How much energy does one search query cost?

0.0003 kWh per search (in 2017)!

https://business.directenergy.com/blog/2017/november/powering-a-google-search
Image source: https://winstonzhao.me/google-redesign

The direct energy consumption of digitalisation

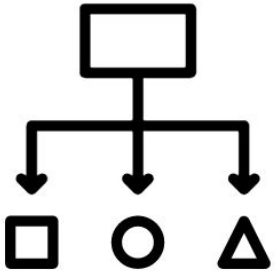
Larissa Schrempp

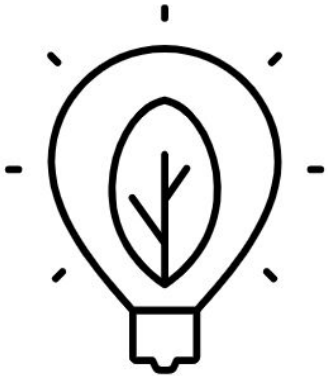
Digitalisation and the Rebound Effect seminar, 24 September 2020

Networks

Data centers

End devices





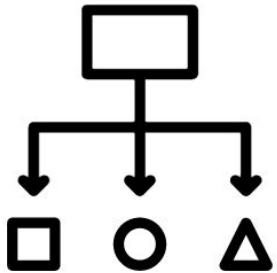
Methodology:
Quantifying ICT energy consumption

Results:
ICT energy consumption values

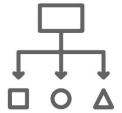
Conclusion

Icon credits: Ralf Schmitzer, DinosoftLab, Andri Graphic

Methodology: Quantifying ICT energy consumption



Networking:
How to calculate the average energy consumption by data transferred?

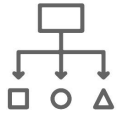


Top-down

Bottom-up

Model-based

Extrapolation



Top-down

Bottom-up

Model-based

Extrapolation

Quantifying ICT energy consumption: Top-down

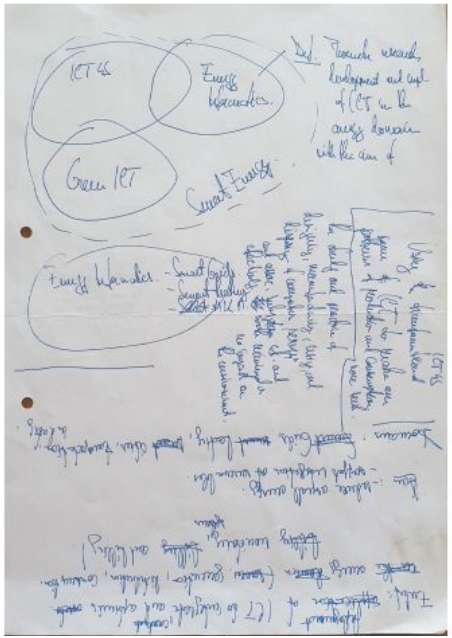


Image source: Vlad Coroamă, Developing and Delivering Scientific Presentations

Quantifying ICT energy consumption: Top-down

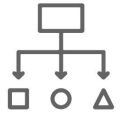
- In general: from the generic to the specific
- Networks:

$$\frac{network - level\ total\ electricity\ consumption}{data\ transferred\ through\ network} = average\ energy\ consumption\ by\ data\ transferred$$

- Requires fewer assumptions than modeling

- Depends on coarse estimates → large estimation error?
- System boundaries matter

Aslan et al. 2017, *Electricity Intensity of Internet Data Transmission: Untangling the Estimates,* Journal of Industrial Ecology, 22 (4), pp. 785-798



Top-down

Bottom-up

Model-based

Extrapolation

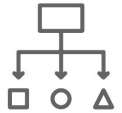
Quantifying ICT energy consumption: Bottom-up

- Direct observations from case studies
- Networks: $$\frac{\textit{sum of electricity consumption per equipment}}{\textit{data transferred through the equipment}}$$

- System boundary is well-defined
- Accurate results within that system boundary

- Values only for specific cases → generalisation is sometimes hard, system boundaries matter

Aslan et al. 2017, *Electricity Intensity of Internet Data Transmission: Untangling the Estimates,* Journal of Industrial Ecology, 22 (4), pp. 785-798



Top-down

Bottom-up

Model-based

Extrapolation

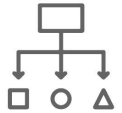
Quantifying ICT energy consumption: Model-based

