

# Environmental costs of computing

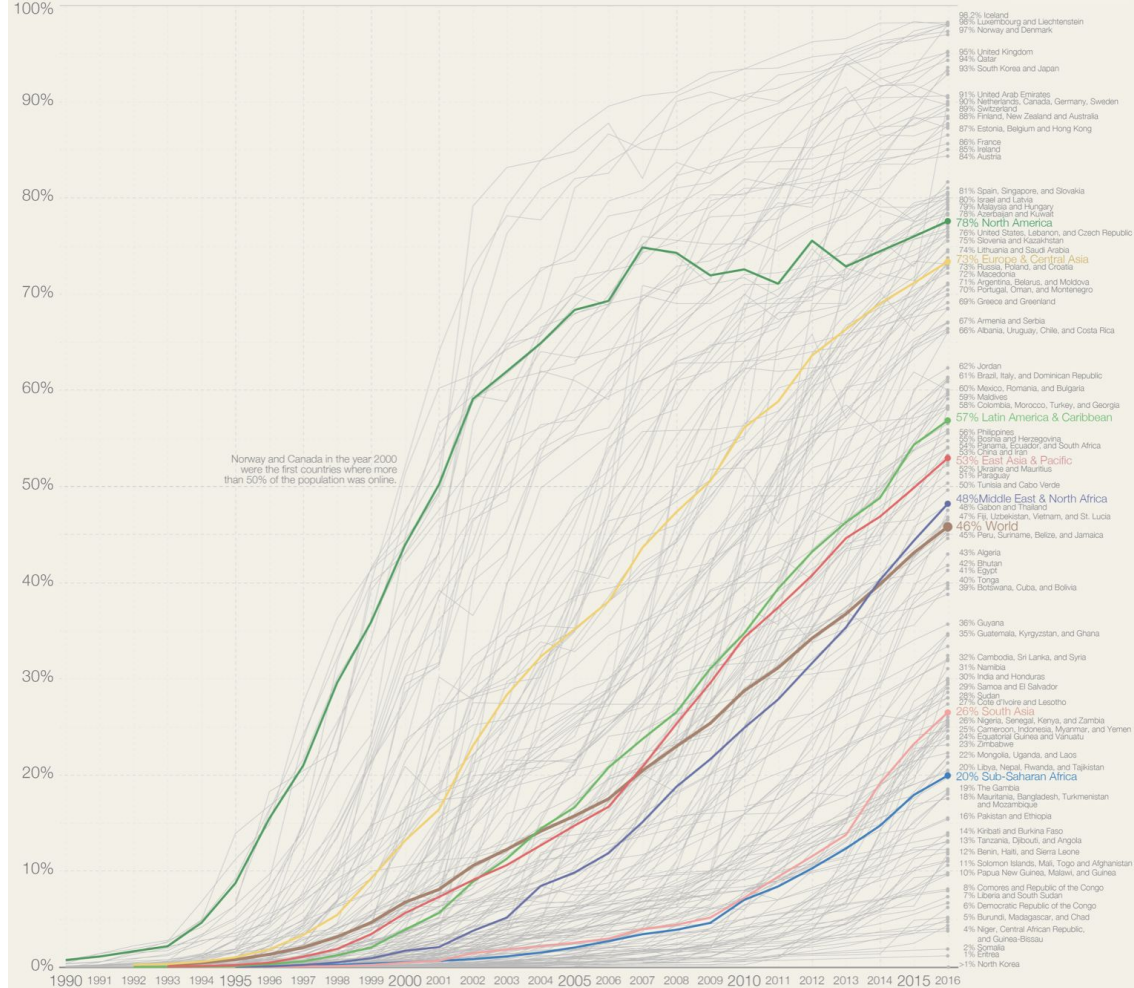
Ian Davenport

# Share of the population using the Internet

Internet users are all who have used the Internet in the last 3 months

## Computing

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



# Finance



[Coinbase last night](#)

## Bitcoin's electricity usage compared with countries

Estimated electricity consumption (terawatt-hours, annualized). Shaded region represents the range of possible values.



