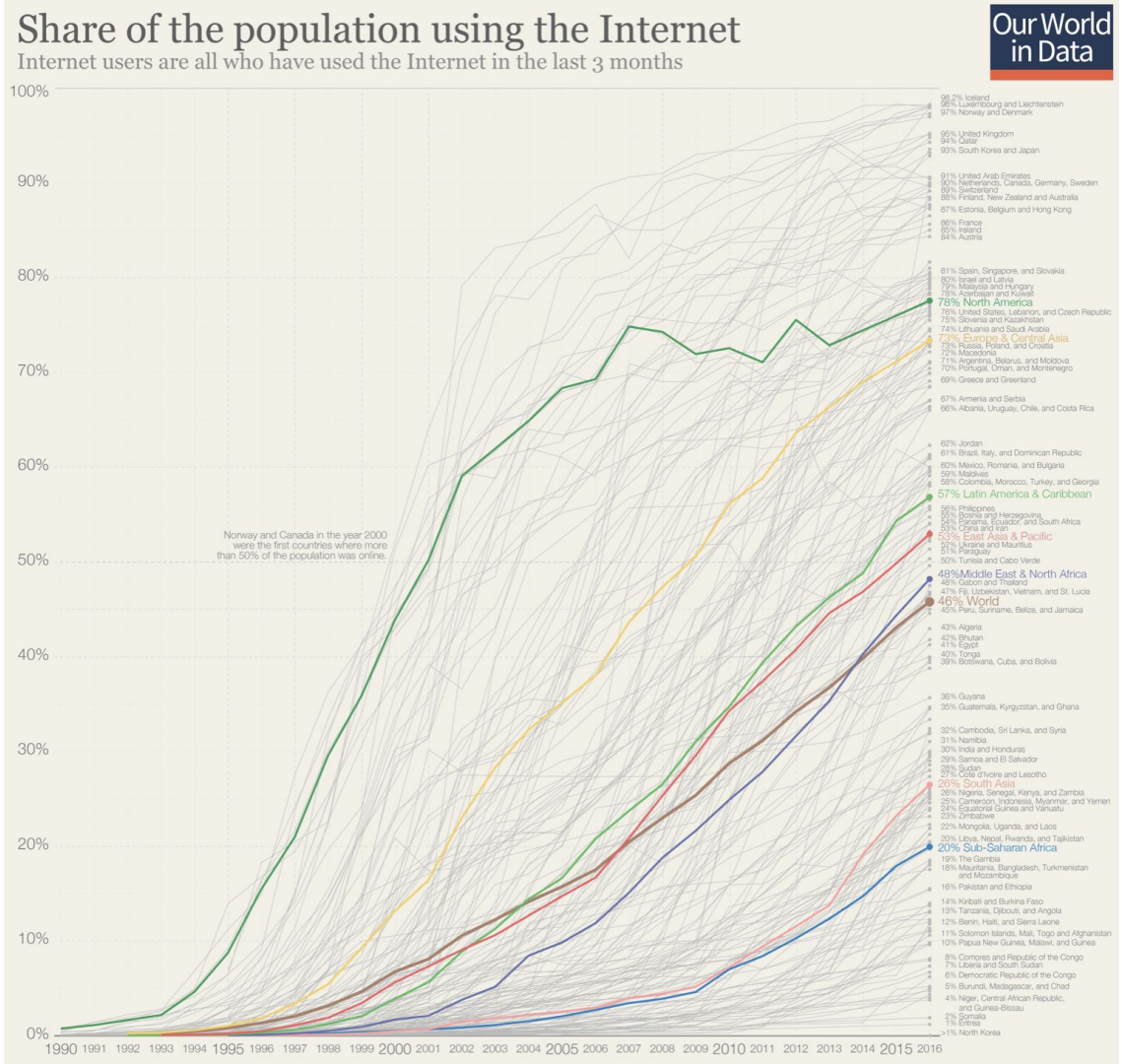
Environmental costs of computing

Ian Davenport

Computing

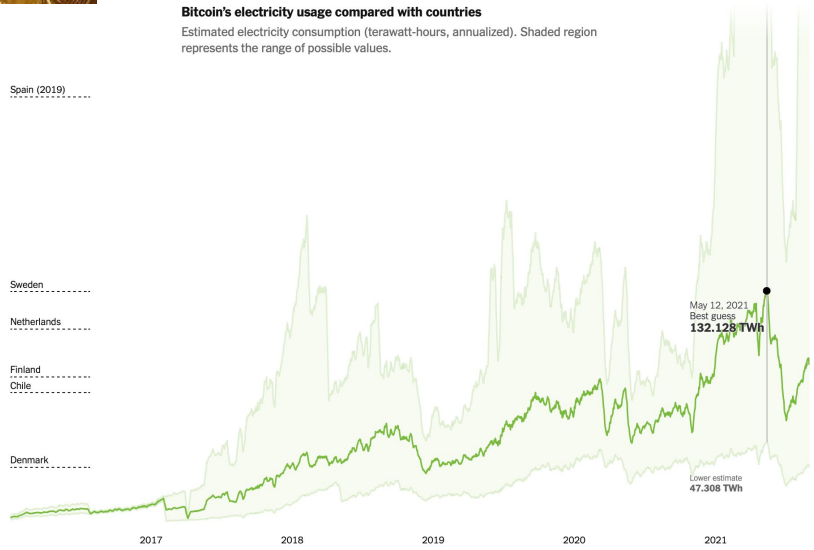
- Feels ubiquitous
- Uses steadily growing
- How much energy?

