

The environmental impact of AI (therefore LLMs) in a nutshell

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Sources of inspiration

- ▶ Discussions with Anne-Laure Ligozat (LISN)
- ▶ Discussions with Florence Maraninchi (LIG)
- ▶ Conference "Comprendre et Agir" by Françoise Berthoud (Research engineer at CNRS) presented on Nov. 15th, 2018 at INRIA Grenoble (France)
- ▶ <https://www.ebi.ac.uk/training/online/courses/sustainable-computing-in-science/>

What kinds of environmental impacts do you think LLMs have?



Introduction

What we talk about (a bit)

Electricity

Water

What we don't talk about (enough)

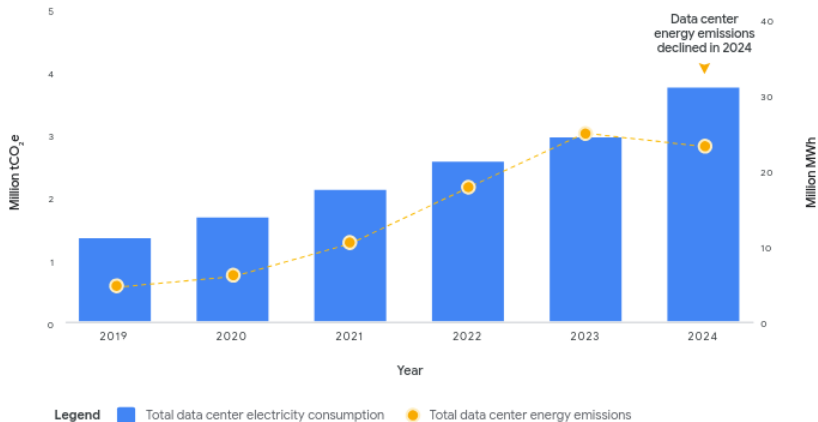
What we missed

Can AI help solving the problem?

To finish

Google data centers electricity consumption (from Google itself)

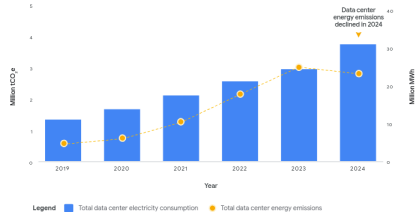
Figure 2. Trajectory of data center electricity consumption and data center energy emissions



<https://www.gstatic.com/gumdrop/sustainability/google-2025-environmental-report.pdf>

Google data centers electricity consumption (from Google itself)

Figure 2. Trajectory of data center electricity consumption and data center energy emissions

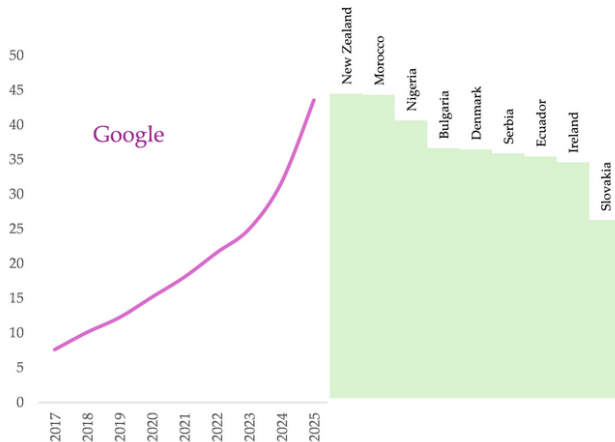


- ▶ How to interpret this graphic?
- ▶ What do they push forward?
- ▶ What does Google electricity consumption correspond to?

Google electricity consumption is that of New Zealand (5 M people)

Google power demand vs similar countries

Google 2025 sustainability report, Ember GER 2024, terawatt hours per year

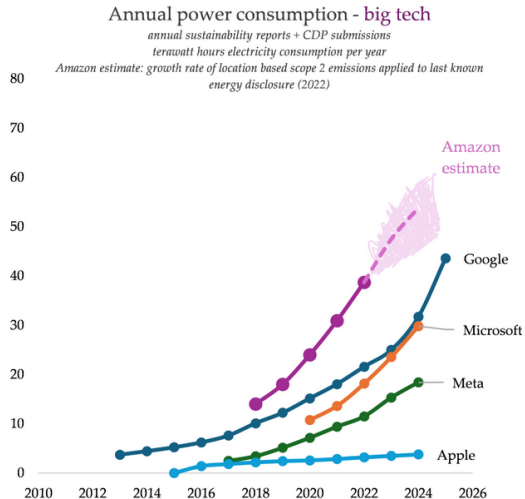


<https://ketanjoshi.co/2026/07/01/googles-exponential-path-to-climate-wrecking-digital-bloat/>

What is the electricity consumption of OpenAI (from OpenAI)?



What about the other BigTech?



<https://ketanjoshi.co/2026/07/01/googles-exponential-path-to-climate-wrecking-digital-bloat/>

What is the global electricity use due to AI?

According to the International Energy Agency (IEA), around 485 terawatt-hours (TWh).² That's equivalent to the annual electricity generation of Germany. And for context, that's around **1.5% of the world's electricity generation**.³

Now, data centers are more than just AI: they're facilities that contain the servers and IT infrastructure behind all of our digital services. That's everything from email and Internet browsing to Netflix streaming, Google Maps, online banking, and messaging friends.

AI data centers are dedicated facilities for running AI models. The distinction between the two is not always clean-cut, but the chart below shows an estimated breakdown.

Non-AI data centers consumed two-thirds of the total, and AI-focused ones, the remaining third. Based on this data from the International Energy Agency, I estimate that **AI consumed around 0.5% of the world's electricity** in 2025.⁴

Another source, the Energy Institute, estimates that data center power demand – including crypto mining – was around 790 TWh in 2025 (or 2.5% of global electricity generation). See below for more on why they differ.