[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

in lbs of CO2 equivalent

Roundtrip flight b/w NY and SF (1 passenger)

1,984

Human life (avg. 1 year)

11,023

American life (avg. 1 year)

36,156

US car including fuel (avg. 1 lifetime)

126,000

Transformer (213M parameters) w/ neural architecture search

626,155

[Figure source](#). Data from [Strubell et al, 2019](#)

# Entertainment

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

## TWITCH ACHIEVEMENTS THROUGH THE YEARS

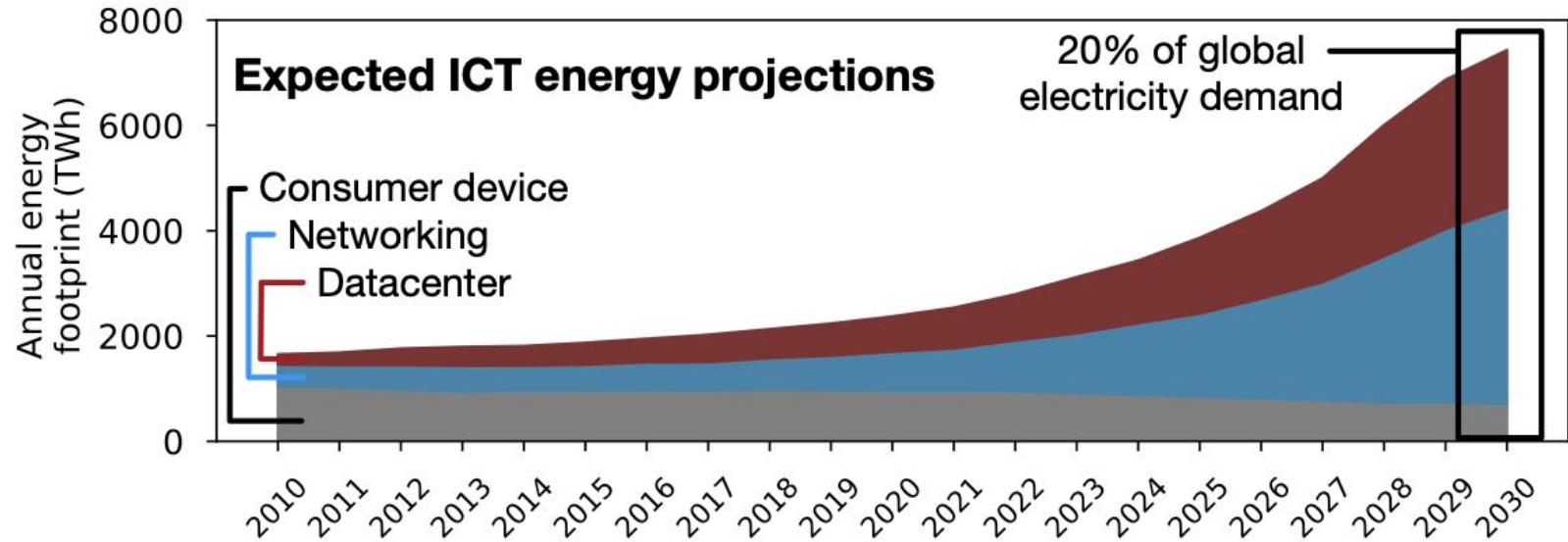
2022

- 469 BILLION minutes watched this year so far ▼ 0.4%
- 8.4 MILLION unique creators streaming each month ▼ 1%
- 2,766,000 average concurrent viewers
- 100,200 average concurrent streamers ▼ 4%

2021

- 8.5 MILLION channels were streaming monthly ▲ 23%
- 1460 BILLION minutes watched overall ▲ 31%
- 2,778,000 average concurrent viewers ▲ 31%
- 105,000 average concurrent streamers ▲ 20%

# A usage projection



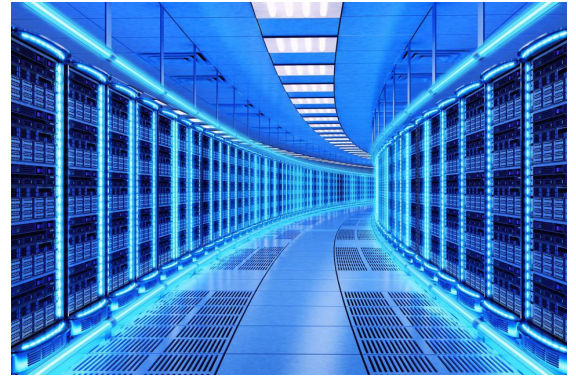
[Gupta et al, 2020](#)

