



UiO : **Faculty of Mathematics and Natural Sciences**
University of Oslo

Green Informatics

Michael Welzl



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Outline

1. Context, overview
2. A closer look
3. What can we do?

Context, overview

Context

- "Green":
environmental sustainability in a broad sense
 - Only environmental: e.g., "connecting the unconnected" is also "Informatics + sustainability"
- **Footprint:** the harm done
 - E.g., CO₂ emissions from compute electricity
 - E.g., water wastage from cooling a data center
- **Handprint:** the opposite
 - E.g., improving Oslo air quality, or fjord water quality
 - E.g., actions to reduce CO₂ emissions

Focus of this talk: ICT CO₂ emissions

- ... because Informatics students should know
 - There is a lot of nonsense in the media; you should know better!
- ... because some things are counter-intuitive and surprising
- ... because otherwise, we could talk forever
 - General environmental footprint and handprint are immensely broad (but we'll get back to the handprint a little bit)

ICT CO2 emissions: two questions

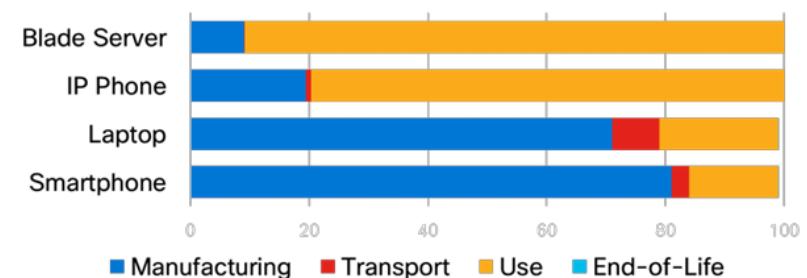
- Question 1: what can we do, as responsible citizens?
- Question 2: what can we do, as Informatics professionals?
- Let's see if you can answer question 1 in the end!

Emotions vs. facts: magnitudes matter

- Saving the planet needs a *big* change
 - Politicians can achieve that: via policy, and by "educating" citizens
 - E.g., if we *all* stop driving fossil cars, the impact is huge
 - This begins with every individual
 - Hence, "every little bit matters" ("alle monner drar") is a part of politics, society, culture & upbringing, and also connected to feelings
 - Yes it's great if we all do tiny things! But, this is the faculty of mathematics & natural sciences: **we care about facts, not feelings!**
- **We must understand:** what is an "*ant*" vs. a "*whale*"
 - Everything we do emits CO₂: every piece of bread we eat
 - As ICT professionals, we should invest time in things that matter!

So, what's the magnitude?

- **2020: ICT: ~4% of global electricity use, ~1.4% of CO₂ emissions**
[<https://doi.org/10.1016/j.telpol.2023.102701>]
 - Approximately CO₂ emissions of a country like Malaysia or Pakistan
 - **Telecommunications: ~ 0.6 – 0.8 % of CO₂ emissions**
 - Approximately CO₂ emissions of a country like the UK
- ⇒ Not the biggest spenders, but definitely significant!
- For all of ICT, **embodied emissions** represent 36% of the total
“Embodied = approx. 1/3 of ICT emissions” is probably reasonable
 - Note: very device dependent
 - e.g., Smartphone: 60-80kg CO₂
70kg = driving ~400 km with a petrol car



AI and data centers

- **AI may have totally changed these numbers:**
25.9.2024 news item: "OpenAI asked US to approve energy-guzzling 5GW data centers, report says" [<https://tinyurl.com/mvuc939v>]
"Bloomberg reviewed an OpenAI document outlining the plan, reporting that 5 gigawatts 'is roughly the equivalent of five nuclear reactors' and warning that each data center will likely require 'more energy than is used to power an entire city or about 3 million homes.' "
- I don't have such new CO₂ numbers
 - The following excludes this craziness
- Note: AI operations are usually in data centers
 - **Good:** energy efficient, good cooling, often run with "green" energy...
 - **Bad:** may have a significant environmental footprint other than CO₂

These things
change so fast!
E.g. DeepSeek is
much less
resource-intensive

Yearly CO₂ emissions in Norway

- “**40.8 million tons CO₂-equivalents (2022)**”
 - <https://ourworldindata.org/co2-and-greenhouse-gas-emissions>
- “**46,7 million tons CO₂-equivalents in Norway, 2023**”
 - <https://www.ssb.no/natur-og-miljo/forurensning-og-klima/statistikk/utslipp-til-luft>
- **Let's say: around 50 million tons in 2024**
 - Quite roughly

Personal footprint vs. global ICT

- **ICT, globally:** around **764 million tons** of CO₂-equivalents
 - So, approximately **15 ganger Norway** (*all of it, not just ICT*)
 - Norway has 5.55 million citizens
 - 50 M CO₂ / 5.55 M people = my personal footprint: **around 9 t**
- This means: if I reduce my footprint by **90%**
... then it's about 0.000001% of ICT's global footprint
- What if we could reduce the global ICT-footprint by **1%** ?
... that would be around **850,000 Norwegians**

850,000 is 17 times VG lista...



© CF Salicath / VG-Lista Topp 20

... imagine the noise!

