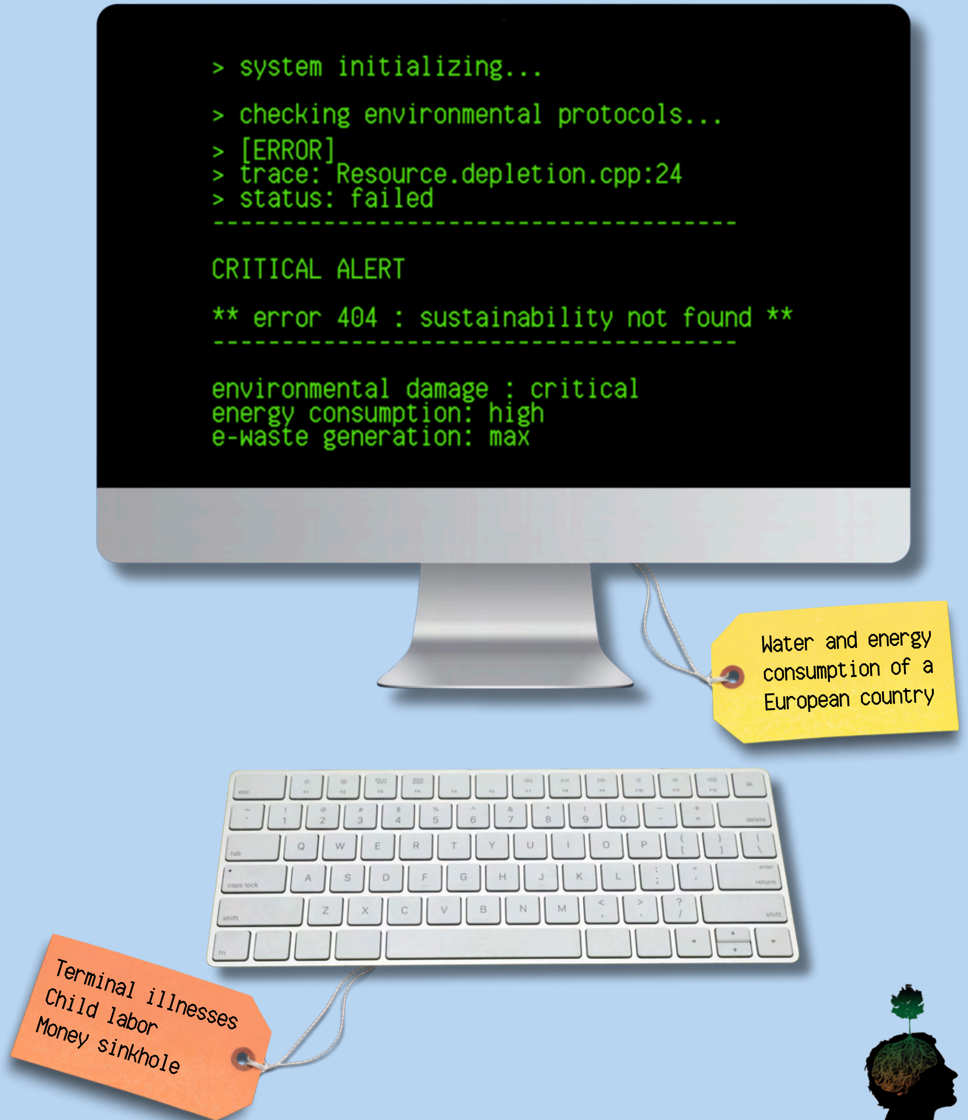
>> E-MPACT

>> Digital world, real footprint



RESILIENT G.A.P.

E-mpact

Digital world, real footprint

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Initiative realised with the contribution of Politecnico di Milano

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Contents

1 Introduction

Ever wonder what it takes to build, run, and trash your devices? This fanzine uncovers the social and environmental costs behind our everyday technology. We trace the hidden path from mining raw materials and powering data centers to the end-of-life and disposal of every gadget that becomes outdated.

In fact, the word technology can encompass almost everything that surrounds us and has in common the fact of appearing old, from a past era compared to the latest novelty, the one that will finally make our lives easier.

So you shouldn't be surprised if, given the title, you will start reading about mining villages where electricity is still a mystery, that planned obsolescence is as old as the first light-bulb, that data centers crave land and water like the farmers of the past and that when everything becomes waste the dear old landfills are still among us.

Since the life-cycle of our electronics is a messy loop, there is no strict rule for reading about it: feel free to skip pages and go through chapters in whatever order you prefer. You might even start from the end to get a glimpse into the AI bubble and our future relationship with technology.

This fanzine will age too: read it quickly to discover the solutions of the present, before they invent better ones.

2 Production Phase

A Periodic Table in Your Palm

We are so used to seeing electronic devices daily that we almost forgot how complex and sophisticated they are: what could appear as a simple phone is, in reality, an ensemble of more than half the elements of the periodic table.[1] Among those, minerals are the biggest fraction in terms of weight, mainly because batteries are the heaviest components in many devices and rely on specific materials to guarantee high performances.

The main ones to be mentioned are certainly: copper, for circuitry and wiring, aluminium, for housing and heat dissipation, lithium, as charge carrier, and cobalt, to increase cathodes' stability.[2]

They all have a second common aspect, other than being fundamental for smartphones to work: they put concerning environmental and social impacts on almost every place in which they are extracted. Among those, one that really stands out is the Democratic Republic of Congo (DRC): the region of Katanga, in the southeastern part of the country, is rich in many valuable metals which have been exploited multiple times throughout history. Even though these mining operations have been going on for centuries, there's never been a substantial improvement in working and living conditions: people providing essential minerals for electrical devices live in villages where electricity is still yet to come.

The Toxic Breath of Cobalt Processing

At present time, DRC is the main country for Cobalt extraction with 76.6% of global production in 2024.[3] In nature, it's commonly bounded with copper, but the two can be easily separated by

[1] Mauro Cordella, Felice Alfieri, and Javier Sanfelix. "Guidance for the Assessment of Material Efficiency: Application to Smartphones". In: *National Library of Medicine* (Jan. 2020). DOI: 10.2760/037522.

[2] Jane E. Jenness et al. *A world of minerals in your mobile device.* 2016. DOI: 10.3133/gip167. URL: https://doi.org/10.3133%2Fgip167.

[3] **canada**.

using sulphuric acid. This does not mean it's a process lacking in dangerous outcomes: the byproduct is a gas made of hydrofluoric acid, sulphur dioxide and sulphuric acid that has no economic value, hence, processing facilities are not interested in containing it. People living nearby have no chances of protecting themselves from this very thin powder that poses everyone under extreme health hazards, including permanent organ damage and potential fatality.[4]

Impacts on the whole population continue further: every portion of land has the potential to become a new mining concession as soon as enough concentrations of valuable materials are found. If the area is inhabited, negative consequences due to land use change and ecosystem fragmentation are inevitable. Furthermore, when human settlements are also present, people are displaced, with little or no possibility to assert their rights.[5]

The Artisanal Trap: A Cycle of Invisible Labour

Moving to direct consequences on workers the situation worsens. Companies, in every stage of the supply chain, declare to only use raw materials extracted in compliance with workers' right, paying attention to safety, fair wages and avoiding child labour. The current state is a lot different: artisanal and small-scale mining is contributing for at least 30% of global production of cobalt, furthermore artisanal miners represent 90% of the total mining workforce in the world.[6] The term artisanal is referring to working conditions in which the almost entirety of the activities is carried out with manual labour, with the lack of technological and safety equipment; everything is done with no formal agreement on wages and health insurance. All these factors make it almost impossible for parents to earn enough to provide for the entire family and

[4] Siddharth Kara. "Cobalt red: How the blood of the Congo powers our lives". In: New York: St. Martin's Press, 2023, p. 124.

[5] Ibid.

[6] The Artisanal and Small-scale Mining Knowledge Sharing Archive. *World Maps of Artisanal and Small-scale Mining*. `https://artisanalmining.org/Inventory/`. 2025.

injuries are more likely to happen due to unsafe conditions; hence, it's very common to see children having to work at a very young age whenever an older family member is not able to do so any more. This creates a closed loop of poverty: parents are not able to send their offspring to school for a sufficient amount of time so that they would get access to better jobs; their only chance is to become informal miners as well and be, one day, incapable of sending their own kids to school. Low wages guarantee an immediate economic advantage for mines' owners and the certainty of having a never-ending workforce for the years to come.[7]

Corporate Window-Dressing and the Supply Chain Blur

Thanks to very few steps between extraction and production all these issues stay in the shadows, so that both companies and consumers can live with no worries whatsoever. Everything starts from the artisanal miners working in the very same concessions where big mining companies are operating. Some of them allow manual labour because it's economically more convenient and they are not concerned with making it less obvious. In fact, public institutions are among those taking advantage of this situation; hence, these extraction activities are not only tolerated but even guaranteed and protected.

Of course, there are also mining areas where everything is carried out with industrial and modern technologies. The primary risk for stakeholders is public exposure of the reality behind the scenes. Consequently, while the heavy machinery contributes significantly to production, they also serve as window-dressing to mask the true nature of the supply chain. Those new and up to date plants are what the rest of the world needs to see, believing that all minerals are processed in that way.