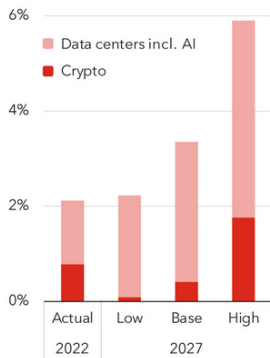
<https://ourworldindata.org/how-much-energy-do-data-centers-and-artificial-intelligence-use>

Beware!

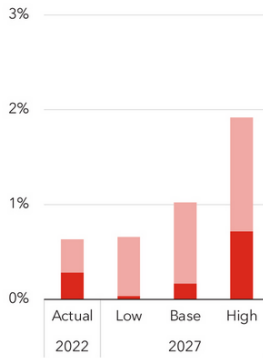
AI vs digital vs data centers

Electricity use: “3.5% [...] would be the current consumption of Japan”

Share of global electricity use



Share of global CO₂ emissions



Source: Hebous and Vernon (2023); Carbon Pricing Assessment Tool; IEA 2024.

Note: All projection scenarios use the average BTC price for 2021-2023. “Base” refers to the average energy-intensity of mining equipment; “Low” and “High” refer to the lowest and highest available energy-intensity, respectively. Crypto emissions decline from 2022 to 2027 under the baseline scenario is mainly driven by the reduction in mining block rewards while assuming no offsetting increase in crypto prices or transaction fees.

IMF

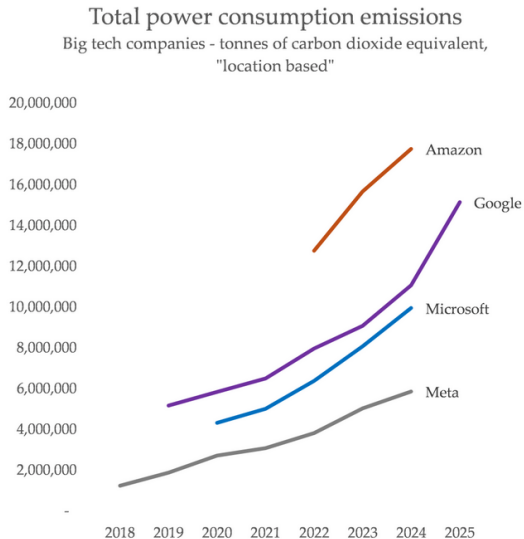
The problematic growth in energy consumption for digital technology

The report shows that the **final energy consumption** of the global digital sector is increasing by approximately **6.2% per year** (2015 to 2019). **This growth rate corresponds to a doubling every 11 years** and is bound to increase in all scenarios that do not include a voluntary change in consumption practices (traffic, terminals).

Final energy consumption (in TWh)	2015	2019	2025	CAGR ¹² 2015/2019	CAGR 2019/2025
Conservative	3,289	4,181	6,041	6.2%	6.5%
Growth			6,860	6.2%	8.6%
Growth less EE			7,335	6.2%	9.8%
New sobriety			4,209	6.2%	0%

https://theshiftproject.org/app/uploads/2025/02/Environmental-impacts-of-digital-technology-5-year-trends-and-5G-governance_March2021.pdf

Beware: Consumption vs emissions

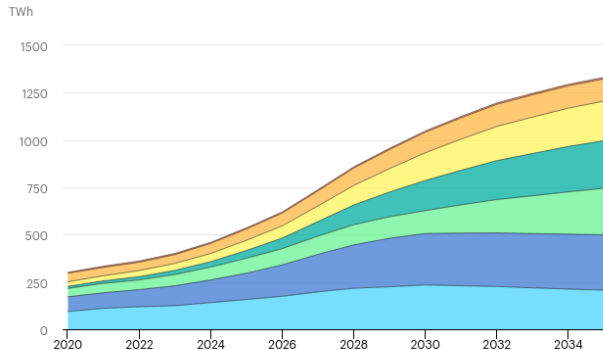


<https://ketanjoshi.co/2026/07/01/googles-exponential-path-to-climate-wrecking-digital-bloat/>

Data centers sources of energy (energy mix): today and planned

Sources of global electricity generation for data centres, Base Case, 2020-2035

Open ↗



IEA. Licence: CC BY 4.0

● Coal ● Natural gas ● Nuclear ● Solar PV ● Wind ● Other renewables ● Other

How much energy to create a model?

Your colleagues presentations at the end of the semester

Conclusion

- ▶ Companies tend to not communicate clearly (when they do)
- ▶ Difficult to evaluate on a global level
- ▶ Beware of what is measured (AI? Everything Digital?)
- ▶ The growth is exponential
- ▶ “Decarbonated” electricity sources tend to consume more water

Tools to measure the carbon footprint of your work

Embedded packages (or libraries), when available for your programming language, are pieces of code that you can add to track energy usage while you run your code without the need for action on your part. These can be convenient, but so far only exist for Python programmers (e.g. [CodeCarbon](#) or [carbontracker](#)) and generally require admin-level access to the machine. It is also worth checking what values of carbon intensity these tools use, as they may not be appropriate or up-to-date for your location.

Server-side tools are directly installed on the shared server infrastructure. They require a server, and therefore are only suitable when using shared computing infrastructure in data centres. These track resource usage from the server side and enable you to see the energy usage and carbon footprint of past jobs. Although they generally require your HPC team to set them up, [GreenAlgorithms4HPC](#) is an example of a tool you can install yourself.

Finally, **online calculators** rely on a user-friendly interface where a range of information about the project can be input. Using an online calculator has the benefit of being applicable to any project, regardless of the programming language or the infrastructure used. The main calculator available for computing carbon footprint estimation is the [Green Algorithms online tool](#), which we will explore in the next section. Not really fitting in these categories, but particularly useful in bioinformatics, are carbon accounting tools embedded in pipeline managers. Nextflow is a popular example of this, and [the nf-co2footprint plugin](#) has been developed to easily track energy usage. If you're using Nextflow, that's likely the best way forward.