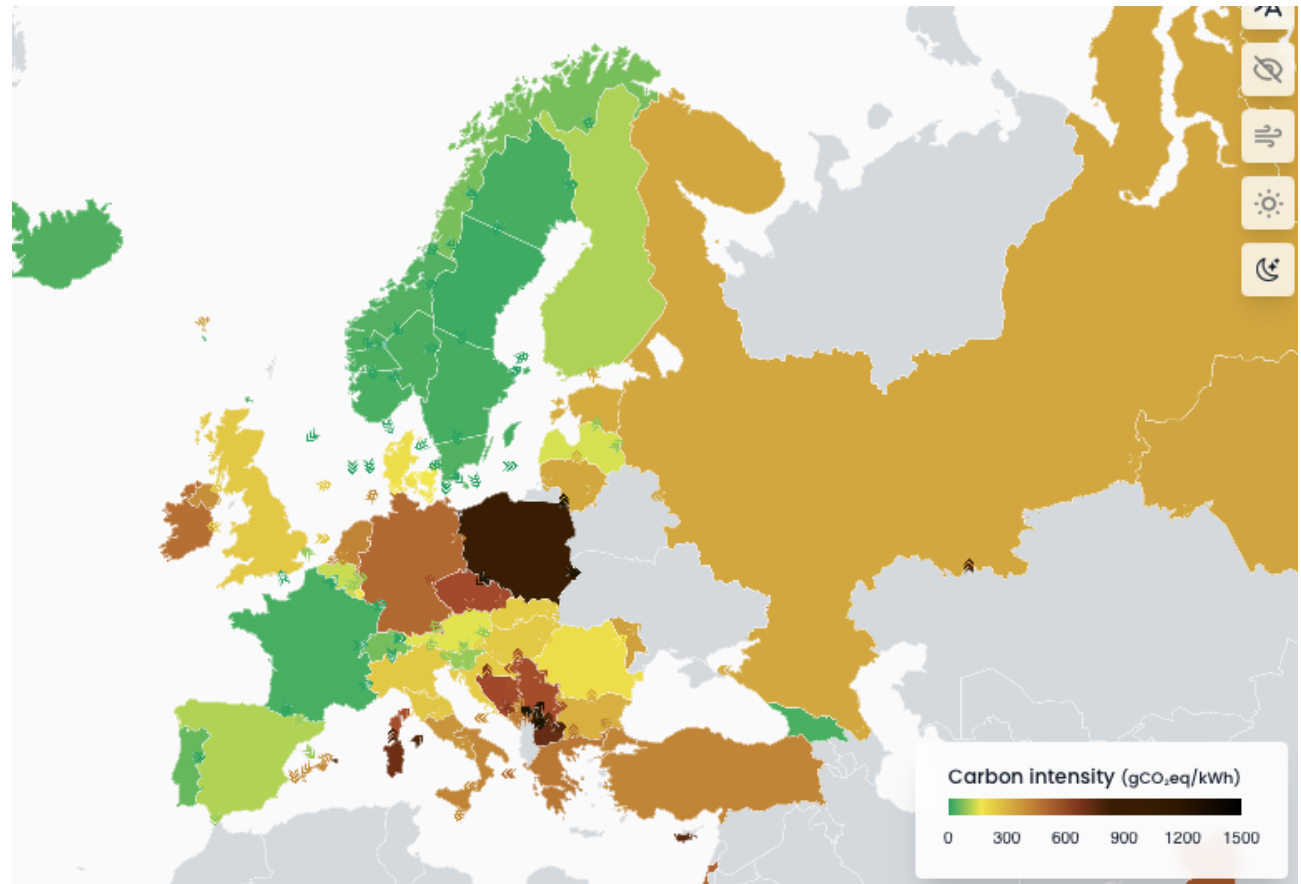
Therefore, it is important to reduce the ICT CO₂ footprint

But where?

At least for operational energy, ideally not in Norway.

CO₂-impact of reducing energy use in Norway:

1/10 of UK
1/20 of Germany
1/34 of Poland



<https://app.electricitymaps.com/map>

8.5.2024

=> **Question 2 matters more for you!**

(as future ICT professionals!)

- With ICT, we can change the world!
- E.g., OO programming is used everywhere.
 - The foundation was created here (Simula language)
- So many other ICT "things" are everywhere now!
 - Just look at the apps on your phone...

Ole-Johan Dahl



(1931 - 2002)

Kristen Nygaard



(1926 - 2002)

Turing award 2001 ("Nobel prize" of Informatics)

A closer look

Misconceptions

- Numbers and comparisons in the media are often wrong
 - It does not really matter how many emails we send (yes of course the effect is more than *zero*... just as with eating bread)
 - ICT is not like aviation (different numbers for CO₂, GHG, warming)
- Tempting, even among scientists, even in research papers, to use numbers and statements that suit the personal narrative
- **Please stop believing these two narratives:**
 1. Exponential ICT growth => exponential CO₂ emission growth
 2. Every single contribution matters, we must be less "wasteful" (= fewer bytes)

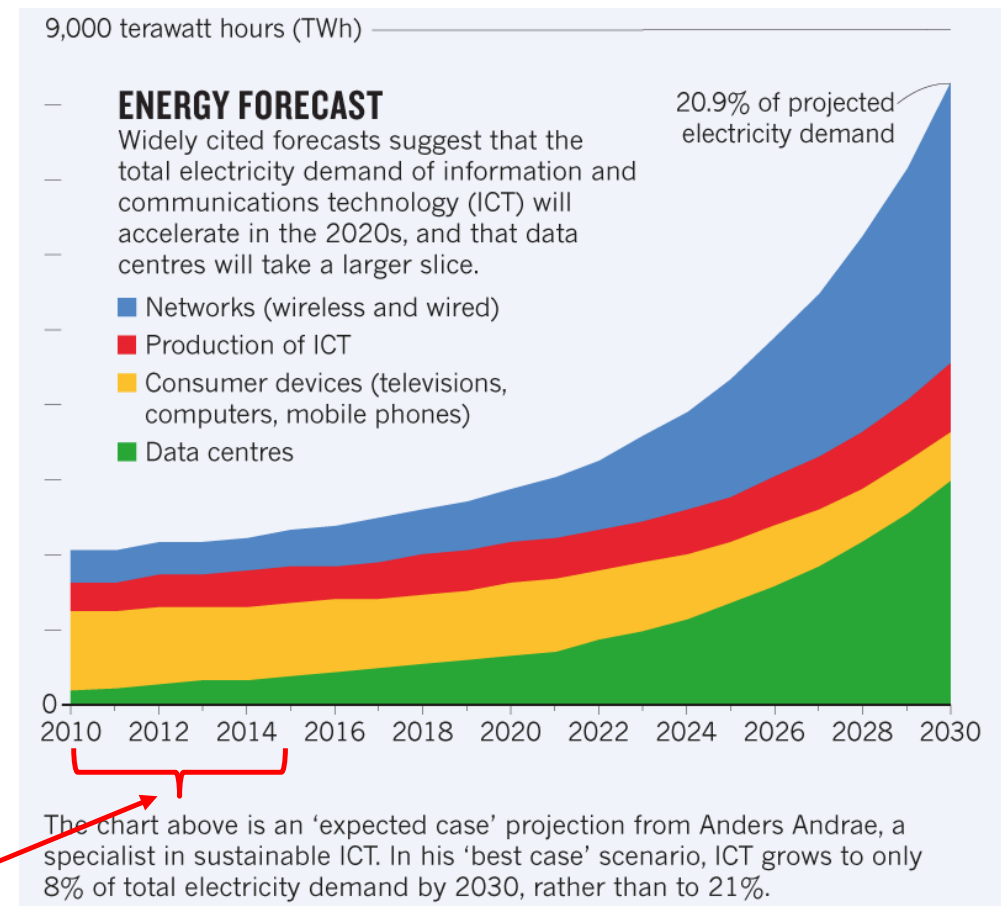
E.g.: "watch less Netflix"

For ICT, these are both wrong.

