Opportunities and Risks of the Digital Transformation for the Environment

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The Digital Age

Transmitting information

smoke signal,
oldest evidence
850 BC
(up to 750 km)








Storing information

stone carving,
oldest evidence
13'000 BC









Internet
1990ies AC


Processing information

abacus,
oldest evidence
2300 BC






Opportunities

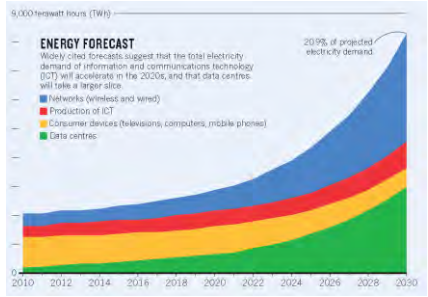
1. **Increasing material and energy efficiency of the digital technology**
   – Moore‘s Law
   – Koomey‘s Law

2. **Substitution potentials**
   – Online vs. print media
   – Videoconferencing vs. travel

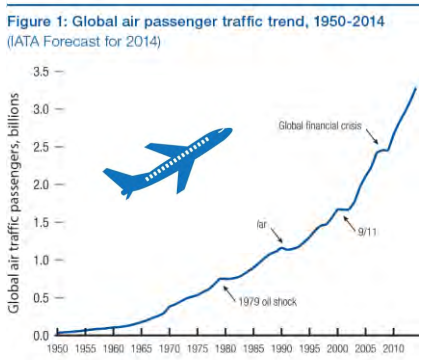
3. **Software as a sustainable product**
   – Software is immaterial
   – Hardware is durable

But...

ICT in total is using more electricity than ever before



Air travel is still growing exponentially



Durables are increasingly made obsolete by software

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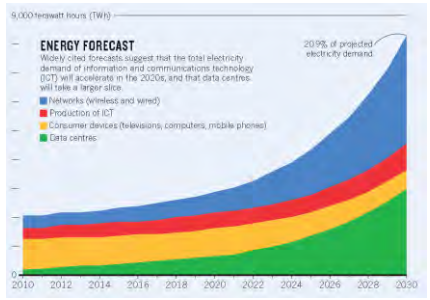

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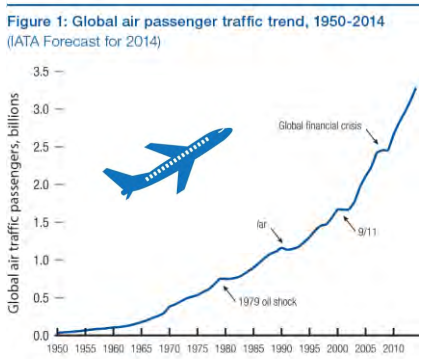

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Materials efficiency

According to Moore‘s Law, the number of transitors that can be placed on a microchip doubles every two years on average.

The first one-chip microprocessor built in 1971 contained **thousands** of transistors:
40 years later, a typical processor consists of **billions** of transistors.

1971

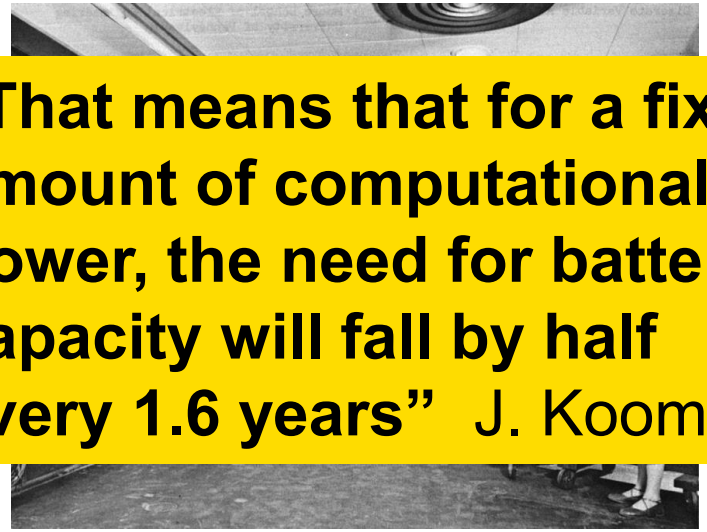
Intel 4004
2300 Transistors

2011

Intel CORE i7 3960X
2.27 Billions (10^9) Transistors

Energy efficiency

The number of computations performed per kWh has doubled every 1.6 years since the time of the first electronic computer ENIAC in 1946 ("Koomey's Law").