<https://www.ebi.ac.uk/training/online/courses/sustainable-computing-in-science/quantifying-the-operational-carbon-footprint-of-our-analysis/the-practice/>

Green algorithms

<https://www.green-algorithms.org/GAapp-overview/>

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(Drinking) Water for cooling data centers

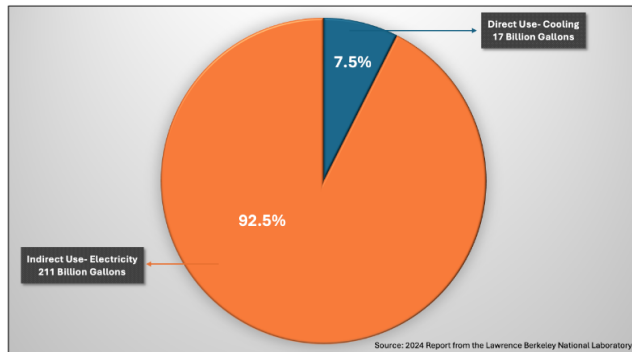


Steam rises above the cooling towers in The Dalles data center in Oregon. These plumes of water vapor create a mist at dusk. Google photo

<https://www.oregonlive.com/silicon-forest/2022/12/google-water-use-is-soaring-in-the-dalles-records-show-with-two-more-data-centers-to-come.html/>

Water use: direct (cooling) and indirect (electricity prod.)

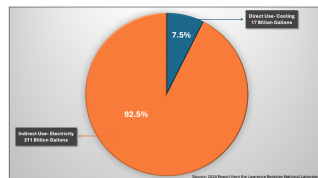
Figure 5. Direct and Indirect Use of Water by Data Centers in the U.S. in 2023.⁹⁵



[Scanlan et al., 2025]

Water use: direct (cooling) and indirect (electricity prod.)

Figure 5. Direct and Indirect Use of Water by Data Centers in the U.S. in 2023.⁹⁵



[Scanlan et al., 2025]

data centers. In this report, the laboratory estimated that in 2023, data centers in the United States consumed 17 billion gallons (66 billion liters) of water and that this number is anticipated to at least double by 2028.⁹⁶ Additionally, the laboratory estimates that the 2023 indirect water consumption through electricity to power U.S. data centers was an additional 211 billion gallons (800 billion liters).⁹⁷

[Scanlan et al., 2025]

How much water to create a model?

The combined scope-1 and scope-2 water withdrawal of global AI is projected to reach 4.2–6.6 billion cubic meters in 2027, more than the total annual water withdrawal of four to six Denmarks or half the U.K.

rated and considered “consumption” due to the global AI demand in 2027. Moreover, these global estimates will be exceeded by the total water withdrawal and consumption attributed to AI in the U.S. alone in 2028 if the projection in Shehabi et al.²⁵ comes to fruition.

Despite its profound environmental and societal impact, the increasing water footprint of AI has received disproportionately less attention from the AI community as well as the general public. For example, while scope-2 carbon emissions are routinely included as part of AI model cards, even scope-1 direct water usage (either withdrawal or consumption) is missing, let alone scope-2 water usage. This may impede inno-

In this article, we advocate for a holistic approach to sustainable AI that extends beyond the carbon footprint to also address the water footprint. Specifically, we present a principled methodology to estimate AI's total water footprint, including both operational water and embodied water. By taking the GPT-3 model with 175 billion parameters as an example,⁴ we show that training GPT-3 in Microsoft's U.S. datacenters can consume a total of 5.4 million liters of water, including 700,000 liters of scope-1 onsite water consumption. Additionally, GPT-3 needs to “drink” (that is, consume) a 500ml bottle of water for roughly 10–50 medium-length responses, depending on when and where it is deployed.

<https://dl.acm.org/doi/epdf/10.1145/3724499> [Li et al., 2025]

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What we don't talk about (enough)

- Data centers are not in the cloud

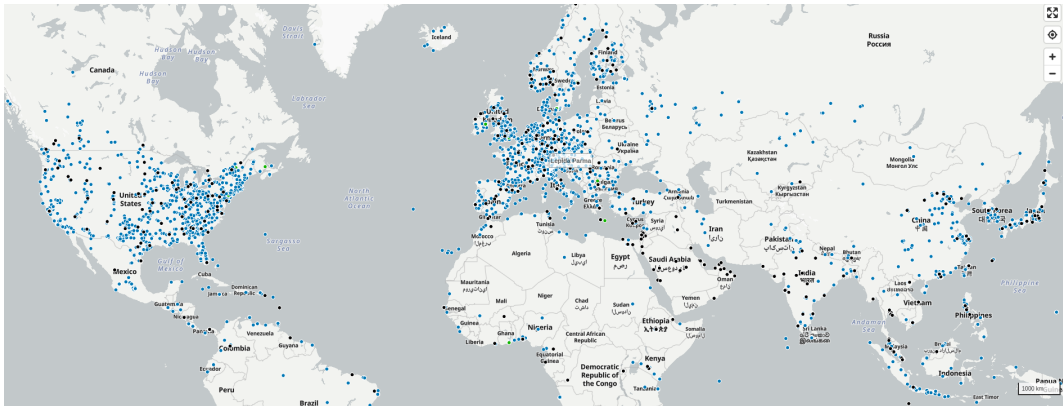
- Extraction (mines)

What we missed

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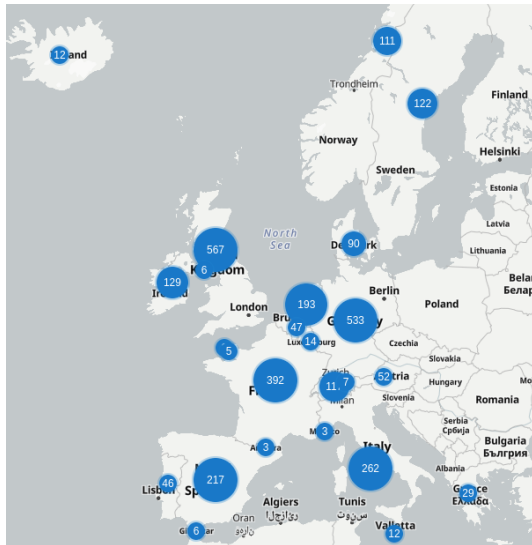
To finish