# Outline

I. Operational energy

II. Hardware + Manufacturing energy

III. Outlook



[Data center concept](#)



[TSMC clean room](#)

# What is a data center?

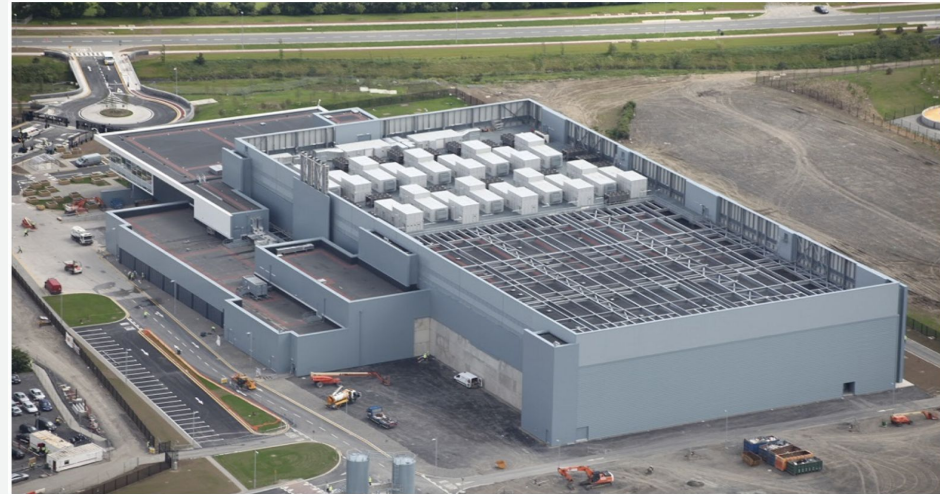
- Space for computers
  - Data storage
  - Computing jobs
  - Networking
- Thousands of them



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

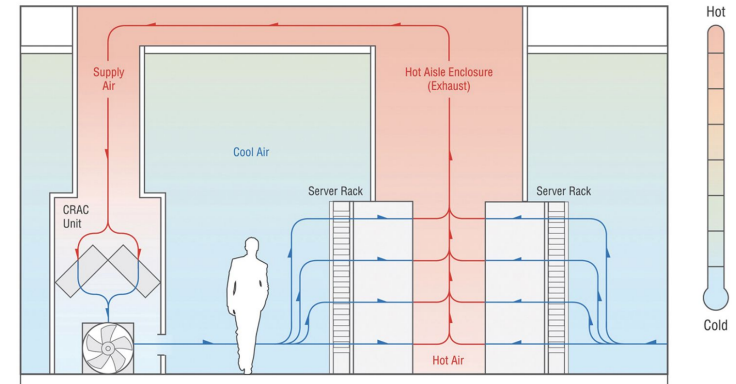
- Variety of methods
- 2.7% electricity demand in EU '18
- Lots of development in cooling tech