To make this trick happen other two types of informal workers are needed. Small traders, that buy ores directly from artisanal miners, and depot' managers, who buy it from them, respectively

[7] Kara, "Cobalt red: How the blood of the Congo powers our lives".

called negotiants and comptoirs. The latter will sell the very same materials to mining companies and processing facilities that in turn will process raw materials all together, making it impossible to trace them back and distinguish between artisanal and industrial production.[8]

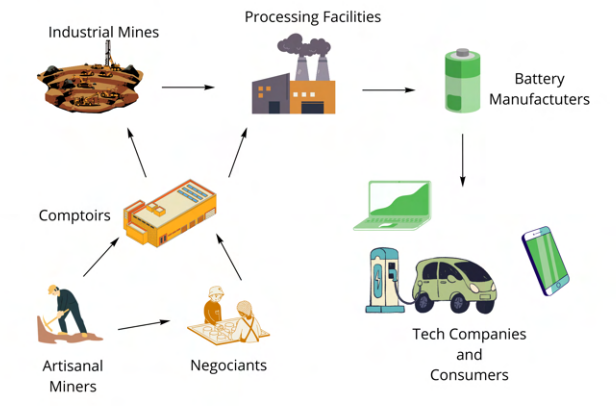

Figure 1: The general supply chain framework[9]

At this point, cobalt is ready to be sold to battery manufacturers that can claim to never have bought anything coming from artisanal mining. From here forward, a second component is necessary: simplifying, modern ion batteries are made of an anode and a cathode, and the latter is commonly made of lithium cobalt oxide.[10]

The Thirst of the Lithium Triangle

The introduction of lithium in this story opens to a new negative impact: intensive water consumption in regions where it's all but abundant. Chile and Australia account for 50% of 2024 global production and together with Argentina they represent almost

[8]Kara, "Cobalt red: How the blood of the Congo powers our lives".

[9]Ibid.

[10]University of Washington Clean Energy Institute. *Lithium-Ion Battery*. `https://artisanalmining.org/Inventory/`. 2023.

70% of the world's known reserves of this metal.[11]

Lithium is not found as a native element in nature; rather, it occurs within mineral compounds, typically in saline brines or hard-rock ores.[12] In Chile, Argentina and Bolivia it's commonly found as brine in underground wells. To extract a sufficient quantity it's necessary to pump out huge volumes of water; subsequently, large ponds are required to obtain highly concentrated lithium salts via a solar evaporation process that typically lasts for 1-2 years.[13]

The biggest concern is not time inefficiency, but the fact that around 90% of the water uptaken is lost upon evaporation and it's removed from the hydrogeological cycle of the region.[14]

Figure 2: Evaporation ponds[15]

[11] Government of Canada. *Cobalt facts*. https://natural-resources.canada.ca/minerals-mining/mining-data-statistics-analysis/minerals-metals-facts/cobalt-facts. 2026.

[12] Wikipedia contributors. *Lithium*. Wikipedia, The Free Encyclopedia. 2024. URL: https://en.wikipedia.org/wiki/Lithium.

[13] Lithium Harvest. *Lithium Extraction Methods*. Lithium Harvest. 2025. URL: https://lithiumharvest.com/knowledge/lithium-extraction/lithium-extraction-methods/.

[14] Rowan T. Halkes et al. "Life cycle assessment and water use impacts of lithium production from salar deposits: Challenges and opportunities". In: *Resources, Conservation and Recycling* 207 (2024). DOI: 10.1016/j.resconrec.2024.107554. URL: https://doi.org/10.1016/j.resconrec.2024.107554.

[15] Nuno Luciano. *Copy of - 2021-02-11.jpg*. https://www.flickr.com/photos/nunoluciano/51147756272/. 2021.

Water resources are depleting as lithium demand keeps increasing: ponds and wetlands are under threat and so are ecosystems and local communities relying on the very same water in one of the most arid regions on the planet. Intuitively, the larger the surface the higher the evaporation rate: mining companies are grabbing big portions of land, again supported by public institutions and with little or no interest in people's opinions and rights.[16]

In Australia instead, they extract lithium directly from rock to save water; the downside is that it's an extremely energy intensive process and has a carbon footprint five times higher.[17] More efficient and sustainable processes are available, but not yet largely used in any part of the world.

Copper and Aluminium: Extraction and Production

Copper and aluminium are fundamental materials for modern industries and play a key role in the energy transition, especially because of their excellent conductivity and wide range of applications in sectors such as electronics, construction, and renewable energy systems. However, their production is complex and resource-intensive, involving multiple stages that have significant environmental, social, and economic impacts.

Copper production begins with the extraction of ore, mainly chalcopyrite, through open-pit or underground mining. Open-pit mining is cheaper and more efficient but has a much greater environmental impact, as it requires removing vast amounts of land and vegetation, leading to habitat destruction and landscape alteration. Underground mining, on the other hand, is less invasive on the surface but more expensive and technologically demanding. In both cases, mining activities cause serious damage to ecosystems and biodiversity.

[16] Charis McGowan. "'The source of all life is here': plan to mine lithium in Chilean salt flat sparks fears of water scarcity". In: *The Guardian* (Jan. 1, 2026). URL: `https://www.theguardian.com/global-development/2026/jan/01/chile-lithium-rio-tinto-fears-colla-indigenous-water-atacama-ecosystem`.

[17] Omer Amar. *Lithium's Environmental Impact: Calculated and Explained.* `https://www.arbor.eco/blog/lithium-environmental-impact`. 2025.

After extraction, the ore is crushed and ground into a fine powder to facilitate the separation of copper from impurities. The next step is flotation, a process that uses water and chemical reagents to isolate copper minerals from the rest of the material. This stage is essential but also resource-intensive, particularly in terms of water use. The resulting concentrate is then subjected to smelting and refining at very high temperatures to obtain pure copper, processes that require large amounts of energy.

Aluminium production follows a similarly impactful path. It starts with the extraction of bauxite, usually through open-pit mining, which leads to deforestation, soil degradation, and loss of biodiversity. Once extracted, bauxite is transported to processing plants where it undergoes the Bayer process, in which it is treated with caustic soda at high temperatures to separate alumina from impurities. This stage produces red mud, a highly toxic and difficult-to-manage waste.[18] The alumina is then converted into aluminium through the Hall-Héroult process, an electrolysis method that requires enormous amounts of electricity.

One of the most important companies in bauxite mining is the Compagnie des Bauxites de Guinée (CBG), located in the Boké region, particularly in the Sangarédi deposit, in Guinea. Over the years, CBG has become one of the world's largest exporters of high-quality bauxite, with an annual production of over 16 million tons. This activity has significantly contributed to Guinea's state revenues, making mining a key part of the country's economic development.[19][20]

[18] Matic Jovičević-Klug et al. "Green steel from red mud through climate-neutral hydrogen plasma reduction". In: *Nature* 625.7996 (Jan. 2024), pp. 703–709. ISSN: 1476-4687. DOI: 10.1038/s41586-023-06901-z. URL: https://doi.org/10.1038/s41586-023-06901-z.

[19] Mining Technology. *CBG Bauxite (Aluminium Ore) Mining Operations*. https://www.mining-technology.com/projects/cbg-bauxite/?utm_source=&utm_medium=19-20482&utm_campaign=recommended-articles-pi&cf-view&cf-view. 2026.

[20] Guinea Mining Insights. *Compagnie des Bauxites de Guinée (CBG)*. https://guineamininginsights.com/mining-companies/compagnie-des-bauxites-de-guinee-cbg. 2026.

Mineral's real price: Water, Energy and Pollution

Both copper and aluminium production release harmful substances into the environment. Copper smelting produces sulphur dioxide (SO_2), which contributes to acid rain, while fine particles and heavy metals such as arsenic and lead are dangerous for human health. Mining also generates large quantities of toxic waste, including tailings in copper extraction and red mud in aluminium production, which can contaminate soil and water if not properly managed. Workers and nearby communities are exposed to serious health risks, including respiratory and chronic diseases.[21]

Water and energy consumption are also major concerns. Copper processing requires extremely high volumes of water, up to 500,000 litres per ton, and the water used is often contaminated with heavy metals and acidic substances, causing acid mine drainage and damaging aquatic ecosystems. At the same time, both copper and aluminium production are highly energy-intensive, especially during smelting and electrolysis, often relying on fossil fuels. This results in significant greenhouse gas emissions: producing one ton of copper generates about 3–5 tons of CO_2, along with additional emissions from heavy machinery used in mining operations.[22]

Mining activities also have important social consequences. In many cases, land becomes unusable for agriculture due to pollution and physical transformation, forcing local communities to abandon traditional livelihoods. As a result, populations often become economically dependent on mining activities, losing autonomy and long-term stability.

The Copper Crisis

However, while demand is growing quickly, supply is struggling to keep up. The problem is not only production, but also the

[21] Farmonaut. *The Critical Relationship Between Metals and Water.* `https://farmonaut.com/mining/copper-and-water-zinc-and-water-copper-and-gold-uses`. 2025.

[22] Sustainability in mining blog - Resourceful Paths Laurie Reemeyer. *What drives GHG emissions from copper production?* `https://www.resourcefulpaths.com/blog/2016/11/23/what-drives-ghg-emissions-from-copper-production`. 2016.