[Our world in data, 2016]



Finance

Coinbase last night



New York Times, 2021

Artificial Intelligence

- 540 billion parameter language models

Cause & Effect

Prompt

```
Which of the following sentences makes more sense?

1. I studied hard because I got an A on the test.
2. I got an A on the test because I studied hard.
```

Model Response

```
I got an A on the test because I studied hard.
```

Emoji Movie Game

Prompt

```
What movie does this emoji describe? 🤖🕴️🌱🌎

1. l.a. confidential
2. wall-e
3. léon: the professional
4. big
5. rush
```

Model Response

```
wall-e
```

Prompt

```
def exercise5():
"""Marie ordered one chicken meal that
costs $12, 5 packs of milk that cost $3
each, 4 apples that cost $1.50 each, and
some boxes of pizza. Marie paid a total of
$50. How many boxes of pizza did Marie
order if box costs $8.50?"""
```

Model Response

```
total_paid = 50
cost_of_pizza_per_box = 8.50
cost_of_meal = 12
cost_of_milk_per_pack = 3
cost_of_apples_per_apple = 1.50
packages_of_milk = 5

return float(total_paid - cost_of_meal-
cost_of_milk_per_pack * packages_of_milk -
cost_of_apples_per_apple * 4)/
cost_of_pizza_per_box
```

[PaLM: Scaling Language models with Pathway]

Artificial Intelligence

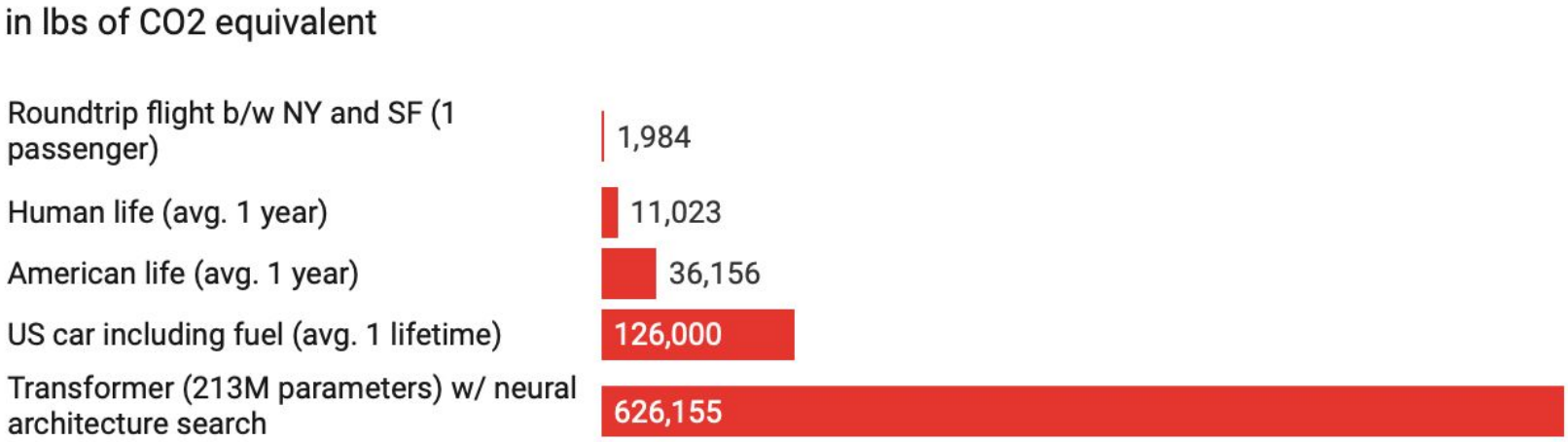


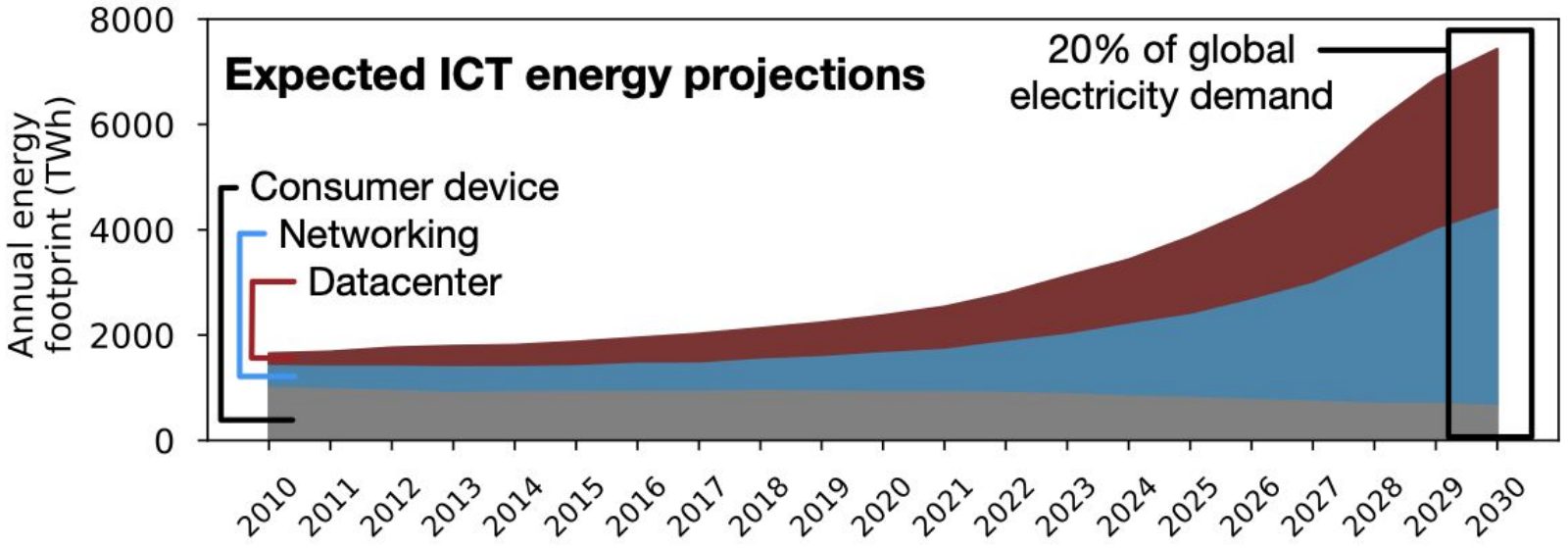
Figure source. Data from Strubell et al, 2019

