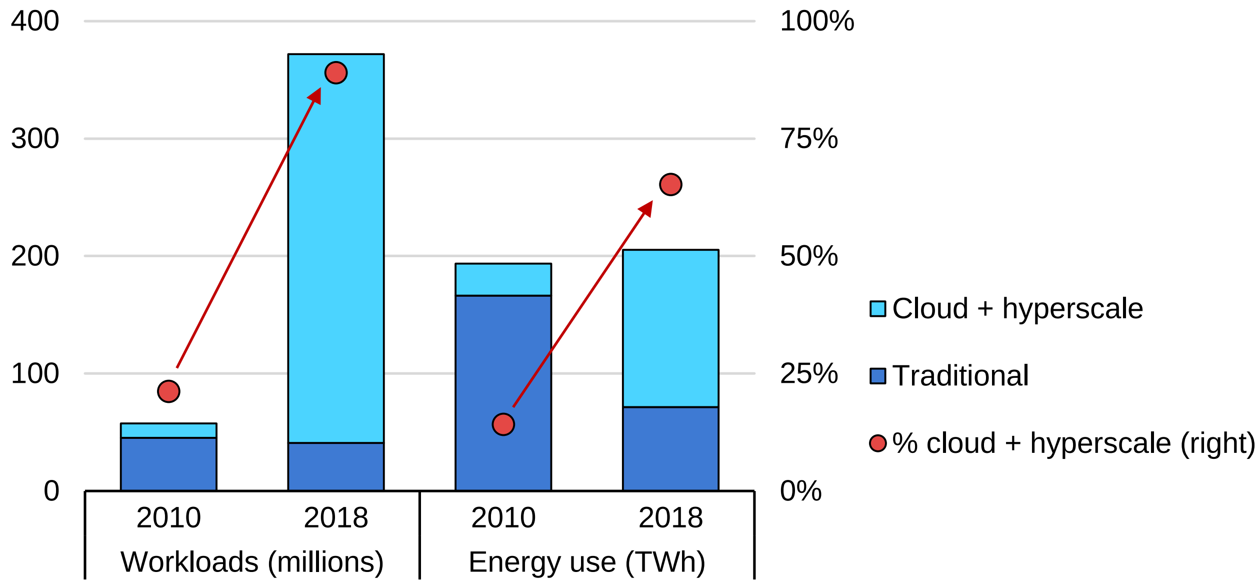
- Improved energy efficiency of IT hardware (servers, drives, network ports)
- Servers with better power scaling capability (i.e. reducing power consumption during idle or low utilisation)
- Declining PUE (i.e. less power for cooling)
- Increased virtualisation + shift to cloud



Source: Masanet et al. (2020). Recalibrating global data center energy-use estimates.

Shift to cloud and hyperscale

Global workloads and energy use by data centre type

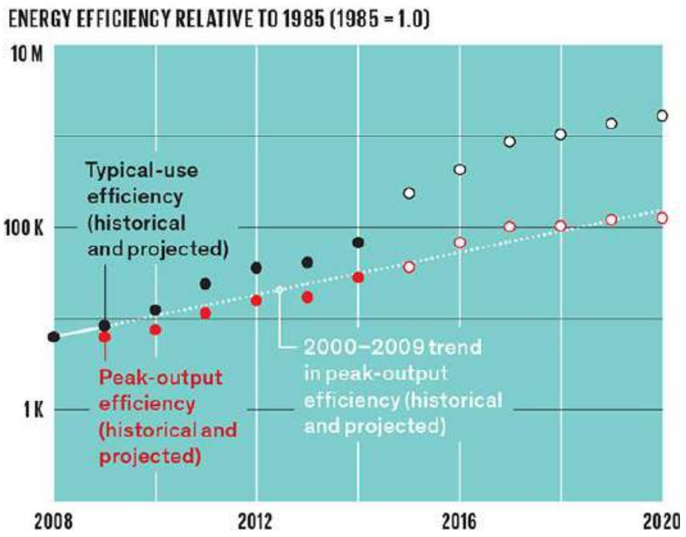


Sources: Masanet et al. (2020). Recalibrating global data center energy-use estimates. Cisco (2018). Global Cloud Index: Forecast and Methodology, 2016-2021.

Cloud and hyperscale data centres account for the majority of workloads (~90%) and energy use (~65%), up from ~20% in 2010

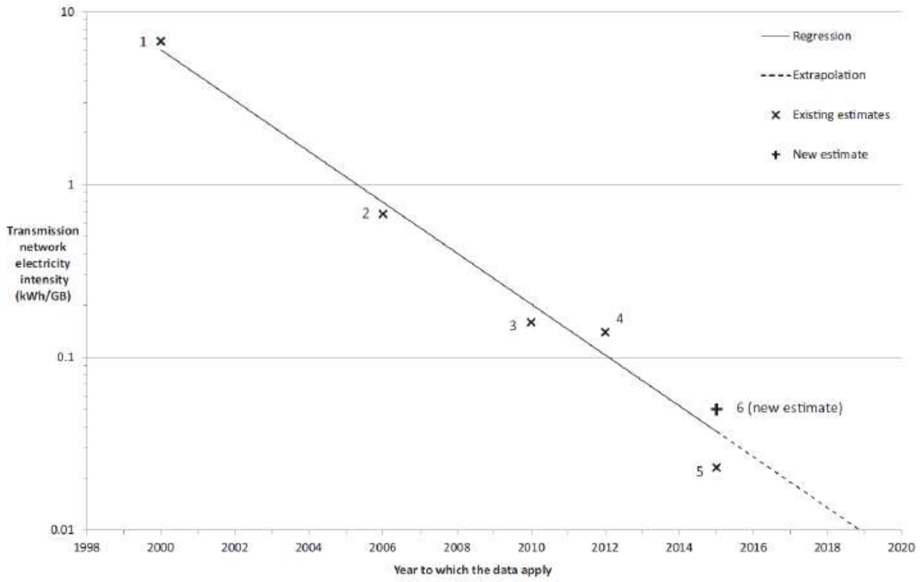
ICT energy efficiency trends

Computing – “Koomey’s Law”



Koomey & Naffziger (2015), Moore’s Law Might Be Slowing Down, But Not Energy Efficiency.

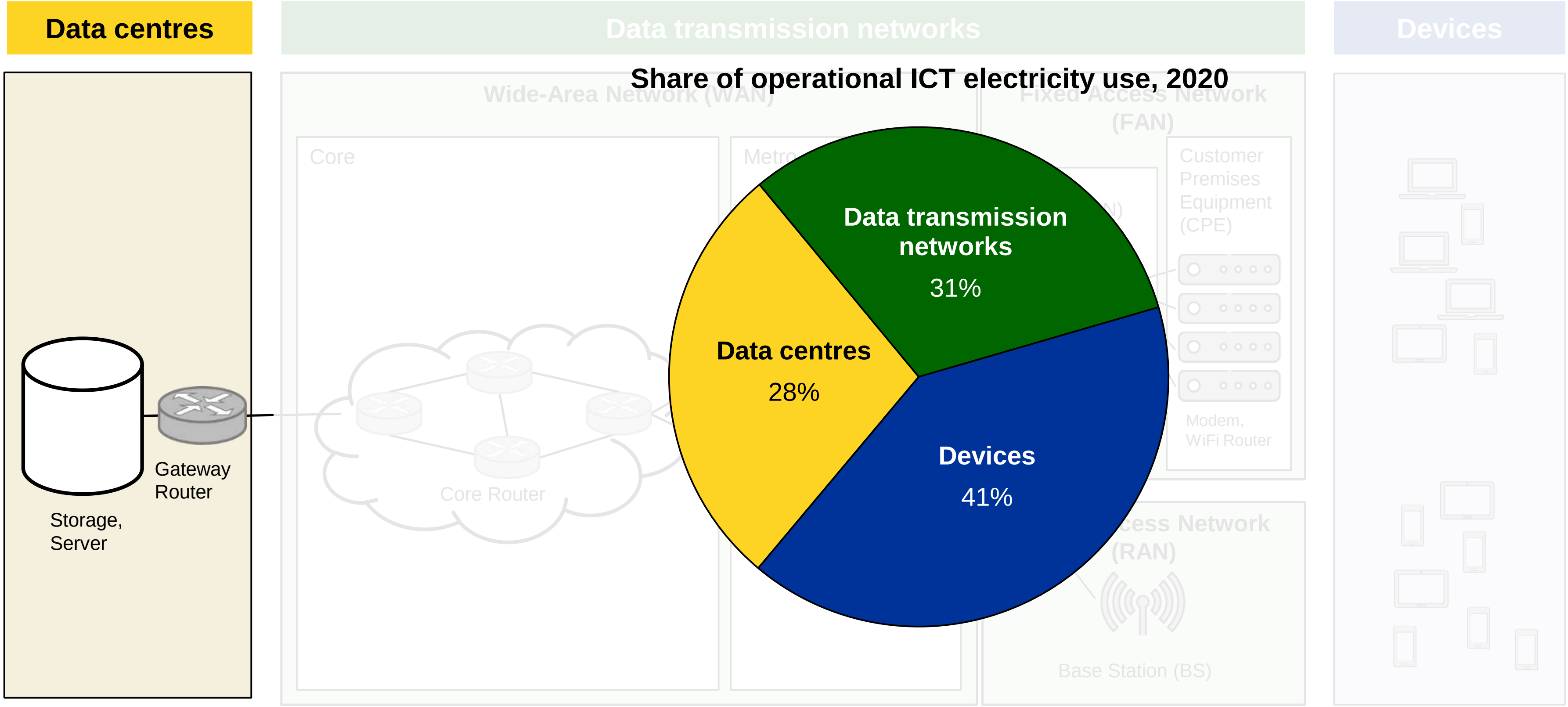
Data transmission



Aslan et al. (2018). Electricity intensity of Internet data transmission: Untangling the estimates.