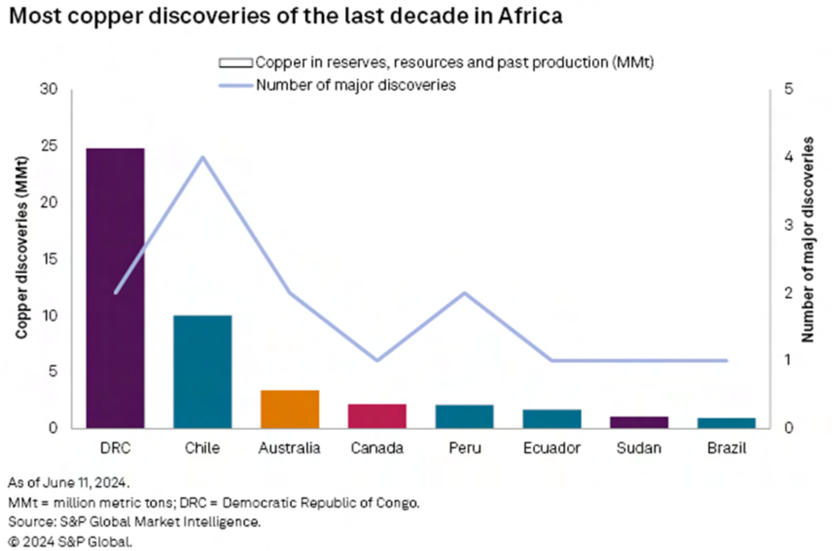

Figure 3: [24]

availability of copper, which is becoming more limited and harder to obtain.[23]

Moreover, most current deposits are of lower quality. Out of 144 deposits still under development, only 16 exceed 10 million tons, a size needed to support a large mine for at least 20 years. Of these, only 5 have a grade above 1%, while most have concentrations below 0.5%. This means more and more rock must be extracted to obtain the same amount of copper.

Even large mines are showing signs of decline. Chile, which produces about 30% of the world's copper, is a clear example: the Chuquicamata[25] mine has seen a 40% drop in production, and

[23] Sean DeCoff. *Major Copper Discoveries*. `https://www.spglobal.com/market-intelligence/en/news-insights/research/major-copper-discoveries`. 2024.

[24] Ibid.

[25] Mining Technology. *Copper, Codelco & Chile*. `https://www.mining-technology.com/features/featurecopper-codelco-chile-4939147/?utm_source=&utm_medium=19-26297&utm_campaign=recommended-articles-pi`. 2016.

the Escondida mine, the largest in the world, has also experienced significant reductions.[26]

Faced with these challenges, the copper sector is moving toward more sustainable solutions. One of the most effective strategies is copper recycling, which now accounts for about 30% of global production. This reduces the need for new mining and helps protect natural ecosystems. Another promising solution is biotechnology. By using certain microorganisms, it is possible to extract copper from minerals through natural processes. These organisms can also absorb heavy metals or transform them into less toxic forms.

Recycling is the Key to Sustainability

In recent years, several efforts have been made to reduce the environmental impact of aluminium production. Among the most innovative solutions is the recovery of red mud, a toxic waste from the Bayer process, which can be reused to improve soil fertility or to produce alternative materials such as cement and bricks.

However, the most effective solution remains aluminium recycling. This material can be reused infinitely without losing its properties, thus reducing the need to extract new bauxite and limiting deforestation and land consumption.[27][28]

If you stick with us, you will find our more about it in chapter 4!

[26] BHP. *Escondida.* `https://www.bhp.com/what-we-do/global-locations/chile/escondida`. 2026.

[27] International Aluminium. *Recycling.* `https://international-aluminium.org/work-areas/recycling/`. 2026.

[28] Mining Technology. *Rio Tinto forms aluminium recycling JV with Giampaolo.* `https://www.mining-technology.com/features/featurecopper-codelco-chile-4939147/?utm_source=&utm_medium=19-26297&utm_campaign=recommended-articles-pi`. 2023.

The Cloud that Dries Up the Land

Now that we have assessed the impact of producing the hardware, it is time to learn what happens when you have these devices in your hand or on the top of your desk. Rest assured that the big deal is not about charging your phone or powering your computer, but it is happening kilometres away from you, maybe even across another ocean in huge establishments that might be bigger than your home-town: the so-called data centers.

What is a Data center?

You've probably never seen one, but your entire digital life lives inside of them. When we talk about the "Cloud," we are not talking about something ethereal or weightless. We are talking about massive, windowless warehouses filled with rows upon rows of humming servers, routers, and switches. The data centers: the physical heart of our modern existence. They are the engine rooms of the 21st century, powering everything from your late-night streams and crypto mining to the complex "thinking" required by AI.

Figure 4: Aerial view of the Google Data Center in Council Bluffs, IA[29]

These buildings are essentially large-scale libraries of processing power, where data flows 24/7 through a hidden nervous system

[29]Luciano, *Copy of - 2021-02-11.jpg.*

of fibre-optic cables buried deep underground. This network connects one center to the next at enormous speeds, allowing information to navigate across the globe in milliseconds. While the internet feels invisible, it is held together by the hard work of approximately 500,000 people who were employed to keep these facilities running in 2023.[30] It is an enormous task, especially considering that in 2024 alone, we created, captured, and copied about 149 zettabytes of information.[31] To put that in perspective, a single zettabyte is equal to a trillion gigabytes.

Not all data centers are created on equal scale. While small-scale local centers handle about 10% of the world's digital load, and large company facilities manage another 20% to 30%, the real giants are the "Hyperscale" data centers. These massive complexes account for a staggering 60% to 70% of all data processing.[32] These are the specialized hubs where AI truly lives. Because AI requires such intense, non-stop calculation, it has migrated toward these mega-warehouses that can provide the energy and space needed to house the most powerful chips on earth.

Why AI Changed the Game

Before the AI boom, data centers were already busy, but AI has turned the volume up to a scream. Traditional cloud computing, like storing a photo or sending an email, is relatively low-impact. AI, however, plays in a different league. It doesn't just store data; it "processes" it through trillions of connections, generating im-

[30] Miguel Yañez-Barnuevo. "Data Center Energy Needs Could Upend Power Grids and Threaten the Climate". In: *Environmental and Energy Study Institute* (Apr. 2025). URL: `https://www.eesi.org/articles/view/data-center-energy-needs-are-upending-power-grids-and-threatening-the-climate`.

[31] Net Zero Insights. *The Environmental Cost of Data Centers*. `https://netzeroinsights.com/resources/data-centers-environmental-cost/`. 2025.

[32] Lorraine De Montenay et al. "Prospective d'évolution des consommations des data centers à court, moyen et long terme de 2024 à 2060". In: *La librairie ADEME* (2026). URL: `https://librairie.ademe.fr/energies/8910-10774-prospective-d-evolution-des-consommations-des-data-centers-a-court-moyen-et-long-terme-de-2024-a-2060.html#product-features`.

[33] Ringmast4r. *Global-Data-Center-Map*. `https://github.com/Ringmast4r/Global-Data-Center-Map`. 2026.

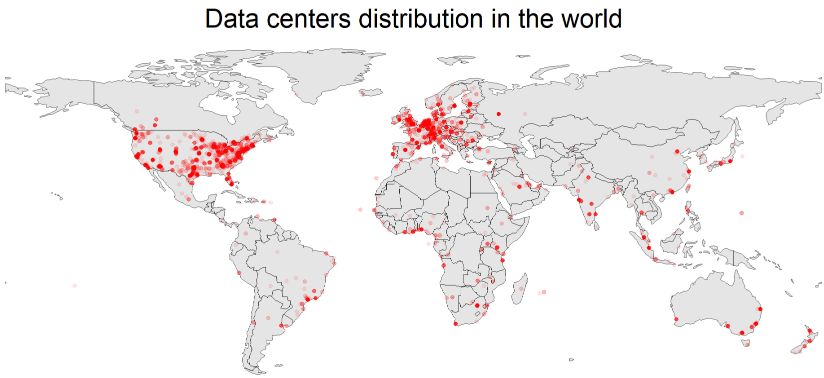

Figure 5: Heat map of data centers location[33]

mense friction and energy demand. This connection is why these quiet, gray buildings have suddenly become the center of a massive environmental debate where our digital ambitions collide with the reality of our planet's resources.

A Bottomless Pit of Energy Consumption

Data centers require electricity to operate. Figure 6 shows how the bill is split. 80% of the energy consumed is due to the computing itself and the cooling of the infrastructure.

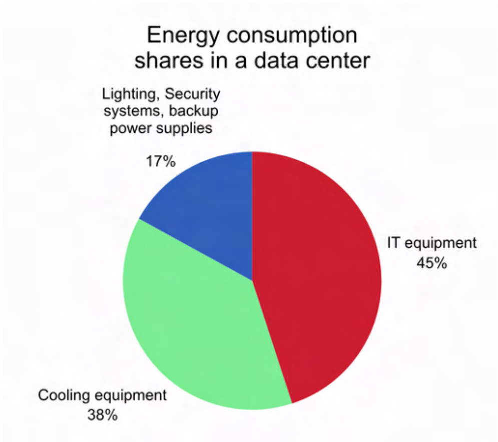

Figure 6: [34]

The use of data centers has increased in recent years and this trend is expected to accelerate, particularly in:

[34] Yañez-Barnuevo, "Data Center Energy Needs Could Upend Power Grids and Threaten the Climate".