(The second: not completely wrong, but mostly – it's just not that simple.)

Narrative 1: exponential growth

- Diagram to the right: often quoted as "Nature"
- This is correct, but:
 - "news feature": **not peer-reviewed!**
 - Instead, "written or commissioned by the journal editors."
- Keep in mind, it's a prediction until 2030
 - Made in 2015! Knowledge



<https://www.nature.com/articles/d41586-018-06610-y>

More about this diagram

- Source and history
 - Nature editors have published this in **2018**, and taken it (referenced) from a **2015** paper: <https://doi.org/10.3390/challe6010117>
 - Criticized in this **2018** paper: <https://doi.org/10.3390/su10093027>
 - **2020** article by the original author: "New perspectives on internet electricity use in 2030" corrects the data (downward):
<https://www.doi.org/10.30538/psrp-eas12020.0038>

- Haven't we all recently learned that exponential growth may not last forever?

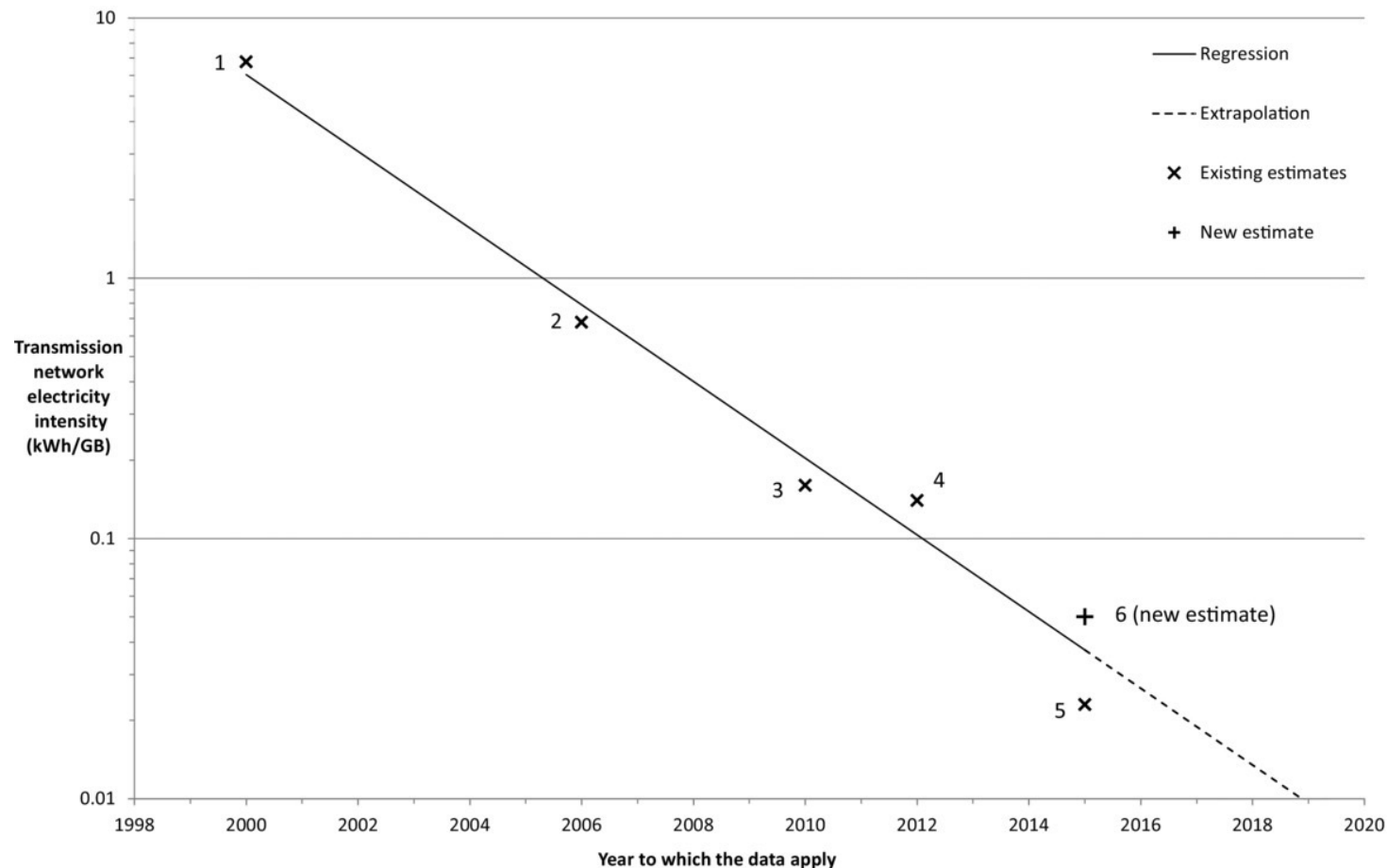


- Still, people use the diagram. Perhaps because of the nice colours?