The energy efficiency of computing and data transmission has doubled every 2-3 years

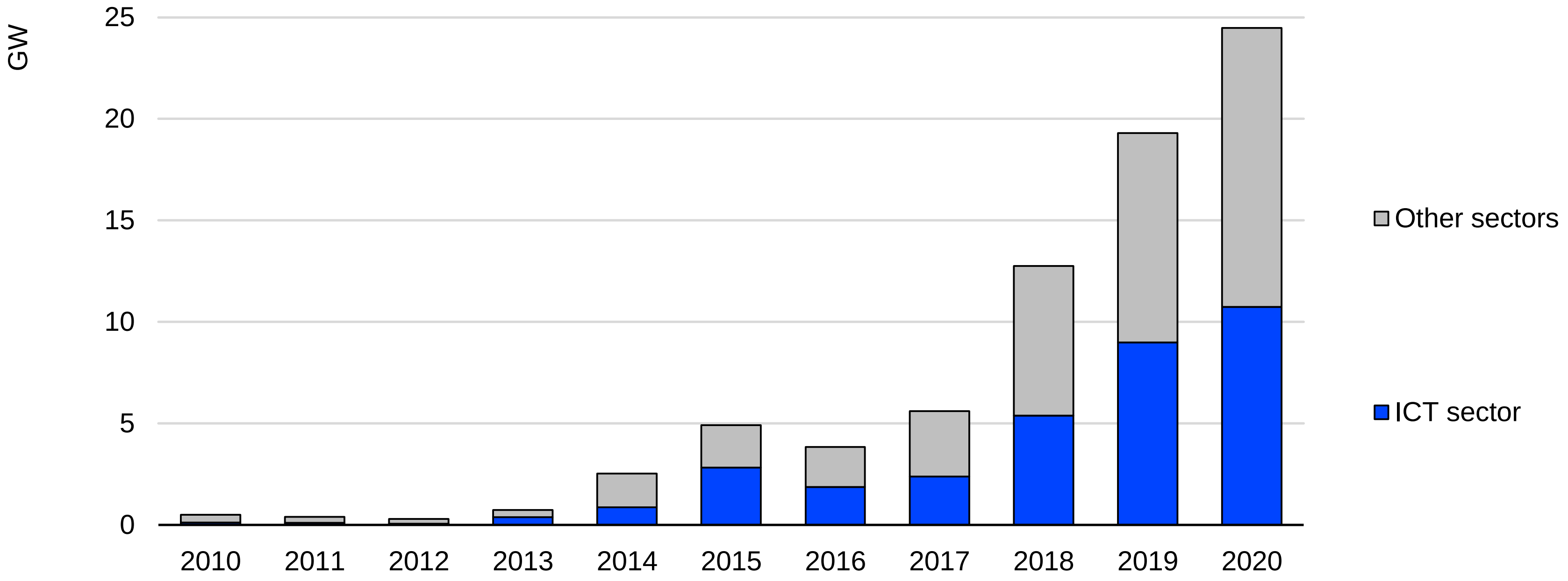
The ICT sector



Overview figure: Coroama (2021), Assessing the net climate impact of digitalisation. Electricity use estimates: ITU (2020), Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement.

Renewable energy procurement

Corporate renewables power purchase agreements



Source: BloombergNEF (2021), Corporate PPA Deal Tracker: January-February 2021.
ICT sectors include Technology and Telecommunications sectors.

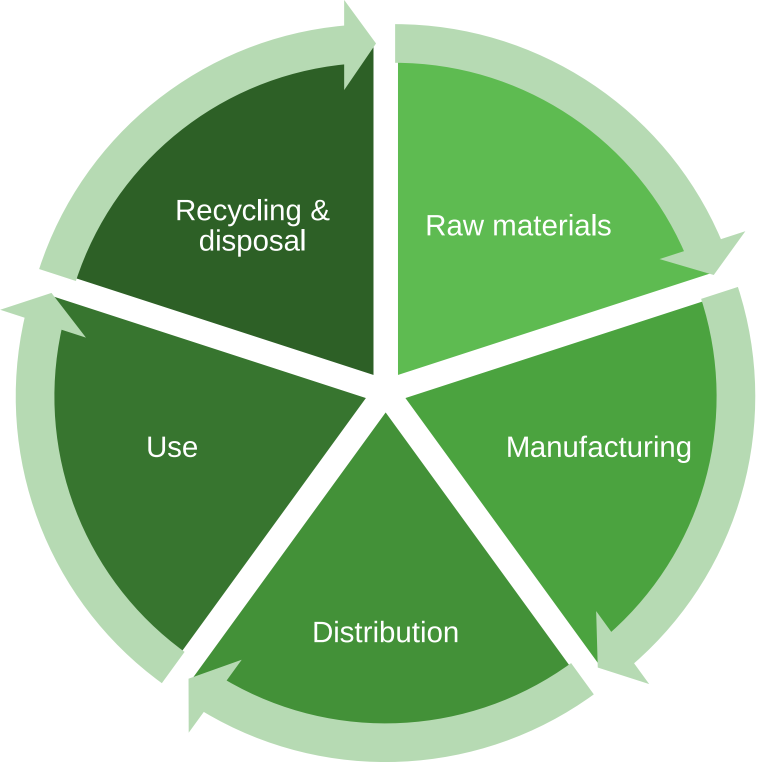
ICT companies have accounted for around half of global corporate renewables procurement in recent years

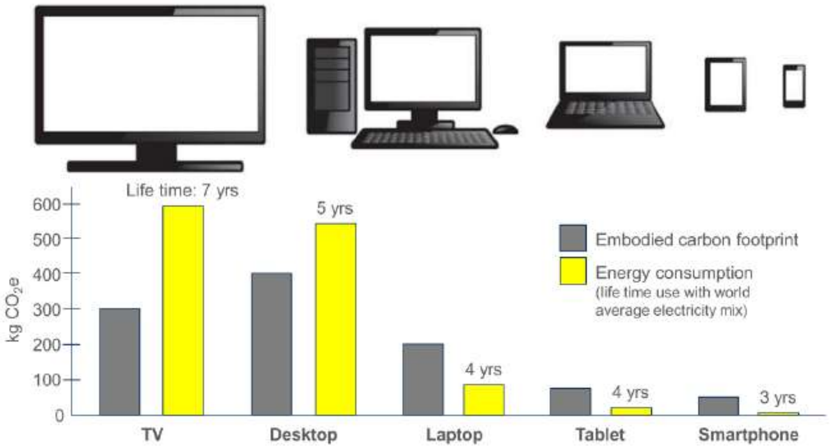
Approaches to clean electricity procurement

	Carbon Offsets *Can enable carbon neutrality and maximize emissions reductions per dollar spent* achieved by purchasing carbon offsets that reduce or prevent global emissions	**100% Annual Matching (Unbundled RECs)** *Can indirectly reduce emissions and support renewable energy* achieved by purchasing renewable electricity attributes / credits (RECs) separately from electricity purchases	**100% Annual Matching (Electricity contracts)** *Can reduce emissions and directly support renewable energy* achieved by purchasing renewable electricity attributes / credits and electricity via long-term contracts	**24/7 Carbon-free Electricity** *Can eliminate emissions from electricity consumption and transform electricity grids* achieved by procuring electricity and associated attributes from a portfolio of resources to match a buyer's electricity demand hour-by-hour, 24/7, with corresponding clean electricity generation within the same electricity grid region	OR **Carbon-optimized Procurement** *Can maximize emissions reductions from an electricity portfolio* achieved by financially supporting and operating a portfolio of resources to maximize emissions reductions in some grid region
Helps combat climate change	✅	✅	✅	✅	✅
Accelerates full-scale transformation of electricity grids	❌	❌	❌	✅	❓
Eliminates all carbon emissions associated with the buyer's electricity use	❌	❌	❌	✅	❌
Directly reduces carbon emissions associated with the buyer's electricity use	❌	❌	✅	✅	❌
Matches *annual* electricity consumption with clean energy	❌	✅	✅	✅	❌
Matches *hourly* electricity consumption with clean energy	❌	❌	❌	✅	❌
Supports investment in clean electricity	❌	❓	✅	✅	✅
Supports investment in clean electricity *in the electric grid region where your electricity is consumed*	❌	❌	✅	✅	❓
Hedges price volatility/risk for the electricity buyer	❌	❌	❓	✅	❌
Maximizes overall emissions reductions per $ spent	✅	❌	❌	❌	❓
Maximizes overall emissions reductions per megawatt-hour generated	❌	❌	❌	❌	✅

Source: Xu et al. (2021). System-level Impacts of 24/7 Carbon-free Electricity Procurement. https://acee.princeton.edu/24-7/.

Environmental impacts throughout the hardware lifecycle





Malmodin & Lunden (2018), The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015

There are environmental impacts beyond energy use and GHG emissions throughout the product lifecycle, including impacts on soil, air, water, biodiversity, and electronic waste.