- In general: a simplified representation of a complex system
- Mathematical approach
- Networks:
  - Equations with parameters: energy consumption of equipment, usage, data flow
- Combine models to develop a meta-model

- Use to make future predictions
- Use to estimate the impact of changes in specific variables

- Highly sensitive to input variable assumptions and boundary choices

Aslan et al. 2017, *Electricity Intensity of Internet Data Transmission: Untangling the Estimates,* Journal of Industrial Ecology, 22 (4), pp. 785-798



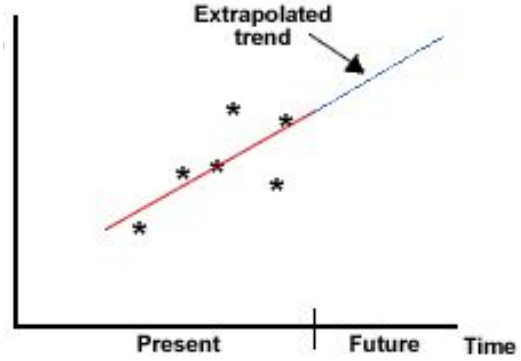
Top-down

Bottom-up

Model-based

Extrapolation

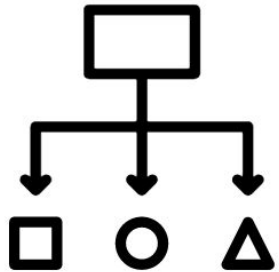
Quantifying ICT energy consumption: Extrapolation

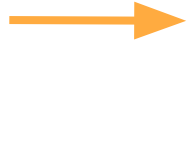


- Easy method to get a first idea

- Accuracy strongly dependent on the original estimates, and assumed rates of change

Aslan et al. 2017, *Electricity Intensity of Internet Data Transmission: Untangling the Estimates,* Journal of Industrial Ecology, 22 (4), pp. 785-798
Graph source: http://www.sanandres.esc.edu.ar/secondary/marketing/page_66.htm, accessed on 12.10.2020