"That means that for a fixed amount of computational power, the need for battery capacity will fall by half every 1.6 years" J. Koomey

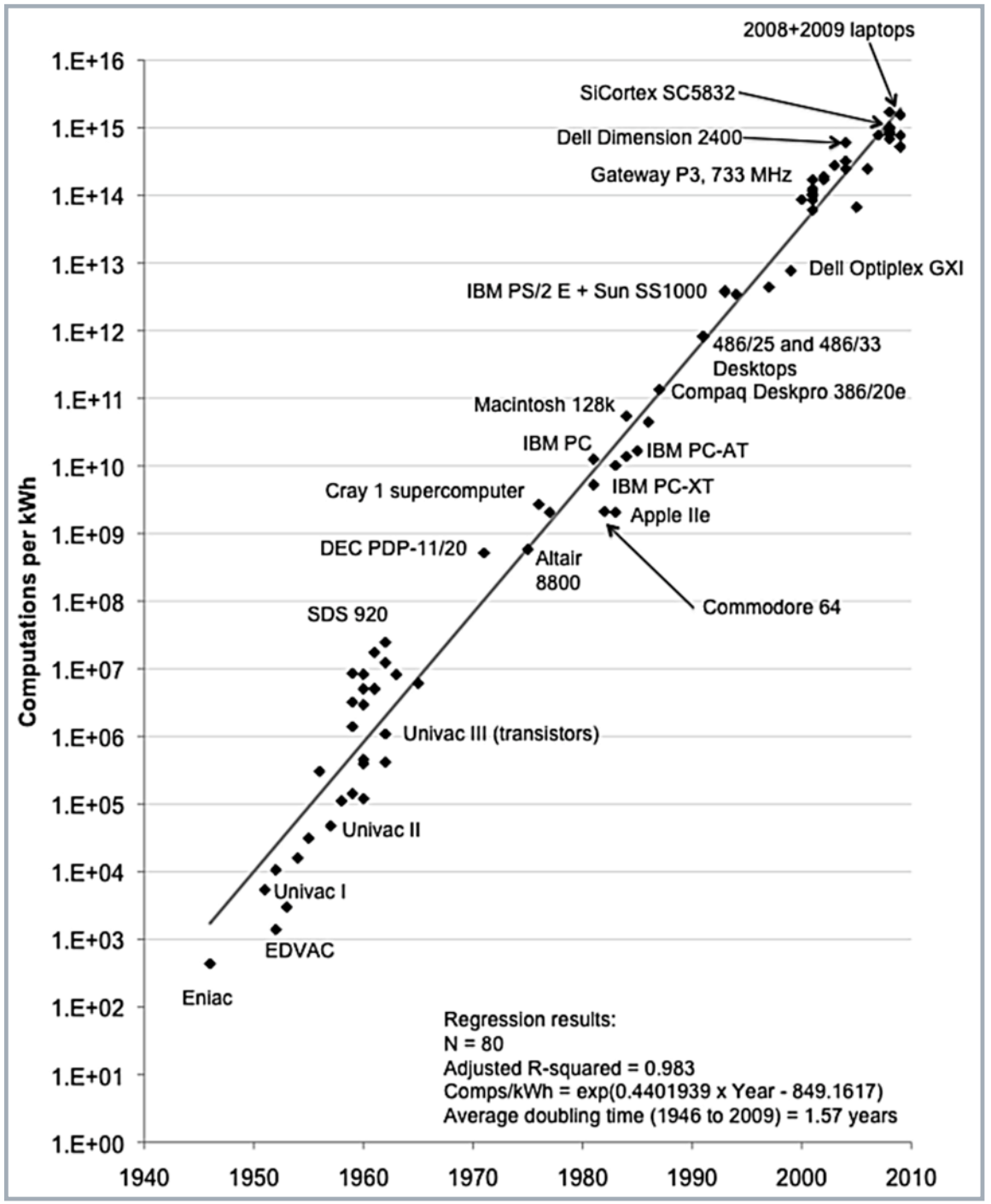
Quadrillion

Trillion

Billion

Million

Thousand



Source: Koomey, J., Berard, S., Sanchez, M. & Wong, H. (2011): Implications of Historical Trends in the Electrical Efficiency of Computing. Annals of the History of Computing, IEEE, 33 (3): 46-54