The Guardian

News | Opinion | Sport | Culture | Lifestyle

Environment ▶ Climate change Wildlife Energy Pollution

Guardian Environment Network Environment

'Tsunami of data' could consume one fifth of global electricity by 2025

Billions of internet-connected devices could produce 3.5% of global emissions within 10 years and 14% by 2040, according to new research, reports Climate Home News

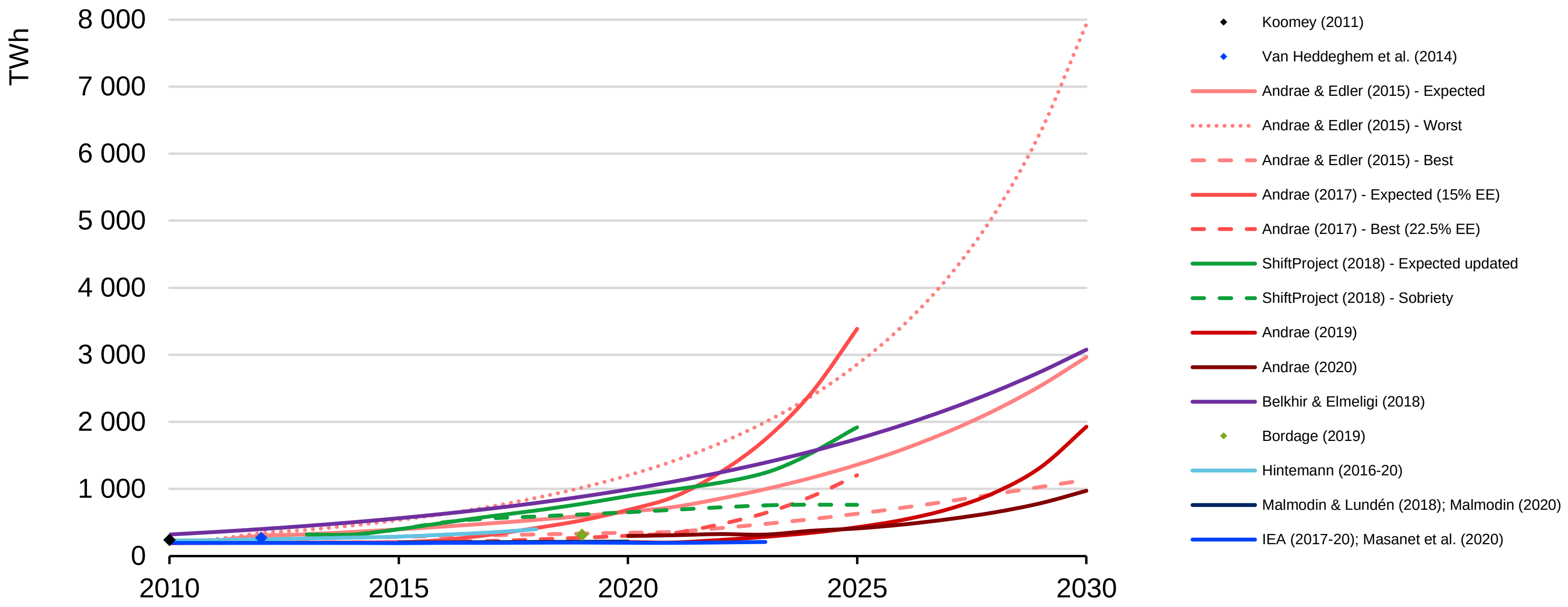
Mon 11 Dec 2017 13.27 GMT

1,454 73

The Guardian (2017). https://www.theguardian.com/environment/2017/dec/11/tsunami-of-data-could-consume-fifth-global-electricity-by-2025.

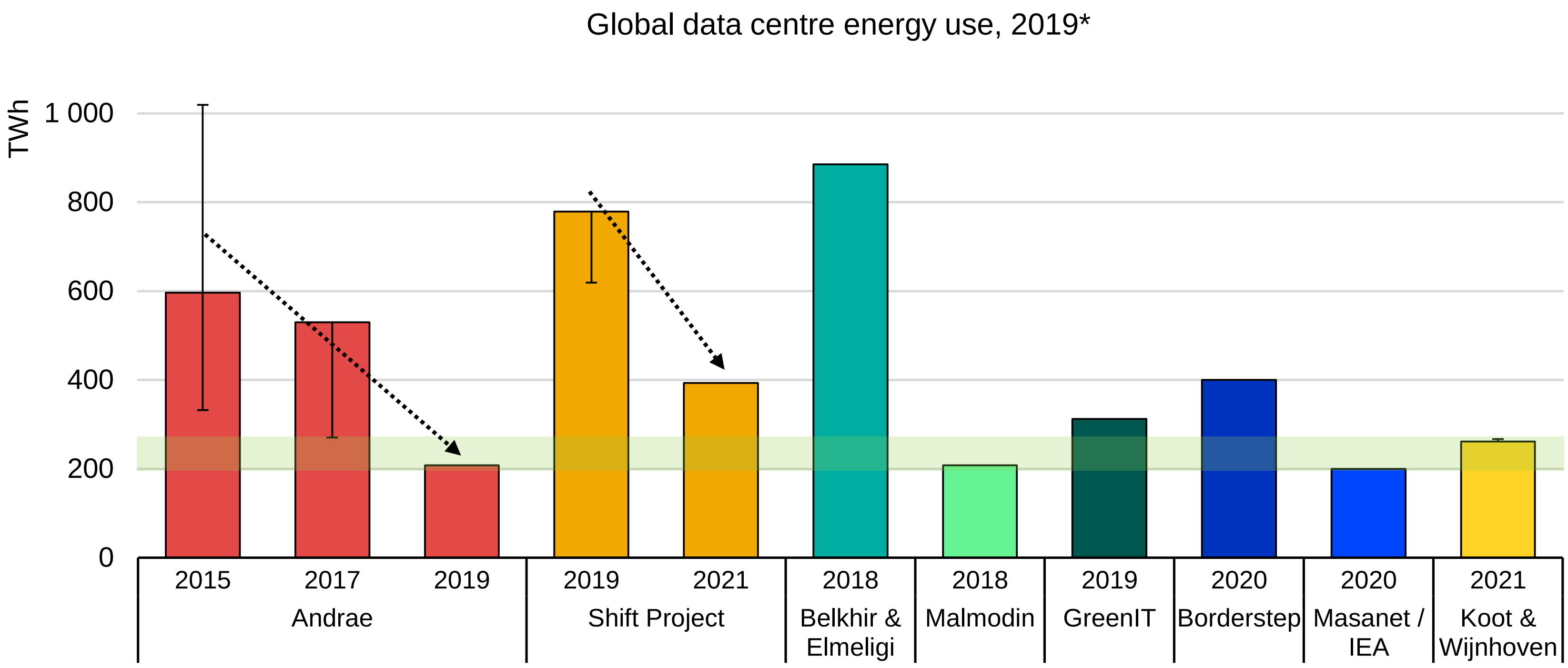
Data centres: comparing global energy use estimates

Global data centre energy consumption, 2010-2030



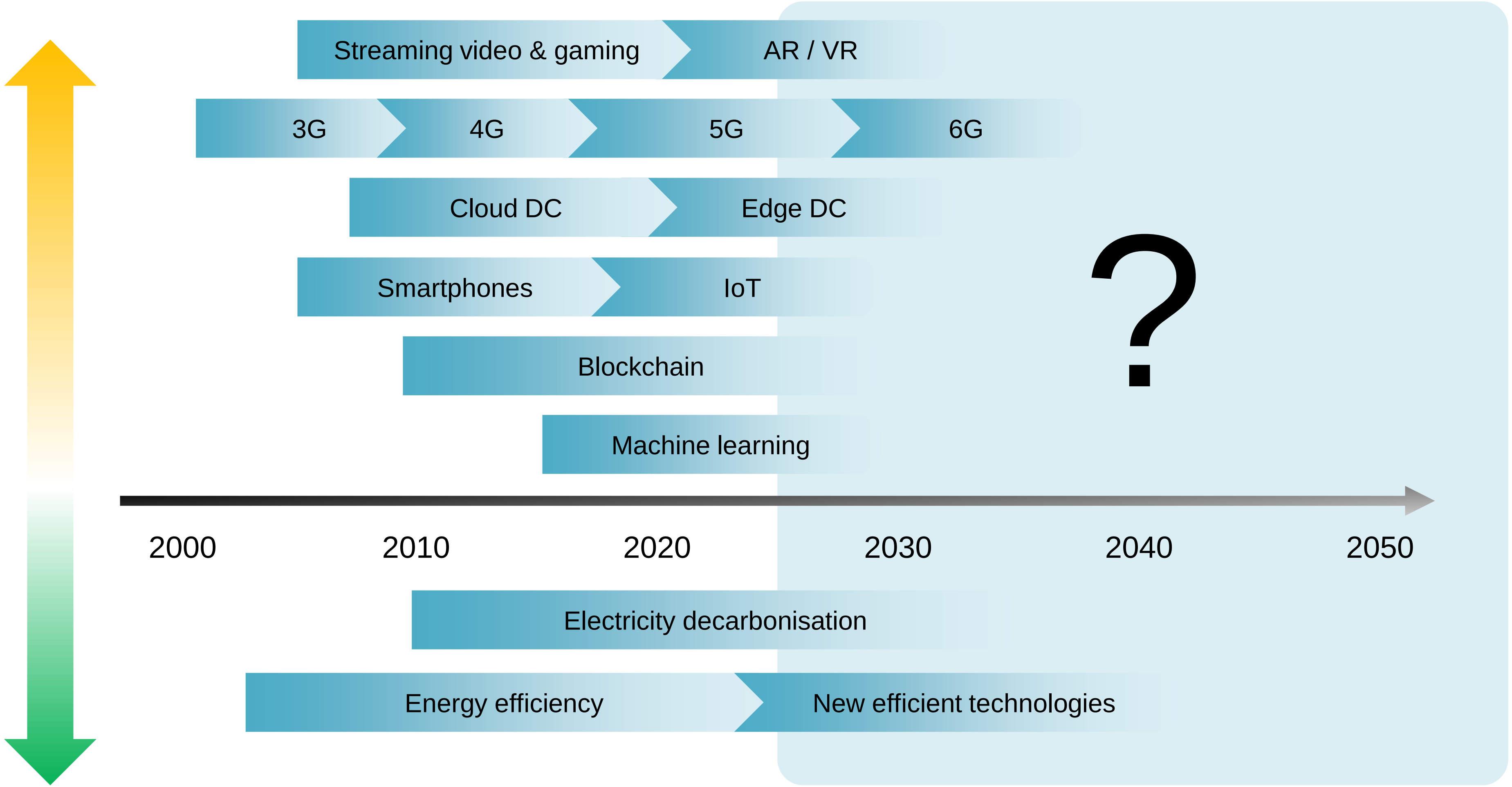
Sources: **Koomey (2011),** Growth in Data Center Electricity Use 2005 to 2010; **Van Heddeghem et al. (2014),** Trends in worldwide ICT electricity consumption from 2007 to 2012; **Andrae & Edler (2015),** On Global Electricity Usage of Communication Technology: Trends to 2030; **Andrae (2017),** Total Power Consumption Forecast; **The Shift Project (2018),** Lean ICT: Towards Digital Sobriety; **Andrae (2019),** Projecting the chiaroscuro of the electricity use of communication and computing from 2018 to 2030; **Andrae (2019),** Comparison of Several Simplistic High-Level Approaches for Estimating the Global Energy and Electricity Use of ICT Networks and Data Centers; **Andrae (2020),** New perspectives on internet electricity use in 2030; **Belkhir & Elmeligi (2018),** Assessing ICT global emissions footprint: Trends to 2040 & recommendations; **Bordage / GreenIT.fr (2019),** Environmental footprint of the digital world; **Hintemann & Claus (2016),** Green Cloud? The current and future development of energy consumption by data centers, networks and end-user devices; **Hintemann / Borderstep (2020),** Efficiency gains are not enough: Data center energy consumption continues to rise significantly; **Malmodin & Lunden (2018),** The Energy and Carbon Footprint of the Global ICT and E&M Sectors 2010–2015; **Malmodin (2020)**, Energy consumption and carbon emissions in the ICT sector (presentation to TechUK); **IEA (2017),** Digitalization & Energy; **IEA (2018-20),** Tracking Clean Energy Progress: Data centres and data transmission networks; **Masanet et al. (2020),** Recalibrating global data center energy-use estimates.

