The Internet meets the Electricity Grid

Challenges in Management for Green Networking

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With significant contributions from Alexander Clemm, Toerless Eckert

Outline

1. Motivation
2. Network sustainability foundations
   a. Foundational sustainability concepts
   b. Energy proportionality and its implications
   c. Structuring the opportunity space
3. On the road towards Net Zero
   a. Assessing and characterizing progress
   b. How far have we come - driving scale and cost at Internet speed
4. Network sustainability challenges and opportunities)
   a. Deployment aspects: power sourcing, HVAC, warm networking
   b. Architecture level
      - Communication patterns and function placement
      - Edge, Core, Compute inside and outside the network
      - Lessons from CDN
   c. Equipment level: Instrumentation and metrics
   d. Network level: Overprovisioning and peak shaving
   e. Protocol level

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Motivation

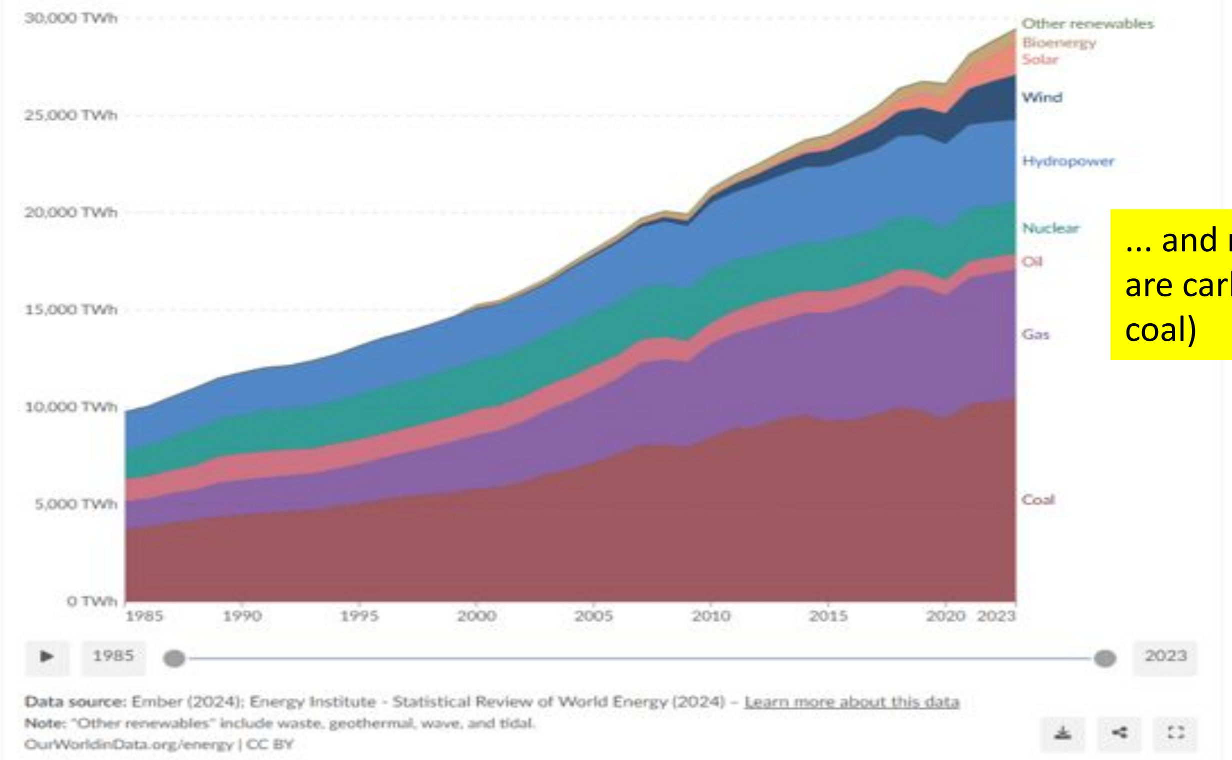
What is “Sustainability”?

> Meeting the needs of the present
> without compromising the ability of future generations to meet their own needs
> [UN Brundtland Commission, 1987]

Specifically associated with environmental sustainability and “carbon footprint”
- The amount of carbon emitted from burning fossil fuels to generate power

Reducing carbon footprint to Net Zero to combat climate change is considered one of mankind’s “Grand Challenges”

Energy demand continues to grow



... and majority of energy sources are carbon-intensive (oil, gas, coal)

Source: https://ourworldindata.org/grapher/electricity-prod-source-stacked

Net Zero

- Refers to the net amount of green house gas emissions
  - Green house gases: CO_2 and other gases (measured in CO_2 equivalents)
  - Net emissions: amount of CO_2 emissions minus amount of CO_2 removed (e.g. absorbed from the atmosphere)
- How to go to Net Zero
  - Use carbon-neutral energy sources (e.g. renewables)
  - Use less energy & become more efficient
    (as renewable sources may not always be available)
  - Avoid emissions in other places

Debatable -
What do you count?
How do you account for it?

Think of Net Zero as an aspiration

Networks as a solution enabler

- Substitute physical mail with e-mail
- Substitute travel with Web meetings
- Teleworking from home
- Replace truck rolls with remote maintenance
- Telemedicine
- IoT solutions
  - Remote surveillance (reducing need for patrols)
  - Smart cities (e.g. smart garbage cans)
  - Smart Agriculture (resource efficiency beyond energy: water, fertilizer, area)

This is great!
So what's the
problem?

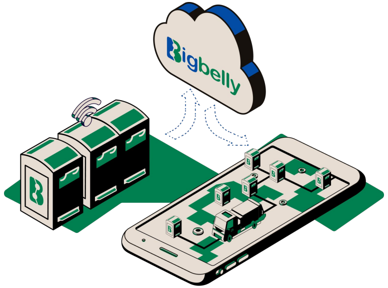
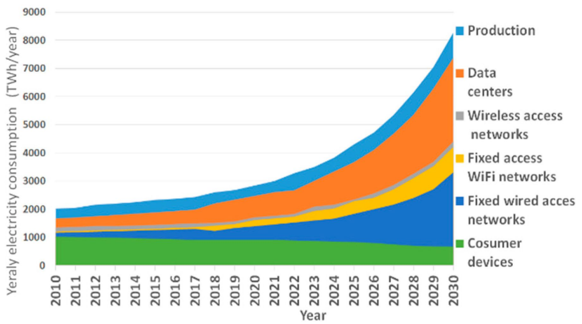


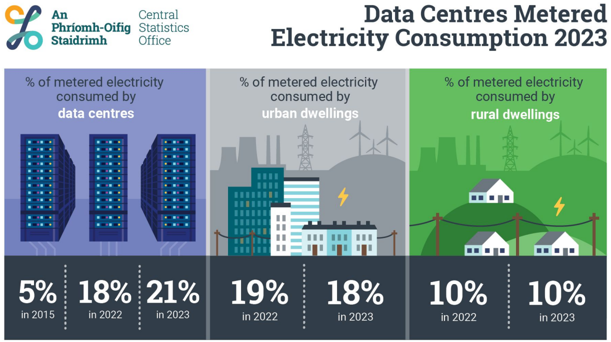
Image credits: John Deere, Bigbelly

ICT and networking share is considerable

- Precise numbers are surprisingly hard to come by
  - Hard to measure, hard to add up
- SMARTer 2030 report: ICT responsible for 2.7% of global emissions [https://unfccc.int/sites/default/files/smarter2030_executive_summary.pdf]
  - 1/3 from communications
- Other reports arrive at a range from 0.5%-1.2%
- Comparable to emissions of medium-sized country
  - e.g. UK: 0.86% [https://ourworldindata.org/co2-emissions]
- As a share this will continue to grow
  - Ireland 2023: DC energy demand surpassing that from urban housing
    [Reference / image credit: https://www.cso.ie/en/releasesandpublications/ep/p-dcmec/datacentresmeteredelectricityconsumption2023/]



Source: J. Lorincz et al, "Greener, energy-efficient and sustainable networks: state-of-the-art and new trends" Sensors, (2019): 4864.



Motivation (contd)

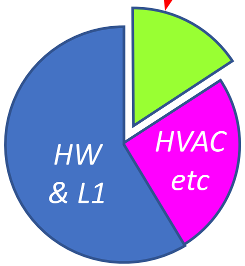
- Networks are a key solution enabler for greater sustainability…
- … but also a problem contributor themselves (even if to a lesser degree)
  - Overall contribution is noticeable, on the order of medium-sized countries
  - Higher power efficiency offset by bandwidth demand
  - Not all substitutions positive – and many inconclusive
    - Compare crypto mining
    - Traffic continues to grow (at a rate of currently 24%/year – roughly doubling every 3 years)
    - Everything everywhere at all times does have a cost
- Even efficiency gains are a double edged sword due to **Jevons paradox**
  - Greater efficiency in use of a resource (and associated falling cost) increases resource use overall
- It's not all bleak – very substantial progress is being made
  - Telefonica report: In 2023, Telefonica's network's energy consumption per PB of data was 41MWh, an 89% reduction since 2015
  - Telefonica achieved reduction of *total* carbon emissions by 51% since 2015, with goal of NetZero in 2040 (Source: Telefonica Consolidated Annual Report 2023)

How can we do better still?

Advancing Network Sustainability

- Key contributors to network sustainability today
  - General hardware advances (e.g. Moore's law – but slowing)
    - Greater feeds & speeds typically translates into less energy / bit
  - Deployment factors (e.g. Nordic locations for datacenters)
  - Antenna technology, transmission (e.g. physical layer stuff)
  - Shift towards sustainable power sources (where available)
- What about other network-specific factors (above L1)?
  - How could protocols help reduce carbon footprint?
  - What about control logic – can we build a "carbon-aware network"?
  - How much of an impact can management technology make?