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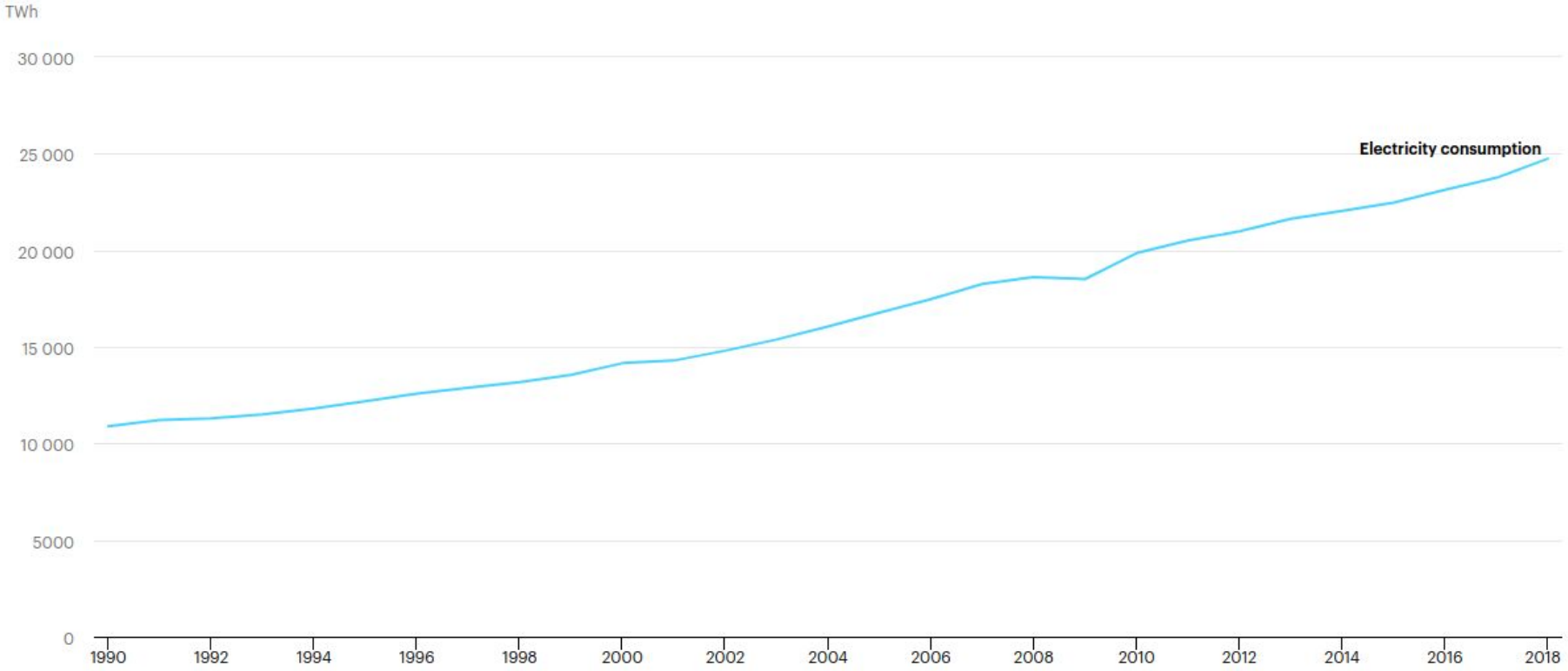
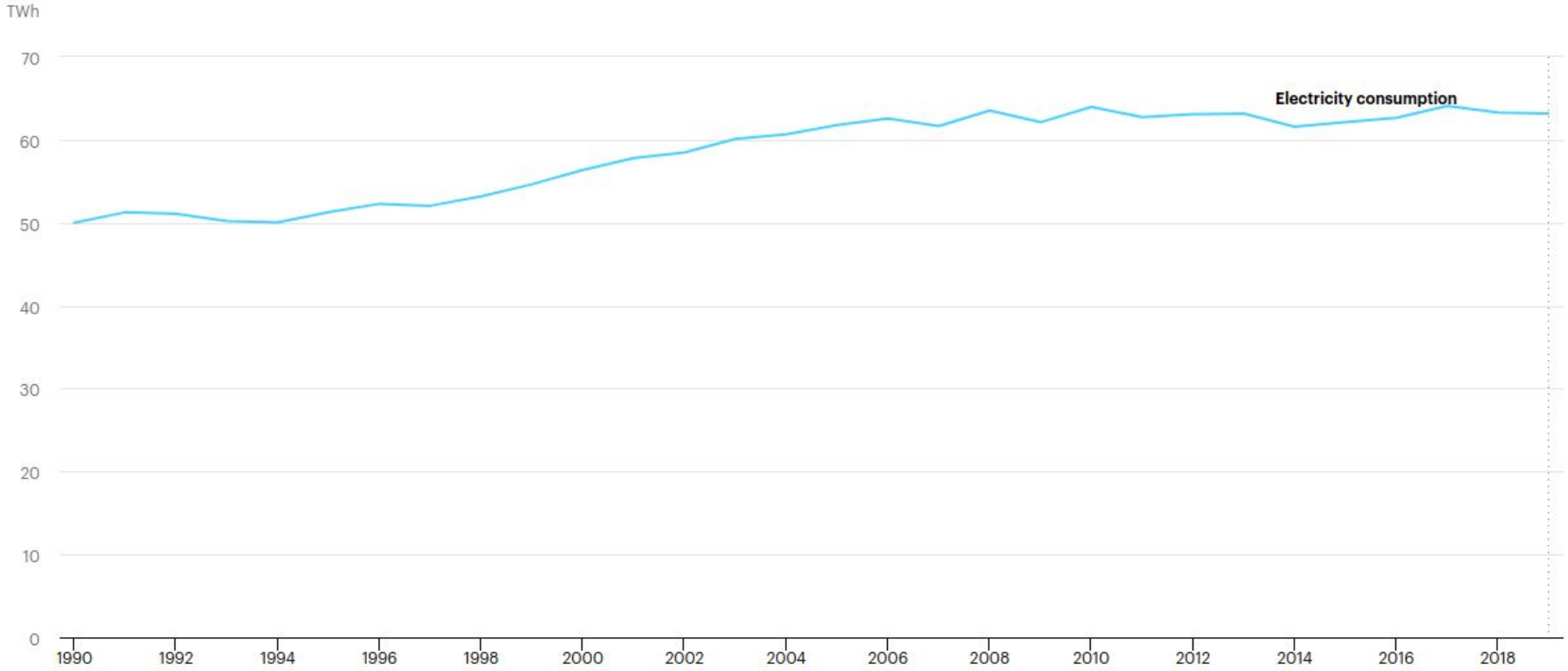
Icon credits: Ralf Schmitzer, DinosoftLab, Andri Graphic