Georgia data center

One way to cool

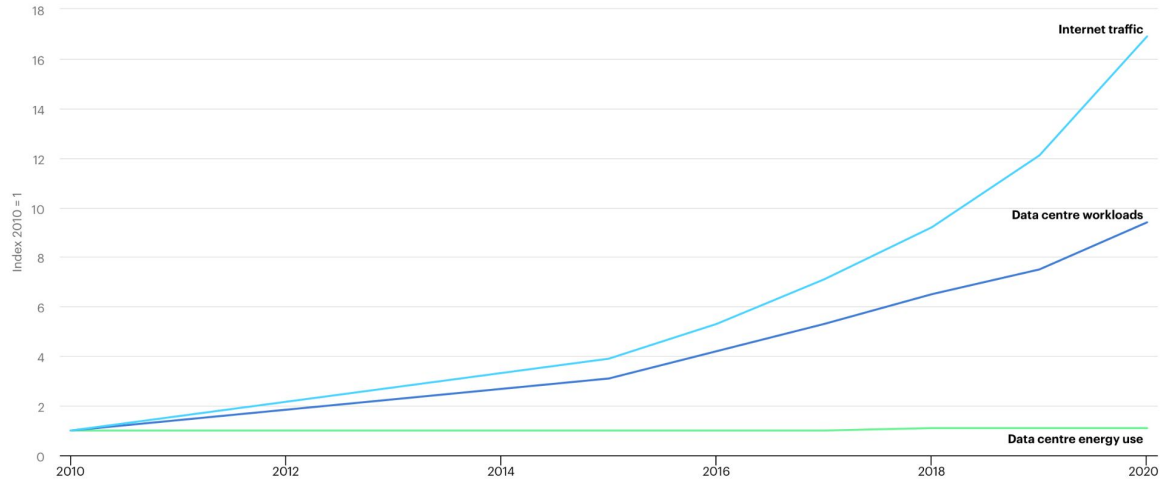


Hot Aisle Enclosure Diagram



# And yet

Global trends in internet traffic, data centres workloads and data centre energy use, 2010-2020

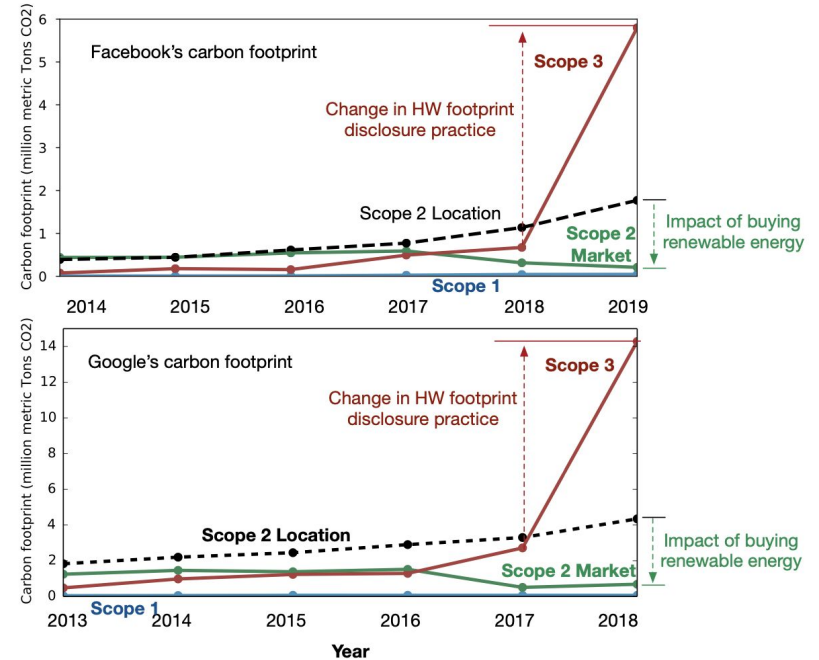


IEA 2021

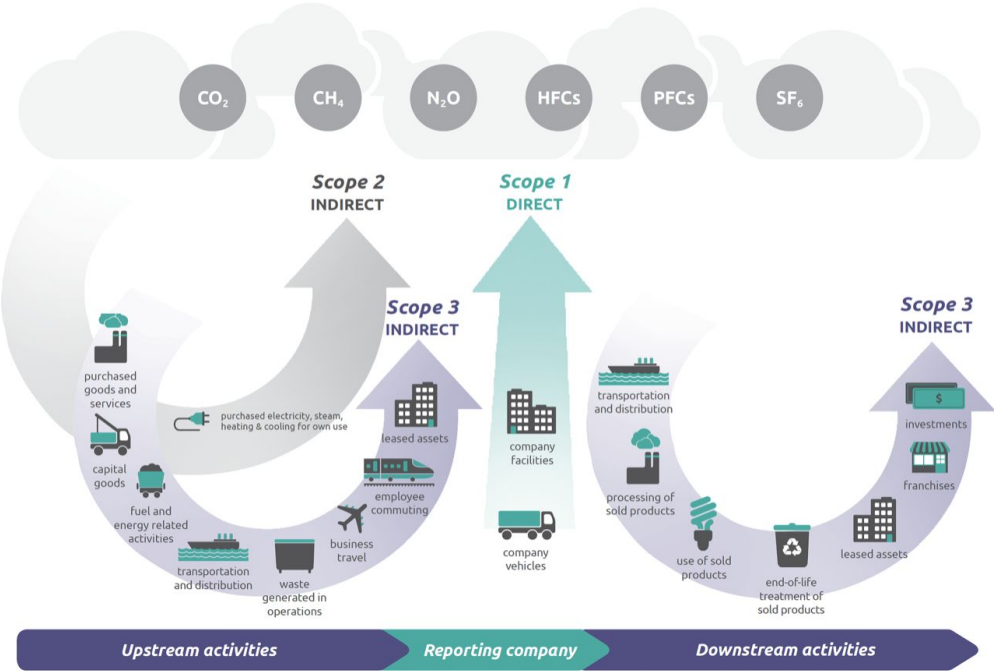
# Where are the emissions?