Factors determined by upper networking layers



Not drawn to scale

The focus of this talk

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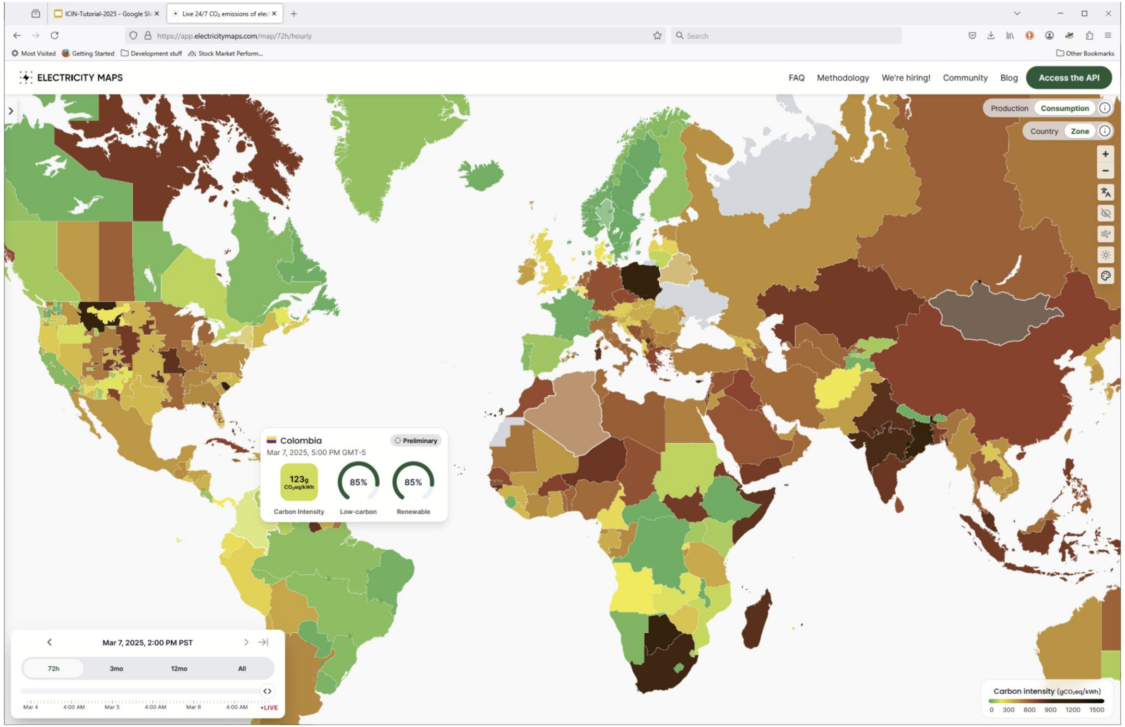
Energy-efficiency vs carbon footprint

- Environmental sustainability associated with climate neutrality
  - It's about greenhouse gas emissions, including (but not limited to) CO^2
  - Carbon equivalence is a measurement term to make greenhouse gas emissions comparable
    - 1 ton of methane has same warming effect as 84 tons of CO^2 □ 84 tons CO^2eq
  - CO^2 is emitted when burning fuels to generate electricity
  - Fossil fuels especially problematic as they release "fossilized" carbon (which had been removed for ages from the atmosphere)
- IT equipment runs on electrical energy
  - If energy mix were 100% renewables, that would not be a problem
  - Generated (at least in part) from burning of fossil fuels

Energy mix



Reference: https://app.electricitymaps.com/zone/

- Varies by
  - Geography
  - Season
  - Time-of-day
- Carbon intensity not the whole story
  - Nuclear
  - Destruction of habitats

Energy vs power vs efficiency

- Power: rate of energy consumption (e.g., kW)
  - 1W = 1J/s
  - Actually, it is not consumed but “drawn”
- Energy: amount of energy (Joule)
  - 1 Wh: one Watt of power delivered for one hour – 3600 J
- Efficiency: amount of energy per unit of value
  - Higher amount of energy used may be acceptable with commensurate amount of value delivered

Energy consumption as proxy for carbon footprint

- Carbon footprint = f(energy consumption, energy mix)
- Energy mix usually a given*, but efficiency in energy use can be influenced...

  ... and a useful indicator of carbon footprint

  ** in some cases, fluctuations in energy mix can be taken advantage of*
  (e.g. TVR, smart workload placement, pollution-aware routing → later)
- Hence, a lot of emphasis given to energy use and energy efficiency
- Often this is associated with energy consumed while equipment is operated/in use

  ... but this is not the entire picture

Energy usage beyond equipment usage

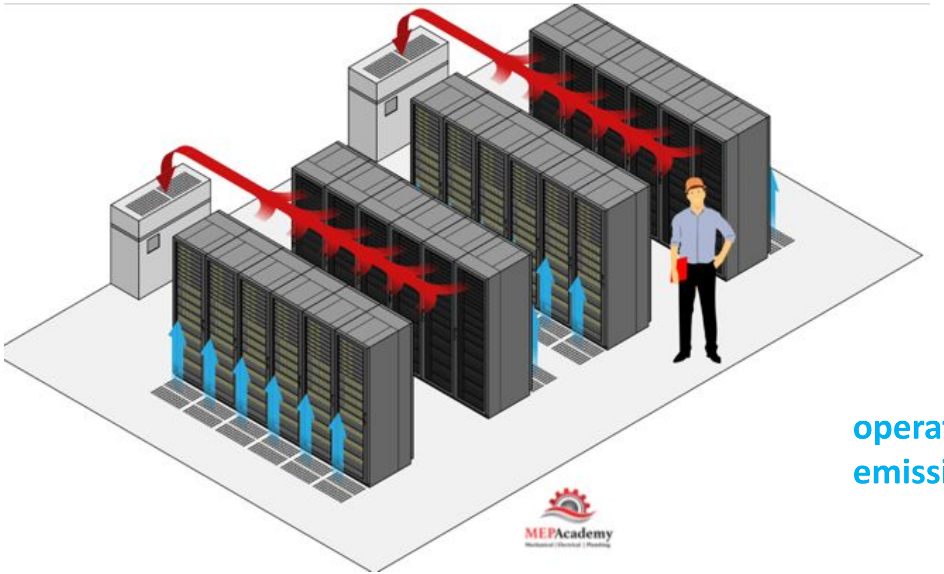
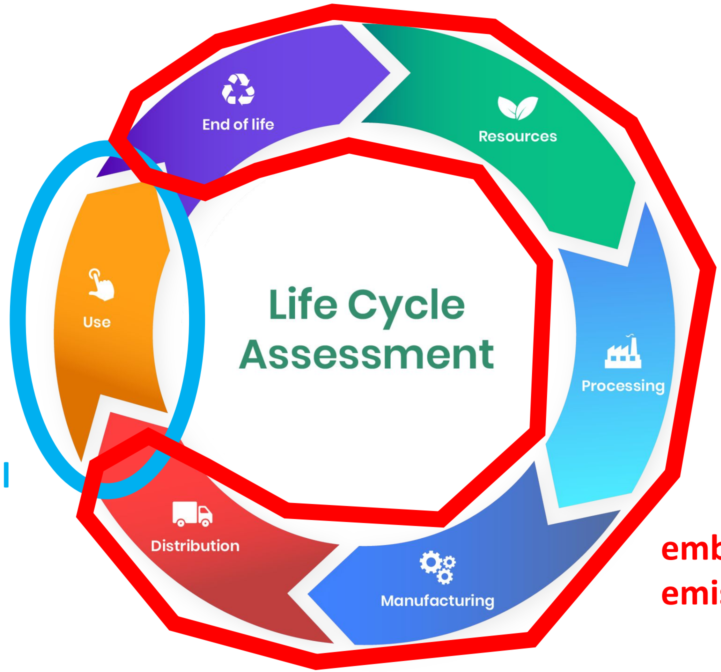


Image: https://mepacademy.com/data-center-hvac-systems/

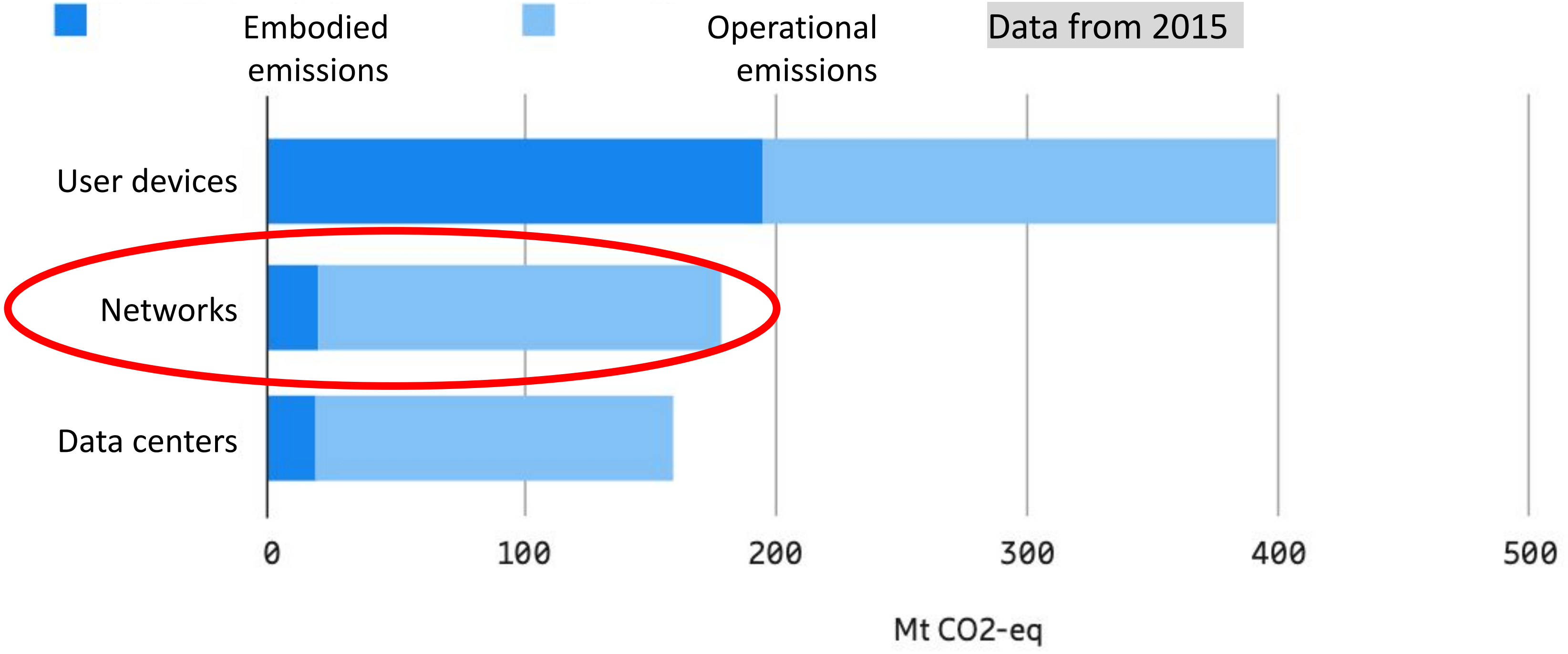


operational emissions

embodied emissions

Image: https://www.oneclicklca.com/life-cycle-assessment-explained/

Embodied vs operational emissions



https://www.ericsson.com/en/reports-and-papers/industrylab/reports/a-quick-guide-to-your-digital-carbon-footprint