Entertainment

- ~8 billion hours of Twitch streaming so far this year

Twitch Tracker

A usage projection



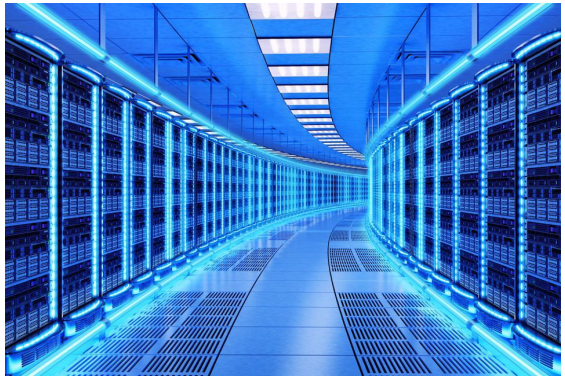
Gupta et al, 2020

Outline

I. Operational energy

II. Hardware + Manufacturing energy

III. Outlook



Data center concept

TSMC clean room

What is a data center?

- Space for computers
  - Data storage
  - Computing jobs
  - Networking

- Thousands of them

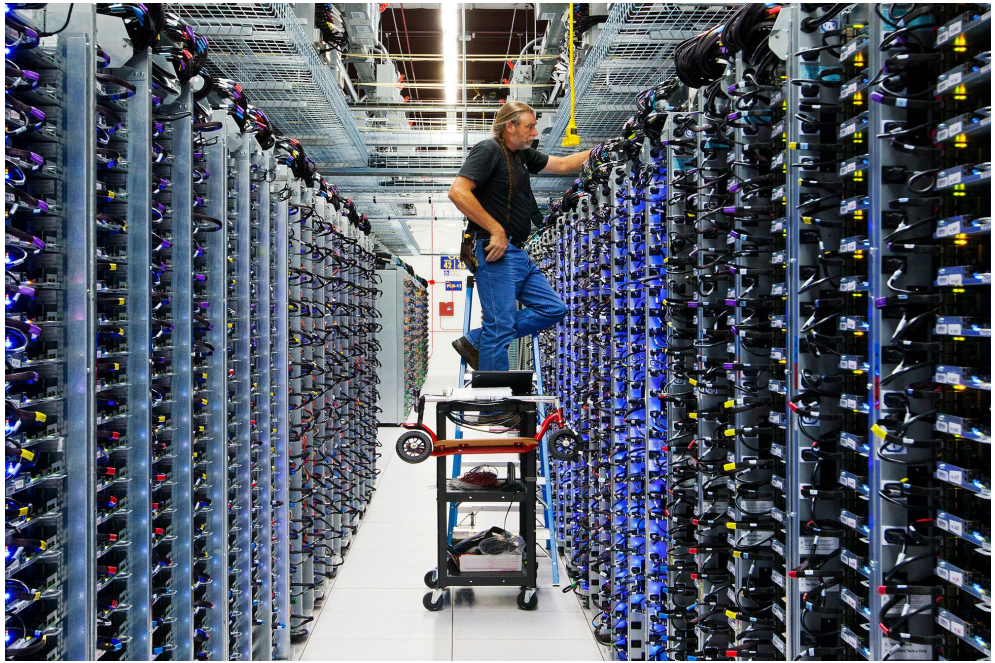
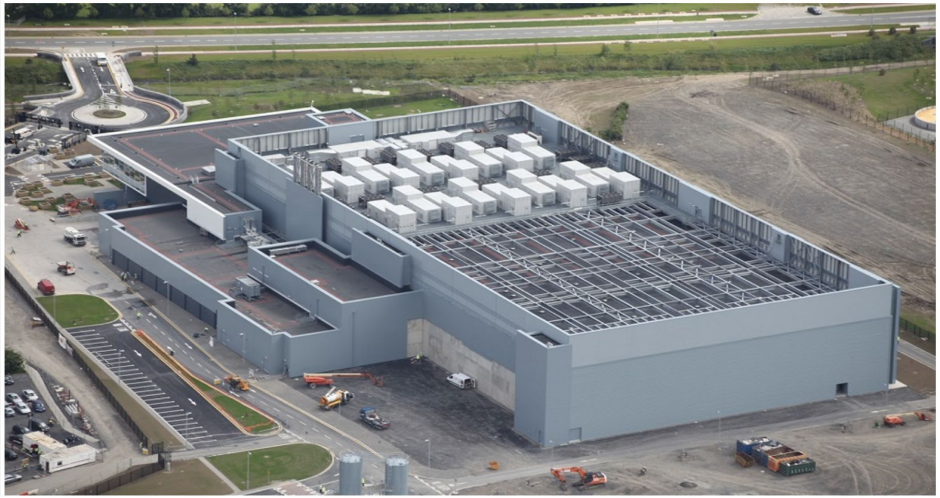