Electricity consumption worldwide, 1990-2018



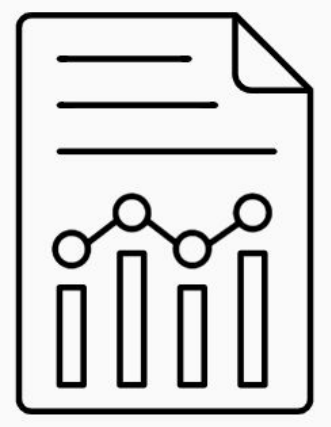
Source: International Energy Agency

Electricity consumption in Switzerland, 1990-2019



Source: International Energy Agency

Results: ICT energy consumption values



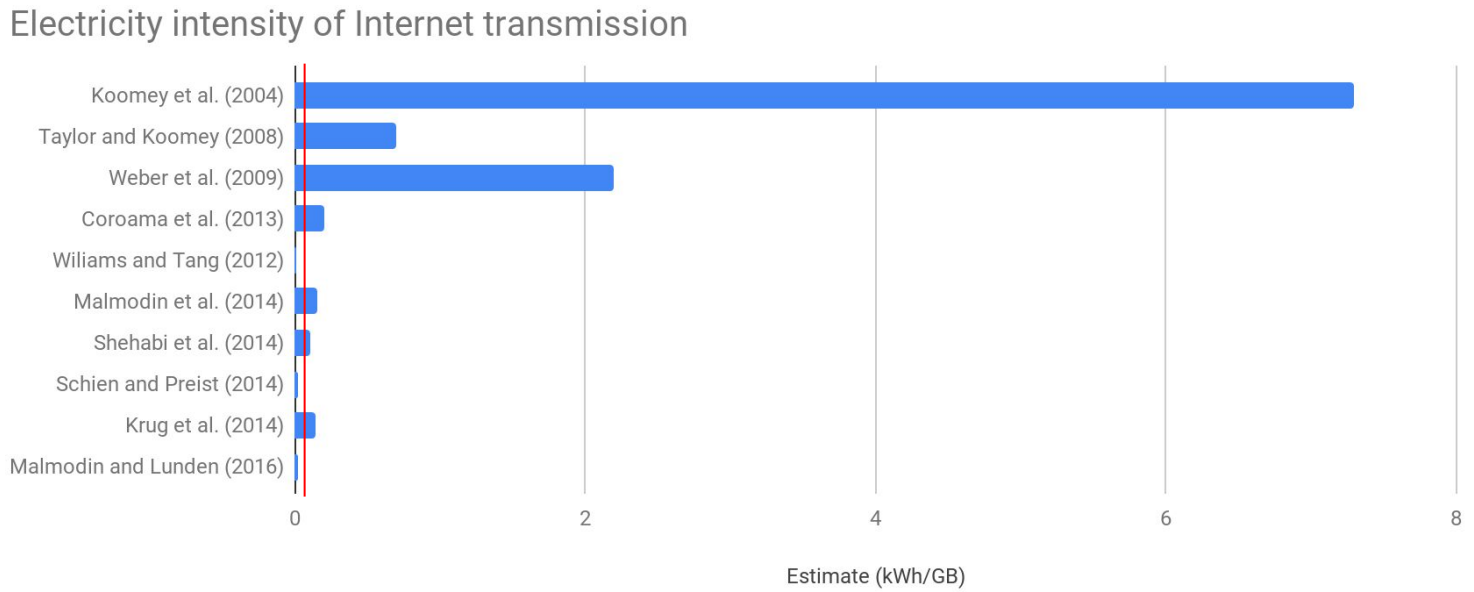
Networks

Data centers

End devices

Energy consumption of networks

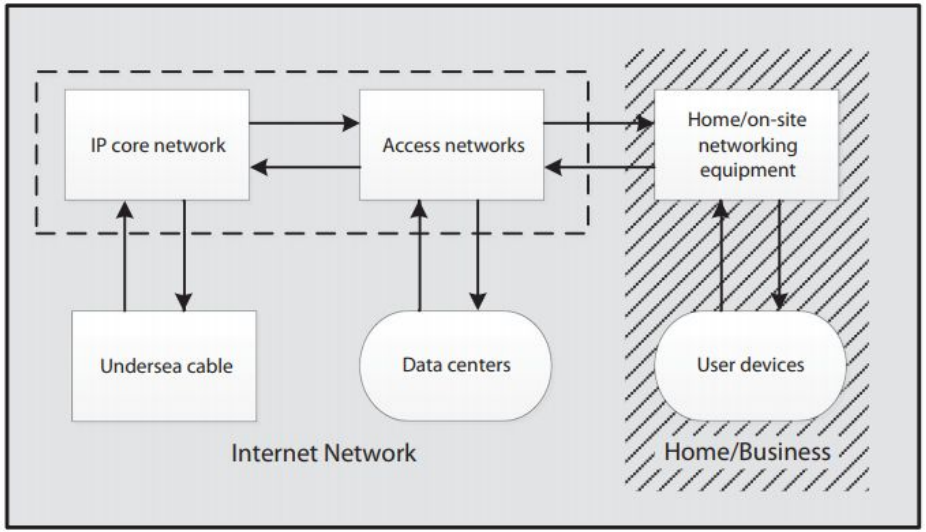
Aslan et al. (2017) - energy used per GB transmitted



Aslan et al. 2017, *Electricity Intensity of Internet Data Transmission: Untangling the Estimates,* Journal of Industrial Ecology, 22 (4), pp. 785-798