- About  $10^7$  g CO<sub>2</sub> - eq
- 0.5-2% global emissions
- Similar to airline industry

[Mb Abu Bakar Siddik et al, 2021](#)



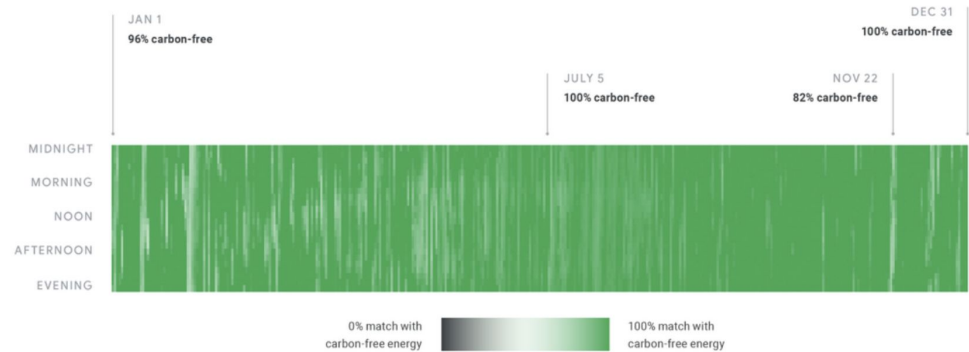
# GHG protocol reminder



# Large purchasers of renewables

- Buy mostly renewables
- Buy offsets when not possible
- [Target 100% renewable '25](#)

Every hour of electricity use at Finland data center in 2017



Last year, 97 percent of our Finland data center's electricity use was matched on an hourly basis with carbon-free sources.

[Google data center in Finland](#)

# Economies of scale

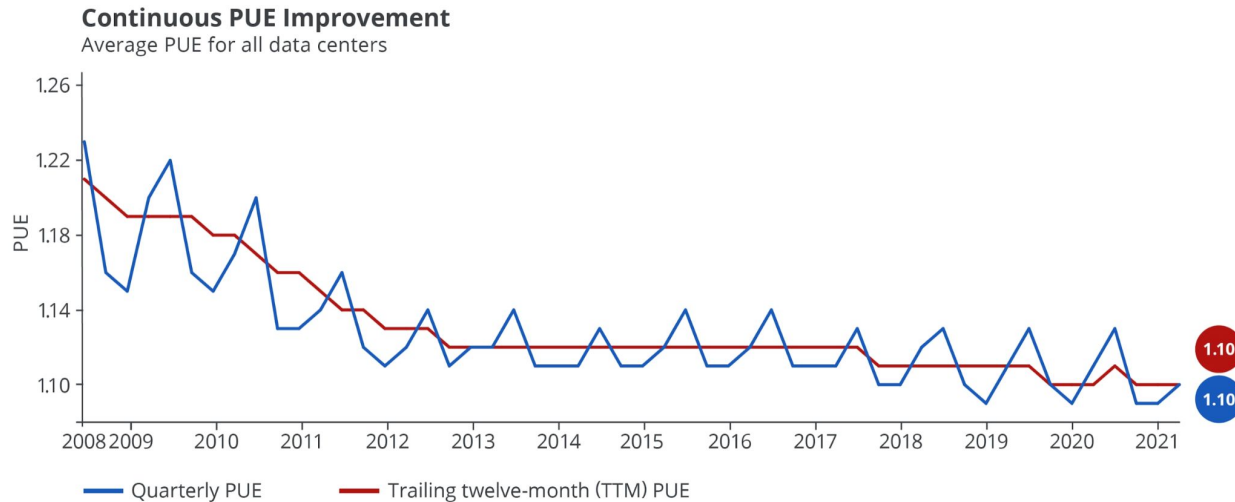
Category	Energy use (million MWh)	Computing workloads (million)	Water intensity (m <sup>3</sup> MWh <sup>-1</sup> )	Carbon intensity (ton CO <sub>2</sub> -eq MWh <sup>-1</sup> )	Water intensity (m <sup>3</sup> /workload)	Carbon intensity (ton CO <sub>2</sub> -eq/ workload)
Internal	26.90	16	7.20	0.45	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