Example: Supercomputing

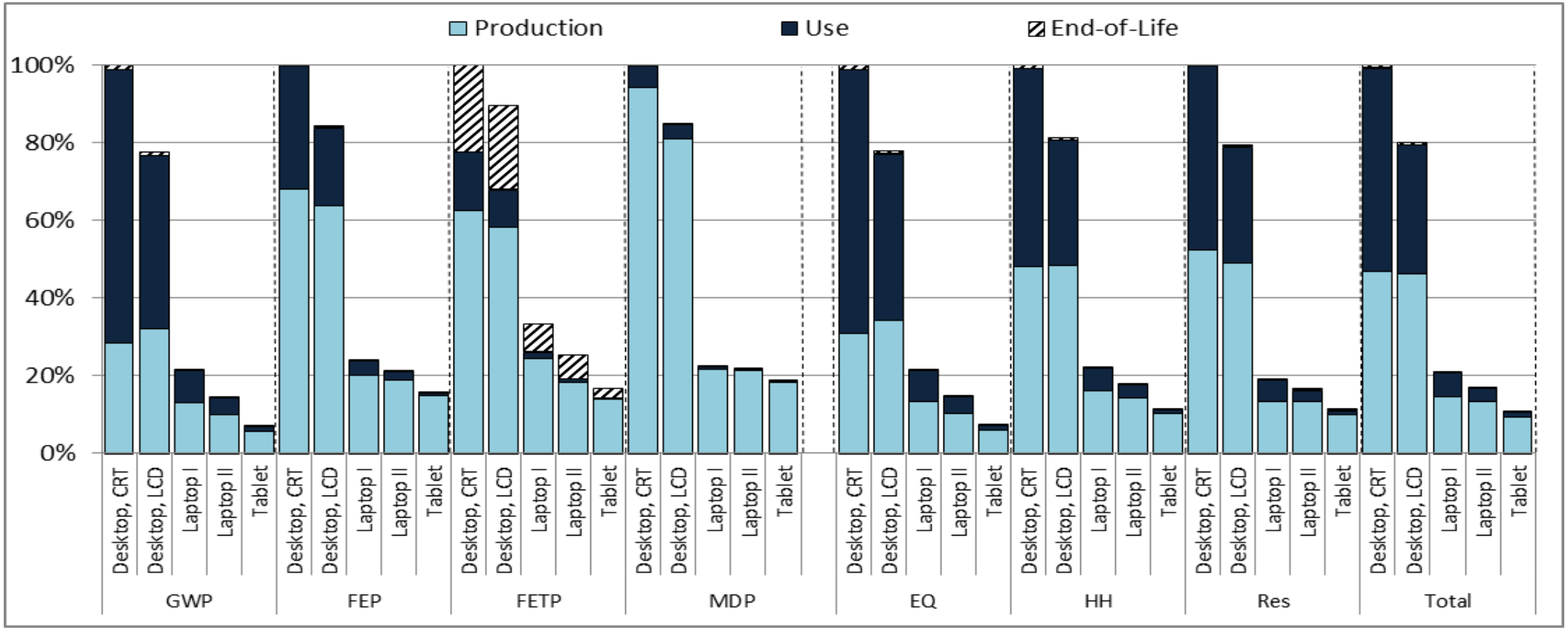
In the 1990ies, the German Climate Computing Centre in Hamburg computed the first climate model showing that climate change is human-made.

Today, the power of their first supercomputer is contained in a smartphone.

This power is now mainly used for video streaming.

Source: DKRZ, 25 Jahre Deutsches Klimarechenzentrum. Hamburg 2013

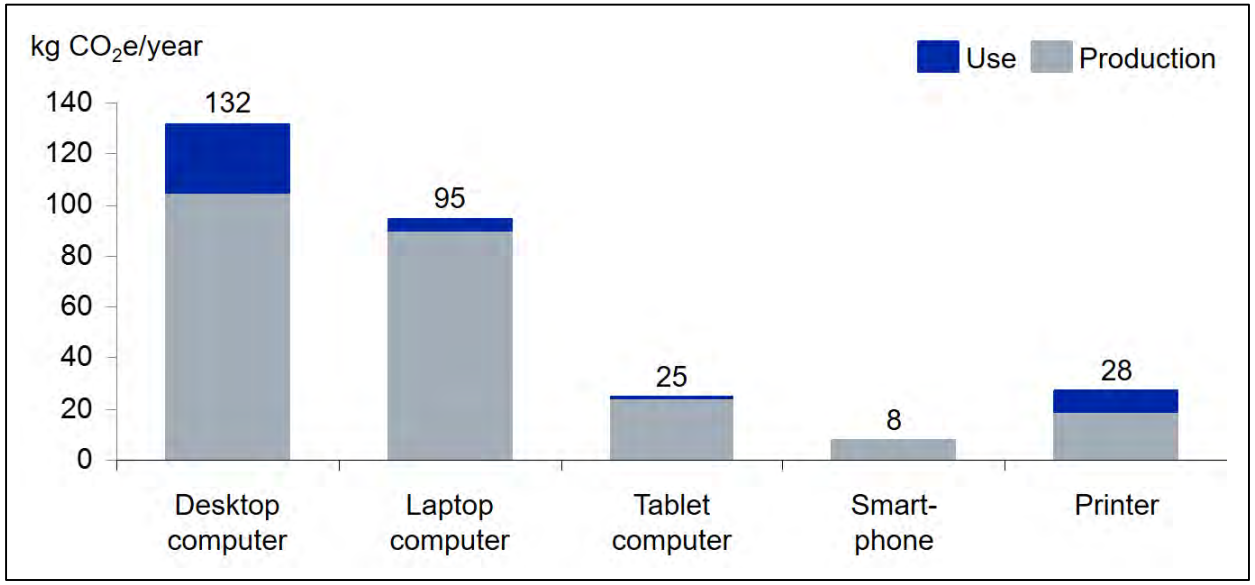
LCA of ICT end-user devices: desktop PCs, laptops, tablets (1 h of use)



Environmental impacts of 1 hour of use of ICT devices (relative to a PC with CRT Screen, which is set at 100%). Midpoint impact categories: **Global Warming Potential (GWP), Freshwater Eutrophication Potential (FEP), Freshwater Ecotoxicity Potential (FETP), Metal Resource Depletion (MDP)**, endpoint damage categories: **Ecosystem Diversity (EQ), Human Health (HH), and Resource availability (Res)**, weighted total.