More about narrative 1

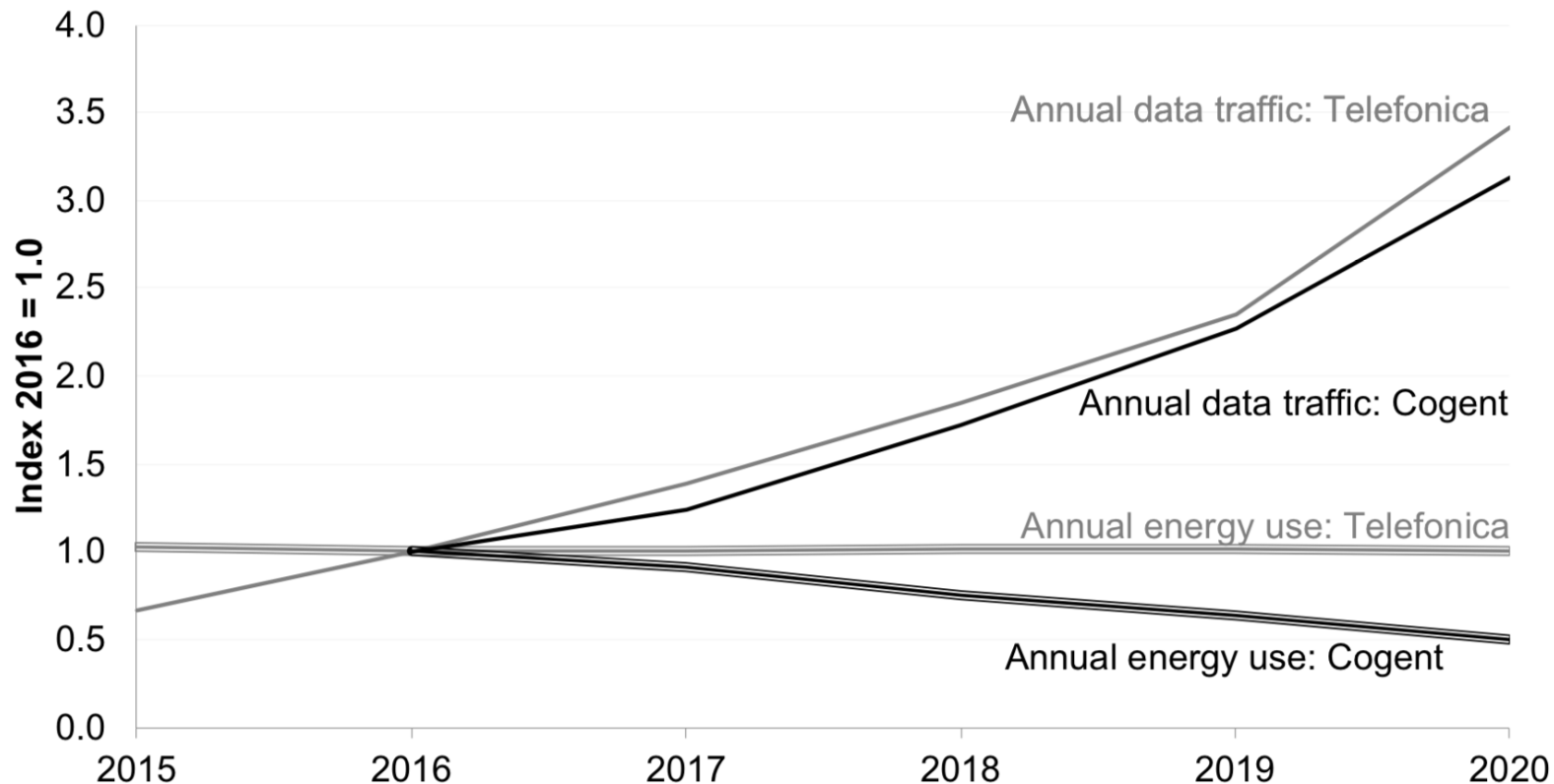
- **Moore's law**: chip densities double every two years
 - Side effect: **Koomey's law**: “at a fixed computing load, the **amount of battery you need will fall by a factor of two every year and a half**” [Wikipedia]
- **Moore's law has been slowing down**
 - **Koomey's law** [Wikipedia]: “in 2011, Koomey re-examined this data and found that after 2000, the **doubling slowed to about once every 2.6 years**”
- Internet traffic, number of users: **exponential & no sign of slowing down**
 - **Could this make the Internet a huge CO2 contributor one day?**

The energy efficiency of telecom hardware



J. Aslan, K. Mayers, J. G. Koomey, and C. France. Electricity intensity of internet data transmission: Untangling the estimates. Journal of Industrial Ecology, 22(4):785–798, 2018

Real ISP energy use



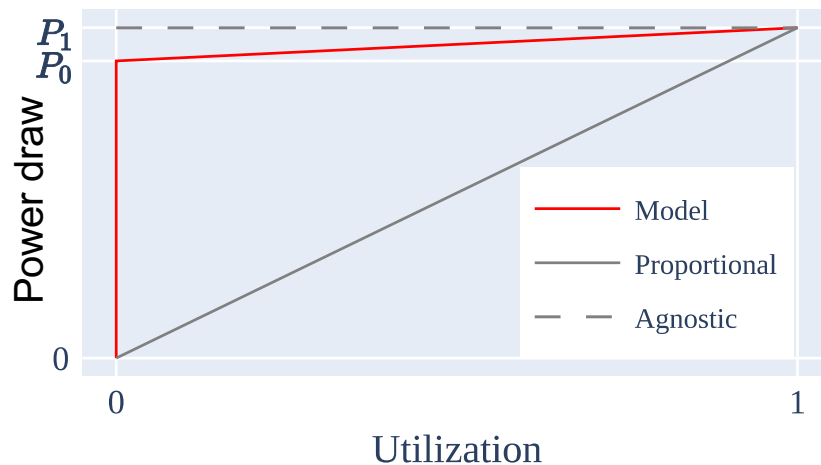
Source: <https://www.koomey.com/post/654896139332616192>

Note, though:
ChatGPT was
released in
2022

In contrast, the **entire ICT sector's emissions have slightly grown:**
about 5% from 2015 to 2020 [<https://doi.org/10.1016/j.telpol.2023.102701>].

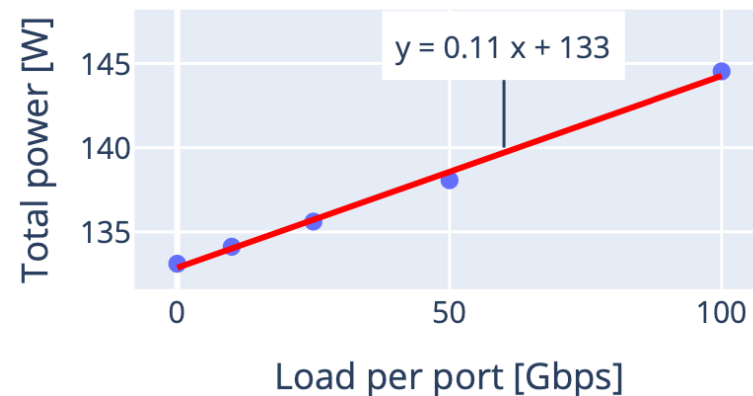
Narrative 2: every single contribution... ... only true for power proportional hardware.

General model (many equipment types)



Romain Jacob and Laurent Vanbever. 2023. The Internet of Tomorrow Must Sleep More and Grow Old. *SIGENERGY Energy Inform. Rev.* 3, 3 (October 2023), 27–32.