Data centers in the World



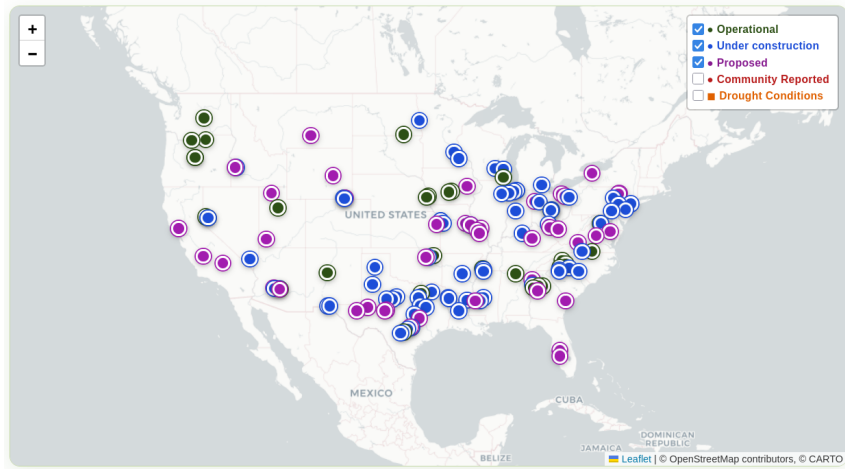
<https://www.datacentermap.com/>

Data centers in Europe



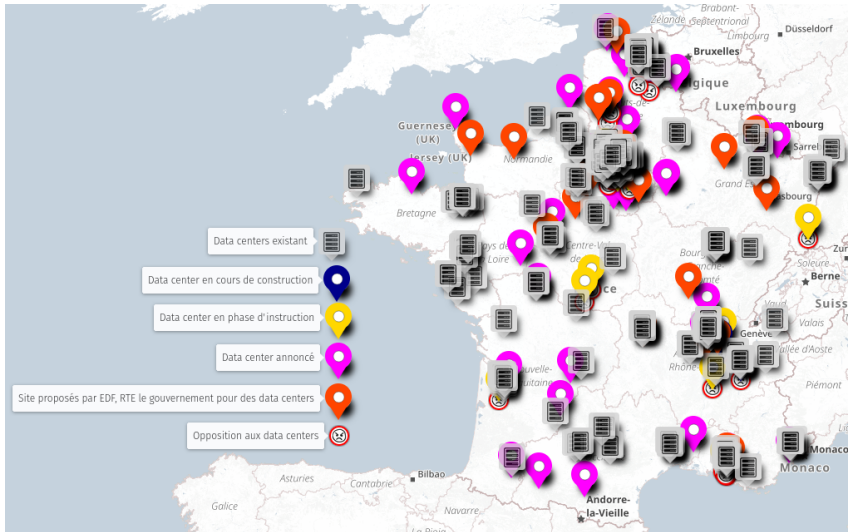
<https://www.datacentermap.com/western-europe/>

An exponential growth (USA)



<https://brockovichdatacenter.com/index.html>

An exponential growth (FR)



[https:](https://lenuageetaitsousnospieds.org/articles/2025-12-11-carte-des-data-centers-des-projets-et-des-contestations-en-france.html)

[//lenuageetaitsousnospieds.org/articles/2025-12-11-carte-des-data-centers-des-projets-et-des-contestations-en-france.html](https://lenuageetaitsousnospieds.org/articles/2025-12-11-carte-des-data-centers-des-projets-et-des-contestations-en-france.html)

The biggest (in size) data center is in China (Hohhot, Inner Mongolia)

994,062 sq. meters



<https://www.youtube.com/watch?v=bT19-B50Rhk>

Inside a data center: Council Bluff, Iowa (Google)



<https://www.gstatic.com/gumdrop/sustainability/google-2025-environmental-report.pdf>

Impact on the ground



CONSTRUCTION

Aerial view of large-scale land clearing for a data center campus, with construction ponds and exposed red clay soil, adjacent to a residential neighborhood

Clarksville, AR · Submitted by community member

<https://brockovichdatacenter.com/community-photos.html>

Marseilles: the place to be

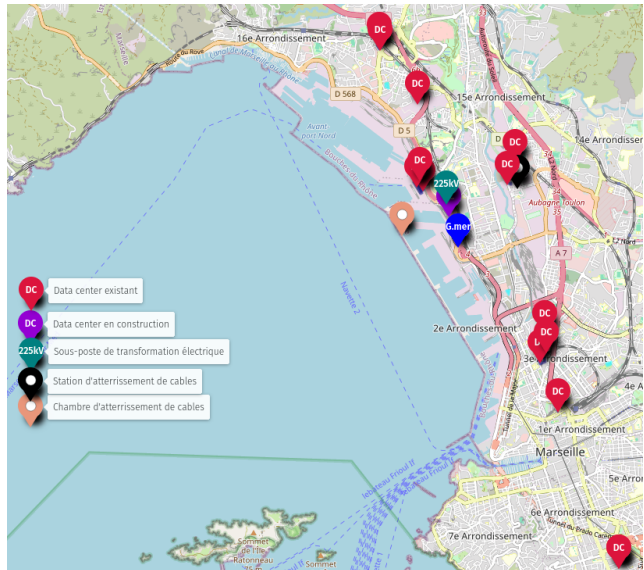


Les data centers MRS3 et MRS4 de Digital Realty, leader mondial des centres de données numériques, dans le Grand port Maritime de Marseille.