Power Usage Efficiency

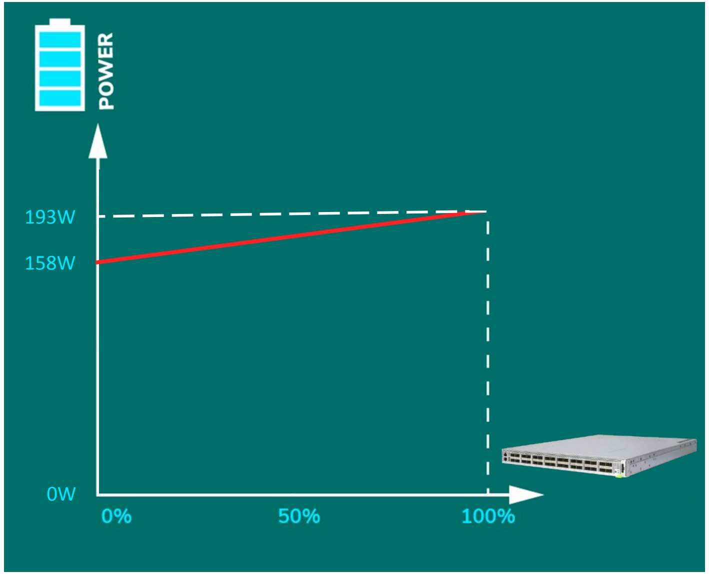
- Network sustainability is in many ways tied to energy usage
- Advancing network sustainability hence needs to ask, how can we minimize energy usage while still having the network deliver what is expected
  - Meeting traffic demands
  - Meeting service level expectations
  - Resilient, Secure, Elastic, ...
  - Cost effective (fortunately, minimizing energy usage helps with that)
- Power Usage Efficiency (PUE): How much energy is used to deliver the value that is ultimately derived from the network

Energy proportionality

- Ideally, energy usage would be proportional to the value delivered
  - Can directly attribute energy use to service demands
  - E.g. transmitting *n* TB of data results in *n* units of energy used
    - Wh/TB
- This would allow to map the problem of how to minimize energy usage to the problem of how to minimize the amount of traffic, e.g.
  - Data compression
  - Smart placement of data and functions (tradeoffs exist – eg compute, need to maintain state)
- These types of solutions have their role (later)
- Unfortunately, the reality is more complex

Idle power

- Power consumption is not linear but incremental
- Most of the power is drawn already when idle
  - CPU, Backplane
  - Transmission ports may be more proportional (eg optical lasers)
- Idle power dominates "productive" power



Credit: Romain Jacob, ETH Zurich

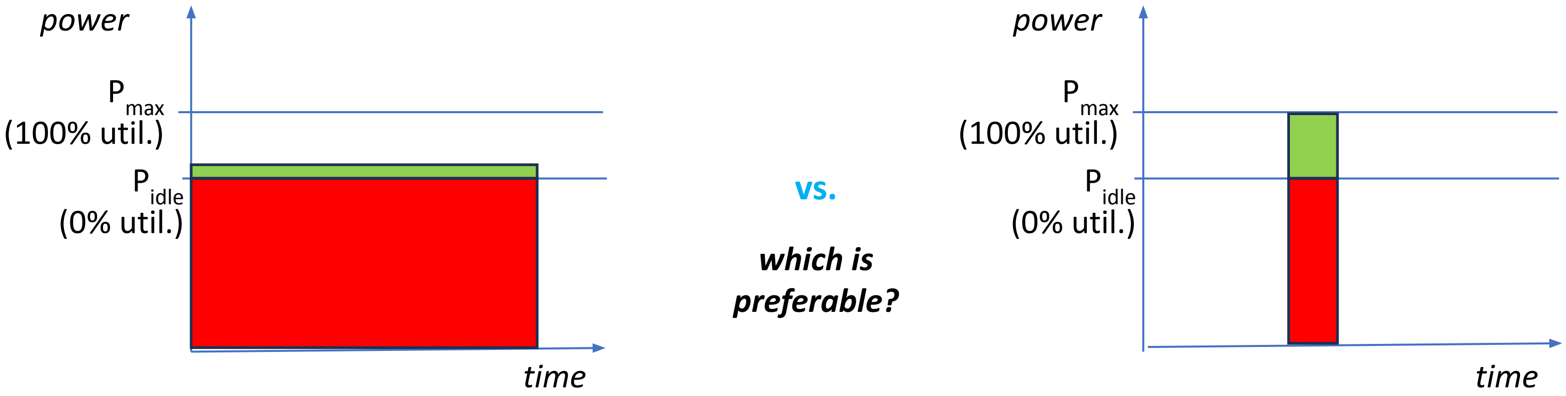
Analogy: public transportation

- Say a train or bus has capacity for *50* passengers
- Same energy usage regardless of whether the bus rides empty or at capacity
  - As long as you have capacity, you can take additional passengers at 0 incremental "cost"
- Implication
  - You do not really conserve energy by minimizing the number of passengers
    Caveat: your 51st passenger _will_ increase (double!) the amount of energy (for 2nd bus)
  - You conserve it by minimizing the number of busses
- How much energy usage do you attribute per passenger
  - 1/50 – share of available capacity that is used? (perhaps more "fair"?)
    Or 1/n – share of actually used capacity (perhaps more accurate?)

Key observations

- Reducing power that is wasted idling is key
- High resource utilization is good (as it maximizes PUE)
- From a sustainability perspective, there is much more gained in taking a resource offline than in, say, reducing resource utilization

  Of course there are tradeoffs (e.g. resilience) & embodied carbon does not go away



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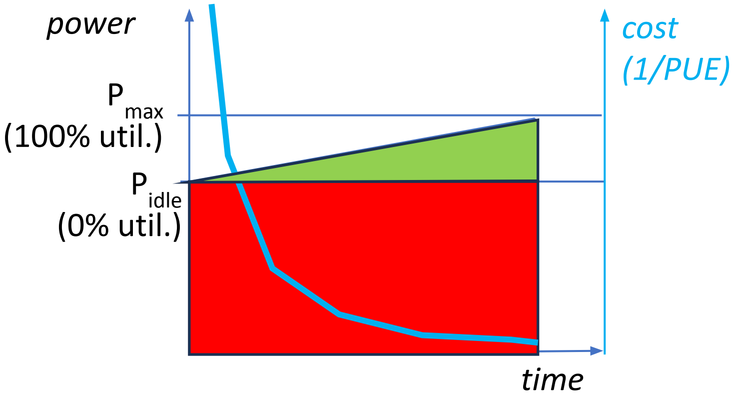
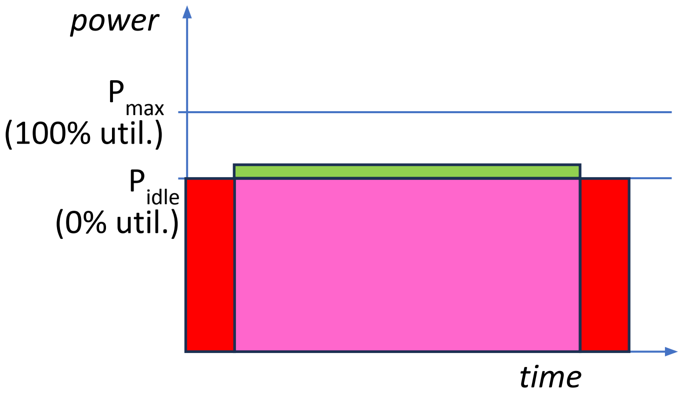
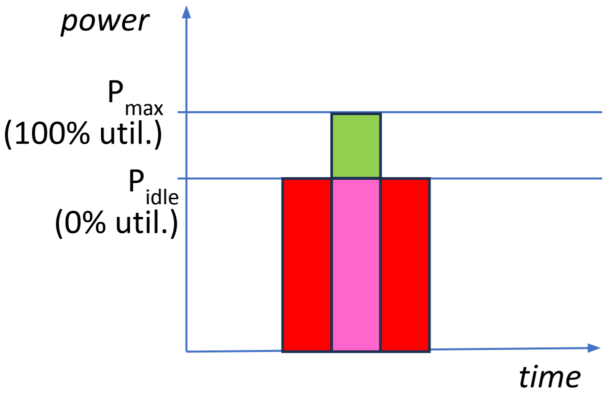


If it only were so simple

- There is overhead and complexity in turning resources on/off
  - Bootup
  - Synchronization
  - Discovery
  - Convergence and propagation of state (including across the network)
- Worse, during that time the resource is not even available



vs.