Energy consumption of networks

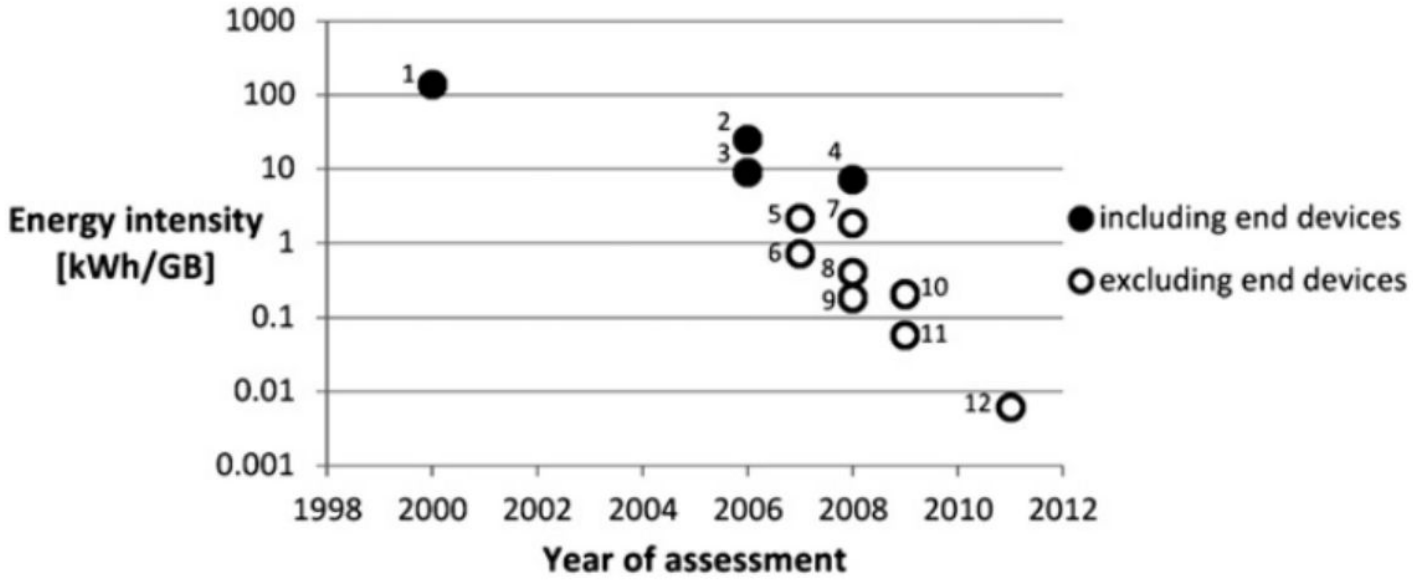
Aslan et al. (2017) - system boundary



Aslan et al. 2017, *Electricity Intensity of Internet Data Transmission: Untangling the Estimates,* Journal of Industrial Ecology, 22 (4), pp. 785-798

Energy consumption of networks

Coroama et al. (2014) - energy used per GB transmitted



Coroama et al. 2014, *Assessing Internet energy intensity: A review of methods and results,* Environmental Impact Assessment Review, 45, pp. 63–48, 2014