- AI
- Blockchain
- Machine to machine (M2M) communications[35]

As demand for computing power continues to grow, the number of data centers is expected to skyrocket, as will their electricity consumption. Global energy demand in developed countries has grown by 2% since 2023, having remained flat since the subprime crisis in 2008. In the US, which hosted 37% of all data centers as of 2024, the electricity demand of data centers could multiply by four by 2030.[37]

Did you know ?		
Energy for 3 LLM queries	≡	Your phone battery[36]

Burn, Baby, Burn

Unfortunately, current and projected data centers are located in carbon-intensive areas (in the US, 548 gCO_2e/kWh vs an average of 369 gCO_2e/kWh), which could render most companies' and states' zero-carbon scenarios ineffective.[39]

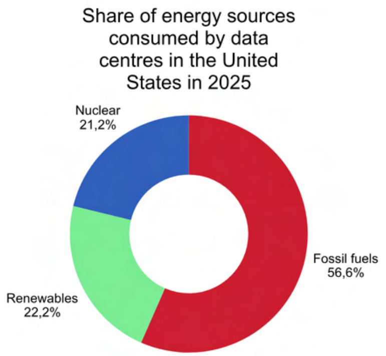

Figure 7: [38]

[35] De Montenay et al., "Prospective d'évolution des consommations des data centers à court, moyen et long terme de 2024 à 2060".

[36] Pranshu Verma and Shelly Tan. "A bottle of water per email; the hidden environmental costs of AI chatbots". In: *Washington Post* (2024). URL: `https://www.washingtonpost.com/technology/2024/09/18/energy-ai-use-electricity-water-data-centers/`.

[37] Yañez-Barnuevo, "Data Center Energy Needs Could Upend Power Grids and Threaten the Climate".

[38] Ibid.

[39] Ibid.

Growing demand for electricity is slowing the closure of coal plants and encouraging the construction of new natural gas generation plants. Indeed, the need for cheap, readily available energy could cut future investment in renewables.[40] Consequently, electricity sector emissions in the US could increase by over 56% between now and 2035.[41]

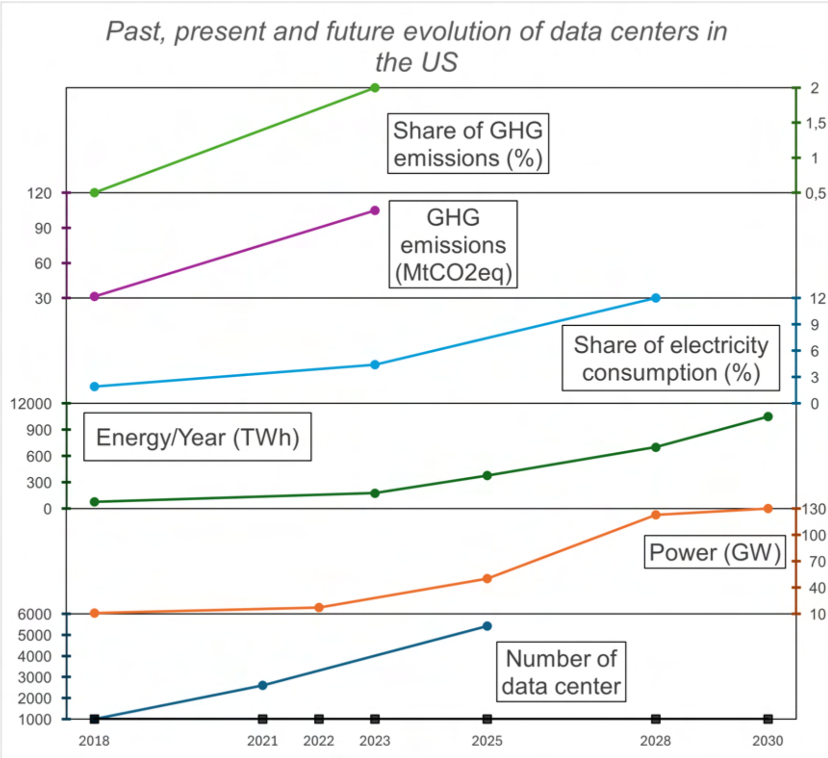

Figure 8: Aggregation of different broadcasts[42]

[40]Ben Murray and Mia DiFelice. "A No Brainer: How AI's Energy and Water Footprints Threaten Climate Progress". In: *Food & Water Watch* (2024). URL: `https://www.washingtonpost.com/technology/2024/09/18/energy-ai-use-electricity-water-data-centers/`.

[41]Yañez-Barnuevo, "Data Center Energy Needs Could Upend Power Grids and Threaten the Climate".

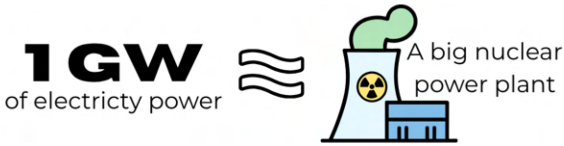

Figure 9: The order of magnitude of electricity power[43]

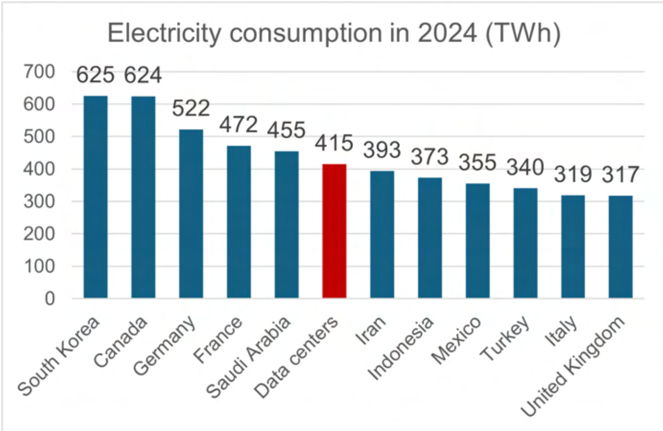

Figure 10: Data centers all together consume as much as large countries[44]

Where is this Leading Us?

The evolution of data center consumption and emissions is highly dependent on incentives or regulations from national policies. As a citizen, you have the power to influence these policies! (See Figure 11)

A Thirsty Revolution

Every time you hit "send" on a ChatGPT prompt or ask an AI to generate an image, a massive, silent machinery springs into ac-

[42] Yañez-Barnuevo, "Data Center Energy Needs Could Upend Power Grids and Threaten the Climate".

[43] Ibid.

[44] International Energy Agency. *Energy demand from AI*. `https://www.iea.org/reports/energy-and-ai/energy-demand-from-ai`. 2026.

[45] De Montenay et al., "Prospective d'évolution des consommations des data centers à court, moyen et long terme de 2024 à 2060".

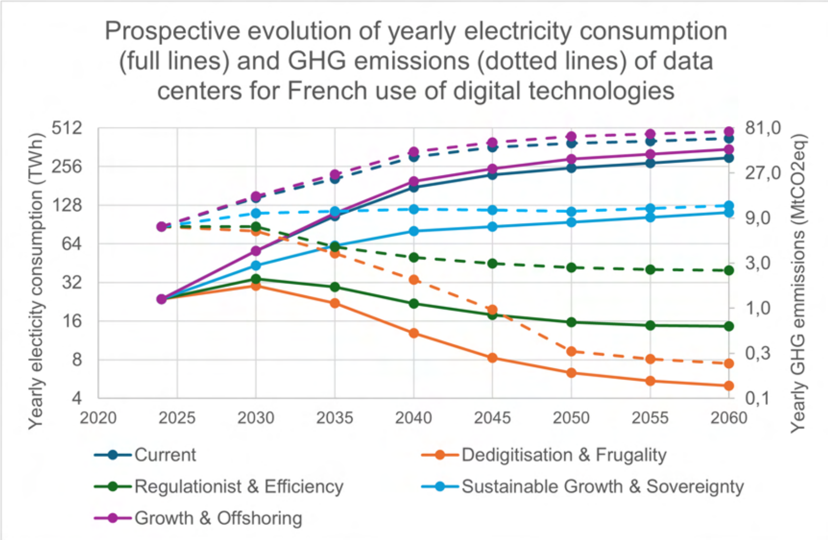

Figure 11: The carbon footprint and energy consumption of data centers depend broadly on public policies[45] (scales are logarithmic)

tion. Behind the seamless interface lies a network of data centers, essentially giant factories that convert electricity into heat. To keep these "digital brains" from melting down, they require an enormous amount of water.

You must be wondering, how much water does a single conversation cost?

Researchers estimate that **a 100-word AI prompt "drinks" roughly one bottle of water**, or about 519 millilitres.[46] While that sounds small, scale it up to millions of users, and the numbers become staggering. By 2027, global AI demand could require up to 6.6 billion cubic meters of freshwater annually,[47] which is roughly half of the United Kingdom's total yearly water usage. In the U.S. alone, data centers already consume 1,699,649,891 litres of water every day, an amount equivalent to the entire **water con-**

[46] Verma and Tan, "A bottle of water per email; the hidden environmental costs of AI chatbots".

[47] BBC World Services. *How AI uses our drinking water*. `https://www.youtube.com/watch?v=b0C56yqIkbk`. 2025.

sumption of the province of Turin.[48]

Why is AI so thirsty?