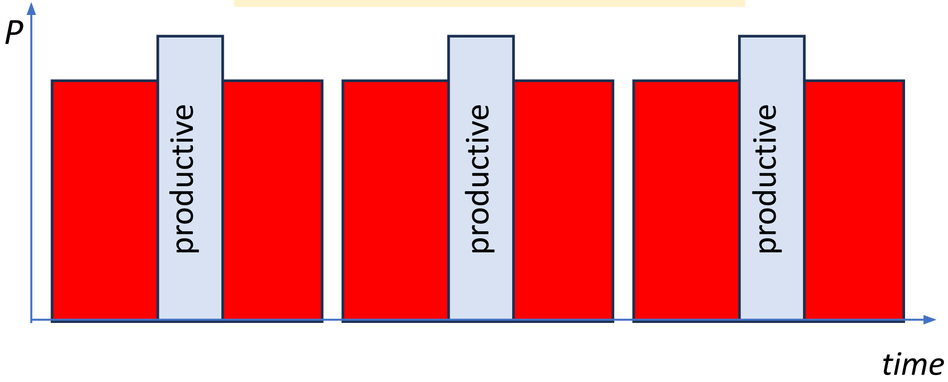
Time scales matter

- Cost/benefit implications

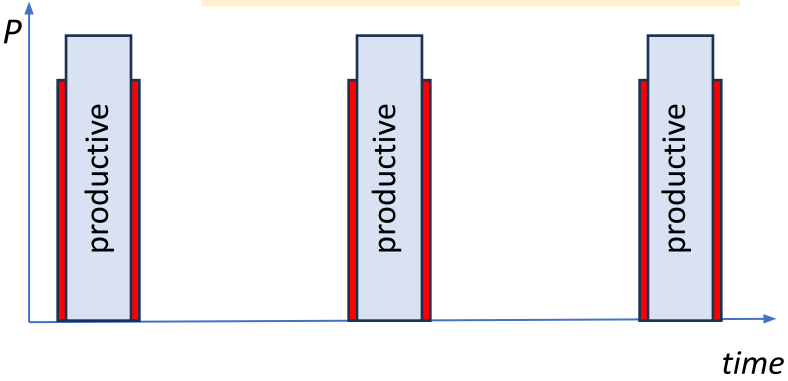
  Any complexity introduced by solutions must be justified by clear gains

- We will discuss this further later

little benefits in savings
large cost in reduced availability
requires long forecasting horizon



large benefits in savings
little cost in reduced availability
short forecasting horizon sufficient



Structuring the opportunity space

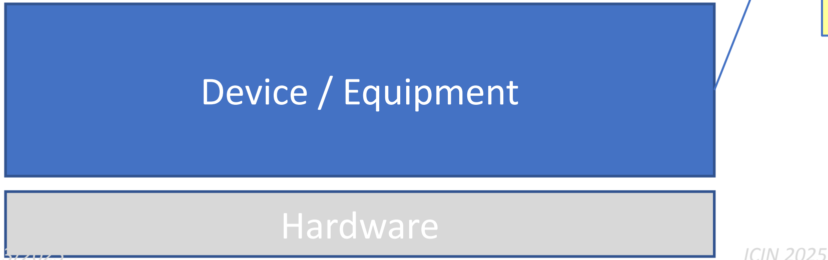
- Most obvious (& arguably largest) opportunities at the hardware layer
  - Ultimately, it is here that power is used
  - Hardware technology
  - Transmission technology
  - Power saving modes
    e.g. WOL, means for downgrading/"rightgrading" of line speeds
  - Extending equipment life cycles
    SDN plays a role here
    Less HW upgrades less raw materials less land use greater bio diversity
  - Other sustainability aspects: recycling, warm computing, ...
- Very important, but we are not hardware engineers
  - A bit fatalistic to wait for others to save us
  - Also, Moore's law is coming to an end – it alone will not save us
- What about upper networking layers? Management technology?

Hardware

Sustainable networking opportunity space

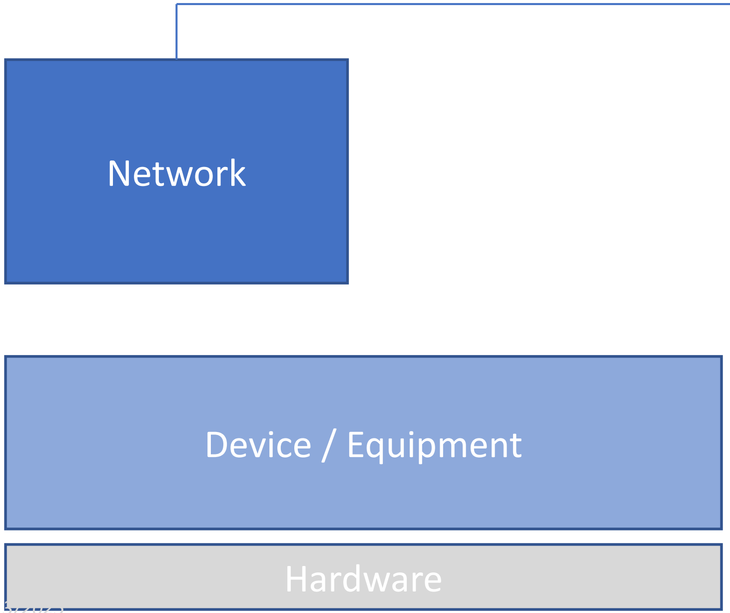
Providing of visibility into power usage as a foundational opportunity!

- **Assess usage, validate effectiveness**
- **Enable control loops** for energy/sustainability optimization schemes
- Requires **Instrumentation for energy metrics**
- Selected challenges+opportunities
  - Definition and instrumentation of management data models
  - Certification and compliance assessment methods
  - Virtualized energy and pollution metrics
  - Accounting for energy mix, energy sources
  - Fair carbon footprint attribution to flows & paths



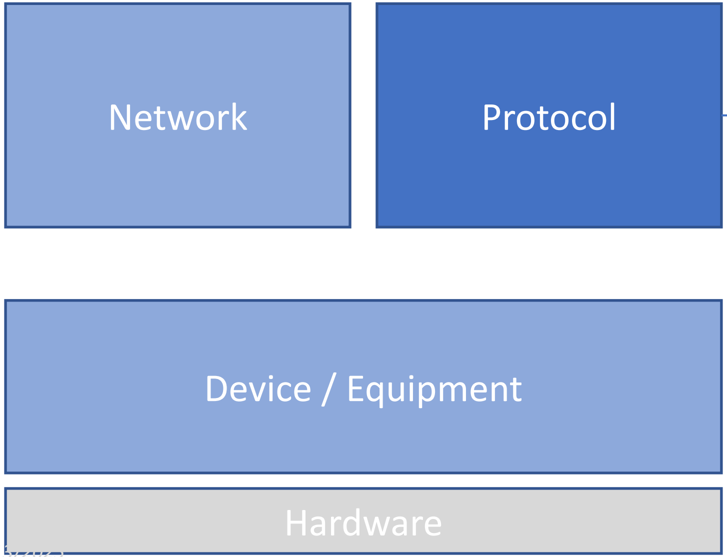
Challenges and Opportunities in Management for Green Networking

One device does not make a network
What about the bigger picture?



- **Network optimization**
  - Energy/carbon/pollution-aware routing & path configuration
  - Deployment / placement of VNFs
  - Optimize carbon footprint while maintaining other goals
  - AI and ML methods
  - Applicability of game-theoretic approaches
  - “Control knobs” for intent-based tradeoffs
- **Energy-related control protocol extensions**
  - Energy as a cost factor – in IGP, SDN controllers
  - Assess carbon intensity of paths,
    optimize networks to minimize overall footprint
- **Carbon-aware traffic steering, pollution-aware routing**
  to steer traffic along greener paths (might vary overtime)
- **Green abstractions**
  taking into account memory, processing, transmission
  can often trade off one versus another

Challenges and Opportunities in Management for Green Networking



How can communication protocols contribute?

- **Protocol enablers for network energy saving mechanisms**
  - Blur mgmt. and control – taking resources on/offline on short time scales
    requires mechanisms for fast discovery, fast state reconvergence
  - Role of autonomics? of IBN?
- **Protocol optimization**
  - Traffic adaptation (e.g. bursty vs smoothened transmission to maximize efficiency;
    control knobs for carbon-aware traffic pacing)
  - Data volume reduction
    (e.g. codings, efficient retransmissions)
- **Instrumentation** (again)
  e.g. energy telemetry at flow & path level

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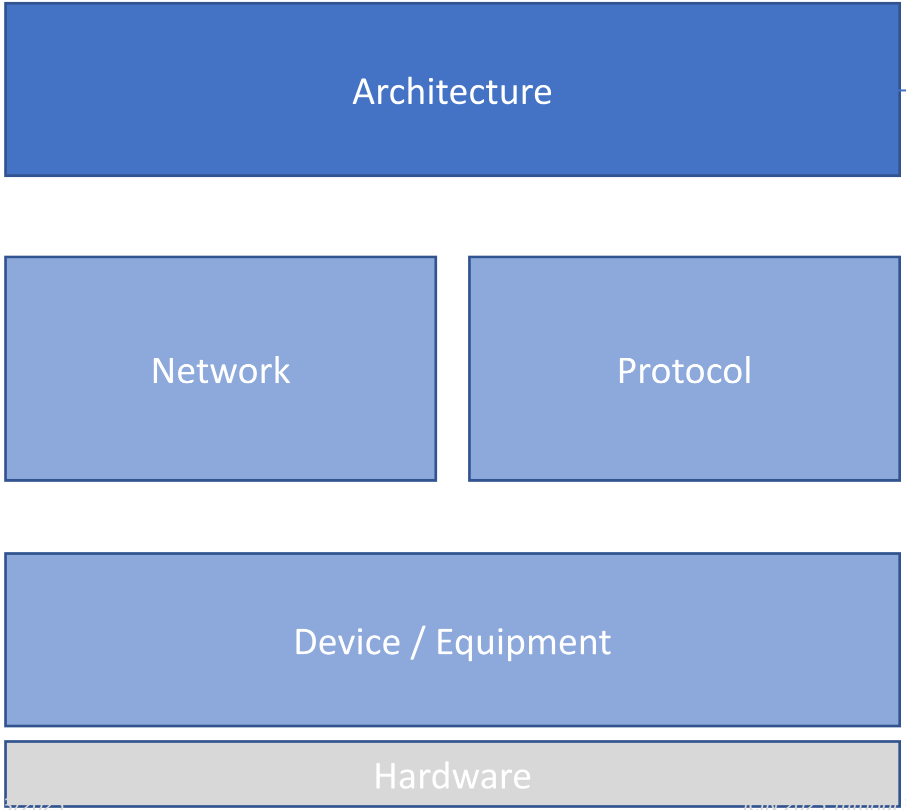
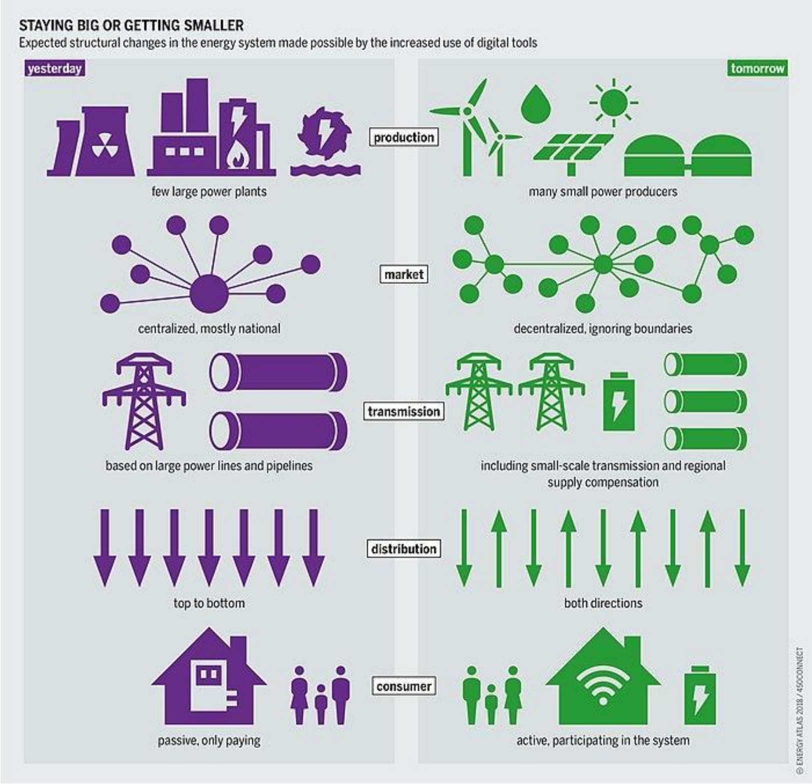