Energy consumption of networks

Worldwide electricity consumption per year

- Van Heddeghem et al. (2014): **200 TWh** per year in **2007**, **330 TWh** per year in **2012**
- → extrapolation: **670 TWh** for **2020**

- Extrapolating Aslan et al. (2017), Coroama et al. (2015): **100 - 250 TWh** per year for **2020**

- Realistic middle value: **400 - 500 TWh** for **2020**

Van Heddeghem et al. 2014, *Trends in worldwide ICT electricity consumption from 2007 to 2012*, Computer Communications, 50, pp. 64–76
Bitkom, Vlad Coroama 2020, *Nachhaltigkeit von Streaming & Co.,* pp. 16-17

Energy consumption of data centers

Energy consumption of data centers

Power Usage Effectiveness (PUE)

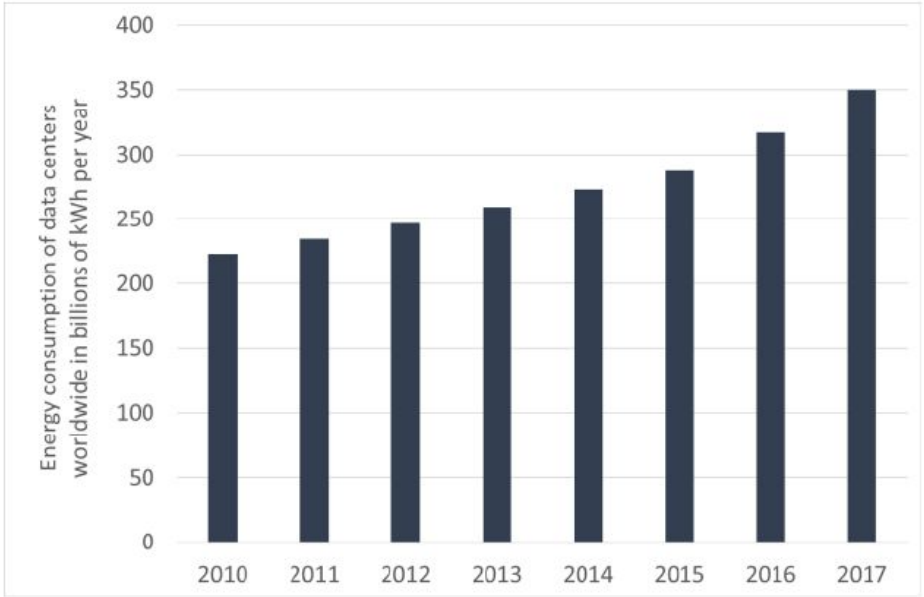
- Indicator for energy efficiency of data center infrastructures

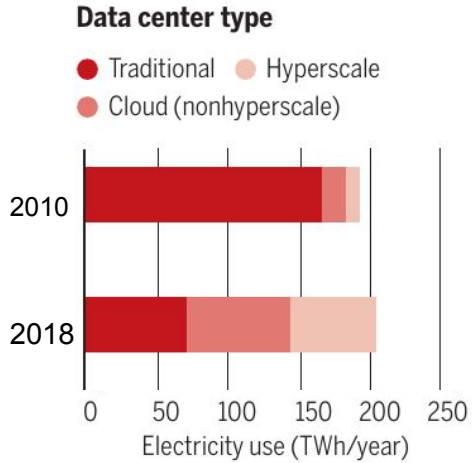
$$\frac{\textit{total amount of energy used by a data center}}{\textit{energy used by its IT equipment}}$$

- Aslan et al. (2017): PUE between **1.25** to **2.0**
- Hintemann, Hinterholzer (2019), values for Germany: **1.98** in 2010, **1.75** in 2017
- Hyperscale data centers: **1.3** or lower