Data centres: comparing global energy use estimates



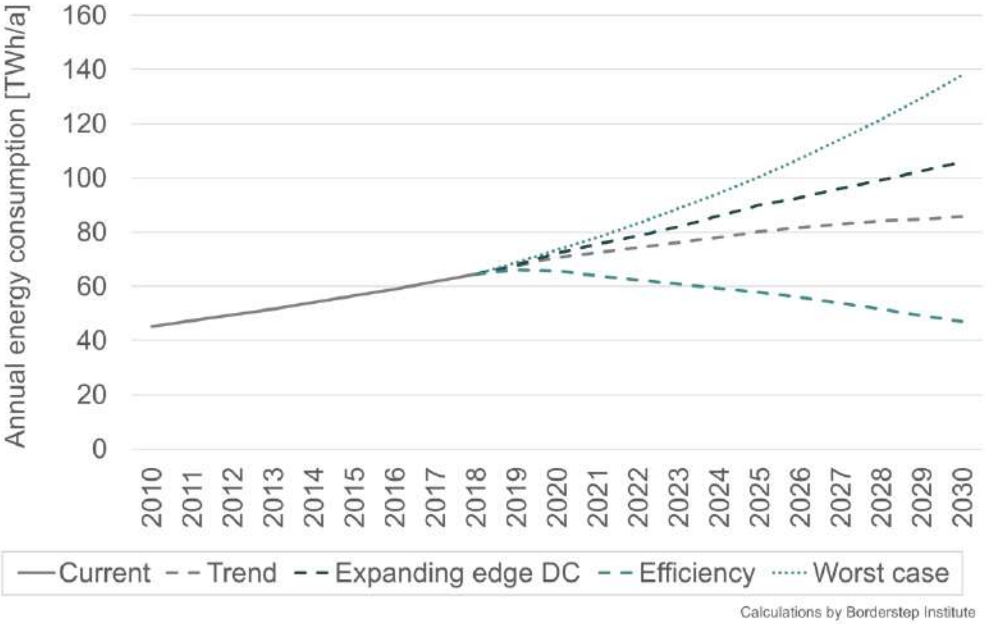
*2019 values except for Borderstep and Malmodin which are 2018. Shift Project (2019) values are extrapolations of stated 2017 and 2020 values.
Values typically exclude cryptocurrency mining, which was likely around 60 TWh in 2019. Shift Project (2021) value in this chart excludes bitcoin.

Sources: Andrae & Edler (2015); Andrae (2017); Andrae (2019); Andrae (2019); Andrae (2020); The Shift Project (2019); The Shift Project (2021); Belkhir & Elmeligi (2018); Malmodin & Lunden (2018); Bordage / GreenIT.fr (2019); Hintemann / Borderstep (2020); IEA (2020); Masanet et al. (2020); Koot & Wijnhoven (2021).


Streaming video & gaming
AR / VR
3G
4G
5G
6G
Cloud DC
Edge DC
Smartphones
IoT
Blockchain
Machine learning
?
2000
2010
2020
2030
2040
2050
Electricity decarbonisation
Energy efficiency
New efficient technologies

European data centre energy projections

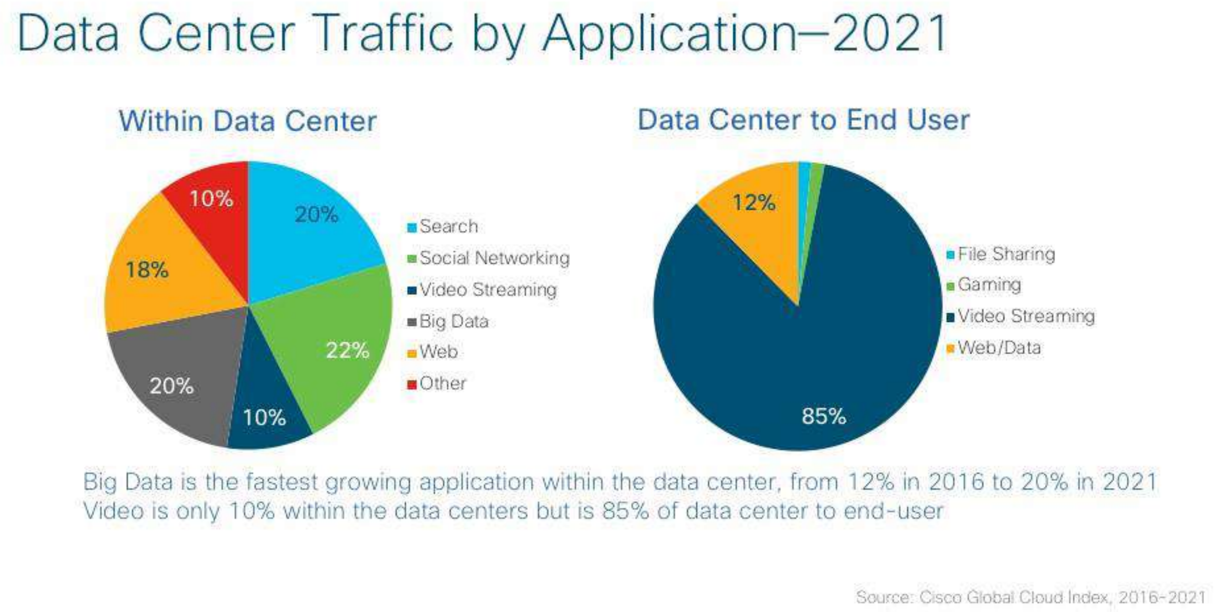
EU28 data centre energy demand, 2010-2030



Montevecchi et al. (2020), Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. https://op.europa.eu/en/publication-detail/-/publication/bf276684-32bd-11eb-b27b-01aa75ed71a1/language-en/format-PDF/source-183168542.

Efficiency can play critical role in reducing energy use from data centres

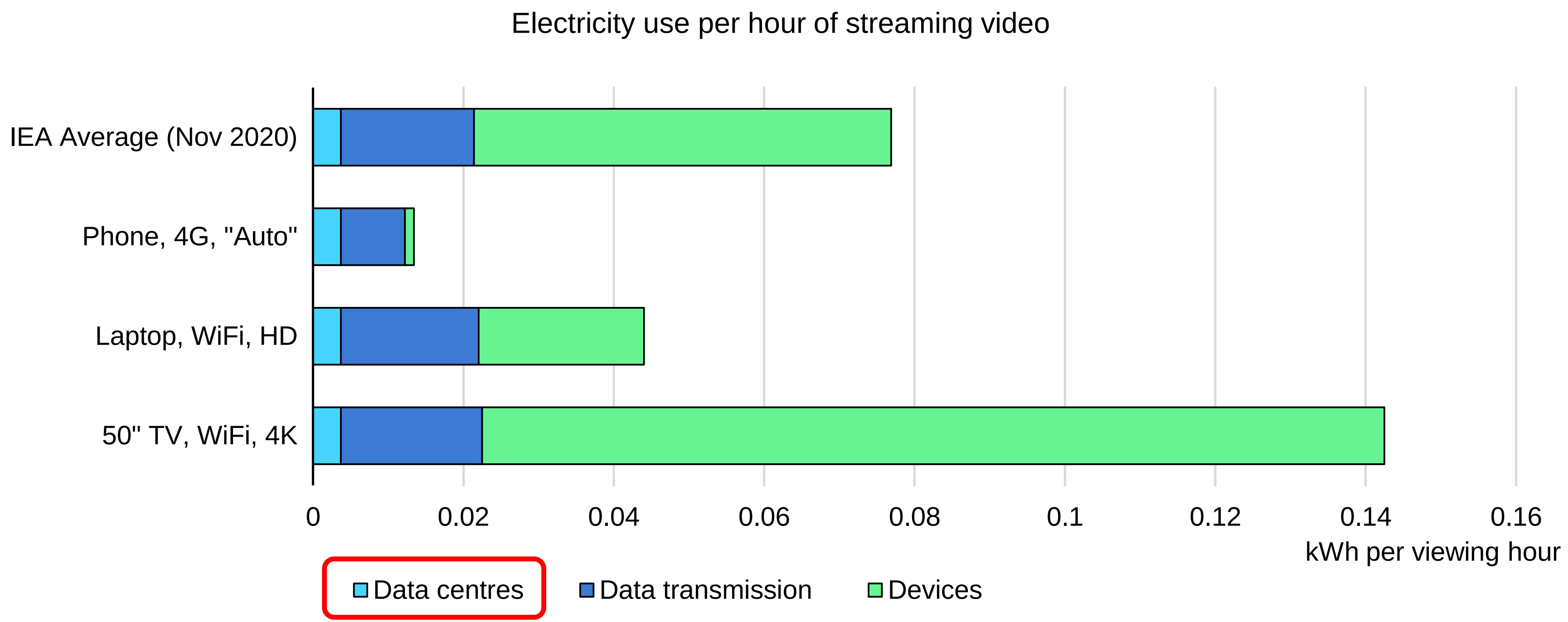
Data centres provide services for a wide range of applications



Cisco (2018). Cisco's Global Cloud Index Study: Acceleration of the Multicloud Era. https://blogs.cisco.com/news/acceleration-of-multicloud-era.