- **Facilitate organization of networking applications** to minimize energy consumption
- **Holistic carbon impact assessment methods** for alternative approaches
- **Examples**: retrieval of content, computation placement (compare CDN/ICN/COIN but from energy perspective)

Not considered here:
Networking for greater energy efficiency

SMART GRID



SYNCRO PHASOR NETWORKS

- Power generators need to feed power with correct phase into grid (50/60Hz)
  - Misfunction can cause severe blackouts
- Requires continuous adjustment using PMU (Phaser Measurement Units) over large geographically distributed area
- NASPI.org (North American Syncro Phasor Initiative): Transition to TCP/IP networking
  - more accurate clock and PMU distribution
  - lower latency
  - higher velocity (more PMUs per second)

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On the road towards Net Zero…

What are the mile markers?

How do we assess the progress?

How do we even account for consumption?

We organized a Dagstuhl Seminar on this topic and had to come up with a way to organize the discussion

- We picked
  1) applications, systems, and stakeholders;
  2) network technologies;
  3) lifecycle and control loops.

How do we progress towards Net Zero in these dimensions

A Taxonomy to Reason about Internet Energy Consumption (presented by R. Jacob (ETH Z) at that Dagstuhl seminar)

Some important dimensions to be aware of include:

- the particular portions of the overall network
  - which part of the network can, or needs to, be optimized, the core network, the access network, the metro area network, the datacenter.
- the network layer: from L1 to L7
- the class of protocols, inter-domain vs intra-domain

A Taxonomy to Reason about Internet Energy Consumption (inspired by R. Jacob (ETH Z) at that Dagstuhl seminar)

Some important dimensions to be aware of include:

- the target users: hyperscalers, ISPs, entreprises, or end-users
- the agent of change: technological, behavioral or regulatory
- the progress strategy: better proportionality, raw improvement, waste reduction, resource, use optimization, etc.
- the metrics
  - energy usage or carbon emissions,
  - in a relative or absolute measurement
  - primary, secondary, final, and useful energy
  - scope 1, scope 2, scope 3 energy

A Taxonomy to Reason about Internet Energy Consumption (inspired by R. Jacob (ETH Z) at that Dagstuhl seminar)

Some important dimensions to be aware of include:

- the life cycle phase: operational or including manufacturing and recycling as well
  - (that is, taking into account the embodied carbon)
- the time scale
  - per packet, per flow timescale to network planning and deployment timescale
  - bursts, daily, weekly, seasonal variations
- primary vs secondary impacts
- the class of reasoning: attributional or consequential

Attributional vs Consequential

- Attributional represents the emissions that can be attributed to one actor in particular, for instance by dividing the total amount of emissions by the number of participants.
- Consequential represent the activities that can be associated as a consequence for an activity.
- Consequential reasoning weighs the pros and cons of decisions often in terms of total carbon emissions rather than focusing on how to allocate the responsibility to each party.

- A bus has capacity for *50* passengers and uses roughly the same energy usage regardless of whether the bus rides empty or at capacity
  - As long as you have capacity, you can take additional passengers at 0 incremental "cost"
- Attributional: each passenger is attributed #bus/#passenger. If only one passenger at a given time, that passenger may be ascribe a huge energy cost.
- Consequential: how much more energy is consumed by adding one passenger.

Primary vs Secondary Impact

Challenge of quantifying the energy consumption of the Internet is that it has indirect effects on resource use in the overall economy.

- structural changes (where new institutional arrangements and technological capabilities become possible because of the Internet)
- substitution effects (where the new technologies substitute for established energy uses).

Substitution effect is the use of the network to replace an activity that would otherwise consume energy - Alex is doing this tutorial from California, saving on the emissions of a plane trip

Structural changes involve a decline in brick-and-mortar retail stores in favor of warehousing of retail goods for direct home delivery, or in movie theaters in favor of video streaming/Netflix.

Scope for a Net Zero Internet

We need a definition of the proper scope:

Here: Network “Host interface” to “Host interface” (actual network transport)

Does it include the “Cloud” –

- Administratively, not the purview of the network operator
    - somebody else’s computers / data-center – compute & storage
- Except it is: integration of the application within the network
    - CDN for instance, but other as well
- Also, there are benefits from taking into account the application
    - Load balancing, but follow-the-sun policies, etc

It is usually estimated that DC use roughly as much energy as the network itself

NOT: End / User devices

- Still, most UE has become very power efficient (due to other incentive, like battery life…)

Scale & Speed

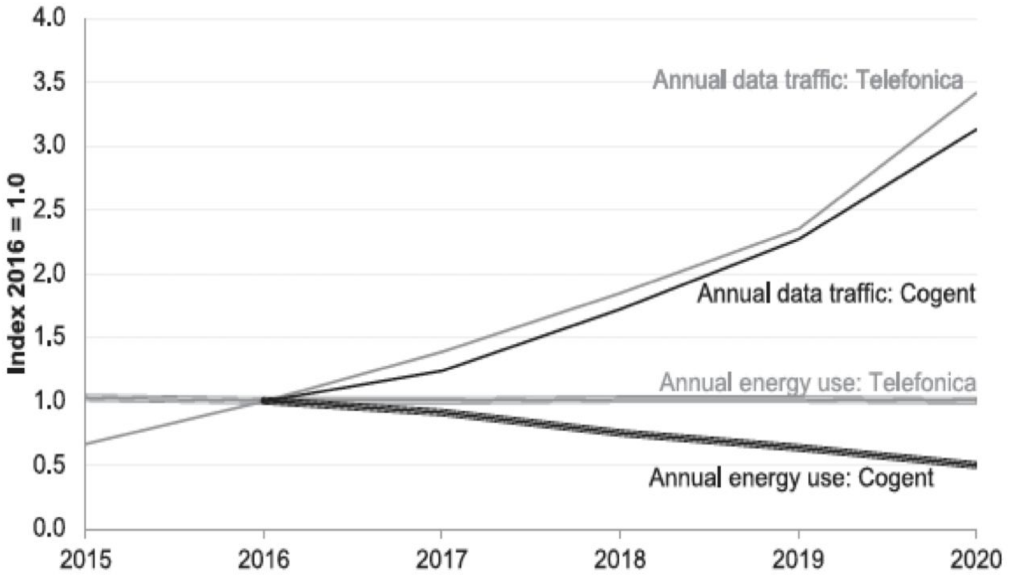

Figure 1. Annual energy use and network data flows for two large network providers, expressed as an index relative to 2016 = 1.0

The faster networks become...

The lower the energy consumption/bit

300 bps modem ... 1 Tbps links

Over time: Same type of packet processing device roughly maintains same degree of power consumption. Many device power consumption has gone down (PC at home!).