The cooling process is the chief culprit. To prevent high-performance chips from overheating, data centers use cooling towers where about 80% of the water used is boiled off and released into the atmosphere as steam.[49] Once that water evaporates, it is effectively gone from the local ecosystem, meaning it can no longer be used for local irrigation, drinking, or hygiene. Furthermore, to prevent bacteria and corrosion in the sensitive hardware, these systems often require clean, drinkable water, putting AI in direct competition with basic human needs.

The thirst of AI starts long before you type your first prompt. It is embedded in the entire lifecycle of the technology. Massive amounts of water are needed to refine raw materials and manufacture the semiconductor chips that power these models. Additionally, a significant part of consumption originates from fossil fuel energy production. In the United States, this accounted for roughly 798 billion litres in 2023, which is as much as the consumption of 9.4 million people, **roughly the population of Rome, Milan, and Turin combined**.[50]

Can We Fix It?

There is a shimmer of hope as Google, Meta, and Microsoft have pledged to be water-neutral by 2030.[51] Experts are developing new liquid cooling innovations: some are experimenting with closed-loop systems that don't evaporate water or using "waste" heat

[48] Murray and DiFelice, "A No Brainer: How AI's Energy and Water Footprints Threaten Climate Progress".

[49] Miguel Yañez-Barnuevo. "Data Centers and Water Consumption". In: *Environmental and Energy Study Institute* (June 2025). URL: `https://www.eesi.org/articles/view/data-centers-and-water-consumption`.

[50] Murray and DiFelice, "A No Brainer: How AI's Energy and Water Footprints Threaten Climate Progress".

[51] Adam Zewe. "Explained: Generative AI's environmental impact". In: *MIT News* (2025). URL: `https://news.mit.edu/2025/explained-generative-ai-environmental-impact-0117`.

from servers to warm local homes. There are even trials to move data centers to the Arctic or underwater to utilize natural cold or even to send the data centers in space. Generative AI is still very young, and while it has moved exponentially fast, we are only just beginning to learn how to minimize its impact on our planet and society.

An Annoying Neighbour

If you were deciding on the location of a new data center, would you choose a place with abundant water, or one where land and energy are cheap? Well, the most common choice is the second option: dry locations, which cause many problems.

Snickety Snake, your Water I Take 🧙‍♂️

Firstly, these areas commonly experience water scarcity, and the local population is highly critical of these new, giant neighbours that suck up vast amounts of water. In drought-stricken Arizona, data centers withdrew vast quantities of water from areas where farmers had to leave fields uncultivated and families had no access to tap water for much of 2023. Furthermore, water usage by data centers reduces water levels and affects fish and water ecosystems in the surrounding area.[52] Not only are data centers greedy for water, they are also very picky: as of 2023, nearly 80 per cent of the water consumed by Google AI data centers in the US came from drinking water sources.[53]

A Financial Burden for the Locals

Secondly, the arrival of a large new neighbour, such as a hyperscale data center, can completely destabilise existing infrastructure and local life. The large volume of wastewater produced by

[52] Murray and DiFelice, "A No Brainer: How AI's Energy and Water Footprints Threaten Climate Progress".

[53] Britney Nguyen. "Google's data centers use as much water as 41 golf courses. Here are the 10 thirstiest". In: *Quartz* (2025). URL: `https://qz.com/google-data-center-consume-water-energy-climate-change-1851760734#googles-data-centers-use-as-much-water-as-41-golf-courses-here-are-the-10-thirstiest`.

data centers can overwhelm water treatment plants, which were not designed to handle such high volumes. Water consumption increases too quickly for local facilities to handle, meaning they have to rely heavily on potable water for data centers rather than reclaimed water. For locals, the data center pushes up their water and electricity bills as demand grows and forces them to adapt their infrastructure at their own expense.[54]

And he is Noisy on Top of That?

The collective hum of servers, fans, and industrial cooling systems can exceed 80 dBA (see Figure 12).

Figure 12: Magnitude of data center noise

Chronic exposure to this level of noise is linked to sleep disturbance, hypertension, anxiety, headaches and cardiovascular risks for nearby residents. Persistent noise can force animals to change their migration patterns, disrupt their communication and alter their natural behaviours. In addition, many data centers are being built on fertile soils and in ecosystems that will never be recovered due to the concrete poured over them.[55]

Querétaro, an Archetypal Example

The situation in the Mexican state of Querétaro is not an isolated case, but rather an example of what is happening in many other areas. The semi-desert municipality of Colón has been experiencing a two-year drought, resulting in dead crops and water rationing. Meanwhile, the local government in Querétaro is offering incentives to companies to build data centers, which generally require large amounts of water to cool their servers. Microsoft, Amazon

[54]Murray and DiFelice, “A No Brainer: How AI’s Energy and Water Footprints Threaten Climate Progress”.

[55]Insights, *The Environmental Cost of Data Centers.*

and Google have combined plans to build data centers with a capacity of 1000 MW. Furthermore, Microsoft holds a concession to extract 25 million litres of water per year from underground for one of its two data center units in Colón, which accounts for 24% of the water allocated to the municipality.[56] In 2025, they consumed over 40 million litres of water. This illustrates how water usage is prioritised in these areas.[57]

[56] Diana Baptista and Fintan McDonnell. "Thirsty data centres spring up in water-poor Mexican town". In: *Context* (2024). URL: https://www.context.news/ai/thirsty-data-centres-spring-up-in-water-poor-mexican-town.

[57] Suzanne Bearne. "Thirsty data centres boom in drought-hit Mexico". In: *BBC* (2025). URL: https://www.context.news/ai/thirsty-data-centres-spring-up-in-water-poor-mexican-town.

Planned Obsolescence: Tech Industry's Smartest Trick?

What is the longest time you have ever used an electronic device? If you are not especially careful, you may notice your phone slowly breaking down after just a couple of years of use, even though it once worked perfectly. At some point, it starts to feel normal, as if replacing was always supposed to be the plan.

Maybe you've even bought a brand-new, shiny laptop, without thinking too much about it. It probably felt necessary, but was it?

This is how modern consumer society thrives. Products are not made to last, but to be replaced, which harms both consumers and the environment. Shorter product life cycles, fragile devices, and rampant consumerism are not exceptions to be resolved, but rather the natural direction preferred by a system that prioritizes profit over quality. This phenomenon is known as "planned obsolescence": the deliberate design of products to become less durable or to foster waste and excessive consumption through marketing and design.[58][59]

However, not all product changes are artificial: some are driven by genuine technological progress, safety requirements, or performance improvements. It might be over the top to imagine companies plotting the precise self-destruction of a product: many times technological improvements come at an environmental cost. For example, sealed batteries improve water resistance, but they also reduce repairability, and software updates keep devices secure and functional over time, while making older models obsolete as more

[58] Carlos Montalvo, David Peck, and Elmer Rietveld. "A Longer Lifetime for Products: Benefits for Consumers and Companies". In: *European Parliament Directorate General for Internal Policies* (2016). URL: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/579000/IPOL_STU(2016)579000_EN.pdf.

[59] Adam Hadhazy. "Here's the truth about the 'planned obsolescence' of tech". In: *BBC* (2016). URL: https://www.bbc.com/future/article/20160612-heres-the-truth-about-the-planned-obsolescence-of-tech.

powerful hardware is required.[60][61]

The challenge lies in distinguishing necessary innovation from strategies that primarily accelerate replacement cycles. The line gets blurry easily, so the questions we should ask ourselves are: what kind of benefit justify what kind of cost? Is making a device half a millimetre thinner worth making repair impossible? Is there transparency, or are companies aiming for "good enough" user benefit to justify unreasonable trade-off?[62][63]

Let's be honest, planned obsolescence is basically a strategy to make sure your stuff dies early, so you have to buy it again. As consumers, we find this completely unfair. It is a corporate game that totally ignores what real people need and heavily hurts the environment, turning our everyday tools into a continuous, forced subscription. This system is carefully designed to trap us, and it does so in two main ways: through the physical hardware and the digital software.

Designed to Fail: How it All Started

If you think planned obsolescence is just some wild conspiracy theory, history says otherwise. This business strategy has been around for almost a century, with well-documented cases of businesses using it to increase their profits.[64]

Let's rewind to 1932. In the midst of the Great Depression, American entrepreneur Bernard London had a bold idea: what if products were designed to expire on purpose? He published a pamphlet

[60] Montalvo, Peck, and Rietveld, "A Longer Lifetime for Products: Benefits for Consumers and Companies".

[61] Hadhazy, "Here's the truth about the 'planned obsolescence' of tech".

[62] Montalvo, Peck, and Rietveld, "A Longer Lifetime for Products: Benefits for Consumers and Companies".

[63] Hadhazy, "Here's the truth about the 'planned obsolescence' of tech".

[64] Julio L. Rivera and Amrine Lallmahomed. "Environmental implications of planned obsolescence and product lifetime: a literature review". In: *International Journal of Sustainable Engineering* 9.2 (2016), pp. 119–129. DOI: 10.1080/19397038.2015.1099757. eprint: https://doi.org/10.1080/19397038.2015.1099757. URL: https://doi.org/10.1080/19397038.2015.1099757.

proposing planned obsolescence as a solution to the economic crisis. It sounds like an odd thing to suggest at a time like that, but his logic was simple: if people were encouraged to replace items sooner, sales and job growth would follow, thereby improving the economy. He even proposed to make that planned obsolescence a legal requirement.