Video streaming accounts for >80% of traffic from data centres and end users, but only ~10% of traffic within data centres

Electricity use from streaming video

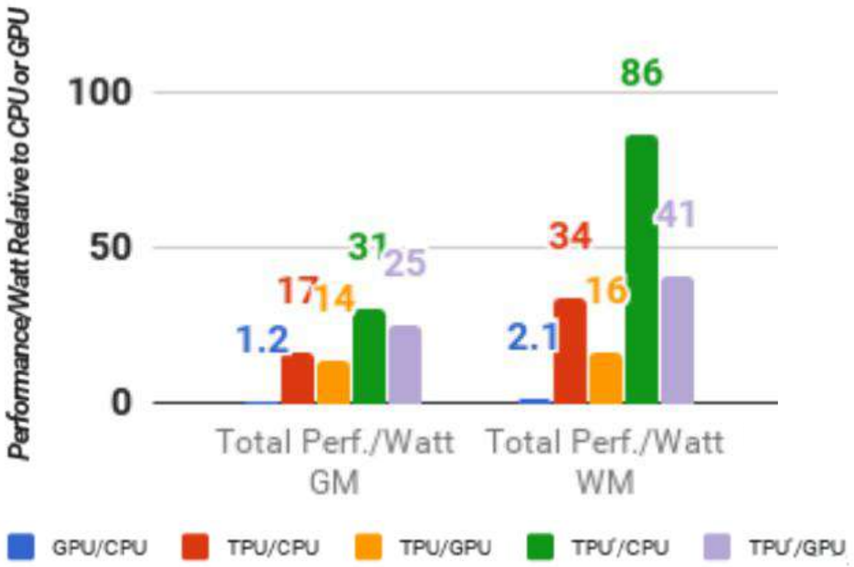


IEA (2020), The carbon footprint of streaming video: fact-checking the headlines. See also: Carbon Trust (2021), Carbon impact of video streaming.

Viewing devices account for the largest share of electricity use and emissions

Energy efficiency gains from specialised hardware

Relative performance/Watt of TPU, GPU and CPU servers



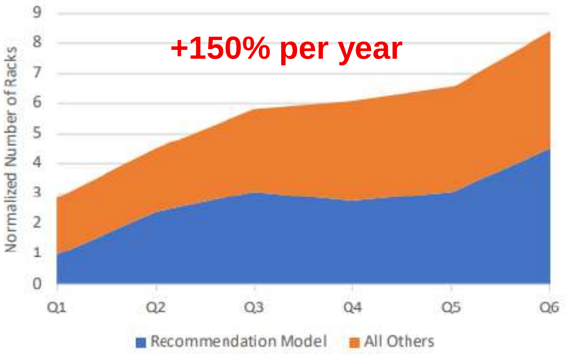
Jouppi et al. (2017). In-Datacenter Performance Analysis of a Tensor Processing Unit. https://dl.acm.org/doi/pdf/10.1145/3140659.3080246

Application-specific integrated circuits (ASICs) for machine learning are 15-30x faster and 30-80x more energy efficient compared to a contemporary CPU or GPU

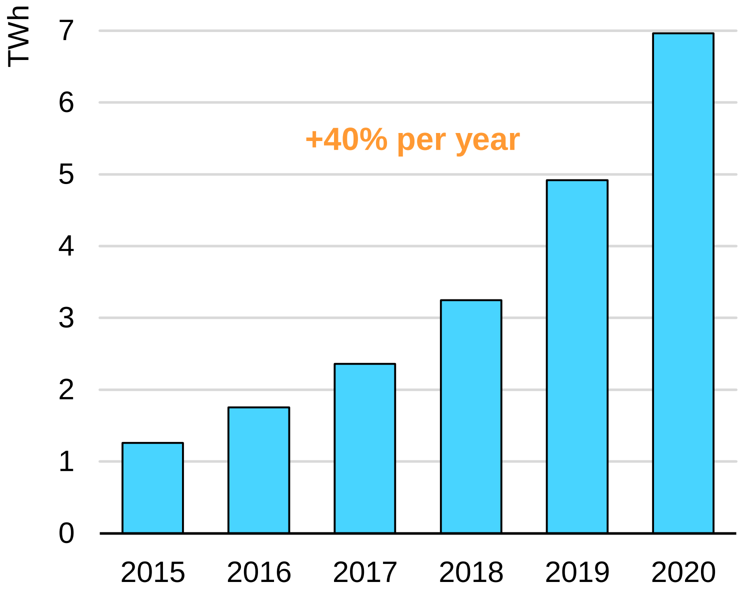
Increasing demand for ML workloads

Server demand for DL inference

Server compute demand for training

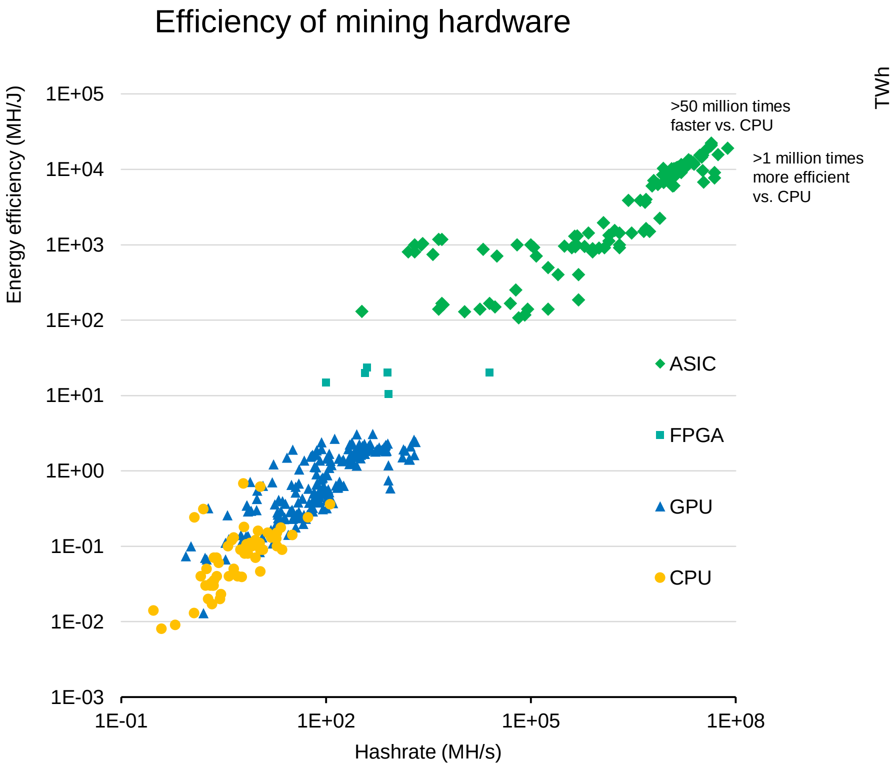


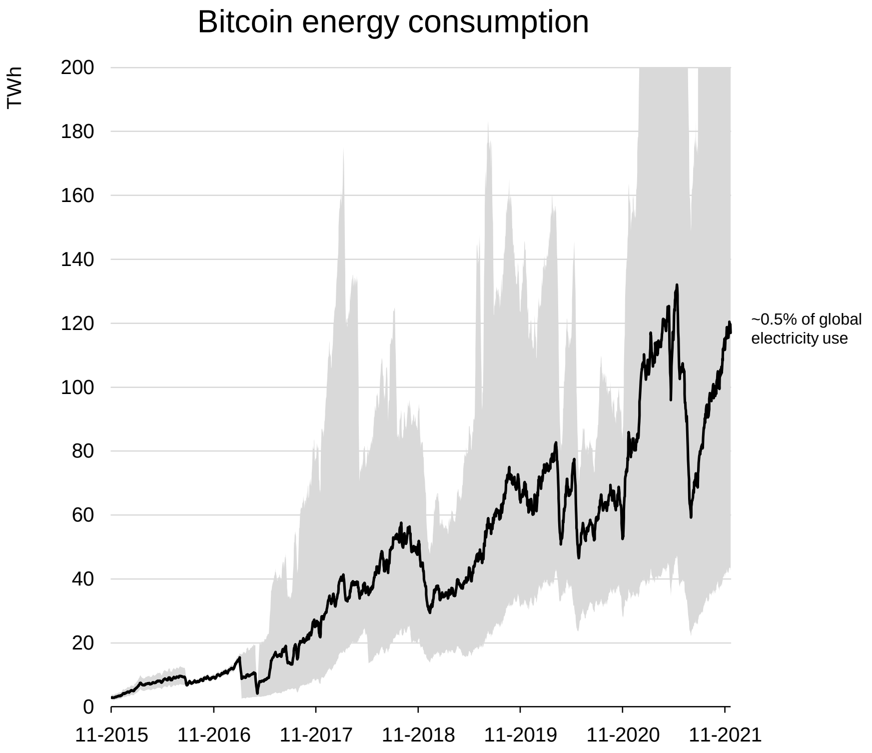
Facebook data centre energy use, 2015-2020



Sources: Park et al. (2018), Deep Learning Inference in Facebook Data Centers: Characterization, Performance Optimizations and Hardware Implications. https://arxiv.org/abs/1811.09886; Naumov et al. (2020), Deep Learning Training in Facebook Data Centers: Design of Scale-up and Scale-out Systems. https://arxiv.org/abs/2003.09518; Facebook (2021), Sustainability Report 2020, https://sustainability.fb.com/wp-content/uploads/2021/06/2020_FB_Sustainability-Data.pdf.