Image by Google

Data Centers

Several at each point. Some secret



AWS data centers

Non descript data center

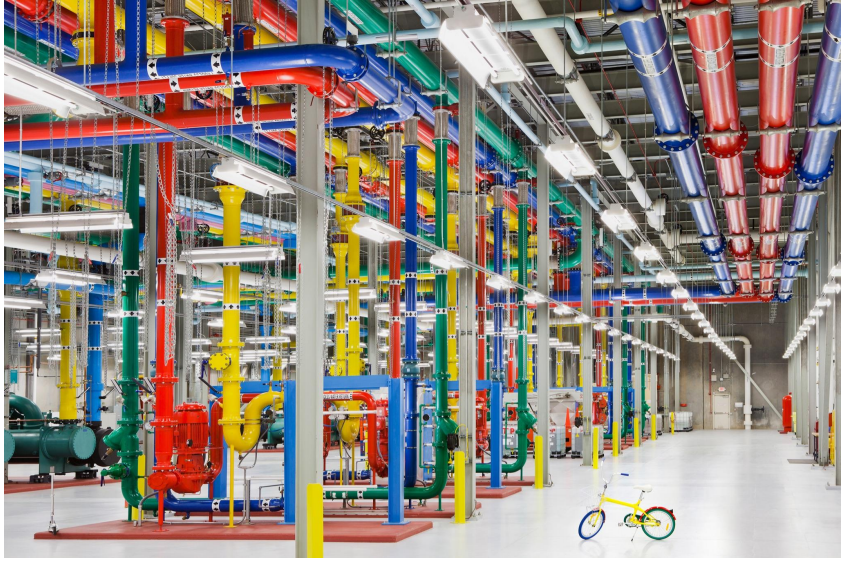
The issue

- Lots of processing
- It gets very hot
- Sensitive equipment

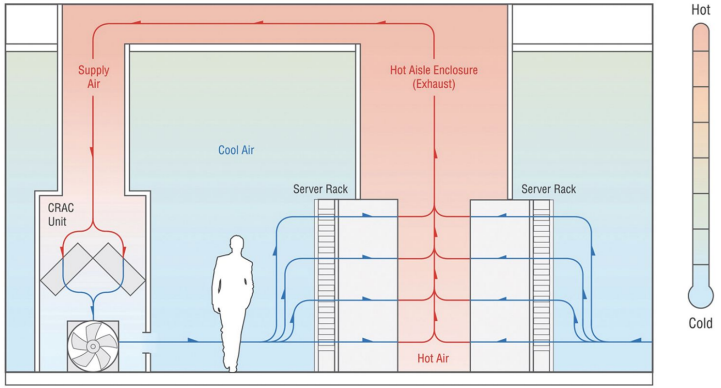
Gilfoyle and Anton

Keeping cool

- Variety of methods
- 2.7% electricity demand in EU ‘18
- Lots of development in cooling tech