Measurements: Tofino network switch



Romain Jacob, Jackie Lim, and Laurent Vanbever. 2023. Does rate adaptation at daily timescales make sense? In *Proceedings of the ACM 2nd Workshop on Sustainable Computer Systems (HotCarbon '23)*.

Measurements: server

	0 bit/s data transmission		10 Gbps data transmission	
	Idle	CPU	CPU + RAM	NIC
Average Power Consumption (Watt)	145.946	190.0	193.735	147.1
	± 0.22	± 0.0	± 0.751	± 0.304

Kristjon Ciko, Michael Welzl, Peyman Teymoori: "Going Dark: A Software "Light Switch" for Internet Servers", *IEEE 29th International Symposium on Local and Metropolitan Area Networks (LANMAN 2023)*, 10-11 July 2023, London, UK.

What about wireless systems?

- **Cellular:** energy has always been important, and is a major part of **5G and 6G**; **power proportionality** (sleep cycling) is definitely also a part of it
- **WiFi:** access points are **somewhat power proportional**
 - But their total system power is quite small
 - **How much? 2023 EU document:** "Code of Conduct on Energy Consumption of Broadband Equipment" ... "sets the (maximum) electricity consumption for broadband equipment sold in the EU and manufactured or procured by participating companies."
<https://tinyurl.com/ysmkrary> Table 14, p.30: **1.9 - 5.0 W** range
- **End systems: wireless transmission somewhat power proportional**

Should we optimize for phones?

- Phone charger: usually ~ 5 W; assume: approx. 1h to fully charge, every day: **1.8 kWh / year**.
 - This is very, very rough (e.g., as phones age, they need longer)
 - <https://www.fortum.com>: modern dishwasher: **0.6-1.5 kWh / cycle**
 - Remember: a phone's emissions are primarily from manufacturing
- So, I wondered, how about TVs? They must need more power, and they receive a large amount of data over WiFi
 - When I enable WiFi on my TV, I get a message:
“Are you sure? This could cost more energy.”

I measured my TV

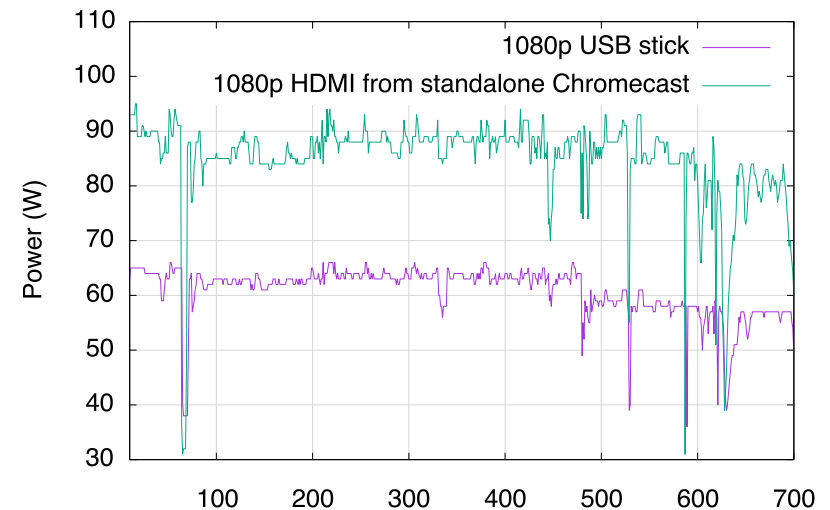
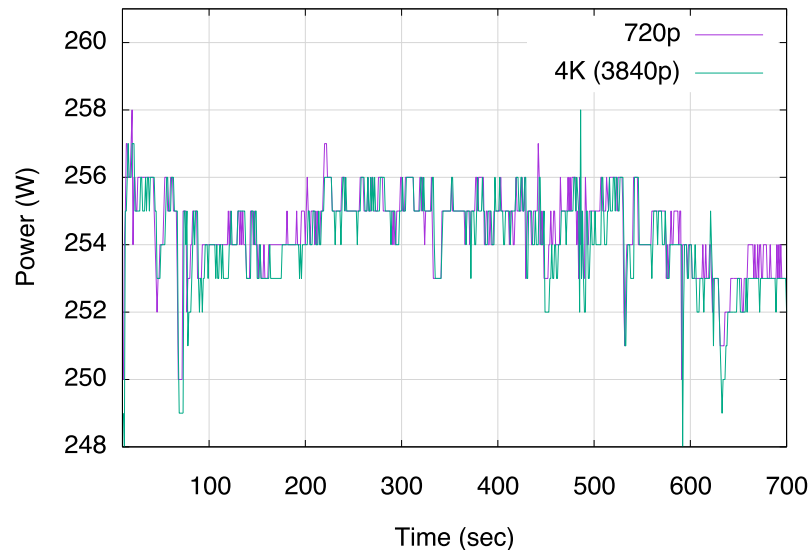
- TCL 65" 4K MiniLED TV, model name 65C935
 - Android TV software version 11 (5.12.2022), kernel version 4.19.116+
 - Everything set to default
 - Energy measurements using GUDE Expert Power Control 1105
- 8 Watts in standby
- 240 Watts when showing the home screen
 - Moving across the icons in the home screen makes the energy usage fluctuate in the order of **tens of Watts**
- Mostly black “no signal” screen for an unconnected HDMI port: 48-49 Watts.



Now let's watch "Tears of Steel"

(Common test movie from <https://mango.blender.org>)

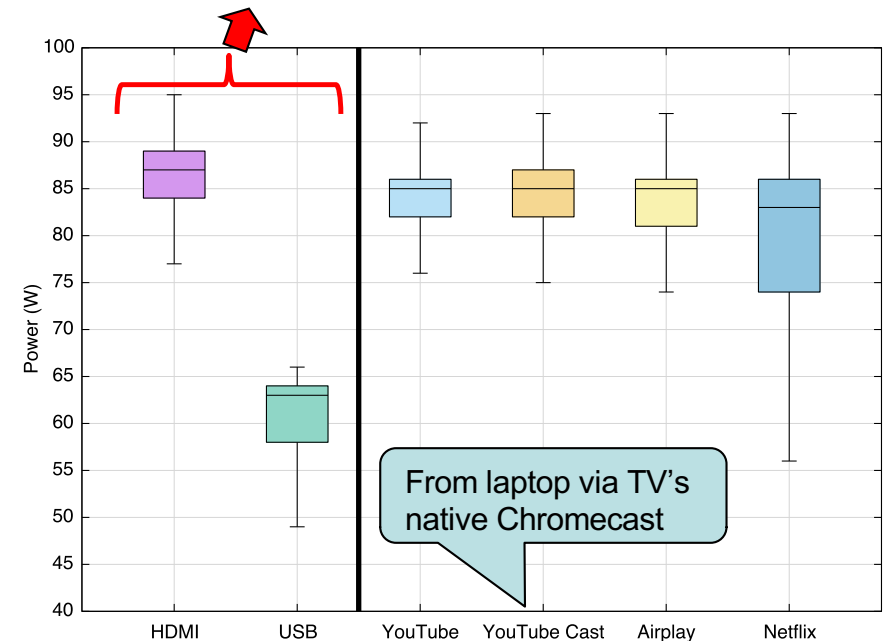
HDMI laptop:
video quality
doesn't matter