Energy consumption of data centers

Energy consumption of data centers worldwide





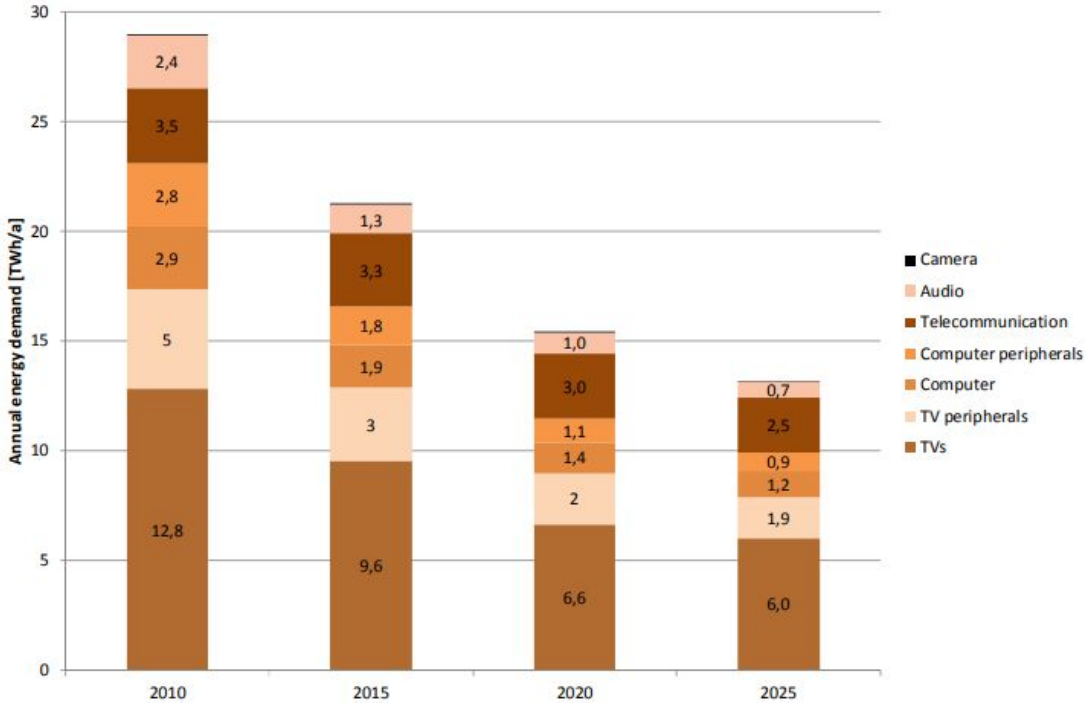
Left: Hintemann, Hinterholzer 2019, *Energy consumption of data centers worldwide,* Proceedings of ICT for Sustainability (ICT4S)
Right: Masanet et al. (2020), *Recalibrating global data center energy-use estimates*, Science, 367 (6481), pp. 984–986

Energy consumption of end devices

- Van Heddeghem et al.: **307 TWh** for 2012
  - With a growth rate of 5%
- Extrapolation: **430 TWh** per year in 2020

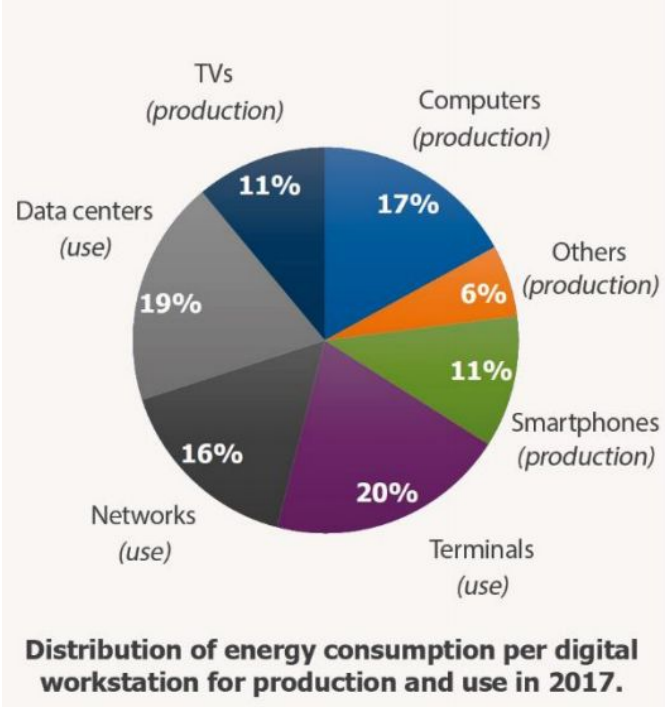
Van Heddeghem et al. 2014, *Trends in worldwide ICT electricity consumption from 2007 to 2012*, Computer Communications, 50, pp. 64–76

Energy consumption of end devices in Germany



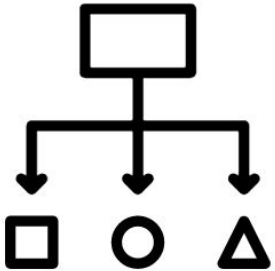
Stobbe et al. 2016, *Energy Efficiency of ICT: Further Improvement through Customized Products*, Proceedings of Electronics Goes Green (EGG)

Energy consumption of end devices



Distribution of energy consumption per digital workstation for production and use in 2017.