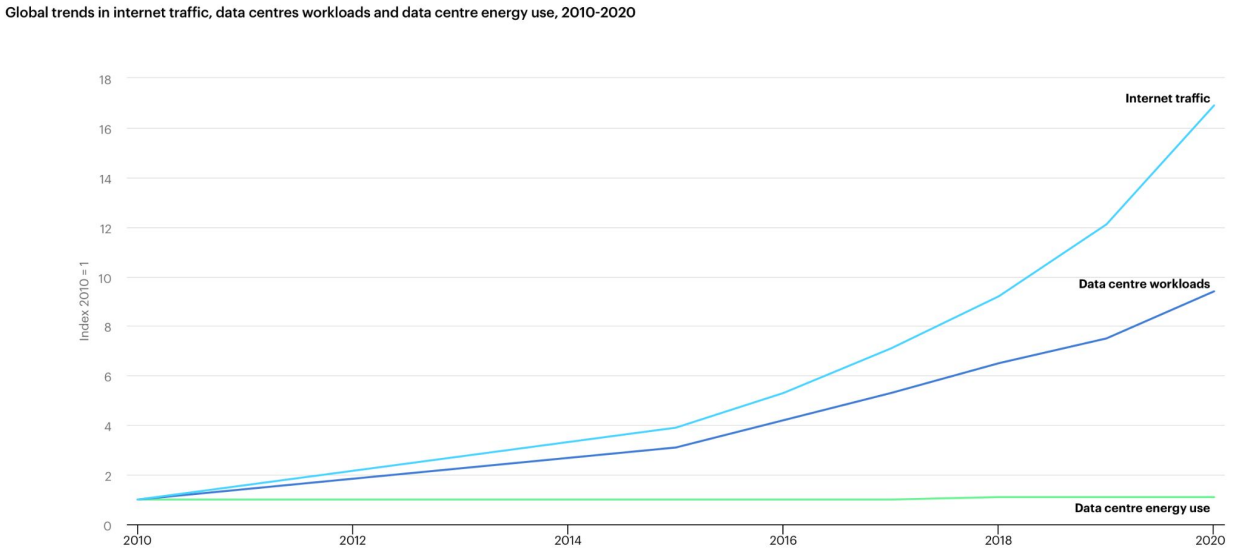
Hot Aisle Enclosure Diagram



Georgia data center

One way to cool

And yet

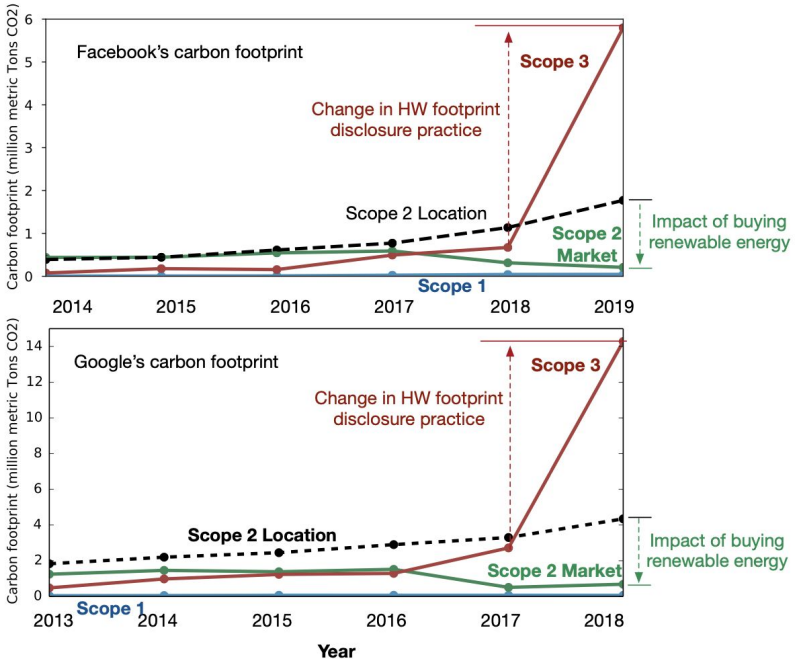


IEA 2021

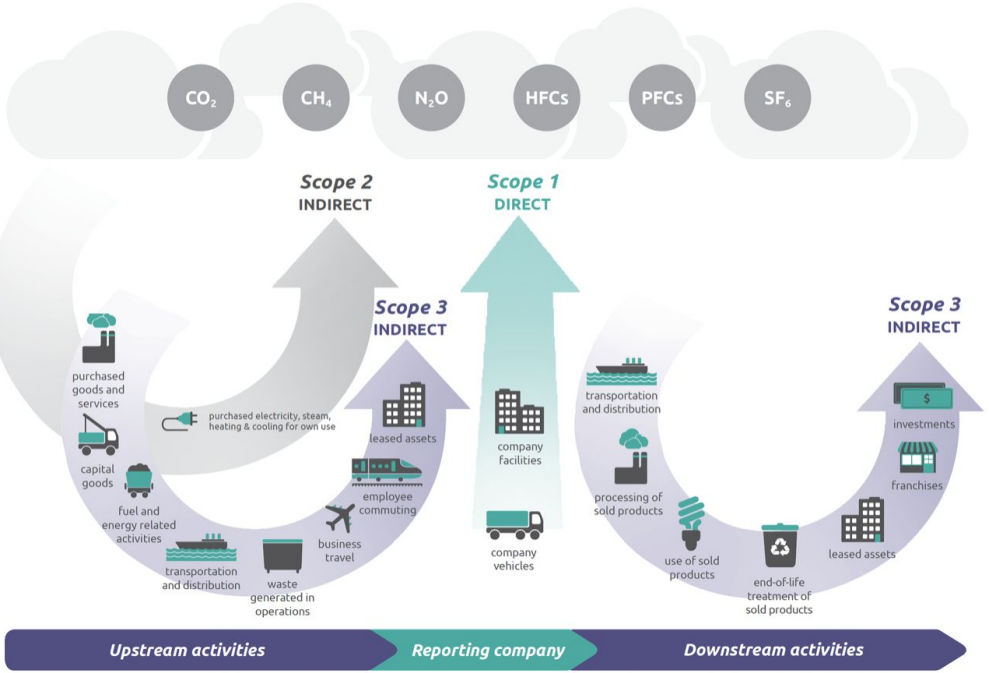
Where are the emissions?

- About 10^7 g CO2 - eq
- 0.5-2% global emissions
- Similar to airline industry

[Mb Abu Bakar Siddik et al, 2021]



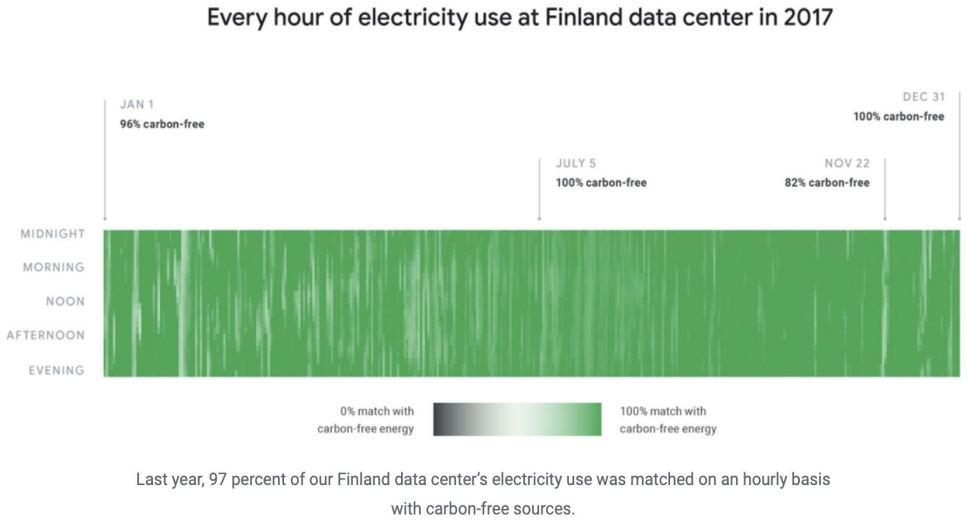
GHG protocol reminder



EPA

Large purchasers of renewables

- Buy mostly renewables
- Buy offsets when not possible
- [Target 100% renewable ‘25]



[Google data center in Finland]