- Standalone Chromecast (3rd generation):
idle 1 W, streaming 2 W
- All tests on the right: 1080p, except Airplay (1920p) and Netflix (3840p).

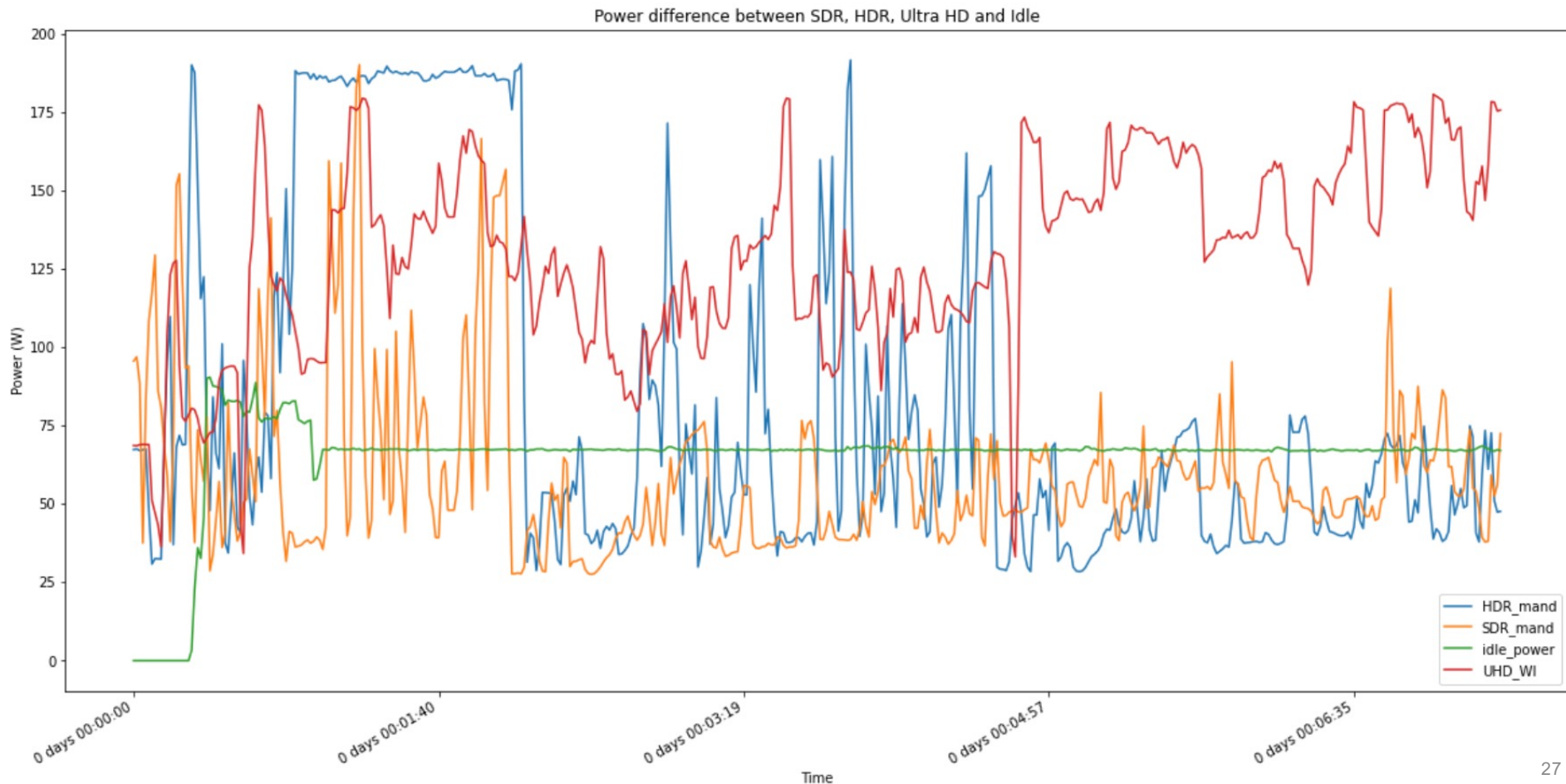
Take-away: HDMI cable is worst, much worse than WiFi; and watching HQ Netflix over WiFi is much **better** than leaving the TV on and idle.

=> My TV really shouldn't warn me about WiFi.



A different TV

Samsung Q88, comparing SDR, HDR (Mandalorian, 1080p), UHD (BBC nature doc) and idle



What can we do?

... to reduce ICT CO₂, as responsible citizens? (question 1)

Some answers:

- Embodied energy:
(maybe *generally* more important in Norway)
 - Think twice about hardware upgrades:
do you really need them?
 - E.g. more Internet capacity may not even yield a "real" benefit
 - Small devices (phone, tablet)
- Operational energy:
 - Save energy by completely turning off unused devices
 - Watch movies on a phone or tablet rather than a TV
 - and if possible, **measure!**
 - I'm not sure about "don't use ChatGPT"; maybe?