/ Photo illustration Gilles Bader

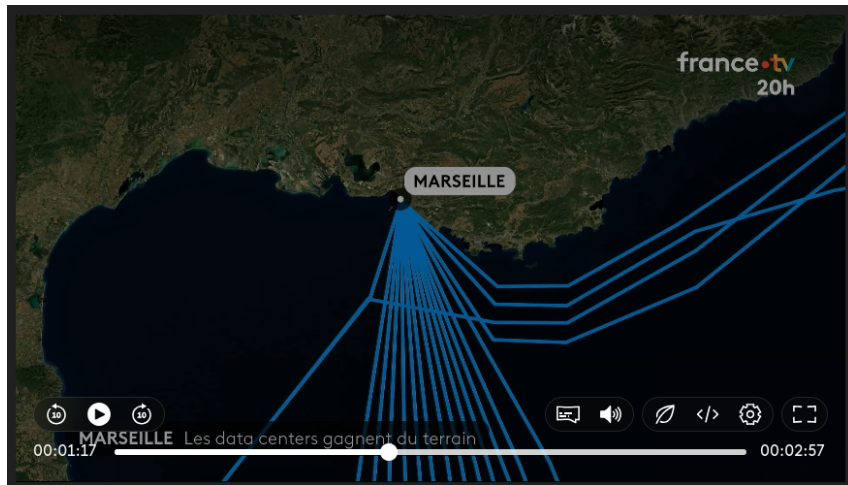
<https://www.laprovence.com/article/ecoplanete/3149290566112514/en-provence-les-defis-de-lintelligence-artificielle>

Marseilles: the place to be



Marseilles: the place to be (why)

18 intercontinental cables



https://www.franceinfo.fr/internet/marseille-les-data-centers-gagnent-du-terrain_7683841.html

Where are data centers located? and why?

While the region's central role in the early stages of the Internet's development gave it a head start as a key data centre hub, its growth can largely be attributed to the region's favourable policy environment, affordable power and highly skilled workforce.

Northern Virginia's selection as one of the four original Network Access Points during the commercialisation of the Internet in the 1990s led it to become a major intersection of the fibre optic backbone network. Following the loss of a USD 1 billion data centre project to neighbouring North Carolina in 2009, Virginia significantly expanded its tax exemption for the sale and use of data centre equipment, and the Virginia General Assembly recently extended these incentives to 2035. Streamlining the municipal government's approval

<https://iea.blob.core.windows.net/assets/de9dea13-b07d-42c5-a398-d1b3ae17d866/EnergyandAI.pdf>

Conflicts of usage: water



Steam rises above the cooling towers in The Dalles data center in Oregon. These plumes of water vapor create a mist at dusk. Google photo

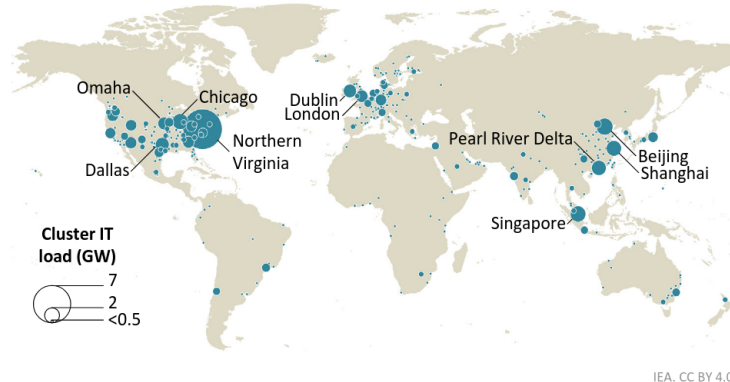
By [Mike Rogoway | The Oregonian/OregonLive](#)

Google's water use in The Dalles has nearly tripled in the past five years, and the company's data centers now consume more than a quarter of all the water used in the city.

That's according to records released this week [after the city settled a lawsuit against The Oregonian/OregonLive](#) and agreed to hand over data on Google's water consumption. The company's water use is poised to

<https://www.oregonlive.com/silicon-forest/2022/12/googles-water-use-is-soaring-in-the-dalles-records-show-with-two-more-data-centers-to-come.html>

Conflicts of usage: electricity



IEA. CC BY 4.0.

*Data centres are often located in large clusters,
potentially creating challenges for local electricity systems*

Notes: GW = gigawatt. We define a data centre cluster as a group of data centres located within 100 km of each other. The ten largest clusters have been named. The Pearl River Delta encompasses the combined capacity of Guangzhou, Shenzhen and Hong Kong (China).

Source: IEA analysis based on data from OMDIA (2025).

Conflicts of usage: electricity (Marseille, 2022)



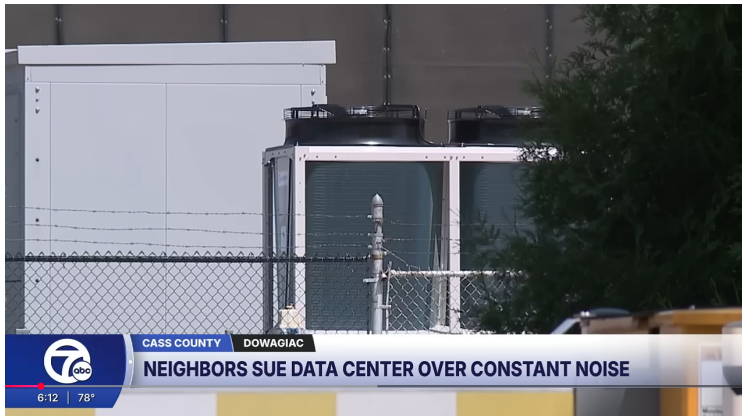
Faire un don

En outre, un des problèmes majeurs réside dans l'opacité qui entoure la réservation de puissance électrique des *data center*. Pour fonctionner, ils bloquent auprès de RTE et d'Enedis un stock d'électricité dont ils n'utiliseront finalement qu'une partie. Ce stock sert à s'assurer qu'aucune coupure d'électricité ne vienne empêcher le fonctionnement en continu des serveurs.