Blockchain and cryptocurrencies



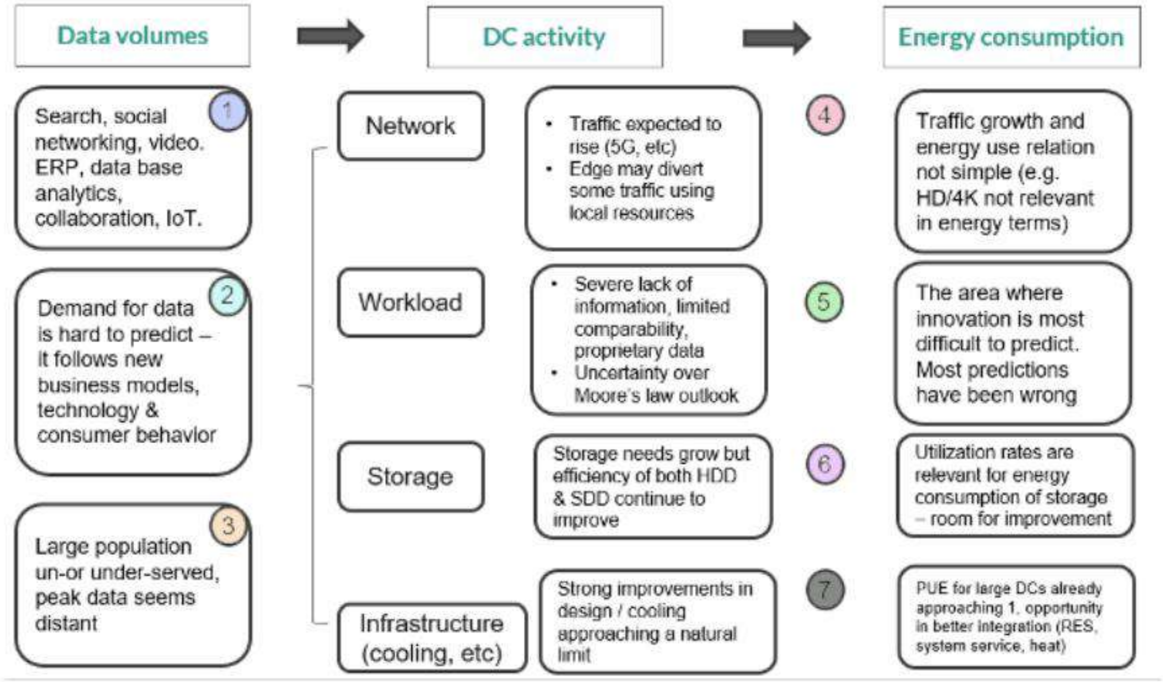


IEA (2019). Bitcoin energy use – mined the gap. https://www.iea.org/commentaries/bitcoin-energy-use-mined-the-gap.

Cambridge Centre for Alternative Finance (2021), Cambridge Bitcoin Electricity Consumption Index. https://www.cbeci.org/.

Drivers of data centre energy use

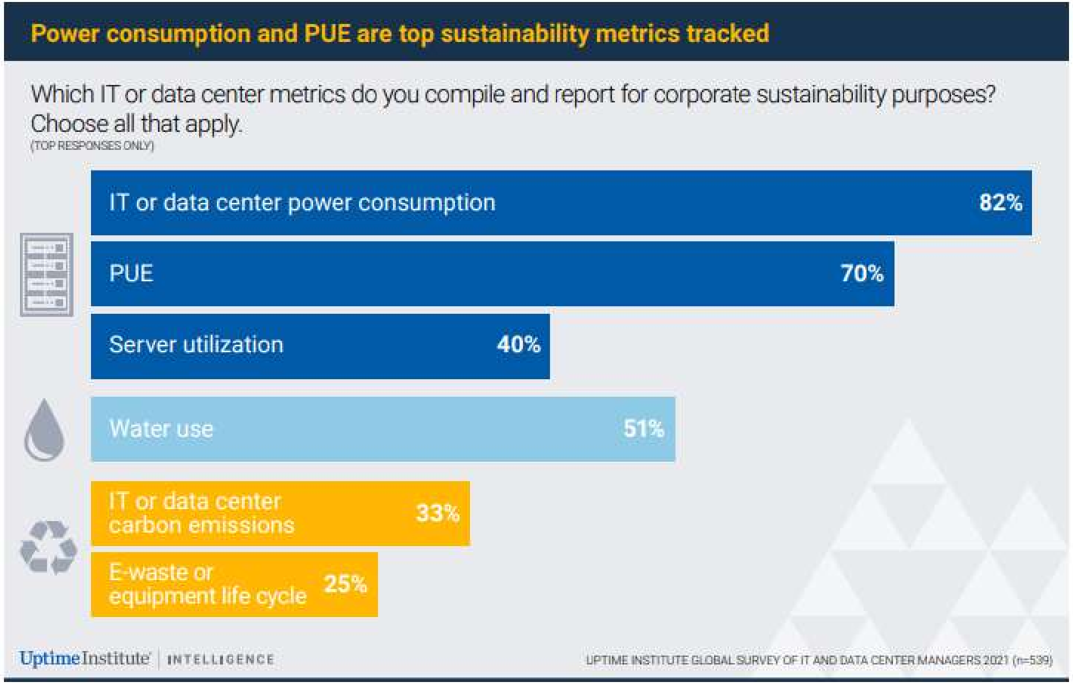
A visual representation of the relationship between demand for data, DC activity and energy consumption



CERRE / Banet et al. (2021). Data centres & the grid: Greening ICT in Europe. https://cerre.eu/wp-content/uploads/2021/10/211013_CERRE_Report_Data-Centres-Greening-ICT_FINAL.pdf

Efficiency and sustainability metrics

- Power Usage Effectiveness (PUE)
- Data Centre Infrastructure Efficiency (DCiE)
- Carbon Usage Effectiveness (CUE)
- Water Usage Effectiveness (WUE)
- Power to Performance Effectiveness (PPE)
- Energy Reuse Factor (ERF)
- Energy Efficiency Ratio (EER)
- Coefficient of Performance (COP)
- Data Centre Energy Productivity (DCeP)



Sources: CERRE / Banet et al. (2021). Data centres & the grid: Greening ICT in Europe. https://cerre.eu/wp-content/uploads/2021/10/211013_CERRE_Report_Data-Centres-Greening-ICT_FINAL.pdf.
Uptime Institute (2021), Uptime Institute Global Data Center Survey 2021. https://uptimeinstitute.com/uptime_assets/4d10650a2a92c06a10e2c70e320498710fed2ef3b402aa82fe7946fae3887055-2021-data-center-industry-survey.pdf.

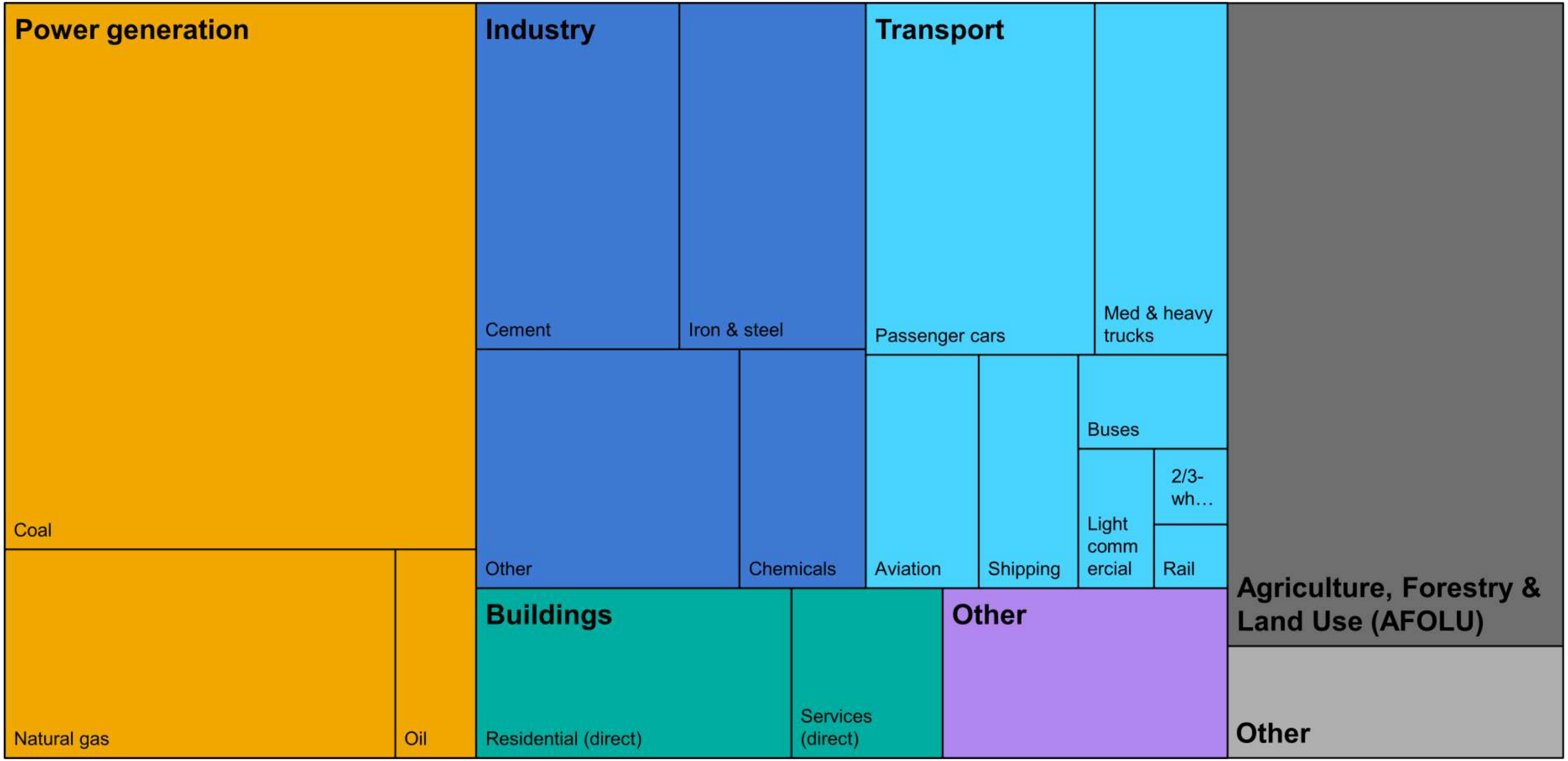
Approaches to reduce energy use and emissions from data centres