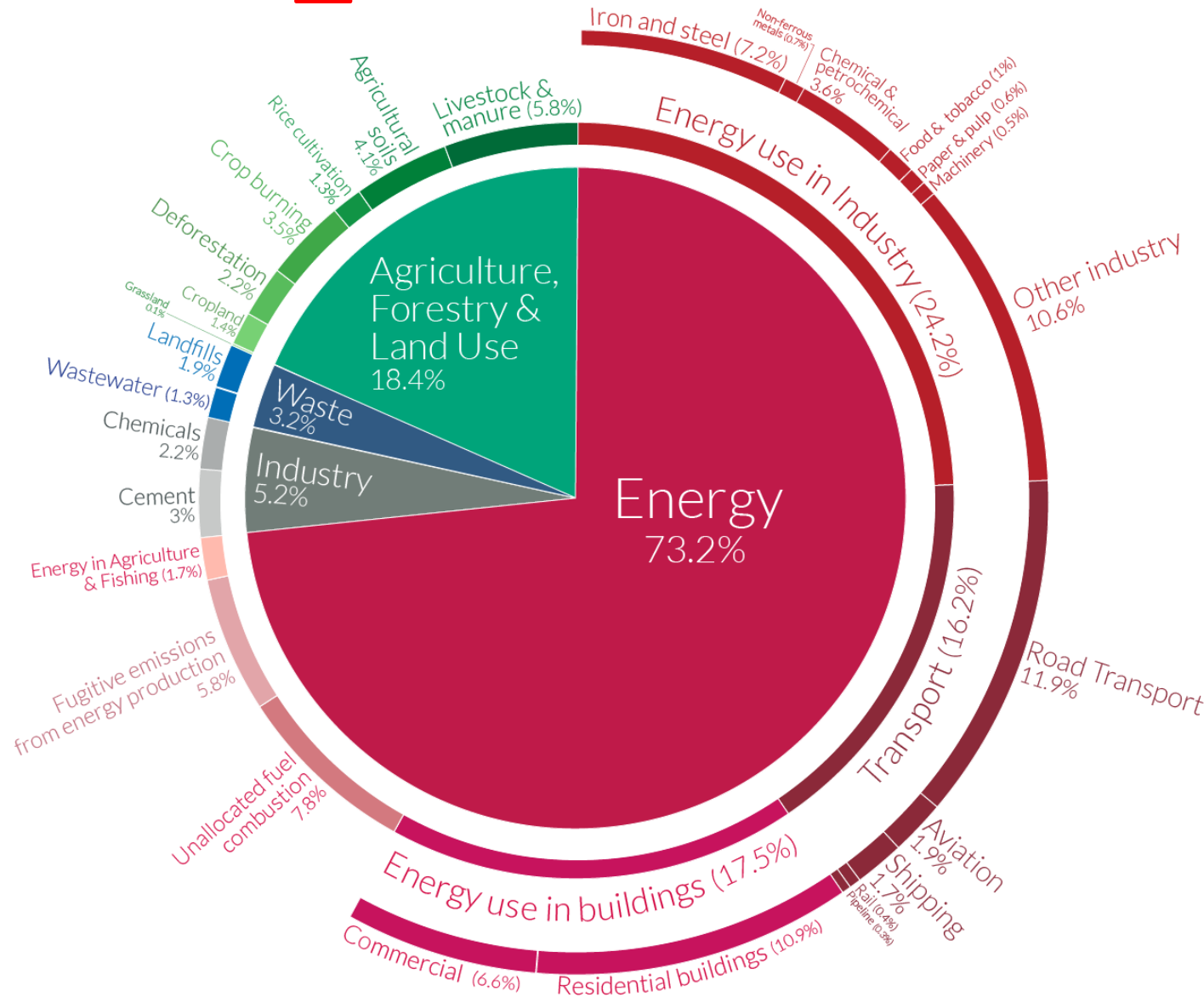
... as an Informatics professional?

- Make ICT equipment more energy efficient ?
 - Jevons paradox, 1865 ("rebound effect"):
Coal use increased with technological improvements
 - In general: efficiency could reduce usage, but efficiency also reduces cost
=> resource demand grows, use increases, emissions increase.
- Does this logic work for everything?
 - Wikipedia once said:
"5G is far more energy efficient than 4G. However, the lower cost will lead to more internet use, which in turn may result in an increase of energy consumption."
... but this statement was removed. - and: is this really true?
- Anyway, **ICT CO2 contributions are small, compared to many other things** (e.g., transport, agriculture, heating, other power use, ..).
 - Perhaps the **handprint** matters more?

Global greenhouse gas emissions by sector



This is shown for the year **2016** – global greenhouse gas emissions were 49.4 billion tonnes CO₂eq.



ICT in general has a positive impact on many of these factors (e.g., travel reduction)

Remember, ICT itself: ~1.4%

Notes:

- “energy” here contains heating, electricity, transport
- Relationships quite constant 1990-2021

An example: Google's Project Contrails

<https://sites.research.google/contrails/>

- Reduces contrails by about **54%**:
avoids flying through moist air
 - Air traffic contributes about **4%** to
global warming, of which **~35%** is due to contrails
 - **54% of 35% = 19%** of the air traffic contribution
 - ... and hence **~0.8% of the global problem**
- ...which is approx. half of ICTs global contribution !**
- If this uses, for example, a whole datacenter, this datacenter's negative effect is completely minimal in relation to the gain it achieves
 - and this is just one project



Thank you!

Questions?

Backup slides

Email

- “A typical office worker sends and receives around 140 emails per day, which, over the course of a year, creates as much CO₂ as *flying from London to Bruges* or watching *955 movies*”
<https://www.cwjobs.co.uk/insights/environmental-impact-of-emails/>
- “Sending 65 emails is roughly equivalent to driving *1km in a car*. (..) Globally, the world’s email usage generates as much CO₂ as having an extra seven million cars on the roads.”
<https://www.sciencefocus.com/planet-earth/the-thought-experiment-what-is-the-carbon-footprint-of-an-email/>
- **This cannot make sense:** what is an "average" email? Sent over which servers, where? Carbon-efficient energy or not? What are the end systems involved? Is a phone the same as a desktop?
 - Also, these numbers just don't add up, and a London-Bruges flight doesn't even exist.
- **This email stuff is everywhere. Where does it come from?**

It comes from the media, of course!



Knighting of **Tim Berners-Lee**, the "inventor of the WWW", by Queen Elizabeth II

NOT generated with AI !