Si les opérateurs publient la réserve d'électricité des *data center*, ils en taisent leur consommation réelle, qui est considérée comme « *un secret d'affaire* », souligne Clément Marquet, chercheur au Centre de sociologie de l'innovation des Mines Paris-PSL. Pour lui, ce manque de transparence participe à

<https://reporterre.net/A-Marseille-la-demesure-des-data-centers>

Some other issues, including: noise



<https://www.youtube.com/watch?v=9wDr2dec474>

See, also: https://www.reddit.com/r/interestingasfuq/comments/1t7293k/this_is_the_sound_a_data_center_makes_around_the/?share_id=VspPWdjZYw330GM23sZtx&utm_name=ioscss

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To finish

Why is AI concerned with mining?

Medium

Search

Write

What goes into making a GPU?

GPUs are silicon layered with tantalum and palladium transistors and capacitors for better storage on a smaller chip, and RAM cards are made from a dizzying array of chemicals and metals, including copper, boron, cobalt, and tungsten2.

<https://medium.com/@vinaysambana1/gpu-graphics-processing-unit-b689219b3a54>

What is rare earth?



<https://www.youtube.com/watch?v=1iNpON9ckTg>

Mining destroys landscape and life (here Cobalt, in Congo)



Image: Simon Dawson/Bloomberg



<https://www.moneyweb.co.za/mineweb/glencore-to-reopen-one-of-worlds-biggest-cobalt-mines-in-congo/>

Mining pollutes: here gold mining (mercury, arsenic, cyanide)



<https://goldture.com/mining/sustainability/water-pollution-and-toxic-runoff/>

Metrics?

Abiotic Depletion Potential (ADP):

assesses the use of fossil minerals and raw materials. The term “abiotic resources” refers to non-living resources such as soil, water, air and minerals.

Unit: This indicator is expressed in kg antimony equivalents (kgSbeq). Antimony (symbol Sb) is the chemical element used as a reference unit to quantify raw material consumption in a life cycle assessment.

Some studies differentiate between impacts related to mineral resources (ADPe or ADPelement) and those related to fossil resources (ADPf or ADPfossils)

<https://boavizta.org/en/blog/empreinte-de-la-fabrication-d-un-serveur>

ADP > 1 means the resource is rarer than Antimony

ADP: some examples

Substance	ADP (calculé en éq. Sb)
Antimoine	1
Aluminium	1.E ⁻⁸
Cadmium	0,33
Cuivre	0,00191
Or	89,5
Indium	0,00903
Fer	8,43. E ⁻⁸
Platine	1,29
Argent	1,84
Titane	4,4. E ⁻⁸
Uranium	0,00287

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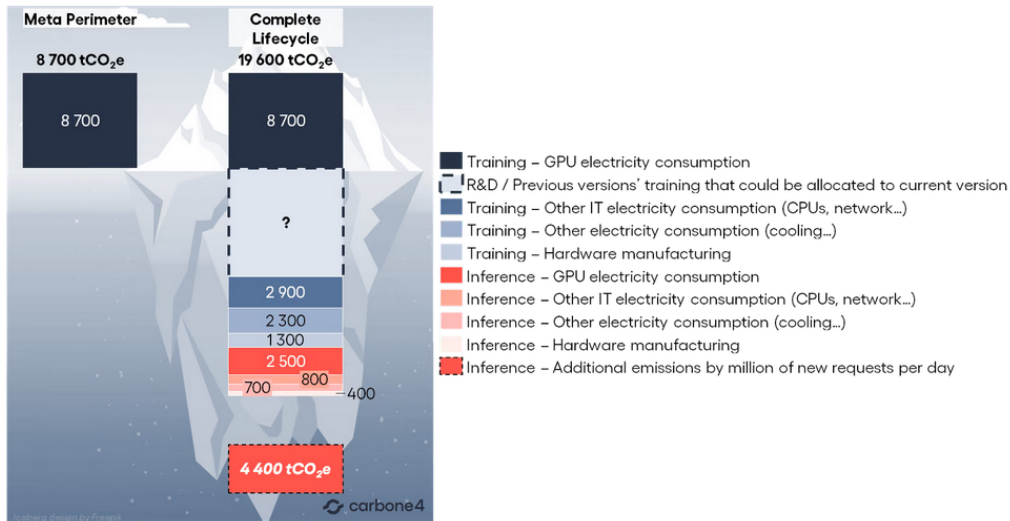
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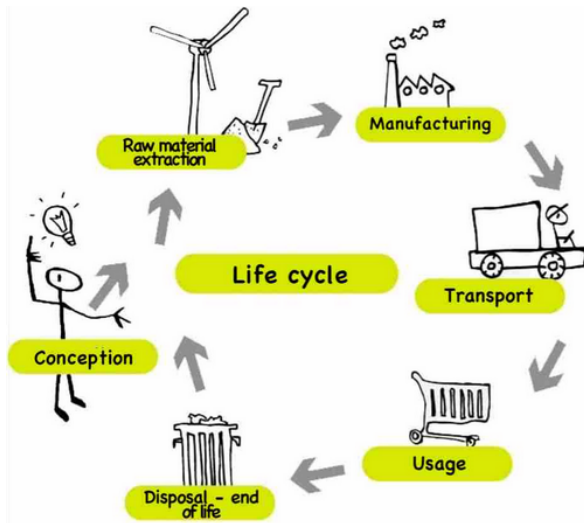
To finish

Example: Meta – but still a lot missing



<https://carbone4.com/en/articles/generative-ai-generating-climate-change>

Life Cycle Analysis (LCA)

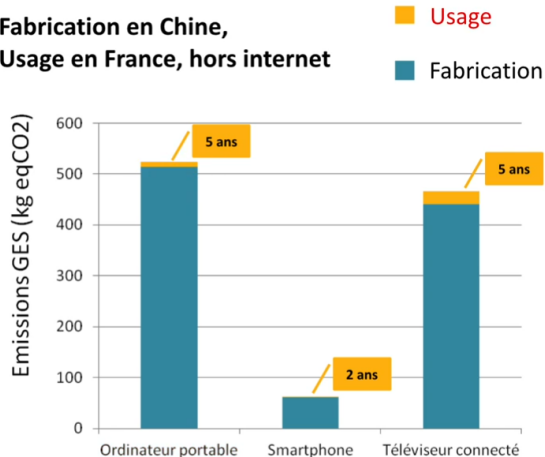


<https://boavizta.org/en/blog/empreinte-de-la-fabrication-d-un-serveur>

Life Cycle Analysis (LCA): the impact of production vs usage

Françoise Berthoud - Ecoinfo - 2018

**Fabrication en Chine,
Usage en France, hors internet**



<https://www.youtube.com/watch?v=b8yL-ikvszE>

Example: Mistral's LCA (Mistral Large 2 Model)