Of course, this idea never became law. Nonetheless, the same logic by which durability presents an economic problem became prominent in the following decades. As markets became saturated, companies faced a problem: if products lasted too long, people stopped buying them. The solution was clear: to make them last less.[65]

It was indeed already happening. Take light bulbs. By the early 1920s, the average lifespan of light-bulbs was nearing 2000 hours, which was great for consumers but not so great for business. That's when lifespans began to shorten instead of lengthening.

In December 1924, top executives from leading light-bulb companies, such as Philips, International General Electric, and OSRAM, met in secret in Geneva, Switzerland. They formed what became known as the "Phoebus Cartel." They all faced a problem: the durability of light-bulbs was making their sales drop. For instance, in 1923, OSRAM sold 62 million light-bulbs, but by the following year, sales dropped to 28 million. To boost sales, the cartel agreed to reduce the lifespan of bulbs to 1000 hours, effectively cutting the existing average in half and setting a precedent for planned obsolescence.[66][67]

They did not stop there. Any factory that did not comply with the agreement, whether by producing bulbs that lasted longer

[65] William Kowinski. "Planned obsolescence's unplanned risks / Computers, cell phones and TVs putting throwaway culture into overdrive". In: *SF Gate* (2006). URL: https://www.sfgate.com/books/article/Planned-obsolescence-s-unplanned-risks-2496471.php.

[66] Hadhazy, "Here's the truth about the 'planned obsolescence' of tech".

[67] Markus Krajewski. "The Great Lightbulb Conspiracy". In: *IEEE Spectrum* (2014). URL: https://spectrum.ieee.org/the-great-lightbulb-conspiracy.

or shorter than the agreed lifespan or by exceeding sales quotas, would be fined.

By 1930, the plan worked: the average lifespan of light-bulbs had decreased to just 1205 hours, and cartel members' sales increased by 25% from 1926 to 1930. However, by the 1930s, the cartel eventually dissolved, but the idea it introduced surely did not.

A century later, the same logic is still alive

Take Apple and the so-called "battery slowdown" controversy. In 2017, users of older iPhones noticed their devices suddenly becoming slower or shutting down altogether. Apple later admitted that performance was reduced, allegedly, to protect ageing batteries. Of course, those batteries were not designed to be easily replaced, and on top of that, Apple was also relentlessly suing small independent iPhone repair shops for offering that service.[68][69]

The company eventually paid up to $500 million in settlements over allegations of a battery slowdown.[70]

This case shows the extent to which companies go to make repairing and reusing as inconvenient as possible. Nobody is forced to buy a new phone. But when repair is made complicated, expensive, or inaccessible, the "choice" becomes pretty obvious.

Take a look at your devices. Today, they are not built to last; they are designed to be replaced. The build quality is often just good enough to survive a couple of years, pushing you straight back into

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[68] Jason Koebler. "Apple Is Still Trying to Sue the Owner of an Independent iPhone Repair Shop". In: *Vice* (2019). URL: `https://www.vice.com/en/article/apple-is-still-trying-to-sue-the-owner-of-an-independent-iphone-repair-shop-louis-rossmann-henrik-huseby/`.

[69] Patrick Greenfield. "Apple apologises for slowing down older iPhones with ageing batteries". In: *The Guardian* (2017). URL: `https://www.theguardian.com/technology/2017/dec/29/apple-apologises-for-slowing-older-iphones-battery-performance?utm_source=chatgpt.com`.

[70] John Harris. "Planned obsolescence: the outrage of our electronic waste mountain". In: *The Guardian* (2020). URL: `https://www.theguardian.com/technology/2017/dec/29/apple-apologises-for-slowing-older-iphones-battery-performance?utm_source=chatgpt.com`.

the store. This hardware obsolescence uses very specific, physical tricks, such as with the batteries.

A few years ago, you could swap a phone battery in ten seconds. Today, lithium-ion batteries, which naturally wear out after two or three years, are sealed tightly inside. When the battery dies, the whole $1,000 device suddenly becomes useless.

Is it really progress if we can't do a simple swap anymore? Glued and locked components. To make our phones one millimetre thinner, manufacturers now solder the memory to the motherboard and use heavy industrial glue for the screens. This makes fixing a single broken part a complete nightmare, and the problem continues when your device breaks: companies heavily limit spare parts, giving them only to their official stores, or they use software locks to block perfectly good components installed by independent repair shops. The result? Crazy repair costs. If fixing a screen costs 70% of the price of a brand-new phone, what are you going to do? You will obviously buy the new one. That is exactly what they want.

This is not an isolated case: many devices today are intentionally difficult to repair. iPhones use proprietary screws that standard tools cannot open. Some Amazon Kindles are sealed with glue, making them nearly impossible to take apart without damaging them. Printer manufacturers like Epson, HP, and Canon have been accused of limiting the lifespan of their products through both software and hardware restrictions. This logic extends beyond electronics to household appliances, where vacuum cleaners, washing machines, and coffee makers are often built with fragile plastic components or sealed units that fail prematurely and are costly to replace. In many cases, spare parts are either unavailable or priced so high that repairing the appliance makes little economic sense, pushing consumers toward buying new products instead.

In contrast, companies like Fairphone show that a different approach is possible, designing smartphones with modular components that users can easily replace themselves. Their devices prioritize repairability and longevity, proving that durability does not have to come at the expense of functionality or design.[71]

Clearly, planned obsolescence is a business strategy: longer lifespans imply a decline in demand for a product, and the solution is to sacrifice quality to sustain sales.

Digital Death: Killed by an Apdate

But what if you take great care of your phone and the hardware survives? Don't worry, some companies have a backup plan: software obsolescence. It is a silent killer for our devices. After a certain amount of time (usually 2 to 5 years), the manufacturer simply stops sending updates. New software is optimized for the latest processors, making older devices slow and laggy. Even if the hardware still works, it becomes obsolete because it can no longer run modern apps safely or efficiently. And your device slowly becomes a digital dinosaur. Your phone isn't physically broken, but it becomes a useless brick just because it can no longer open your bank app or WhatsApp.

Because people are tired of this trap, the Right to Repair movement is fighting back.[72] Supported by new laws in places like the European Union, this movement is demanding something very simple: let us fix the things we own. They want fair repair costs, easy-to-find spare parts, and devices that are built to be opened, not thrown in the trash.

With this legislation, will planned obsolescence become a memory of the past? Unfortunately, the answer may still be no, because there is one last factor that manufacturers can exploit to make their products obsolete: you.

[71] https://www.fairphone.com/

[72] Svensson, Sahra and Richter, Jessika Luth and Maitre-Ekern, Eléonore and Pihlajarinne, Taina and Maigret, Aline and Dalhammar, Carl. *The Emerging 'Right to Repair' legislation in the EU and the U.S.*. eng. 2018. URL: %7Bhttps://lup.lub.lu.se/search/files/63585584/Svensson_et_al._Going_Green_CARE_INNOVATION_2018_PREPRINT.pdf%7D.

Playing with your Mind: Marketing and Perceived Obsolescence

The most dangerous weapon tech companies have isn't engineering; it's psychology. We really need to understand the difference between actual obsolescence (the battery is completely dead, the screen is shattered, nothing works) and perceived obsolescence.[73]

Let's go back in time again: when Henry Ford introduced the Model T in 1908, he imagined it as an affordable tool that would last in time. These are his own words: "We want the man who buys one of our cars never to have to buy another".[74] For a while, it worked: by 1920, everyone who could afford a car owned one.

When the market began to slow down, the company General Motors took a different approach, experimenting with something very simple: each year, they would release cars in new, limited colours. Nothing revolutionary, but enough to make last year's model feel old.[75] The engine was the same, the function was the same, but the way consumers viewed the product changed. They were very open about it, too: GM's head of design described the goal as "dynamic obsolescence". He stated, "Our big job is to hasten obsolescence. In 1934, the average car ownership span was five years; by 1955, it had dropped to two years. When it becomes one year, we will have a perfect score."[76]

Does that sound like a familiar tactic?

Perceived obsolescence is when your device works perfectly fine, but the company makes you feel like it belongs to a museum. How do they play with our minds? The annual launch. Every year, companies throw massive, spectacular events to announce

[73] Tamar Makov and Colin Fitzpatrick. "Is repairability enough? big data insights into smartphone obsolescence and consumer interest in repair". In: *Journal of Cleaner Production* 313 (2021), p. 127561. ISSN: 0959-6526. DOI: `https://doi.org/10.1016/j.jclepro.2021.127561`. URL: `https://www.sciencedirect.com/science/article/pii/S0959652621017790`.

[74] Rich McEachran. "Designing Things to Last". In: *Works That Work* 10 (2021). URL: `https://worksthatwork.com/10/planned-obsolescence`.

[75] Hadhazy, "Here's the truth about the 'planned obsolescence' of tech".

[76] McEachran, "Designing Things to Last".

their new products. This creates FOMO (Fear Of Missing Out). They want you to panic that you are being left behind in the past. Let's look closely at the "new" versions. Usually, the changes are ridiculously small: one extra camera lens, slightly flatter edges, or a new colour. But these tiny details are crucial. They serve as a social signal, a status. They let everyone in the room know who has the "old" phone and who has the "new" one. Your device isn't just a tool anymore; it's a status symbol for the consumer.