Economies of scale

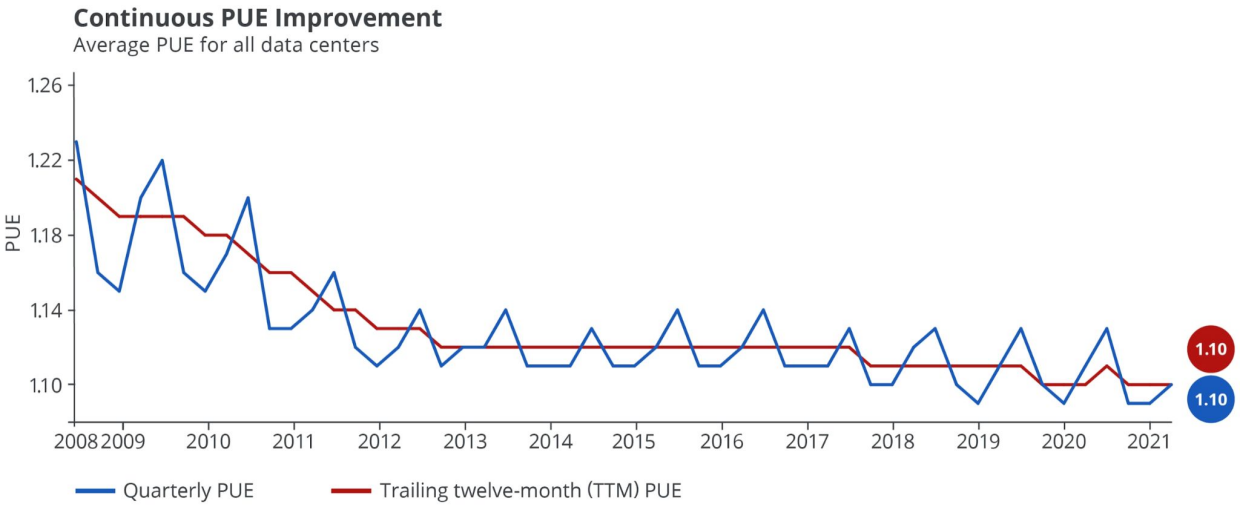
Category	Energy use (million MWh)	Computing workloads (million)	Water intensity (m^3 MWh^{-1})	Carbon intensity (ton CO_2-eq MWh^{-1})	Water intensity (m^3/workload)	Carbon intensity (ton CO_2-eq/ workload)
Internal	26.90	16	7.20	0.45	12.15	0.75
Colocation	22.40	41	7.00	0.42	3.85	0.25
Hyperscale	22.85	76	7.00	0.44	2.10	0.15

Mb Abu Bakar Siddik et al, 2021

Power usage efficiency (PUE)

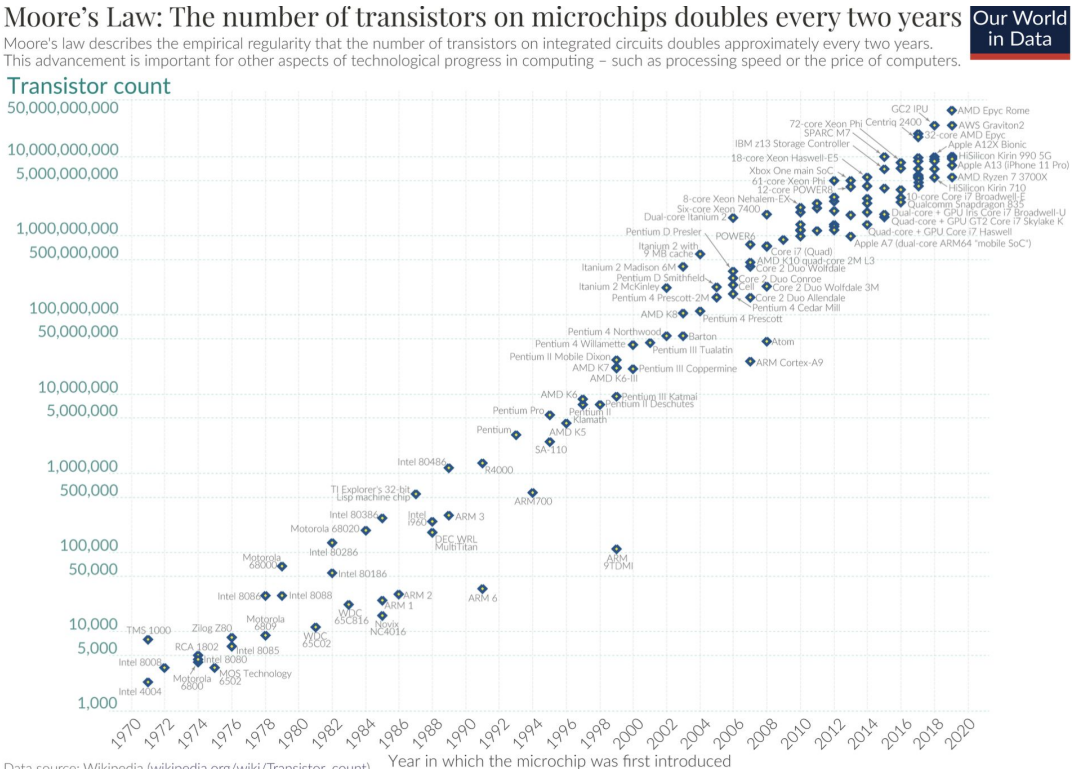
Industry average ~ 2

$$\mathrm{PUE} = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}} = 1 + \frac{\text{Non IT Facility Energy}}{\text{IT Equipment Energy}}$$