Source: Hischier, R., Wäger, P.A. (2015): The Transition from Desktop Computers to Tablets: A Model for Increasing Resource Efficiency? In: ICT Innovations for Sustainability. Springer, 243-256

Production dominates clearly with clean electricity mix in use phase (GWP, 1 year of use)



swisscom

WWF

Data for Switzerland, 2015

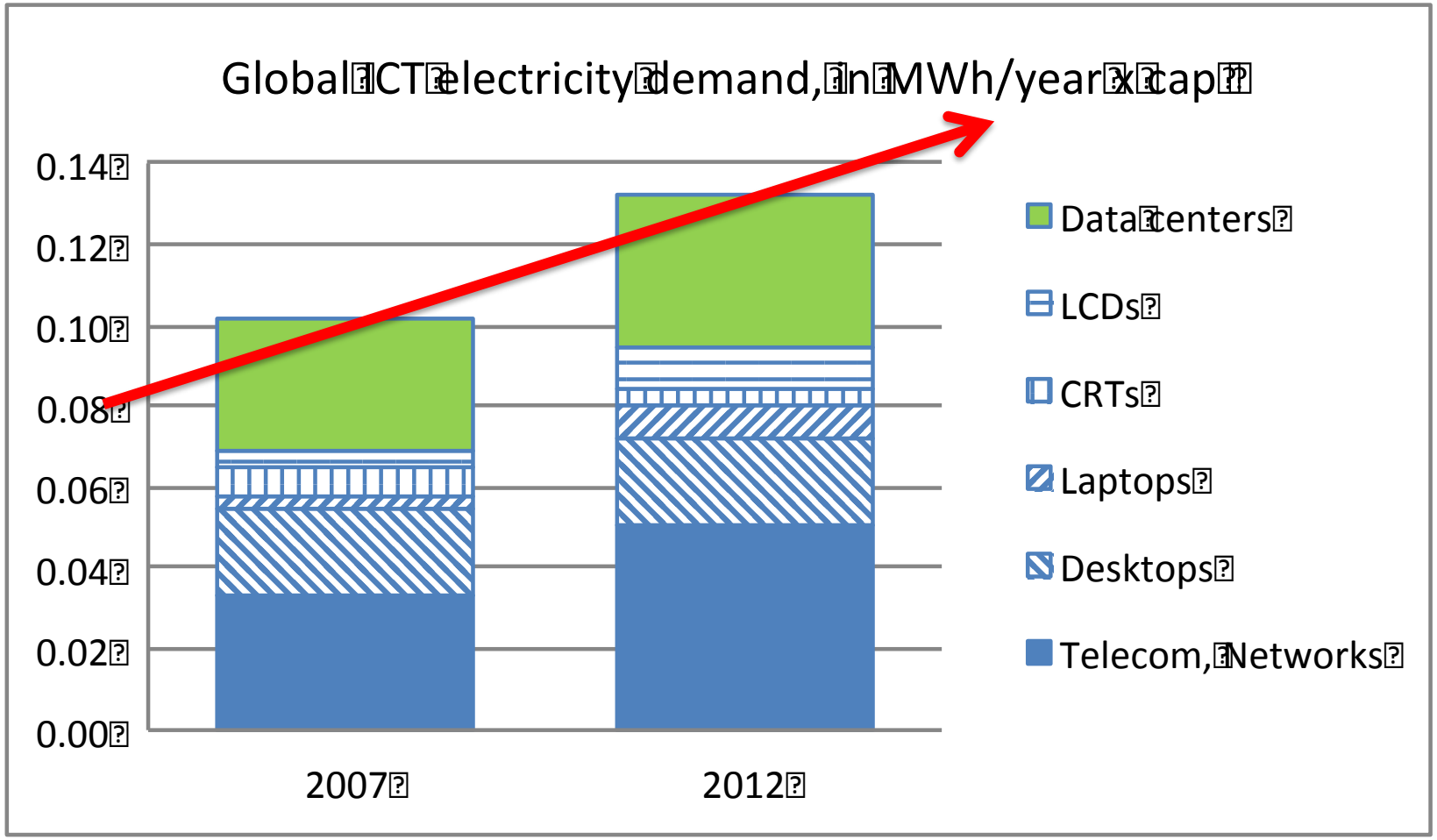
Source: Hilty, L. M.; Bieser, J. T. C. (2017): Opportunities and Risks of Digitalization for Climate Protection in Switzerland. Report, University of Zurich
http://www.zora.uzh.ch/id/eprint/141128/

Assumptions: Swiss supplier electricity mix for use phase and average service life of the devices (6.0, 4.0, 5.5, 3.3, 4.0 years).

For **end-user devices**, production of the devices has a clearly higher global warming potential than their use.

This result should, however, **not be generalized to servers**. For servers (which are operated 7*24 hours/week over 4-8 years), the use phase usually dominates the overall GWP.