Distance matters:

Electrical / Optical transmission over longer distance dwarfs other power consumption in wide-area networks (packet processing)

Summary #2 How the network did/does save energy

Internet architecture core principles
to support fast growth with lower cost/energy

- Converged networks
  - Datagram multiplexing, IntServ, DiffServ, Re-use of caching
- Federated Networks
  - No central control
- End-to-end principle
  - Addressing, Transport
- End-to-end encryption

Internet Growth + Moore‘s law
allowed for never before seen reduction of energy/bit

- 300bps ... 1Gbps data connection at roughly same energy use: 3 Million times faster

Digitization

- Networked solutions are most often more energy efficient than non-networked Physical transport / production of physical products / people

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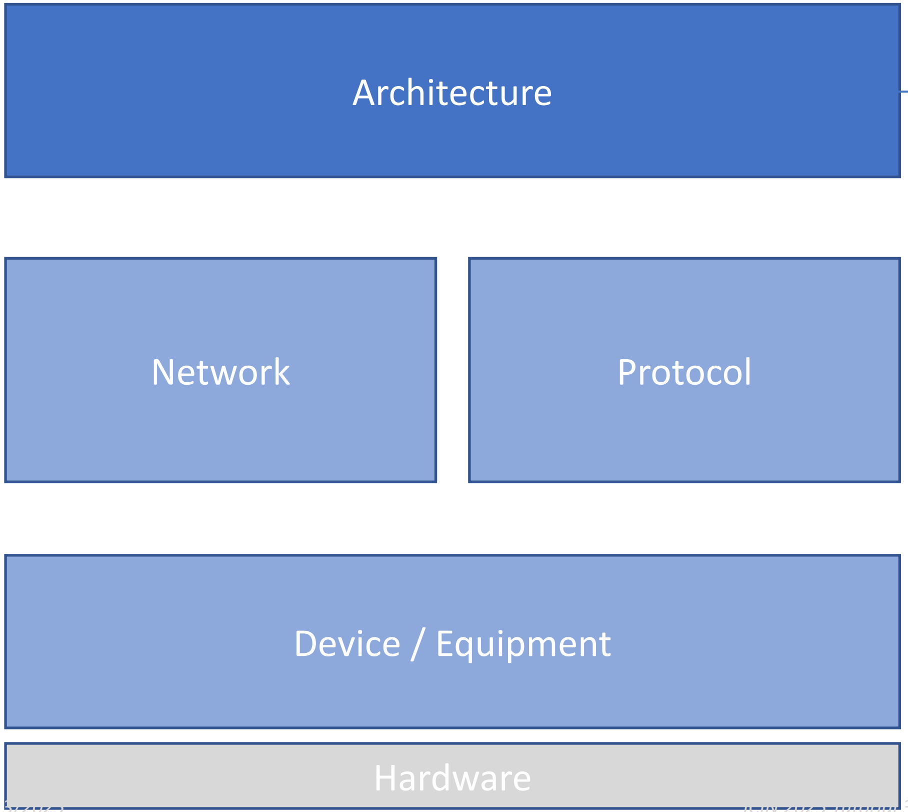
Challenges and Opportunities in Management for Green Networking



- **Facilitate organization of networking applications** to minimize energy consumption
- **Holistic carbon impact assessment methods** for alternative approaches
- **Examples**: retrieval of content, computation placement (compare CDN/ICN/COIN but from energy perspective)

Deployment Aspects

Basic (

Energy

In part

- the
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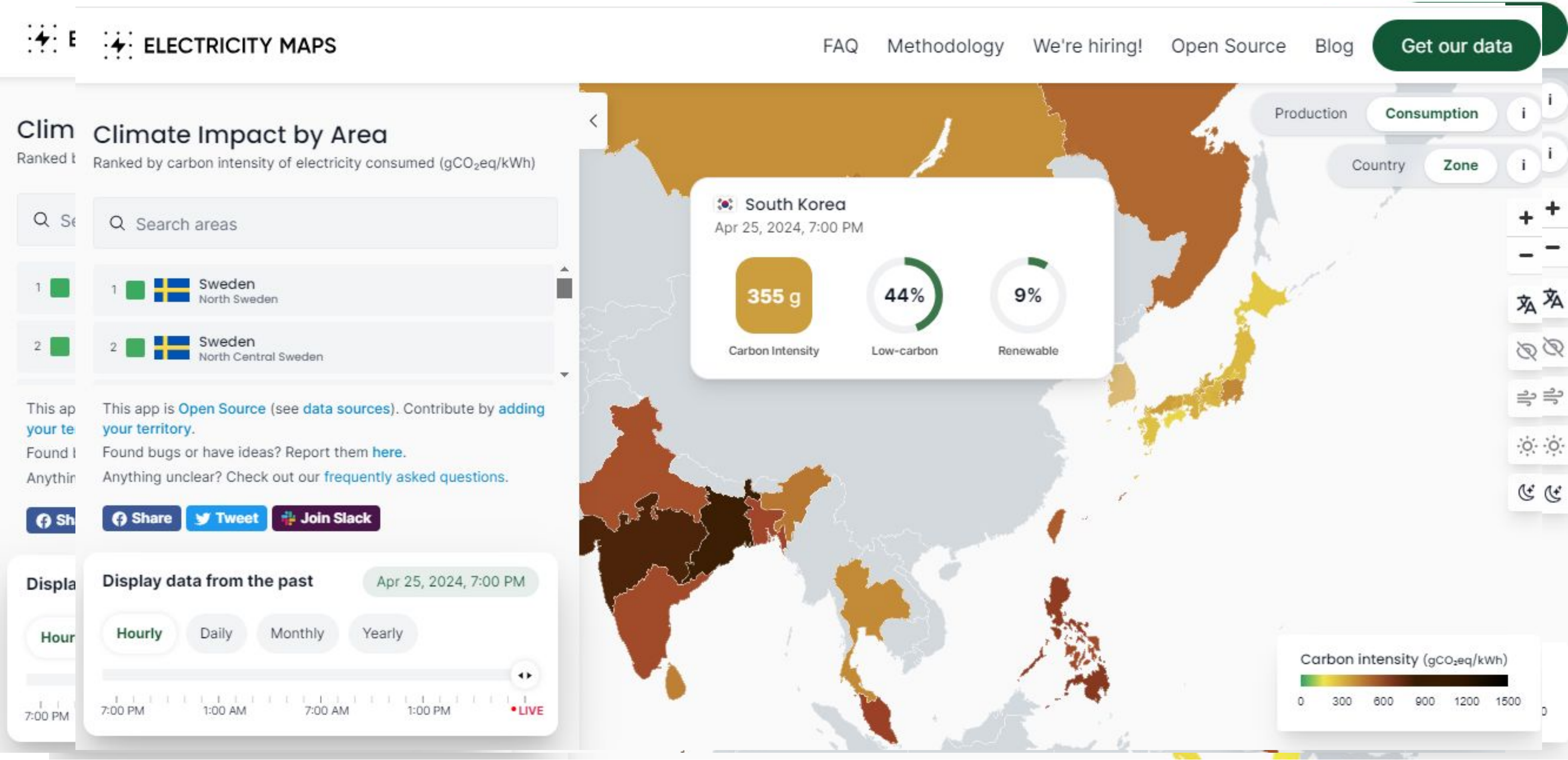
  -
  -



Power source

Spacial/geographic dimension, but al

Energy may be temporarily efficient

- seasonal drivers to renewable (sn hydroelectric)
- diurnal patterns for solar/wind


electrek

Exclusives | Autos | Alt. Transport | Autonomy | Energy | Tesla Shop | Store

GREEN ENERGY | ELECTREK GREEN ENERGY BRIEF | EGEB | SOLAR POWER | WIND POWER

California exceeds 100% of energy demand with renewables over a record 30 days

Michelle Lewis | Apr 15 2024 - 10:29 am PT | 206 Comments

"Solar on Palm Desert Walmart" by Walmart Corporate is licensed under CC BY 2.0

In a major clean energy benchmark, wind, solar, and hydro exceeded 100% of demand on California's main grid for 30 of the past 38 days.

Stanford University professor of civil and environmental engineering Mark Z. Jacobson has been tracking California's renewables performance, and he shares his findings on Twitter (X) when the state breaks records. Yesterday he posted:

Co-location of energy generation and consumption

2-4% lost in transmission - 8-15% lost in the whole distribution process

Pollution from Musk's unpermitted xAI power project hits hardest in Black communities

Elon Musk's xAI has installed far more gas turbines without federal permits at its Colossus 2 data center project in Tennessee than it has publicly acknowledged, and the pollution is hitting predominantly Black neighborhoods the hardest, a Reuters analysis found.

By **Disha Raychaudhuri** and **Valerie Volcovici**

July 14, 2026 3:00 AM PDT · Updated July 14, 2026

Aa

Utah

This article is more than **2 months old**

'Irresponsible': backlash as Utah approves datacenter twice the size of Manhattan

Facility would require more power than entire state uses and suck up vast amount of water in drought-stricken area

Energy Efficiency

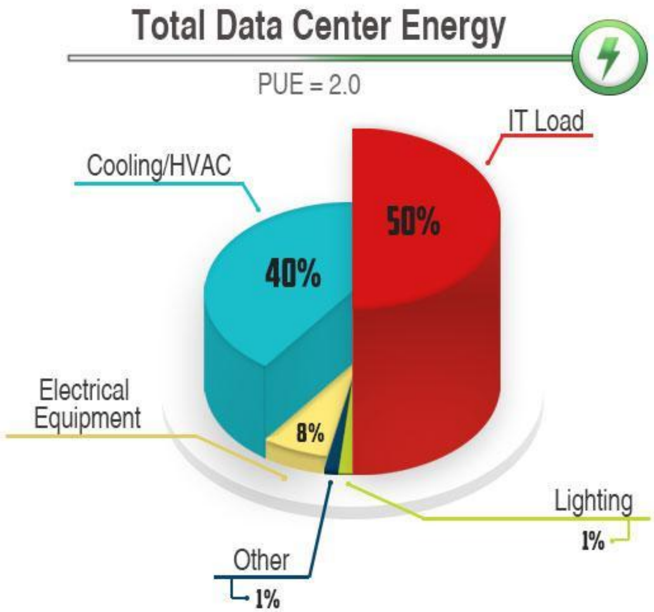
In the data center, energy consumption is a major OpEx.

Energy goes to: computing, but also cooling, lighting, etc.