<https://www.pinterest.com/pin/552535448023449857/>

- His brother, **Mike Berners-Lee**, is a professor at Lancaster University, and he has written popular books about climate change
- ***Could it be that the media find this family interesting?***

Mike Berners-Lee talked to the media

- (..) the footprint of an email also varies dramatically, from 0.3g CO₂ for a spam email to 4g (..) CO₂ for a regular email and 50g (..) CO₂ for one with a photo or hefty attachment, according to **Mike Berners-Lee**, a fellow at Lancaster University who researches carbon footprints. These figures, however, were crunched by Berners-Lee 10 years ago. Charlotte Freitag, a carbon footprint expert at Small World Consulting, the company founded by Berners-Lee, says the impact of emailing may have gone up.
<https://www.bbc.com/future/article/20200305-why-your-internet-habits-are-not-as-clean-as-you-think>
- With new data in hand, **Berners-Lee** estimates that an individual email can be anywhere from from 0.03g CO₂ to 26g CO₂.
<https://sedna.com/whats-the-carbon-footprint-of-your-email/>
- 1 email = 1g carbon = 0.000001 tonnes CO₂ per email
(Source: **Mike Berners-Lee**)
<https://www.ovoenergy.com/ovo-newsroom/press-releases/2019/november/think-before-you-thank-if-every-brit-sent-one-less-thank-you-email-a-day-we-would-save-16433-tonnes-of-carbon-a-year-the-same-as-81152-flights-to-madrid.html>
- **Mike Berners-Lee**, a respected professor on the topic whose research was used in the Ovo Energy work, told the Financial Times it was based on "back-of-the-envelope" maths from 2010 - and **while useful to start conversations, there were bigger questions.**
<https://www.bbc.com/news/technology-55002423>

He Shall Be Forgiven!

- Informing the public = a part of our job description
<https://www.uio.no/english/about/regulations/personnel/core/uio-salary-policy.html>
 - "Assessment of the salary level for the individual employee shall be based on the principles described under item 1 General principles of the salary policy; see in particular paragraphs 5 and 6. In addition, the following criteria shall be used:"
 - Item 4: "**dissemination, profiling and publicising of research-based knowledge**"
- You know this especially well if you ever wrote a project proposal or even led a project
 - The EU calls it "communication" (as opposed to "dissemination")
- **But: think twice about what you tell the media.**

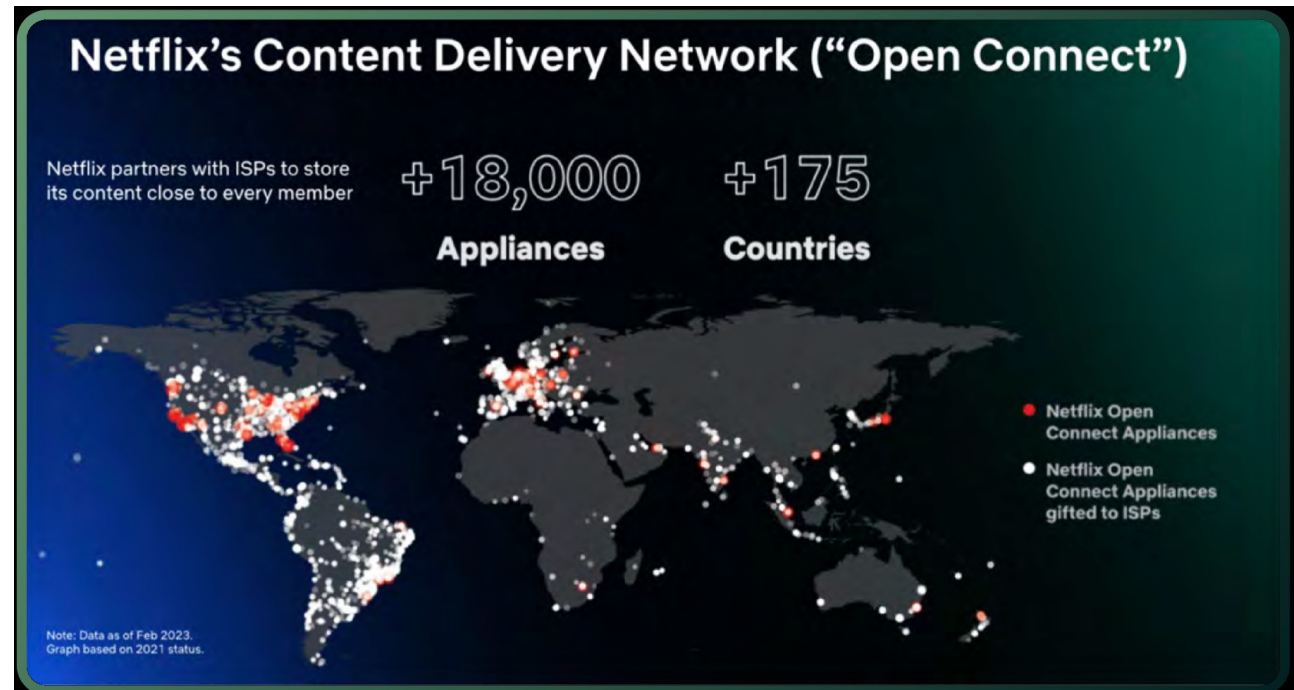
Netflix reported CO₂ emission numbers

- Netflix ESG Report 2023, <https://tinyurl.com/22859b5e>
- **2022:** Corporate 38%, production 59%, streaming 3%
- **2023:** Corporate 61%, production 35%, streaming 5%
 - 2023 production decline due to strikes
- Streaming breakdown:
 - 1% data center (encoding)
 - 10% ISPs (Content Distribution Network (CDN))
 - 89% user premises
 - 46% screen
 - 43% home routers & peripherals

Netflix' net

10% of 3 - 5%

- About the 10% ISP
 - It's about **CDN servers**, not about **transmission bitrate**
 - Netflix adapts bitrate to the device: TVs ~ 10 x mobile phones
 - Restricting video resolution (as in pandemic) does not reduce energy consumption or emissions by the wired network
 - Perhaps an effect in the wireless last hop, but very small
- CDN also offers an opportunity to adapt to carbon efficiency
 - Transmitting packets is more efficient than transmitting power



Video streaming in absolute terms

- *"Researchers at the University of Bristol spent a decade developing a tool to calculate the carbon footprint of streaming and other everyday internet uses, such as browsing news stories (..). The calculator uses the latest scientific protocols to measure emissions (i.e., lifecycle assessments) and data directly from the entertainment and media companies who rely on streaming delivery themselves, compared to the generic estimations of past studies."*
<https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/carbon-impact-of-video-streaming>
- 1h streaming in Europe: approx. 55 gCO₂e
 - = microwaving 4 bags of popcorn, or three boils in an electric kettle in the UK.
 - "Previous guesswork profiled in the media had this figure as high as 3200 gCO₂e, or as much as microwaving 200 bags of popcorn."
 - **Attributional reasoning:**
If you stream 1h less tonight, you do not directly save 55 gCO₂e!