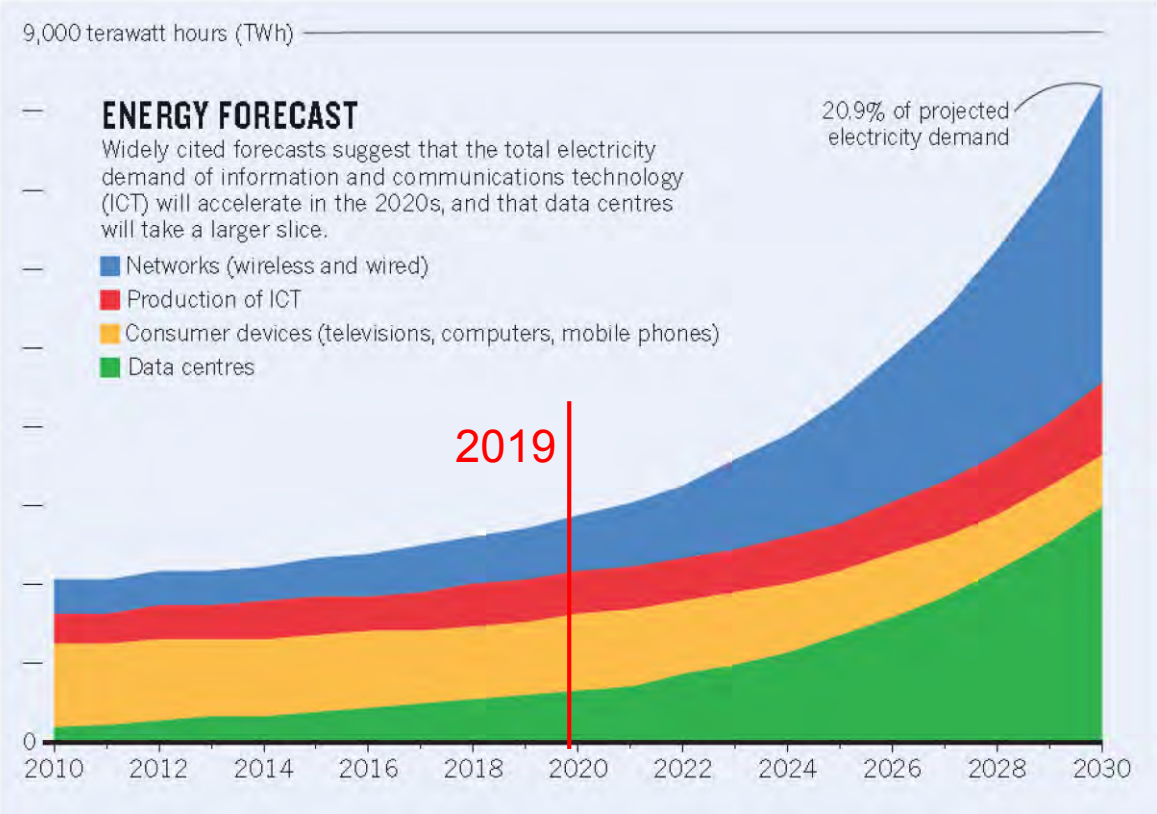
Per-capita annual use-phase ICT electricity consumption



Global energy demand of ICT is increasing fast, despite the increasing energy efficiency of all devices involved.

Source: Aebischer, B., Hilty, L.M. (2015): The Energy Demand of ICT: A Historical Perspective and Current Methodological Challenges. In: ICT Innovations for Sustainability. Springer, 71-103

Development of world-wide ICT electricity demand



'Expected case' projection from Anders Andrae

Jones, N. (2018): The information factories: Data centres are chewing up wast amounts of energy – so researchers are trying to make them more efficient. Springer Nature, Vol 561, 163-166

Andrae, A.; Edler, T. (2015): Challenges 6, 117-157

Open methodological questions

Network electricity consumption:

- Bottom-up or top-down calculation?
- How to separate transmission from processing and storage?
- How to deal with mobile access networks (5G plus legacy running in parallel)

End-user devices:

- Issues in calculating production phase energy consumption

Clément, L.P.; Jacquemotte, Q.; Hilty, L.M.: Sources of Variation in Life Cycle Assessment of Smartphones and Tablet Computers. Environmental Impact Assessment Review (submitted for publication)

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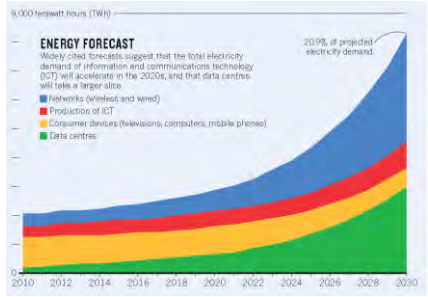

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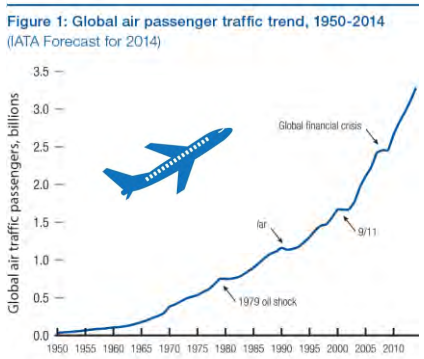