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



[Google PUE Trends](#)

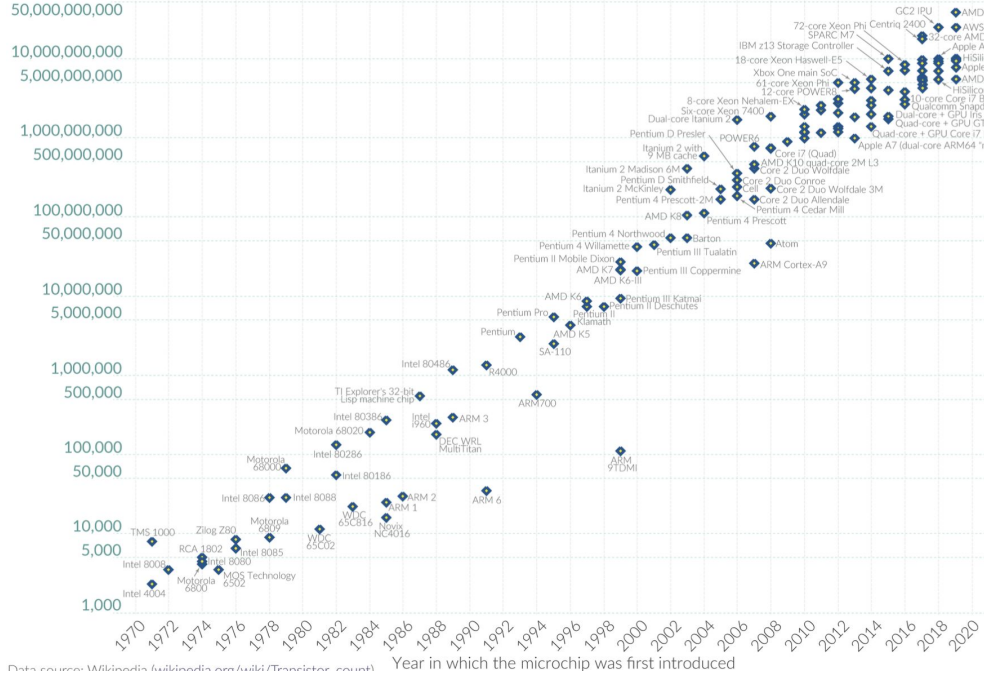
# Hardware tailwinds

## Moore's Law: The number of transistors on microchips doubles every two years

Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important for other aspects of technological progress in computing – such as processing speed or the price of computers.