		GHG Emissions	Water Consumption	Materials Consumption
				
INFRASTRUCTURE	1 Model conception Download and storage of training data, developers' laptops embodied impacts and power consumption	<1%	<1%	<1%
	2 Datacenter construction Building and support equipment manufacturing	<1%	<1%	1.5%
	3 Hardware embodied impacts Server manufacturing transportation and end-of-life	11%	5%	61%
COMPUTING	4 Model training & inference Power and water use of servers and support equipment	85.5%	91%	29%
	5 Network traffic of tokens Transfer of requests to inference clusters and responses back to users	<1%	<1%	<1%
USAGE	6 End-user equipment Embodied impacts and power consumption	3%	2%	7%
	7 Downstream 'enabled' impacts Indirect impacts that result from the product's use	N/A	N/A	N/A

Full development life cycle of Moshi, a speech-to-text model by Kyutai

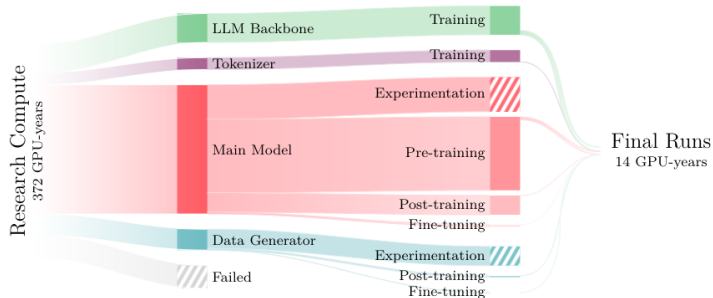


Figure 1: **From research to final compute.** *Research Compute* is split among individual model components and their respective training phases. *Failed* reflects the cost of failed experiments, and *Experimentation* gathers early versions that differ significantly from the definitive architecture and training scheme choices for specific components. *Final Runs* isolates the compute of training only one definitive version of each model component.

[López-Rauhut et al., 2026]
<https://arxiv.org/pdf/2604.11154>

What didn't we talk about?



E-Waste: “only 20% is documented to be collected and properly recycled”

Françoise Berthoud - Ecoinfo - 2018



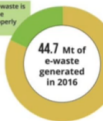
Taux de collecte

2



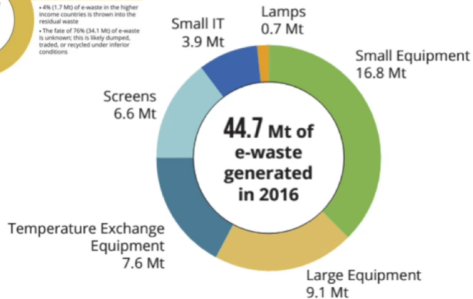
Les Déchets électroniques

20% (8.9 Mt) of e-waste is documented to be collected and properly recycled



80% (35.8 Mt) of e-waste is not documented

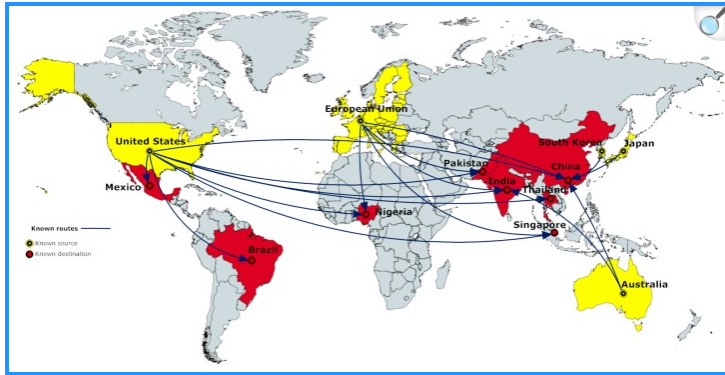
- 4% (1.7 Mt) of e-waste in the higher income countries is thrown into the residual waste
- The fate of 76% (34.1 Mt) of e-waste is unknown; this is likely dumped, traded, or recycled under inferior conditions



The global e-wastemonitor –2017, United Nations University.

<https://www.youtube.com/watch?v=b8yL-ikvszE>

Illegal e-waste: "from economically and socially developed regions to countries with significantly lower levels of overall development"



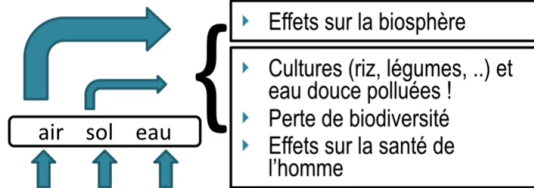
Known routes of illegal e-waste trade (Figure designed by the authors using data by the University of Northampton, not dated (n.d.), cited in Lungdren's report [9]).

<https://pmc.ncbi.nlm.nih.gov/articles/PMC4997475/figure/ijerph-13-00789-f001/> [L et al., 2016]

Illegal e-waste implies pollution

Françoise Berthoud - Ecoinfo - 2018

Pollution



2

- ▶ Polluants organiques persistants
- ▶ Métaux lourds (cuivre, nickel, zinc, étain, plomb, arsenic, gallium, germanium, indium, mercure, sélénium, thallium) : non dégradable et bio-accumulables
- ▶ Phtalates (issus des plastiques) : bio-accumulables, persistants
- ▶ Solvants , agents tensio-actifs (bioamplification), composés chimiques perfluorés, dioxine, furane
- ▶ Etc.

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Can AI help solving the problem?