Key performance indicator:

Power Usage Effectiveness - PUE

Namely, the ratio of *total power* into the data center divided by the *power that goes to the servers/IT equipment*



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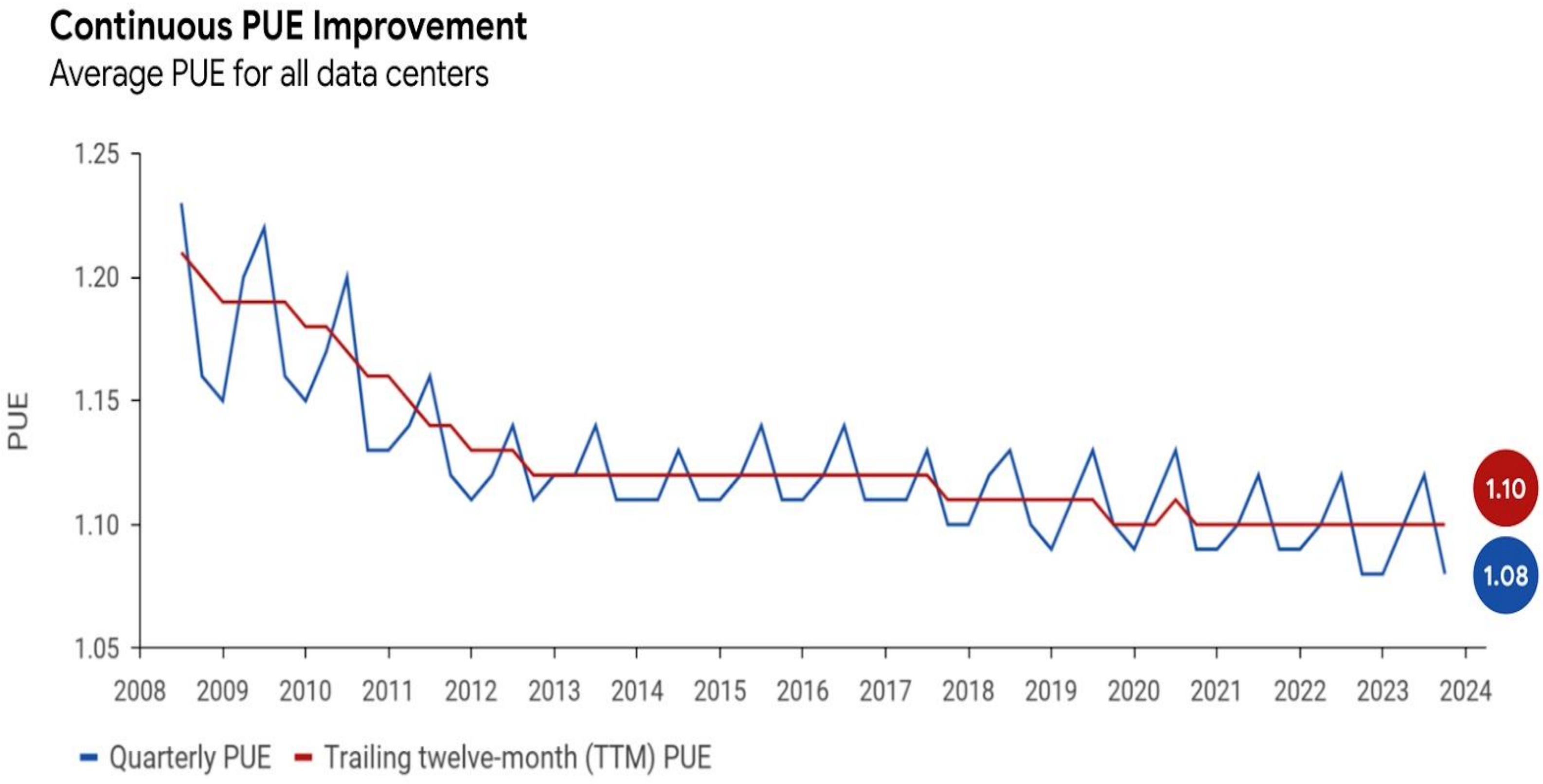


Efficient Cooling of the DC Infrastructure

Techniques to cool DC:

- Air cooling
- Free cooling
- Hot/cold aisle containment
- Direct evaporative cooling
- Liquid immersion cooling
- Direct-to-chip liquid cooling (- lowest PUE)

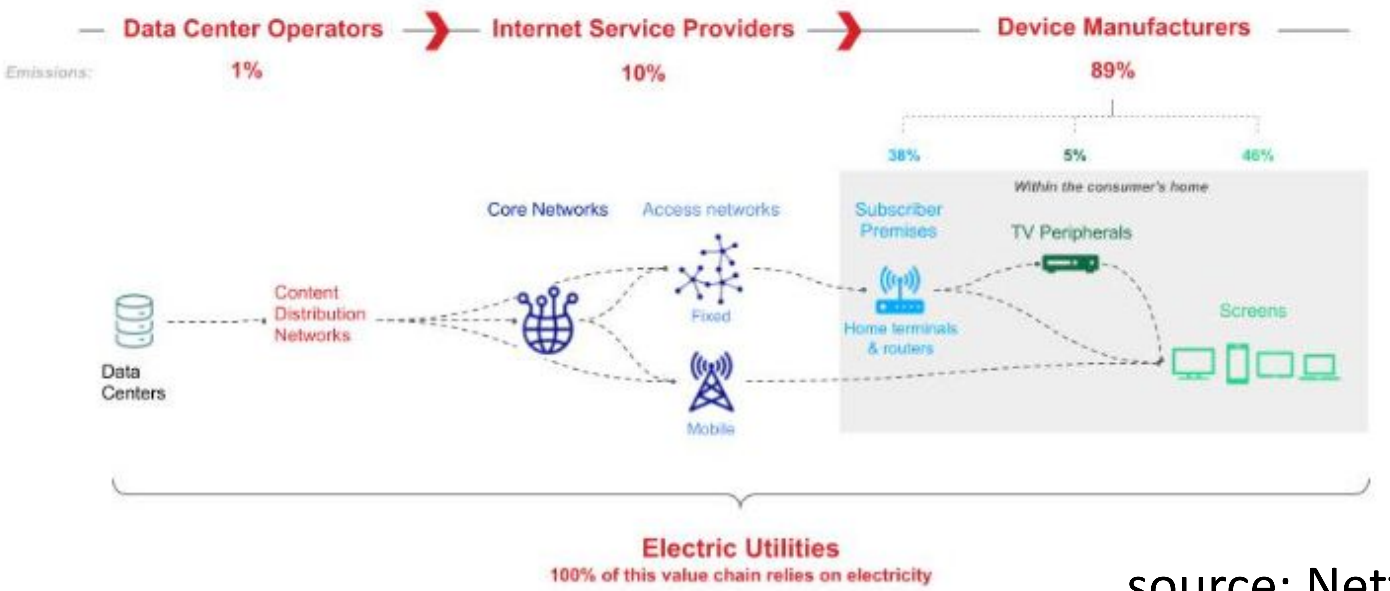
Can the network operate efficiently?

Key questions:

- how far do the similarities extend?
- what about the part of the infrastructure that can't be consolidated in one place?

Architecture Level

CDN, a case study



source: Netflix

Greening of Streaming

iea.org/commentaries/the-carbon-footprint-of-streaming-video-fact-checking-the-hea...

New Chrome available

Another claim estimates that watching a YouTube video uses over 1600W of electricity, equivalent to the consumption of 15 big screen TVs

comparable in scope to the Shift Project analysis – accounted for only 0.36kgCO2e per hour.

However, because the energy efficiency of data centres and networks is improving rapidly – doubling every couple of years – energy use and emissions from streaming today should be substantially lower.

Looking at electricity consumption alone, the original Shift Project figures imply that one hour of Netflix consumes 6.1 kilowatt hours (kWh) of electricity. This is enough to drive a Tesla Model S more than 30km, power an LED lightbulb constantly for a month, or boil a kettle once a day for nearly three months. The corrected figures imply that one hour of Netflix consumes 0.8 kWh.

With 167 million Netflix subscribers watching an average of two hours per day, the corrected Shift Project figures imply that Netflix streaming consumes around 94 terawatt hours (TWh) per year, which is 200 times larger than figures reported by Netflix (0.45TWh in 2019).

Another recent claim on Channel 4 Dispatches estir... that 7bn YouTube views of a 2017 hit song – "Despacito", by Luis Fonsi and Daddy Yankee, featuring Justin Beiber –

...tprint of Video Streaming

...Keller*, Marco Dinuzzi*, Zhejiayu Ma†

...e d'Azur, France
...cast, France

...r 2, 2023

parameters of the models, e.g. the energy efficiency per GB of the delivery network; (2) We analyse and compare the models under study in a number of scenarios; (3) We question some of the modeling assumptions made using a real deployment of a streaming server in a controlled environment with up to 2000 clients; (4) We propose a technique to reconcile the models and obtain a CO_2 estimate in between 60 and 140 grams when considering the average worldwide electricity efficiency.

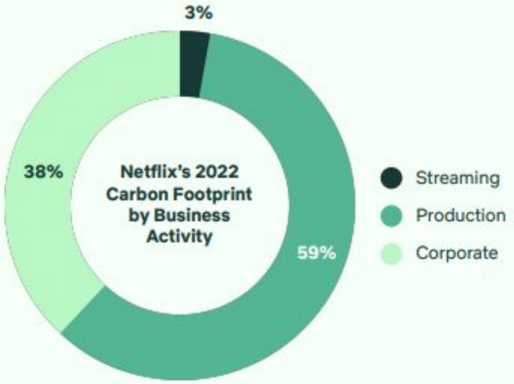
2 Models Analysis

Borrowing the life cycle assessment (LCA) vocabulary,

Netflix ESG

CARBON FOOTPRINT COMPONENTS

Over half of our emissions (all scopes) are related to the production and licensing of films, series and games ("production"). The second largest source of emissions is in our corporate operations ("corporate"), followed by our data center providers ("streaming").



Netflix ESG Report 2022

Emissions Reductions

TRACKING PROGRESS AGAINST OUR 2030 SCIENCE-BASED TARGET

We track progress against our Scope 1 and 2 emissions target using target-based emissions figures noted in the carbon footprint table above. Target-based emissions only account for emissions reductions resulting from specific decarbonization actions and those related to direct renewable energy supply (e.g., onsite generation, utility and landlord supply, power purchase agreements or direct investments), but not for emissions reductions resulting from our annual purchase of renewable energy certificates (or environmental attribute certificates).

- 2022 Scope 1 and 2 emissions are **12% lower**[15] year-over-year, though they remain slightly higher than our 2019 baseline year due to growth in the business.
- The combined impact of our emissions reductions initiatives across our four priority levers in 2022 resulted in a **30% lower** Scope 1 and 2 footprint value than would have otherwise been reported.
- The vast majority of our emission reductions still come from renewable energy and renewable fuels. Transitioning from diesel to electric will take time to scale to a level that will have a measurable impact on emissions reductions.