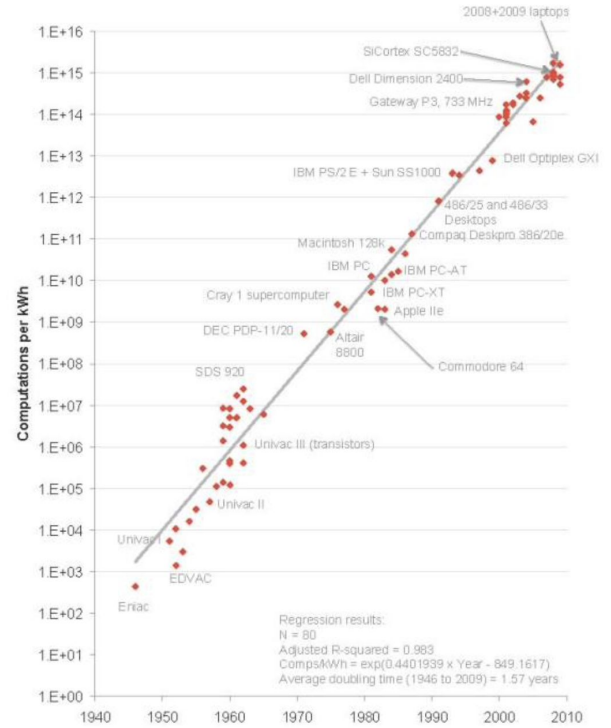
Our World  
in Data

### Transistor count



Data source: Wikipedia (wikipedia.org/wiki/Transistor\_count)

Moore's Law

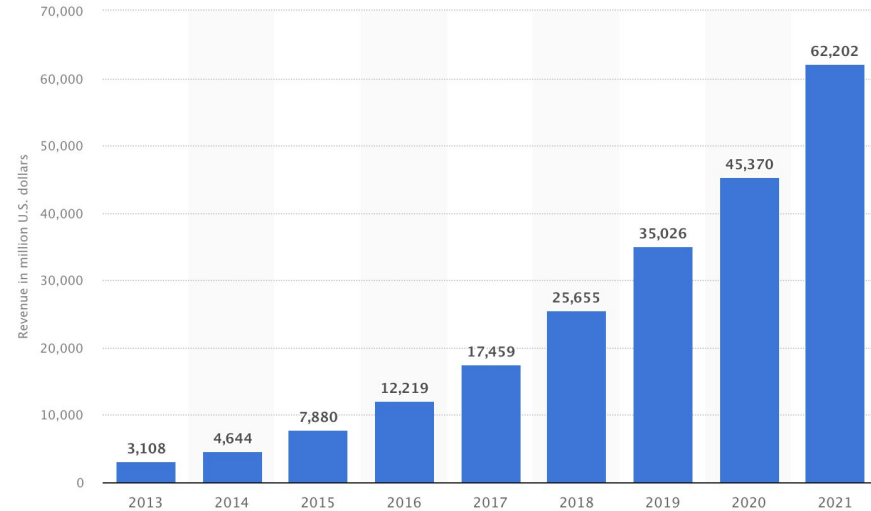


Koomey's Law

## 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

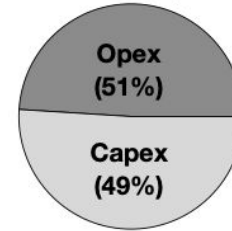
- Operational Expenditures

- Running services
- Keeping the lights on

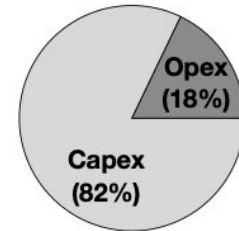
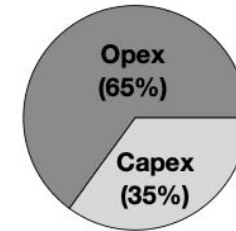
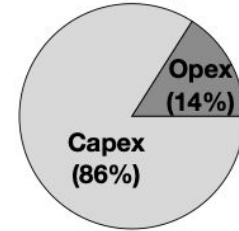
- Capital Expenditures