News from Google

Innovation & AI ▾

Products & platforms ▾

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Accelerating climate action with AI

Nov 20, 2023
5 min read

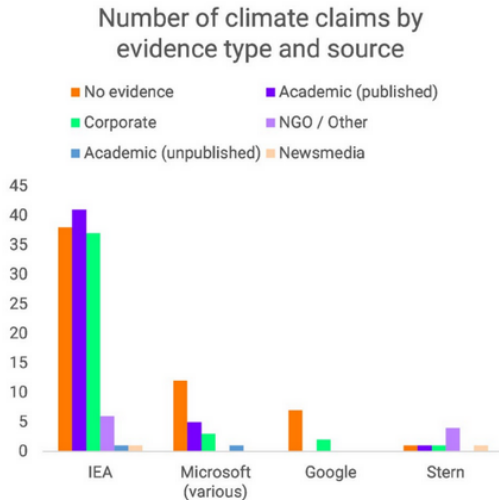
AI has the potential to mitigate 5-10% of global greenhouse gas emissions according to our new report with Boston Consulting Group.

Yossi Matias
VP Engineering & Research
and Crisis Response Lead

Kate Brandt
Chief Sustainability Officer,
Google

<https://blog.google/company-news/outreach-and-initiatives/sustainability/report-ai-sustainability-google-cop28/>

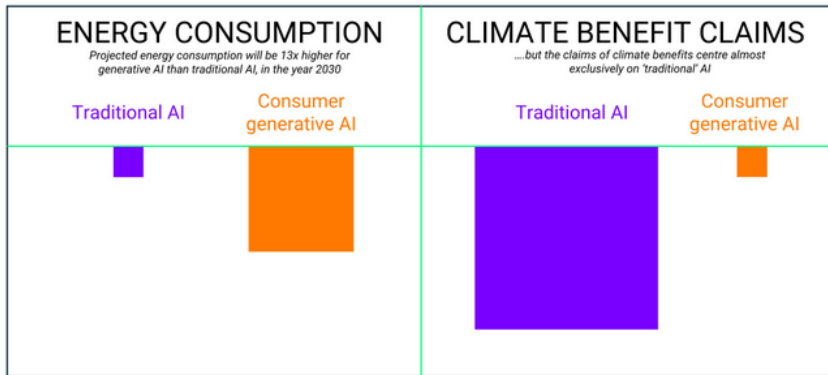
Which sources for these types of claims?



https://drive.google.com/file/d/12l1W4W25b-_ff6yFNJABkfal9_9oevxe/view/

Which AI?

analysis of 8 sources, 154 claims of climate benefits for AI applications

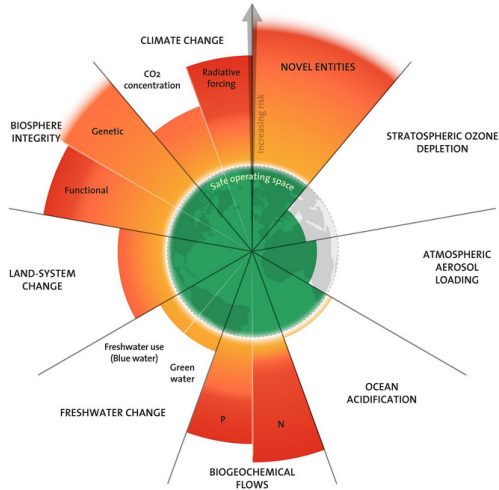


<https://ketanjoshi.co/2026/02/17/big-tech-greenwashing-report/>

Conclusion

- ▶ Remember there is only one earth (and you're living on it)
- ▶ Use the appropriate tool for your usage:
 - ▶ Which tool to count words in a document?
 - ▶ Which tool to tokenize a document?
 - ▶ Which tool to write your thesis?

A lot more to research



The 2025 update to the Planetary boundaries. Licensed under CC BY-NC-ND 3.0. Credit: "Azote for Stockholm Resilience Centre, based on analysis in Sakschewski and Caesar et al. 2025".

<https://www.stockholmresilience.org/research/planetary-boundaries.html>

Introduction

What we talk about (a bit)

What we don't talk about (enough)

What we missed

Can AI help solving the problem?

To finish

WYHTR: What You Have To Remember



- ▶ Electricity and water consumption (big picture)
- ▶ Datacenters and extraction (basics)
- ▶ Lifecycle analysis

Exercise

Find which big tech companies have reached their clean energy targets (claim is col4)

Table 2.2 ▶ Emissions reduction and clean energy targets of corporate data centre operators

Company	Estimated data centre capacity (MW)	Net zero emissions target year	Corporate clean, green or renewable electricity target*	Current share	Hourly matching target*
Meta	9 780	2030	100% renewable since 2020	100%	
Google	8 960	2030	100% renewable since 2017	100%	100% by 2030
Amazon	7 660	2040	100% renewable since 2023	100%	
Microsoft	6 970	2030	100% renewable by 2025	100%	100% by 2030

<https://iea.blob.core.windows.net/assets/de9dea13-b07d-42c5-a398-d1b3ae17d866/EnergyandAI.pdf>

Going further

- ▶ La transition est-elle un leurre ? (FR, 2025) Jean-Baptiste Fressoz (from 11:20):
<https://www.youtube.com/watch?v=gMPrpHClbas>

-  L, E., A, M., and KP, T. (2016).
Quantifying the effect of macroeconomic and social factors on illegal e-waste trade.
[Int J Environ Res Public Health, 13\(8\):789.](#)
-  Li, P., Yang, J., Islam, M. A., and Ren, S. (2025).
Making ai less 'thirsty'.
[Commun. ACM, 68\(7\):54–61.](#)
-  López-Rauhut, M., Landrieu, L., Aubry, M., and Ligozat, A.-L. (2026).
Environmental footprint of genAI research: Insights from the moshi foundation model.
[Transactions on Machine Learning Research.](#)
-  Scanlan, M. K., McCauley, P., and Sutherland, C. (2025).
Powering progress or peril? the hidden environmental costs of data centers and ai.
[SSRN.](#)