Planned obsolescence isn't an accident; it's a very smart, very profitable ecosystem. It relies on a mix of anti-repair design choices and brilliant psychological manipulation. This practice has created a massive mountain of electronic waste (e-waste) globally and works like a continuous tax on our wallets. If we want to move toward a more sustainable future, we need strong Right to Repair laws. But more importantly, we need to wake up as consumers. Next time you want to buy the latest gadget, ask yourself: is my old phone actually broken, or did a clever marketing campaign just make me feel bored with it?

E-waste

With a bigger and bigger production of electronic equipment, there is an inevitable growing production of waste, the so called E-waste.

This waste stream comes with two crucial aspects:

1. Since it contains harmful substances, it needs a proper treatment to protect human and environmental health.

2. It also contains useful and precious materials, such as metals, that if recovered would reduce the need for new extractions of natural resources.[77]

Precious metals that can be recycled from E-waste are called secondary raw materials (materie prime seconde), and include platinum, gold, silver, cadmium, mercury, arsenic and lead.

Even though we commonly say "e-waste", in the directive framework we read about WEEE: Waste from Electronic and Electric Equipment. Based on which directive, WEEE is divided in many categories (6 for the European directive, 5 for the Italian one). It usually includes refrigerators, screens, lamps, small and large equipment such as household appliances, small IT and Telecommunication Equipment. In this chapter we will be looking at the whole range of e-waste, considering for example also batteries for energy storage or electric vehicles, but with a special focus on devices for information technology.

Evolution of Disposal Habits

We started our journey from the extraction and manufacturing of materials, now we wonder: what happens when we no longer use them?

[77]Iren S.p.A. *E-waste, che cosa sono e come possono essere riciclati.* `https://www.gruppoiren.it/it/everyday/vivere-sostenibile/2024/e-waste-cosa-sono-come-riciclarli.html`. 2024.

Let's take, as an example, the devices we use the most in our daily lives. In 2024, around 14% of EU citizens recycled their desktop computer, 11% their laptop and tablet, and almost 11% their mobile phones.[78]

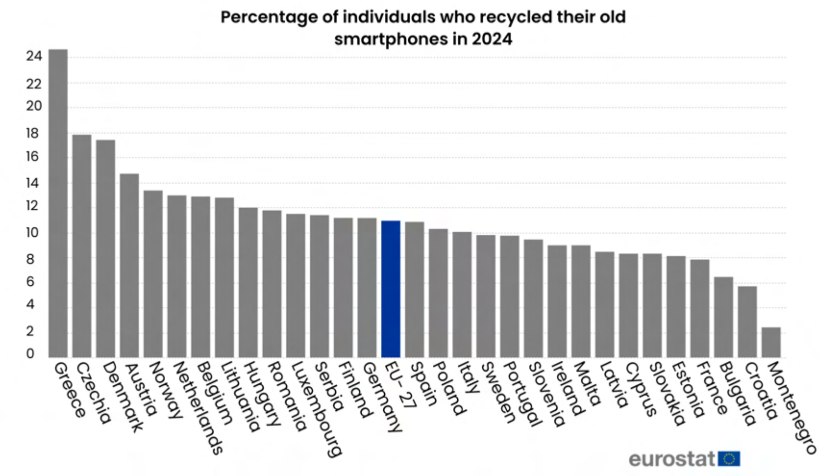

Figure 13: Percentage of individuals recycling their old smartphones in 2024[79]

But since less than 15% of these items undergo recycling, where do all the rest go? Most of the devices do not enter the recycling process not because they are improperly disposed of (less than 2% as EU average), or because they are sold again (18%), but because we leave them… at home (51%).

Let's be honest: you probably have a 'just in case' drawer. It's where old smartphones and laptops go to retire, kept more for the memories than the hardware. But while they sit there gathering dust, the valuable minerals inside them stay trapped. This habit could explain the graph below: while EEE on the market are growing exponentially, WEEE collected and recycled simply cannot keep up.

[78]eurostat. *Disposal of ICT devices no longer in use*. https://ec.europa.eu/eurostat/databrowser/view/ISOC_ECO_DD__custom_20207118/default/bar?lang=en&page=time:2024. 2026.

[79]Ibid.

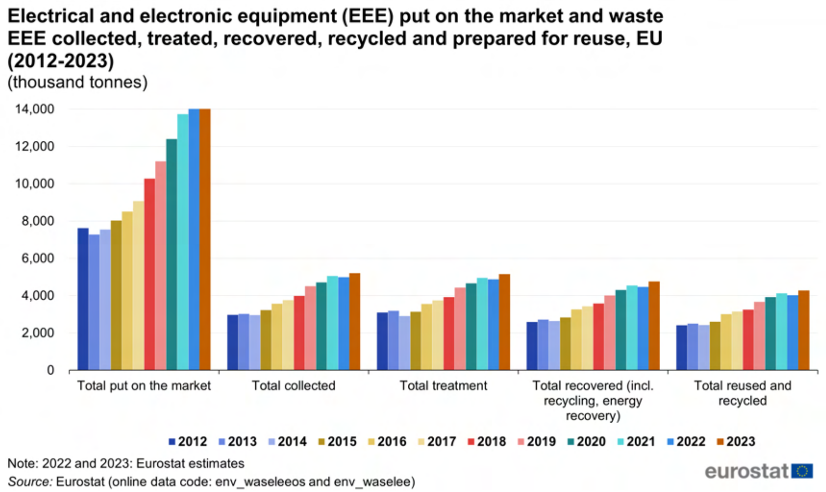

Figure 14: Electrical and electronic equipment EU data 2012-2023[80]

Recycling Process

Despite some initiatives to reduce e-waste production - such as digital product passport,[81] right-to-repair initiatives, and design for Re-X strategies, which aim to advance circularity and extend product life, e-waste is expected to grow exponentially. But no matter how much we reuse, re-manufacture, refurbish and repair, we will always end up needing proper waste management.

The management of electronic waste generally follows five main technical pathways, as shown in the picture.

- *Physical Disassembly*: the initial stage where components are separated manually or mechanically. This occurs either formally in safe, specialized facilities or informally under hazardous conditions.

[80] eurostat, *Disposal of ICT devices no longer in use.*

[81] Passaporto Digitale. *Digital Product Passport: The Future of Transparency.* https://passaporto-digitale.eu/en/what-is-digital-passport/. 2026.

[82] Rachel L. Smith and Sara Behdad. "From present to future: A review of e-waste recycling processes". In: *Waste Management* 204 (2025), p. 114863. ISSN: 0956-053X. DOI: https://doi.org/10.1016/j.wasman.2025.114863. URL: https://www.sciencedirect.com/science/article/pii/S0956053X25002740.

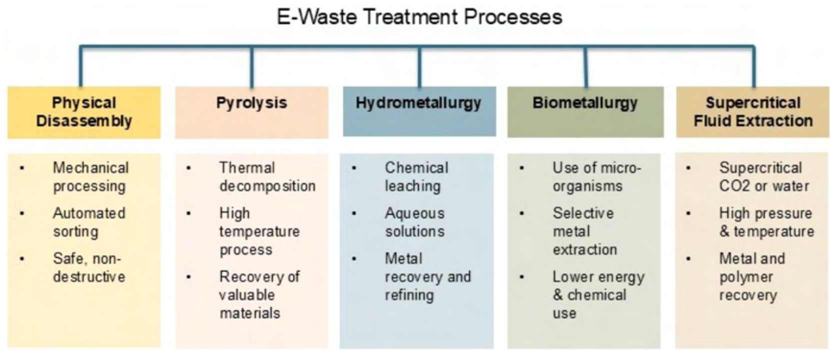

Figure 15: Five main technologies for e-waste recycling[82]

- *Pyrolysis*: a process of thermal decomposition at high temperatures without oxygen. It simplifies complex compounds into metal-rich by-products and pyrolytic liquids that can serve as bio-fuel.

- *Hydrometallurgy*: this method uses aqueous solutions and chemical leachates to extract precious metals like gold (Au) and copper (Cu). While more economically feasible and less polluting to the air than pyrolysis, it risks contaminating water and soil with acid residues if performed informally.

- *Biometallurgy (Bioleaching)*: developed to mitigate the impacts of hydrometallurgy, this approach utilizes microorganisms, including fungi and various bacteria, to extract valuable materials.

- *Supercritical Fluid Extraction*: a process using fluids like water or carbon dioxide at temperatures and pressures above their critical state to act as solvents for e-waste components.

Benefits of Formal Recycling: E-waste or E-resource?

A proper e-waste management would be beneficial not only from an environmental and social perspective, but for the economics as well. For example, to get 1.2 kg of cobalt you need a ton of its ore, while with a ton of mobile phones you get 63 kg of cobalt.[83]

[83] Pengwei He, Chang Wang, and Lyushui Zuo. “The present and future availability

Cobalt, as we already saw, is a critical and essential element used in electronics, as well as many other sectors of the global economy.[84] Its most prominent role is in the production of lithium-ion batteries, which power everything from smartphones to electric vehicles, making it indispensable for the ongoing transition to more sustainable technologies.