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Videoconferencing vs. travel

A case study

Davos

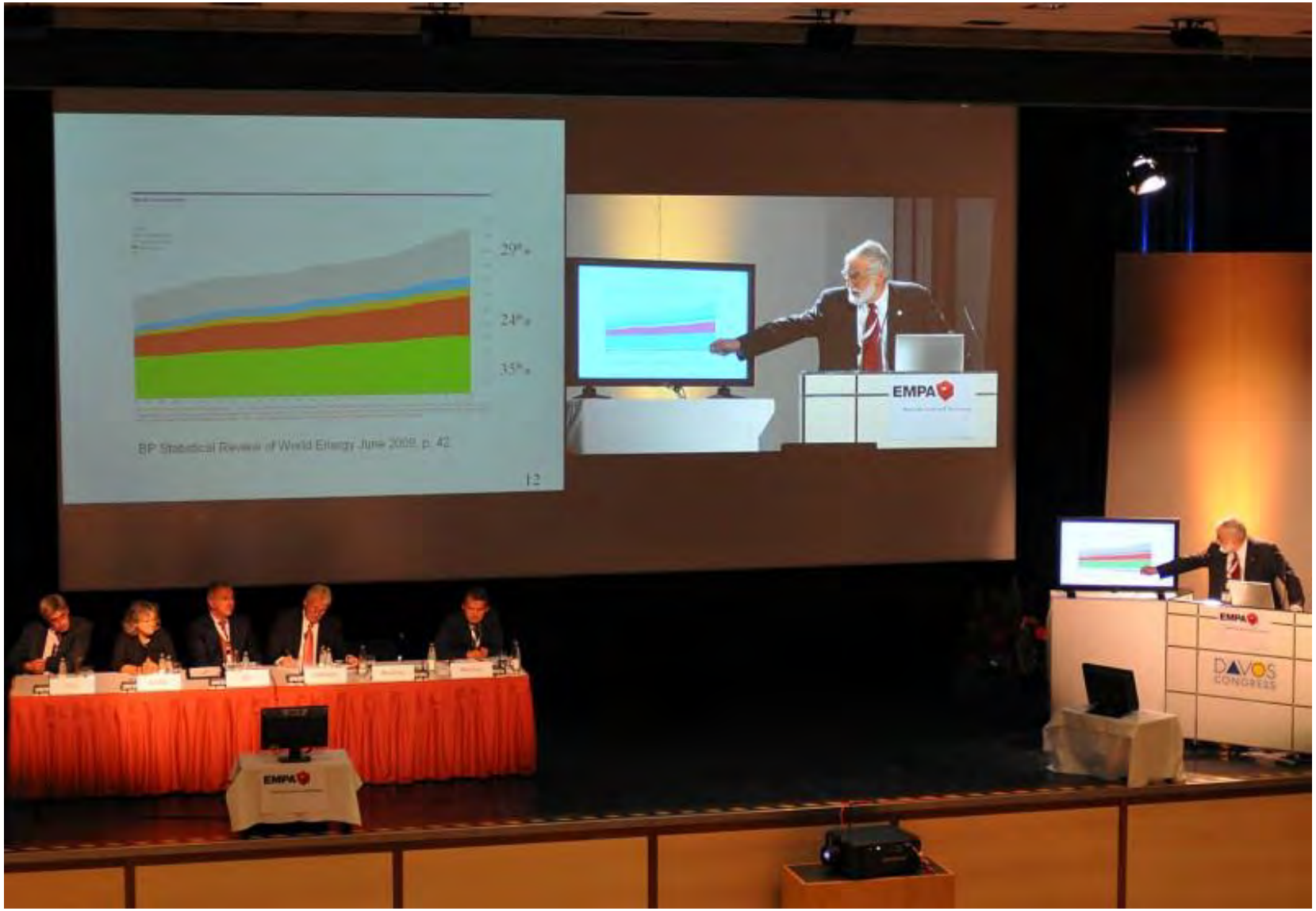
Nagoya

SWITCH
Serving Swiss Universities

World Resources Forum

CISCO

Not only transmitting speakers and presentations…



Dennis Meadows speaking in Davos.

…but also making the remote audience visible in life-size

Enabling eye contact between speaker and remote audience

It is essential for speakers to see whom they are talking to and to receive non-verbal cues from the audience.

Enabling informal communication during breaks

Telepresence kiosks placed in the coffee break and lunch/dinner areas were used for discussion and for fun.