- Hardware purchases
- Building

iPhone 3  
carbon footprint



iPhone 11  
carbon footprint



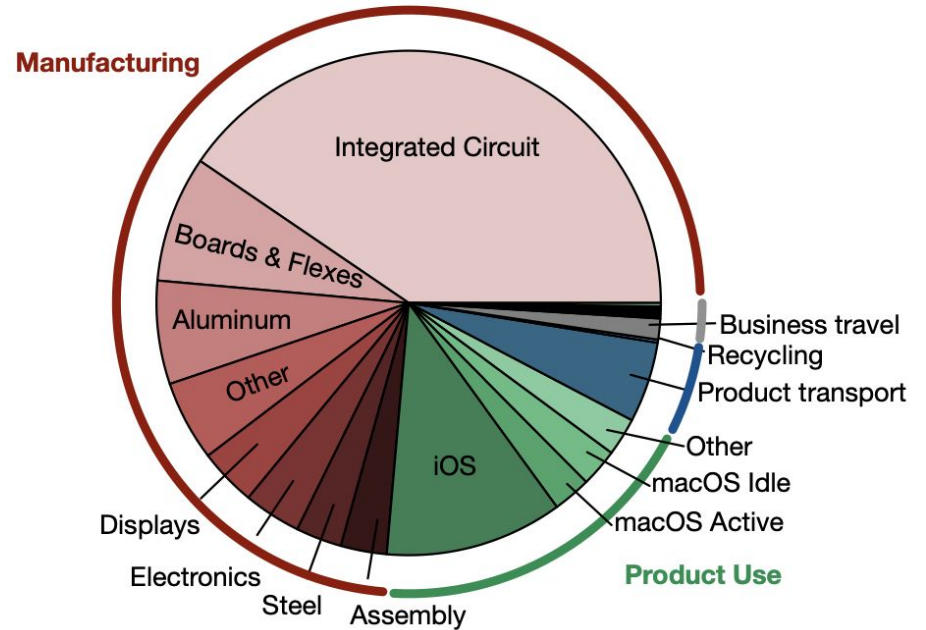
*Without renewables*

*With renewables*

**Facebook (2018) carbon footprint**

# 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

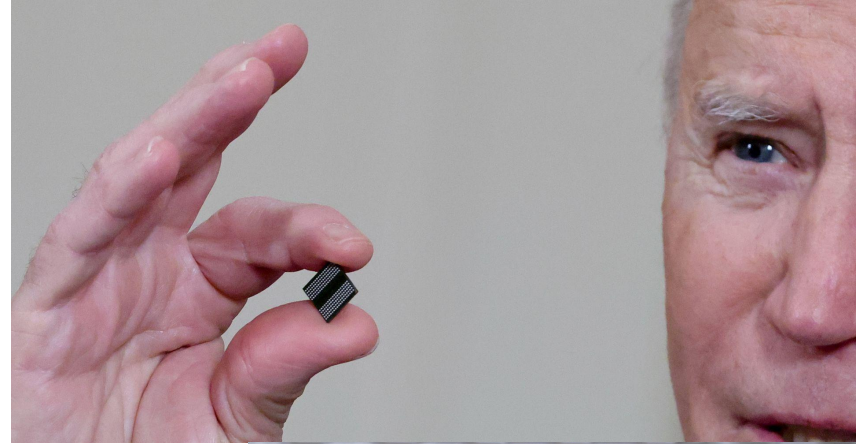
- [TSMC 15 million tons](#) CO2 in 2020
- 30% emissions from chemicals
- 60% from energy procurement

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

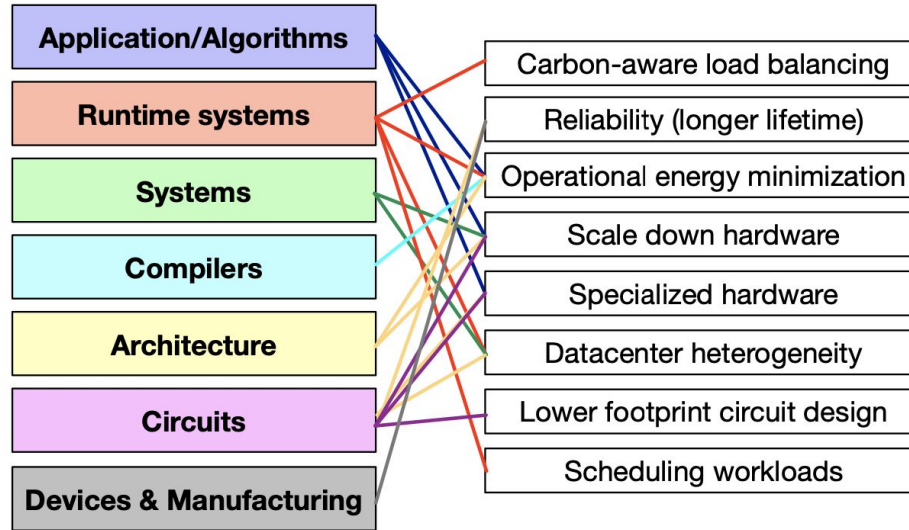


# Summary

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

Thanks!

# Addenda



[Some ideas for improvements](#)

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).