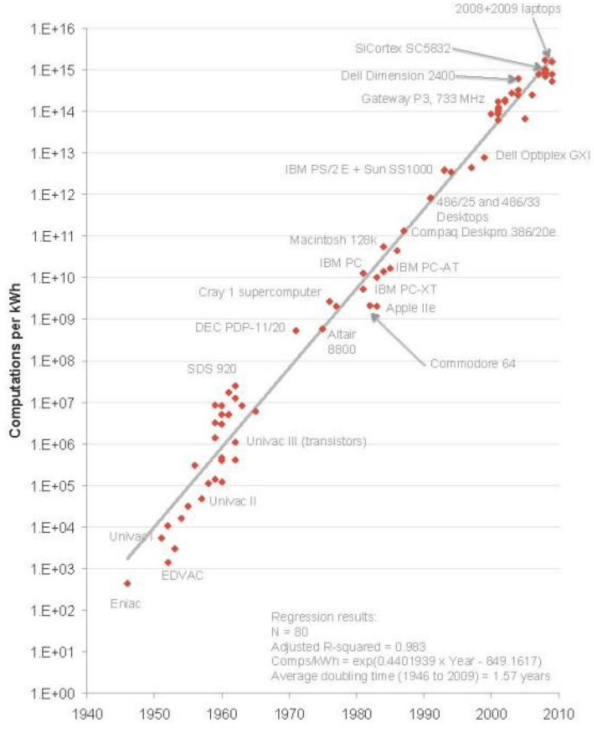


Google PUE Trends

Hardware tailwinds



Data source: Wikipedia (wikipedia.org/wiki/Transistor_count)



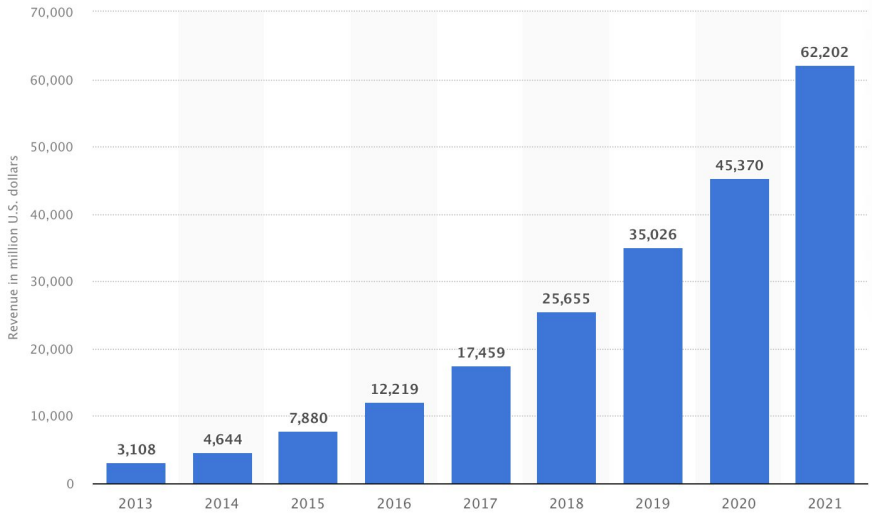
[Moore's Law]

[Koomey's Law]

In summary

- Economics says hyperscale wins
- Extra revenue ↔ Increased investment
- Great for environment!

Amazon's cloud business grows almost 37%, but slows from last quarter

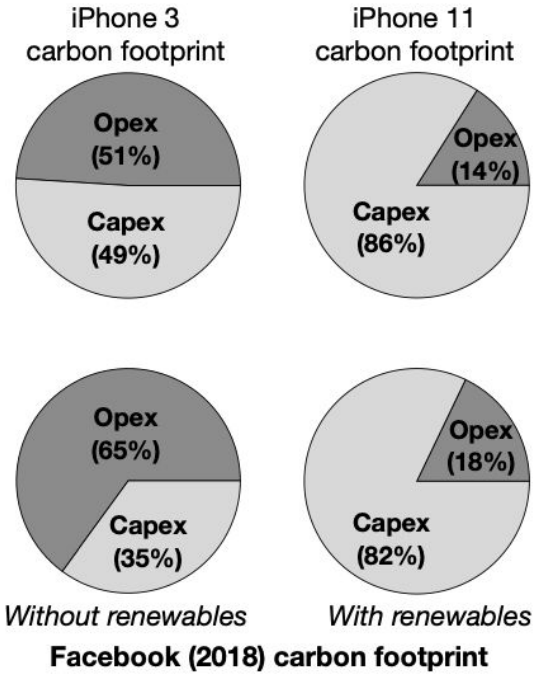


AMZN, Earnings

Some words on hardware

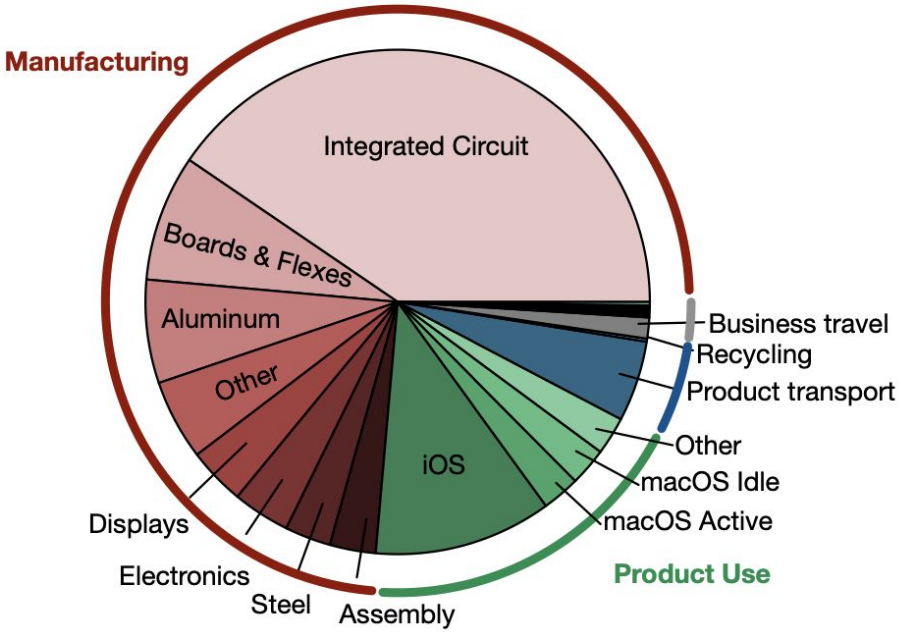
Mostly capital expenditure emissions

- Operational Expenditures
  - Running services
  - Keeping the lights on
- Capital Expenditures
  - Hardware purchases
  - Building