Coroama, V. C.; Hilty, L. M.; Birtel, M.: Effects of Internet-Based Multiple-Site Conferences on Greenhouse Gas Emissions. Telematics and Informatics 29 2012, 362-374

Results of the Davos/Nagoya Case Study

Accompanying research showed that by connecting the two sites with telepresence systems, we **avoided 70-80 intercontinental flights with an average of 3.6 tons of CO_2e emissions.**

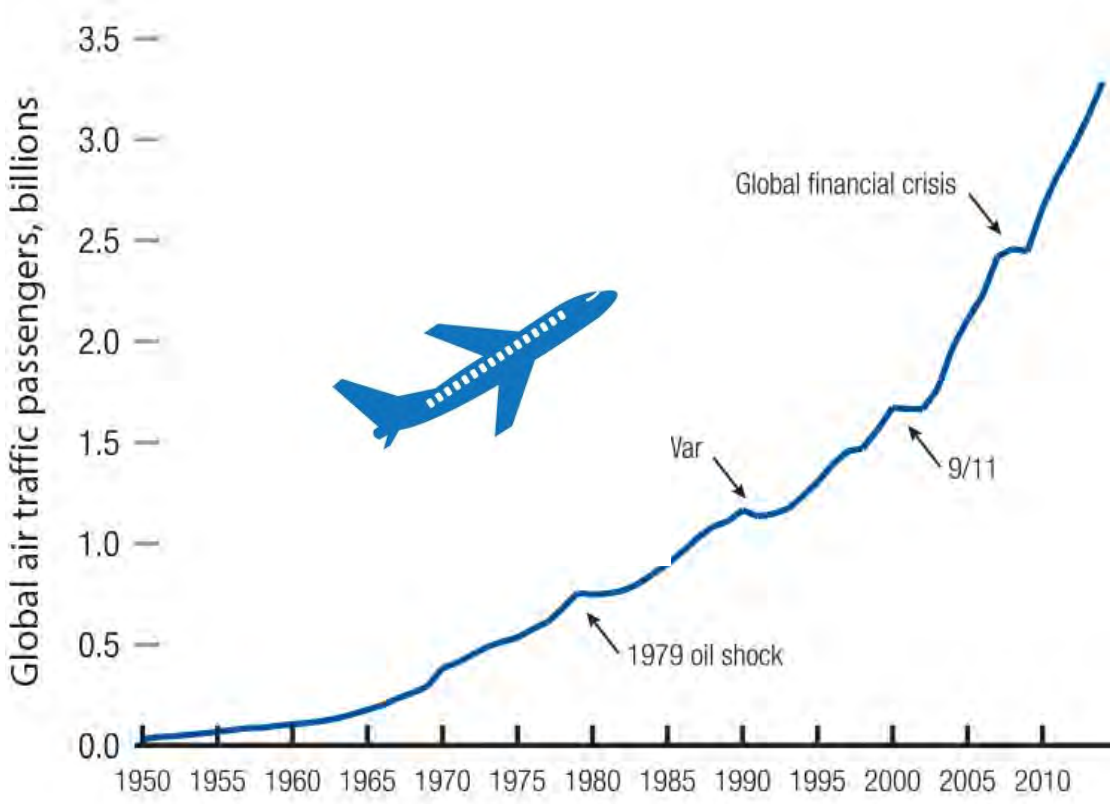
Study	Year of reference	Power per stream	Power for 8 streams	Power for local equipent	Energy for VC (3 days)	CO2e emissions (0.63 kg CO_2e/kWh)	Flights to be saved
Coroama et al. (2013)	2009	449 W	3588 W	9000 W	302 kWh	190 kg	0.053
Preist et al. (2019)	2016	54 W	432 W	9000 W	226 kWh	143 kg	0.040
Ferreboeuf et al. (2019)	2018?	1000 W	8000 W	9000 W	408 kWh	257 kg	0.071

Coroama, V. C.; Hilty, L. M.; Heiri, E.; Horn, F.: The Direct Energy Demand of Internet Data Flows. Journal of Industrial Ecology 17 (5) 2013, 680–688

Preist, C.; Schien, D.; Shabajee, P. (2019): Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19). ACM, Paper 397

Ferreboeuf, H.; Berthoud, F.; Bihouix, P.; Fabre, P.; Kaplan, D.; Lefèvre, L.; Monnin, A.; Ridoux, O.; Vaija, S.; Vautier, M.; Verne, X.; Ducass, A. (2019): Lean ICT – towards digital sobriety. Report to the Shift Project.

Exponential growth of air travel



Air travel has more than **doubled every two decades.**

The International Air Transport Association (IATA) predicts **another doubling of flight passengers for 2017-2037.**

Sources:

World Bank (2019): Air transport, passengers carried. Civil Aviation Statistics of the World and ICAO staff estimates.

IATA – International Air Transport Association (2918). IATA Forecast Predicts 8.2 billion Air Travelers in 2037.

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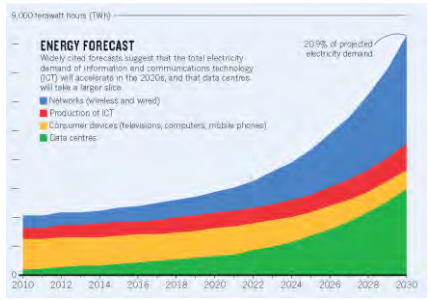

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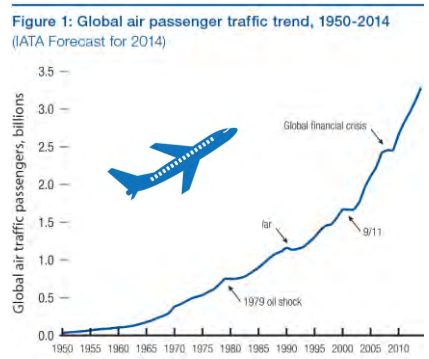


Durables are increasingly made obsolete by software

Software as a sustainable product

– Software is immaterial, it is interpreted by hardware.