Andrea & Edler 2015, *The Shift Project 2018*



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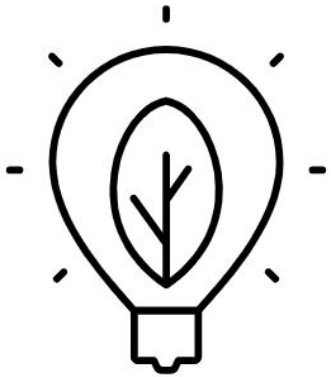

Conclusion

Methodology

Which approach?

System boundary?

Year?

Energy consumption of ICT

Increasing energy efficiency

⇏

Reducing energy consumption

Future?

Moore's Law?

Focus on renewable energies and using waste heat!

Thank you!

How digitalisation can lead to energy savings

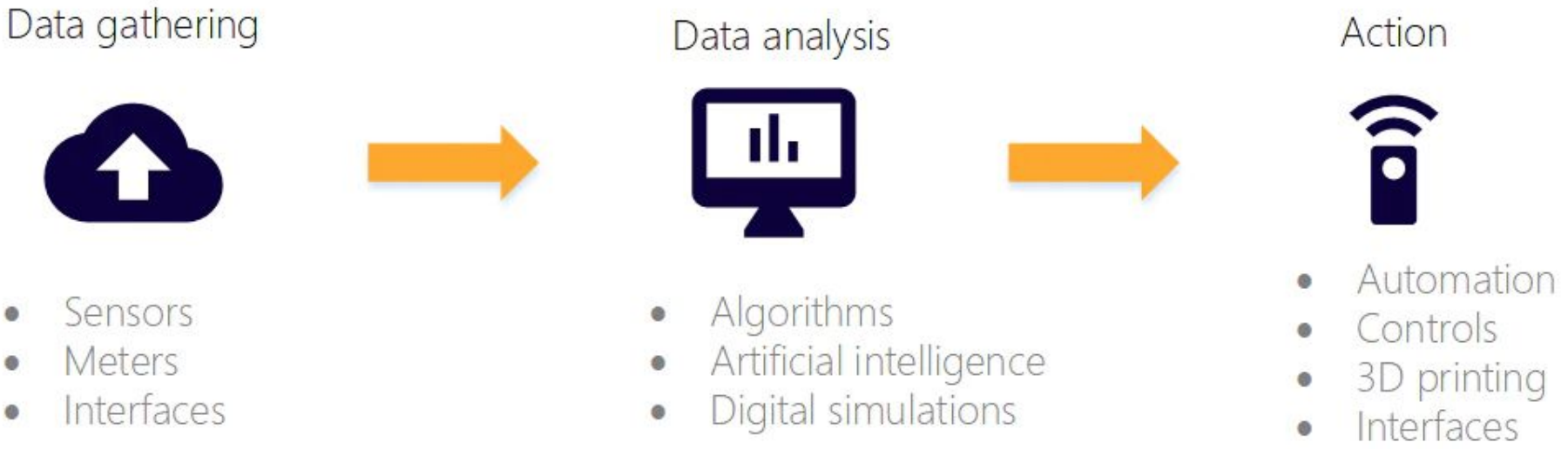

Image source: https://www.iea.org/articles/energy-efficiency-and-digitalisation

Energy consumption of networks

Van Heddeghem et al. (2014) - Worldwide electricity consumption per year

Communication networks

- **Customer premises access equipment** (CPAE)
- **Office networks**
- **Telecom operator networks** (including cooling and power provisioning overhead)

Network equipment used in data centers is accounted for under 'data centers ' below.

Van Heddeghem et al. 2014, *Trends in worldwide ICT electricity consumption from 2007 to 2012*, Computer Communications, 50, pp. 64–76

Hyperscale data centers

- Infrastructure as a service
- Dynamically allocate hardware based on the use case
  - Enables a database to grow as needed

Image source: https://tipsmake.com/alibaba-surpasses-amazon-and-microsoft-becoming-asias-largest-cloud-service-provider