Emissions at Apple

- 25 million metric tons CO2 ‘19
  - BP 374 million tons CO2 ‘20
- Mostly from manufacturing
- Split depends on device



Gupta et al, 2021

Emissions breakdown for chip fab

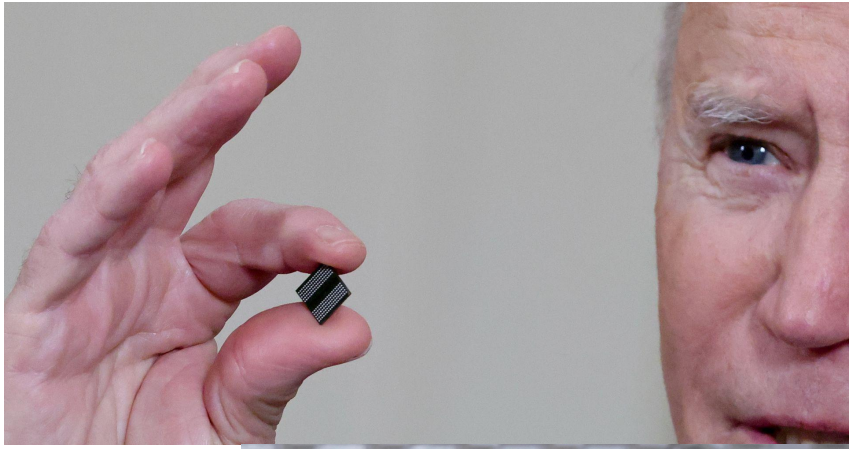
Technology company	Scope 1	Scope 2	Scope 3
Chip manufacturer	Burning PFCs, chemicals, gases	Energy for fabrication	Raw materials, hardware use
Mobile-device vendor	Natural gas, diesel	Energy for offices	Chip manufacturing, hardware use
Data-center operator	Natural gas, diesel	Energy for data centers	Server-hardware manufacturing, construction

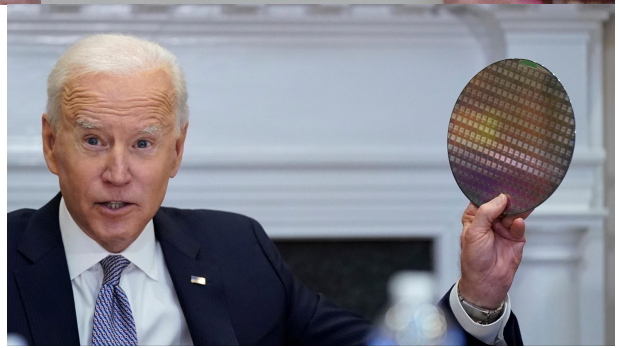
- TSMC 15 million tons CO2 in 2020
- 30% emissions from chemicals
- 60% from energy procurement

Chip manufacturing is crazy!

Carbon reductions for chip fabs

- Use more renewables to power plants
  - Difficult logistically esp in Taiwan
  - 40% by ‘30
- Seek further hardware optimization
- Spread out manufacturing





Summary

- Exponential growth in demand
- Exponential growth in efficiency
- Fabrication and construction most of emissions
- Use more renewables

Thanks!

Addenda

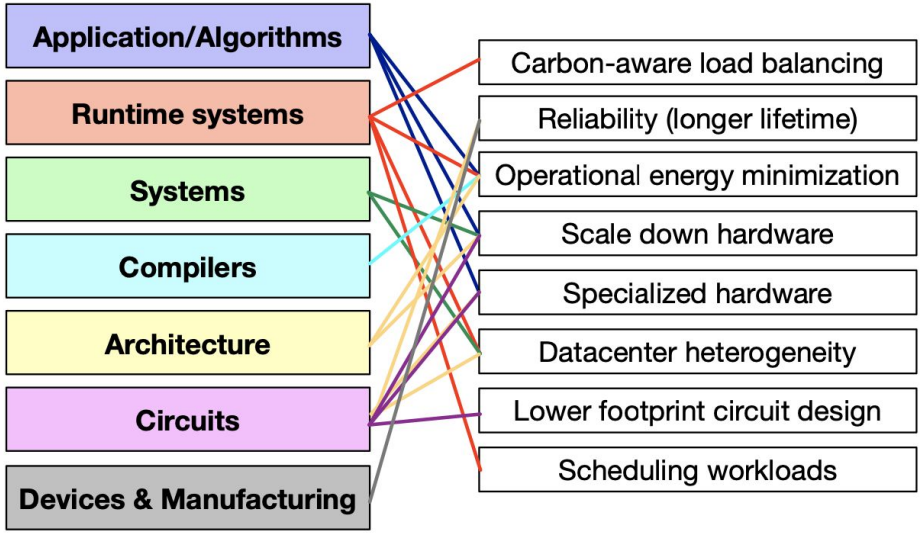


Fig. 15. Reducing the carbon output of computer systems requires cross-layer optimization across the computing stack. The potential opportunities (right) overlap with multiple stack layers (left).

Some ideas for improvements