– Hardware is not worn out by interpreting software, it ages for other reasons such as corrosion or mechanical damage.

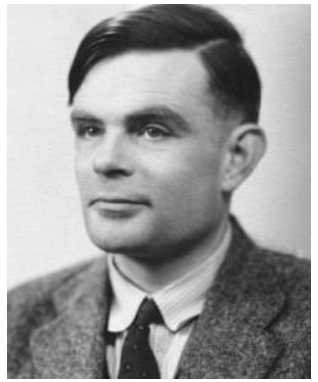
Background

– Alan Turing has proven that für every computable function there is a Turing Machine (TM) that can compute the function, and there is a special TM, called **Universal Turing Machine (UTM**), which can simulate all TMs.

– The UTM must just be given a **description** of the TM it is supposed to simulate.

– **Build one machine, use infinitely many by just describing them.**

– John von Neumann created the architecture that came quite close to this ideal for practical purposes (Von Neumann architecture).



Alan Turing (1912-1954)

John von Neumann (1903-1959)

Obsolescence by software – turning Turing‘s principle upside down

Programmed obsolescence

Examples:

– Code that is **counting** printed pages or battery cycles to reduce the quality of the service at some point

– Code that **recognizes replacment parts** from competitors to deny the service

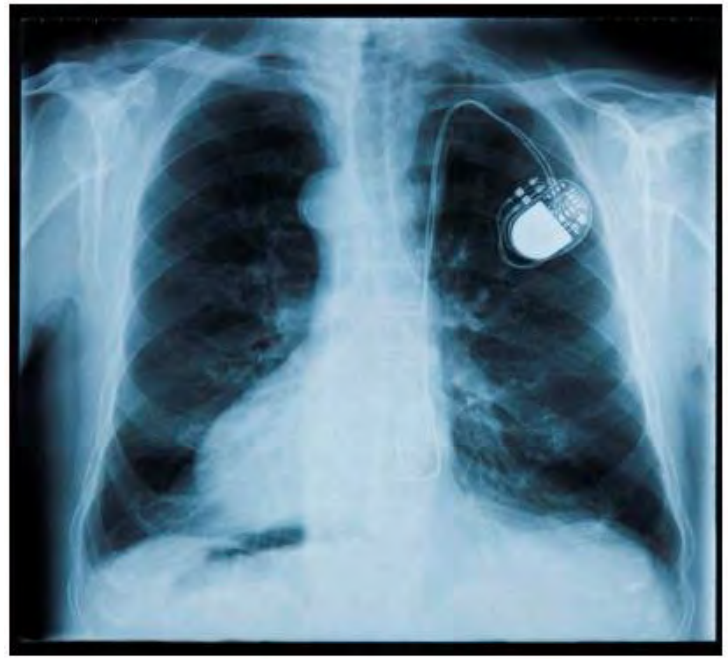
Software-induced obsolescence

– Subsequent versions of software products come with increasing hardware requirements, so that functioning devices have to be replaced by more powerful ones.

– Older version oft software products are no longer „supported“ with security updates.

→ *Obsolescence is increasingly connected to cybersecurity issues*

Example: Smart pacemakers



Advantages of smart pacemakers

– *They can be updated.* Only the software, not hardware has to be changed.

– They can better adapt to the situation, which extends battery life.

→ *less surgery needed.*

Disadvantages of smart pacemakers

– *They can be updated.*

– „An FDA advisory issued in early 2017 confirmed the potential for an attacker to remotely access a patient's device".

→ *hacking/cybersecurity risks already led to recalls,*

CARDIOLOGY NEWS

Pacemaker Recall Highlights Security Concerns for Implantable Devices

Source: Kuehn, B. M. (2018): Pacemaker Recall Highlights Security Concerns for Implantable Devices. Circulation. 2018;138:1597–1598. DOI: 10.1161/CIRCULATIONAHA.118.037331

Internet of Things (IoT)

Increasing amount of „smart“ things

- Software-controlled and connected to the Internet
- Under external control by updates
- For the owner of the smart thing, it is not transparent what it does and whose purpose it serves.

→ *Information asymmetry*

→ *Obsolescence by software spreads to products and infrastructures beyond ICT devices.*

Conclusions

Digital technologies are increasingly material and energy efficient, but rebound effects are over-compensating for this progress.

There are open methodological questions in LCA for digital ICT, in particular for the network infrastructure.

The environmental impact of videostreaming/videoconferencing compared to air travel is much smaller for meaningful functional units.

All software-controlled objects are prone to software-induced obsolescence, security plays an inglorious role in obsolescence.

This problem is extending from ICT devices to a broad range of smart things and infrastructures.

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