[15] In addition to emissions reductions from our decarbonization efforts, external factors also influence the calculated emissions total, including data improvements (e.g., improved data quality, updated emissions factors) and changes in core business activities from year to year (e.g., number of self-managed vs. partner-managed productions which can shift the emissions representation between Scopes).

Netflix ESG

" a goal of 100% renewable by 2025…"

DATA CENTERS AND CONTENT DISTRIBUTION NETWORK (CDN)

Carbon Trust's white paper on the Carbon Impacts of Video Streaming determined that the use-phase emissions associated with data center and CDN operations are small (<1%) compared to the rest of the video streaming value chain.

Netflix partners with Amazon Web Services (AWS) for our data storage and cloud computation needs. AWS has a goal of using 100% renewable energy by 2025. In 2022, AWS reported via their customer carbon footprint tool that our carbon footprint was reduced by approximately **98%** compared to last year. This is due to AWS's renewable energy usage and purchasing, and energy efficiency initiatives.

This trend is consistent with research findings, which show that the energy intensity of global data centers has decreased by 20% annually since 2010. This is a notable improvement compared with recent annual efficiency gains in other major demand sectors (e.g., aviation and industry), which are an order of magnitude lower[20].

When it comes to distributing our content to our members, Netflix invests heavily in making this process as efficient as possible with our Open Connect program. We make 18,000 servers available for free to Internet Service Providers who operate them in their data centers across 6,000 locations in over 175 countries[21]. So when our members press play, instead of the film or series being streamed from halfway around the world, it's streamed from around the corner — increasing efficiency for operators while also ensuring a high-quality, no-lag experience for consumers. On top of that, we've developed encoding technology to reduce file sizes and optimize bandwidth use while maintaining high video quality for consumers. Over the past five years, we have been able to cut our bit rates by roughly **50%**. This is in addition to the significant efficiency gains the telecom industry has achieved within their own networks[21].

We are encouraged by the strong energy efficiency and renewable energy usage trends of both AWS and our own Open Connect program, and are committed to continually decarbonizing these processes over time. Refer to our recent blog post Energy Efficiency in Streaming: Innovation Reaping Rewards to learn more.

Netflix ESG Report 2022

[20] E. Masanet, A. Shehabi, N. Lei, S. Smith, J. Koomey, "Recalibrating global data center energy-use estimates," Science Magazine, 2020
[21] Co-CEO Greg Peters' Keynote Address to the 2023 Mobile World Congress

Architecture Level

From Netflix data:

- CDN is an energy efficient way to deliver the service
- No baseline comparison to “without CDN” scenario
    - Cost on the network would be prohibitive
        - 15% of Internet traffic as it is
    - Who remembers the throttling of Netflix?
- Design of CDN architecture most likely a net energy reduction
- Can it be generalized?

Softwarization/Containerization

Function placement:

- NVF moves functions into containers
- SDN softwarize the control plane

Shift from appliance to software

- increase data center energy use
- reduce client use

But what about the edge?

- is there a scaling effect if servers at edge?

Architecture Level

Key methods to reduce consumption:

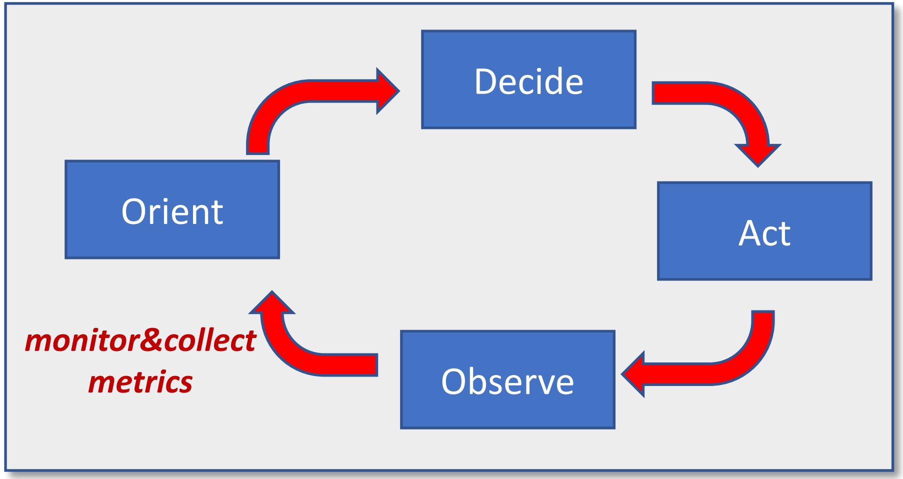
- consolidate usage on a platform with high utilization
  - potentially turn off other resources
  - no down time when the idle power consumption is drawn: always churning
- optimize that platform to deliver the service efficiently
  - dedicated hardware acceleration for this platform/service
  - economically feasible to get a more efficient platform since high utilization
- CDN -> reduce network consumption by placing function at the edge and reduce overall network utilization

At the network architecture level, can we use this line of thinking beyond content distribution?

Opportunities for greening the network

- E.g. Management, Deployment, Network Optimization
  - Provisioning, dimensioning, managing oversubscription, …
  - Energy usage is a great parameter to optimize, just like utilization, cost, etc
  - VM+VNF placement, planning of routes/segments/paths
  - Moderating tradeoffs: carbon intensity versus service levels, utilization versus service levels, caching versus access, etc
- E.g. Control
  - Selecting from greener path alternatives, carbon intensity as a cost
- E.g. Network architecture (e.g. where to cache from carbon standpoint)
- **It all starts with visibility**
  - "If you can't measure it, you can't manage it" (Peter Drucker)
  - … or assess effectiveness of solutions, or devise solutions relying on control loops…
- And **visibility starts with the right metrics** – foundation for everything else
  - Actionable and where IETF may be able to make an impact

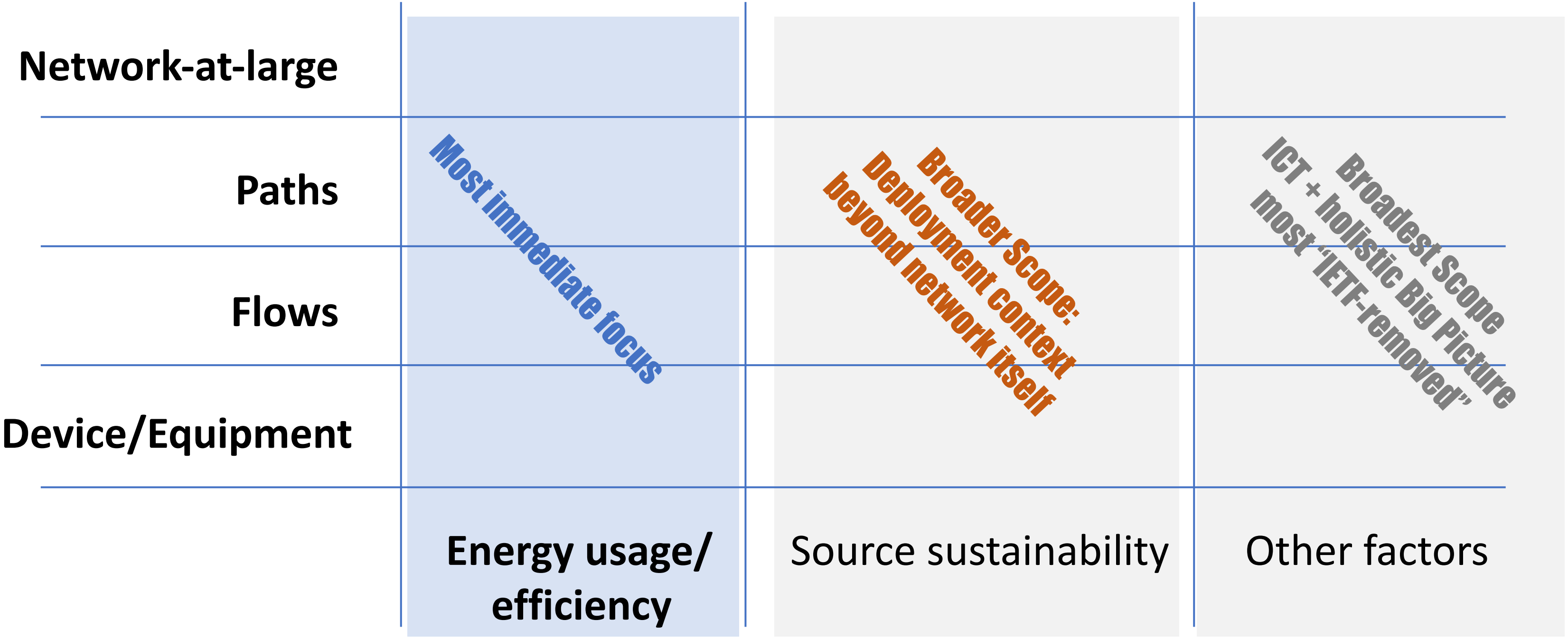
Metrics



- What metrics are needed
  - To assess effectiveness of a solution?
  - To compare alternative designs?
  - To optimize network deployments?
  - To make better control decisions?
  - To make better management decisions?
- What should metrics cover
  - Energy usage efficiency (scope: network itself)
  - Energy sources (scope: network++)
  - Other aspects: HVAC, manufacturing lifecycle, …
- How can a holistic picture be provided
  - Account for the whole picture, not just a part
  - E.g. device energy usage vs device lifecycle vs deployment environment energy usage
  - Tradeoffs – e.g. edge vs core, storage/memory vs bandwidth

For the following discussion, see also https://datatracker.ietf.org/doc/draft-cx-green-green-metrics/
Starter set of metrics, augmented with with use cases / applications / motivation

Structuring the metrics space



Disclaimers for what follows:

Not a comprehensive list of metrics, some may be speculative,
some may be less straightforward to instrument than others, usefulness may hinge on particular use cases

Conclusion

- Several layers to impact the management of energy/emission consumption within the network
    - Device / Protocol/ Network /Architetcure
    - Other dimensions possible
    - Need to Integrate the Interfaces to the Electric Grid
- Visibility into the network requires metrics
    - Again, metrics should debate whether or not to include some info about the power supply, including potential grid requirements