- Improve data collection and transparency (for statistics/modelling and for cloud customers*)
- Commit to efficiency and climate targets and implement measures to achieve them, including developing and tracking relevant efficiency metrics
- Increase flexibility of data centre operations
- Use data centres to drive renewable energy use
- Invest in RD&D for efficient next-generation computing and communications technologies
- Reduce lifecycle environmental impacts

For expanded discussion on these issues, see: IEA (2021), Data centres and data transmission networks and IEA (2019), Data centres and energy – from global headlines to local headaches?

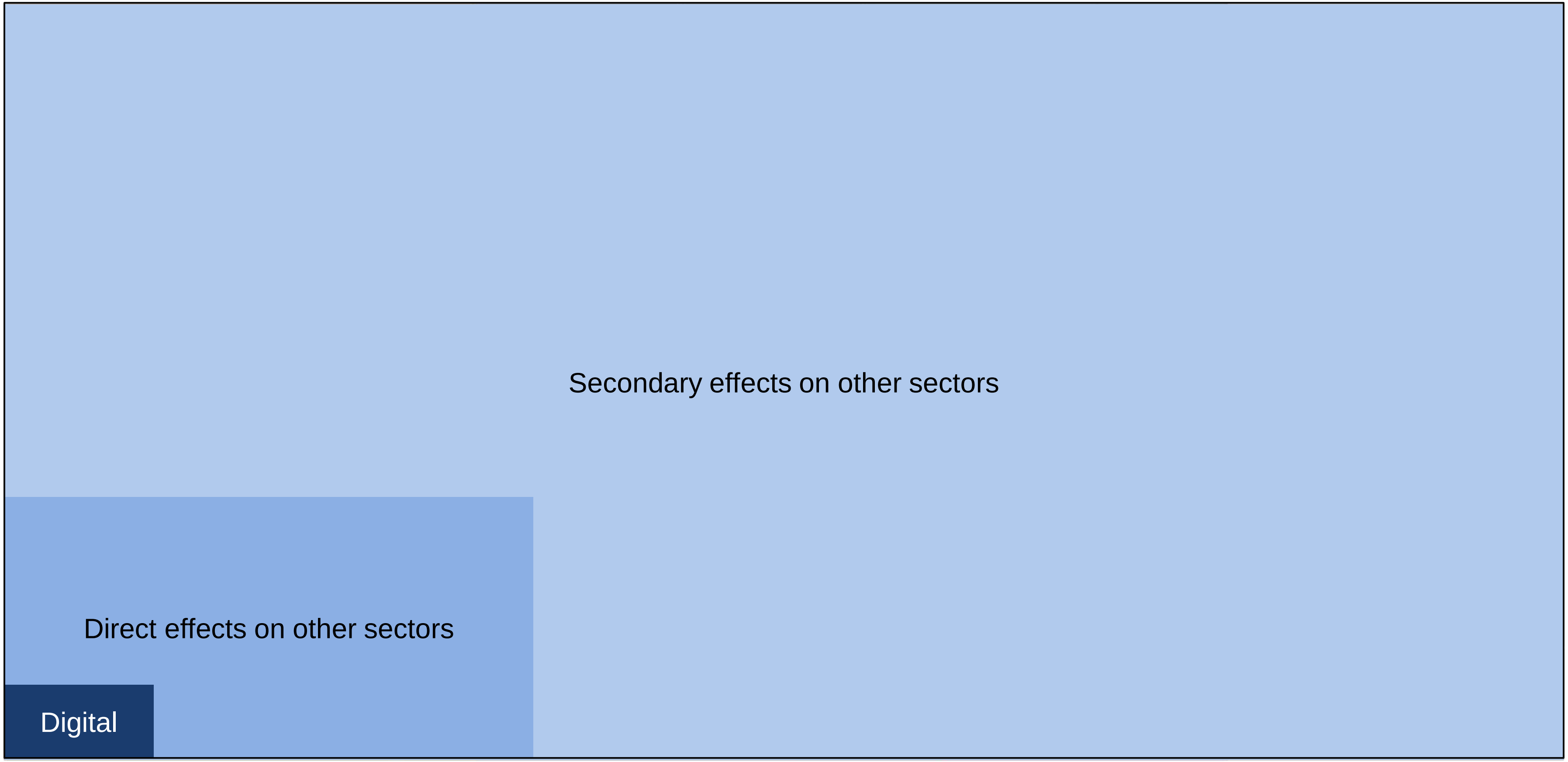
*Examples of carbon calculators for cloud: Cloud Carbon Footprint (2021); ML CO2 Impact (2021); Microsoft (2021), Emissions Impact Dashboard; Google (2021), Carbon Footprint.

Greenhouse gas emissions come from many sectors and sources

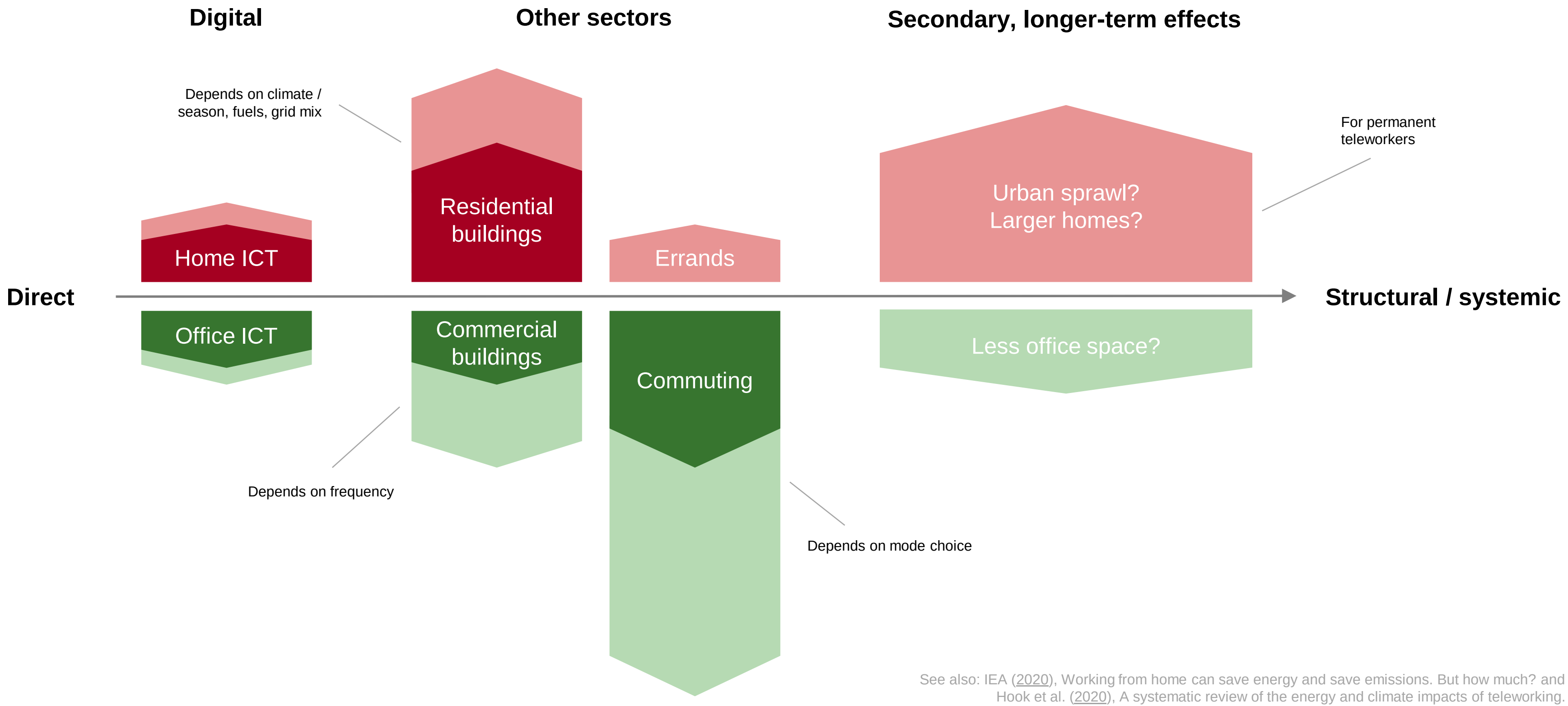


Source: Our World in Data (2020). Emissions by sector. IEA (2020), Energy Technology Perspectives.

Direct and indirect effects of digital technologies

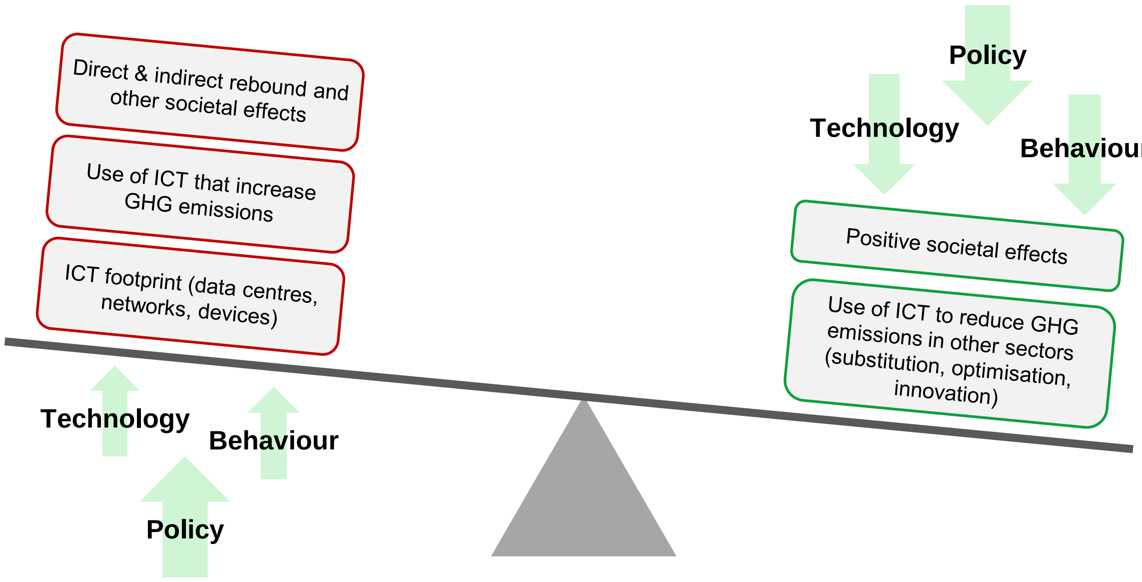


Changes in energy use and emissions from teleworking



See also: IEA (2020), Working from home can save energy and save emissions. But how much? and Hook et al. (2020), A systematic review of the energy and climate impacts of teleworking.

Influencing the net climate impacts of digitalisation

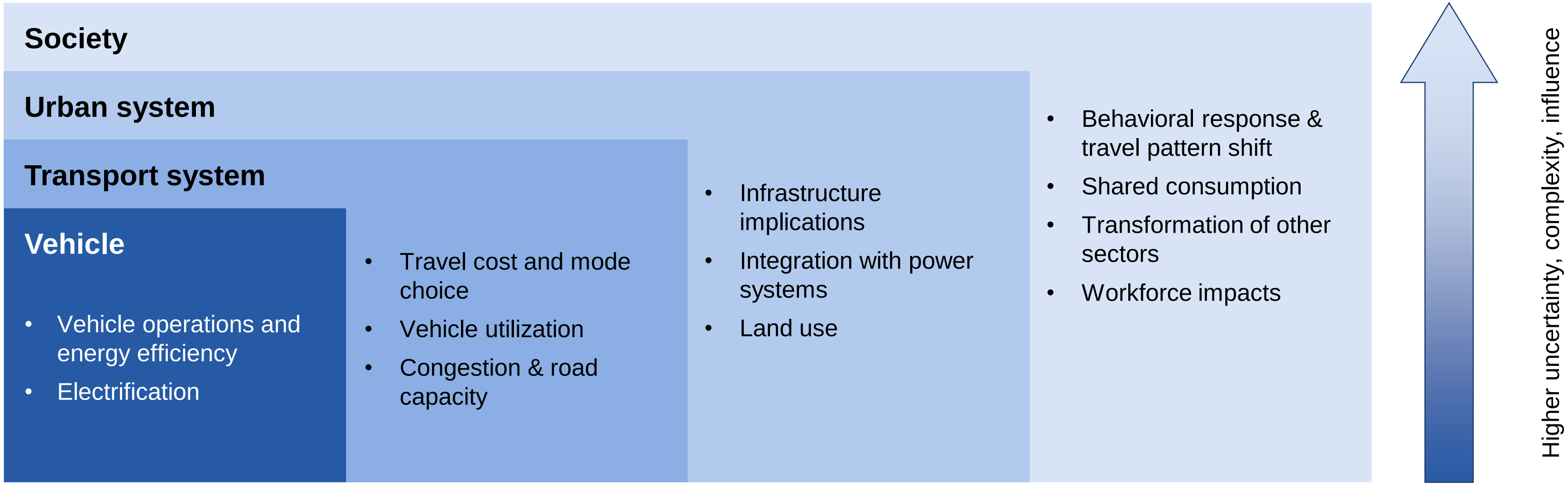


Adapted from Bergmark (2021), Assessing the net climate impact of digitalisation.

Policy choices will play a central role in shaping the net energy and emission impacts of digitalisation

Applying digital technologies in the energy sector

- **Buildings:** smart building controls & thermostats; connected appliances & lighting
- **Industry:** robotics; digital twins; 3D printing; machine learning
- **Transport:** shared mobility services; automated & connected vehicles; freight optimisation



Taiebat et al. (2018), A Review on Energy, Environmental, and Sustainability Implications of Connected and Automated Vehicles. https://pubs.acs.org/doi/10.1021/acs.est.8b00127.

Applying digital technologies in the energy sector

- **Buildings:** smart building controls & thermostats; connected appliances & lighting
- **Industry:** robotics; digital twins; 3D printing; machine learning
- **Transport:** shared mobility services; automated & connected vehicles; freight optimisation
- **Electricity:** IoT and automation to improve efficiency and reduce maintenance costs; machine learning to improve solar and wind forecasts, and better match supply and demand from increasingly decentralised sources
- **Oil & gas:** machine learning to reduce costs of detecting methane leaks
- **Energy access:** mobile services and infrastructure to facilitate electricity access
- **Policy:** data collection; modelling; assessing policy options and effectiveness

See also IEA (2017), Digitalization & Energy.

Net impacts on energy use and emissions will be shaped by climate policy

Tracking Clean Energy Progress 2021

Power

- Renewable power
  - Solar PV
  - Wind
  - Hydropower
  - Bioenergy
  - Geothermal
  - CSP
  - Ocean
- Nuclear power
- Gas-fired power
- Coal-fired power
- CCUS in power

Industry

- Chemicals
- Iron and steel
- Cement
- Pulp and paper
- Aluminium
- CCUS in industry & transformation

Transport

- Electric vehicles
- Fuel economy
- Trucks & buses
- Transport biofuels
- Aviation
- Shipping
- Rail

Buildings

- Building envelopes
- Heating
- Heat pumps
- District heating
- Cooling
- Lighting
- Appliances & equipment
- Data centres & networks

Fuel supply

- Methane emissions from oil and gas
- Flaring emissions

Energy integration

- Energy storage
- Hydrogen
- Smart grids
- Demand response
- Direct air capture

IEA (2021). Tracking Clean Energy Progress. https://www.iea.org/topics/tracking-clean-energy-progress

Key takeaways

- Globally, direct energy use and emissions from digital technologies have been relatively flat over the past decade, thanks to rapid energy efficiency improvements and declining carbon intensity of electricity.
- However, trends and local impacts vary considerably between countries and regions. Proactive planning and policies can ensure that data centres play a role in helping and not hindering clean energy transitions.
- Over the next decade, demand for digital technologies and services is expected to grow rapidly. Limiting emissions growth hinges on progress on energy efficiency (incl. RD&D into next-generation tech), zero-carbon electricity, and decarbonising supply chains.
- More data and robust approaches to analysis are needed to understand data centre energy use and track progress.
- The effects of digitalisation on other sectors and activities are potentially much larger than its direct footprint, but these effects are complex and difficult to quantify.
- Strong climate policies are needed to ensure digital technologies are applied to reduce emissions (and not increase them).

Further reading

- **IEA analysis:**
  - **Direct footprint of ICT:** Tracking Clean Energy Progress: Data centres & networks (2021); Bitcoin energy use (2019); Data centres: global and local impacts (2019); Carbon footprint of streaming video (2020).
  - **Effects on energy systems and other sectors:** Digitalization & Energy (2017); Energy and emissions savings from working from home (June 2020); 5 ways Big Tech could have big impacts on clean energy transitions (2021).
- **Other key papers:**
  - **Focus on data centres in Europe:** CERRE (2021), Data centres & the grid: Greening ICT in Europe. Montevecchi et al. (2020), Energy-efficient Cloud Computing Technologies and Policies for an Eco-friendly Cloud Market. BloombergNEF, Statkraft, Eaton (2021). Data Centers and Decarbonization: Unlocking Flexibility in Europe's Data Centers.
  - **Comprehensive reviews of digitalisation and climate:** Royal Society (2020), Digital technology and the planet: harnessing computing to achieve net zero. Freitag et al. (2020), The climate impact of ICT: A review of estimates, trends and regulations. Hook et al. (2020), A systematic review of the energy and climate impacts of teleworking. Rolnick et al. (2019), Tackling Climate Change with Machine Learning.
  - **Frameworks and methodologies to consider direct and indirect effects:** Horner et al. (2016), Known unknowns: indirect energy effects of ICT; Pohl et al. (2020), How LCA contributes to the environmental assessment of higher order effects of ICT application: A review of different approaches; Coroamă et al. (2020) and Bergmark et al. (2020), A Methodology for Assessing the Environmental Effects Induced by ICT Services.
  - Please see the slides for additional key papers, e.g. Masanet et al. (2020).

Questions?

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