The same applies to many other materials like gold, copper, silver and palladium, in a process known as Urban Mining: the extraction of secondary raw materials from waste, making cities and urban environments the new suppliers instead of the classical and harmful mines.[85]

Not only materials saving, but energy as well: extracting and refining virgin metals is incredibly energy-intensive compared to recycling. Recycling aluminium, for example, uses about 95% less energy than producing it from bauxite. Not to mention the benefits in terms of industrial independence: EU strongly relies on China for the import of rare earth elements, Congo for Cobalt and Chile for lithium. Urban mining could provide 20% of the EU demand for these critical materials in 2030.[86]

At this point you could be wondering: do we have an instrument to support both efficiency, health and environmental protection?

Fortunately, the answer is yes, and this instrument is European regulations. Indeed, the EU adopted a directive[87] on e-waste management, setting ambitious targets for the collection of WEEE

of high-tech minerals in waste mobile phones: Evidence from China". In: *Journal of Cleaner Production* 192 (2018), pp. 940–949. ISSN: 0959-6526. DOI: https://doi.org/10.1016/j.jclepro.2018.04.222. URL: https://www.sciencedirect.com/science/article/pii/S0959652618312587.

[84] Cobalt Institute. *About Cobalt*. https://www.cobaltinstitute.org/global-cobalt/about-cobalt/. 2026.

[85] Iren S.p.A. *U come Urban mining, come funziona il processo che estrae materie prime secondarie dai rifiuti*. https://www.gruppoiren.it/it/everyday/abcircular/2023/urban-mining-come-funziona.html. 2024.

[86] Entrepreneurship Directorate-General for Internal Market Industry and SMEs - European Commission. *Critical Raw Materials Act*. https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials/critical-raw-materials-act_en. 2024.

[87] EUR-Lex. *Making the most of waste electrical and electronic equipment*. https:

(85% of the total WEEE production) and encouraging collaboration between producers and recyclers to design electrical equipment which can be reused, dismantled or recovered in line with the eco-design principles and directives. Another crucial aspect of this directive is the application of the polluters pay principle: the producers are financially responsible for the cost of collection, treatment, recovery and environmentally sound disposal of all their products. This means then when you are buying a new smartphone or laptop, you are already charged for the cost of its end of life management. So, you've already paid for the recycling, you might as well actually go do it! You can bring your electronic devices to a collection center, there are many in the university.

If you are heading to a shop instead, remember they are obliged by this directive to offer these services:

- 1-for-1: Retailers must take your old device when you buy a similar new one.
- 1-for-0: Large shops are legally required to accept small electronics (like old phones or cables) for free, even if you don't buy anything at all.

When talking about the benefits of reusing and recycling WEEE we can not forget to mention batteries. As it is stated in an article from IEA,[88] International Energy Agency, the global battery markets are growing strongly, since "they are becoming a cornerstone of the automotive sector, a critical source of flexibility for power systems, and an increasingly important source of back-up power for digital infrastructure, including data centres and artificial intelligence."

Not only do we see an increase in battery demand (global lithium-ion battery deployment in 2025 was six times as high as in 2020),

//eur-lex.europa.eu/EN/legal-content/summary/making-the-most-of-waste-electrical-and-electronic-equipment.html?fromSummary=20. 2012.

[88] International Energy Agency. *Global battery markets are growing strongly – and so are the supply risks.* https://www.iea.org/commentaries/global-battery-markets-are-growing-strongly-and-so-are-the-supply-risks. 2026.

but also a shift in its consumption: the way we think about batteries has dramatically changed in the last decade. In 2015, nearly half of global battery demand came from portable electronics; by 2025, this share had fallen to below 5%, with electric vehicles and energy storage growing exponentially.

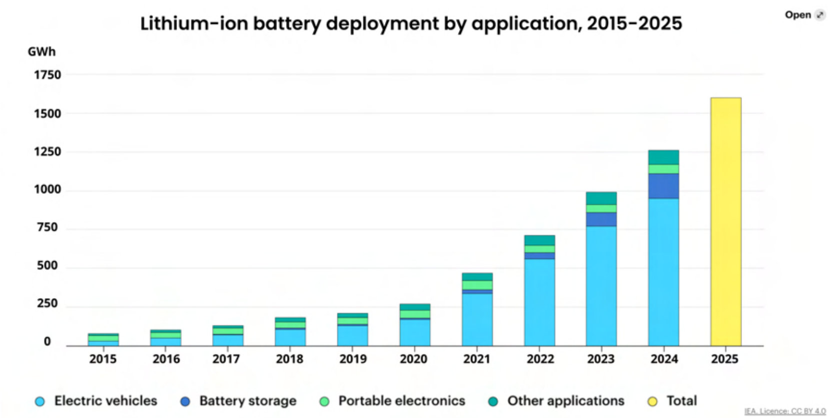

Figure 16: Lithium-ion battery deployment by application[89]

Since most of the battery consumption nowadays is driven by electric vehicles, let's consider what happens to an EV battery in the car's end of life. If the battery is still viable it can be repurposed for a second life application, typically for stationary energy storage at aleatory renewable energy production plants (photovoltaic, wind power).[90] This expands its life up to 10 years, avoiding the need for new extractions and, hence, lowering their total impact. Then, final recycling is still required to recover lithium and cobalt.

[89] Agency, *Global battery markets are growing strongly – and so are the supply risks.*

[90] Zeshan Alam and Shabbir H. Gheewala. "Recharging the planet: The sustainability potential of second-life electric vehicle batteries". In: *Journal of Energy Storage* 144 (2026), p. 119720. ISSN: 2352-152X. DOI: `https://doi.org/10.1016/j.est.2025.119720`. URL: `https://www.sciencedirect.com/science/article/pii/S2352152X25044342`.

Informal Recycling: The Shadow Economy of E-Waste

Despite the many advantages of formal recycling, this one is often bypassed by a massive informal sector that fills the gaps where official collection and re-manufacturing fall short. As a matter of fact, informal sector recycling dominates the End-of-Life (EoL) value chain in developing countries. This sector is not driven by a lack of skill, but by a brutal economic reality: informal recycling is often more profitable due to lower labour costs, limited regulation, and higher processing volumes. In India, for instance, an impressive 95% of e-waste recycling is carried out informally.[91] Sticking with India, the story becomes more interesting when we find out that 70% of the e-waste managed is imported. We already saw this mechanism when talking about fast fashion: the Global South is treated as the dumping ground of the Global North, as it was another form of colonialism. Indeed, it is: waste colonialism. An estimated 15 million people sustain a multi-stage recycling economy by extracting value from imported waste, and, in Shanghai alone, nearly 200,000 individuals manage up to 38% of all municipal recycling activities.[92]

This illegal outsourcing of e-waste to developing countries has serious environmental and socioeconomic consequences.

From an **environmental point of view**, most critical impacts regard water and soil contamination. After improper physical treatment, the waste often undergoes high risk methods such as acid bath leaching and open burning, which differs from pyrolysis because it is uncontrolled and releases toxic substances in the atmosphere, such as heavy metals (HM) and fine particulate matter. HMs such as cadmium and lead are not biodegradable and

[91] Deblina Dutta and Sudha Goel. "Understanding the gap between formal and informal e-waste recycling facilities in India". In: *Waste Management* 125 (2021), pp. 163–171. ISSN: 0956-053X. DOI: https://doi.org/10.1016/j.wasman.2021.02.045. URL: https://www.sciencedirect.com/science/article/pii/S0956053X21001148.

[92] Hong Yang et al. "Waste management, informal recycling, environmental pollution and public health". In: *Journal of Epidemiology and Community Health* 72.3 (Dec. 2017), pp. 237–243. ISSN: 1470-2738. DOI: 10.1136/jech-2016-208597. URL: http://dx.doi.org/10.1136/jech-2016-208597.

tend to bioaccumulate in organisms, particularly the ones at the top of the food chain, damaging the neurological, endocrine and reproductive systems in various wildlife species.[93]

From a **social point of view**, people involved in e-waste handling in the informal sector are often marginalized and referred to as scavengers, and operate in unsafe conditions without benefits. Most of the time, they are not aware of the occupational health hazards they are exposed to.[94] While providing essential livelihoods, the sector is characterized by excessively long hours, a lack of basic rights, risk of injury and high psychological stress. The previously mentioned open burning and acid bath leaching methods are linked to cancer and impaired cognitive development, while workers face a cocktail of respiratory risks from inhaling methane and pathogenic bio-aerosols.[95][96] The most acute effects occur in children, for example in Guiyu, China, stillbirth rates reached 4.6 times that of control sites in other parts of the country.[97]

Ultimately, the lack of formal infrastructure dedicated to the sector leads to large-scale dumping of components that cannot be remanufactured and from which raw materials cannot be extracted. This creates a striking regional imbalance: while high-value fractions are shipped back to the Global North, the developing world is left to manage the hazardous remains.[98] These leftovers of the informal recycling process accumulate in dumping sites, leading to the transfer of toxins to local populations and facilitating the

[93] Government of Canada. *Wildlife and landscape science research topics: metals toxicology.* `https://www.canada.ca/en/environment-climate-change/services/wildlife-research-landscape-science/research-topics/metals-toxicology.html`. 2010.

[94] Dutta and Goel, "Understanding the gap between formal and informal e-waste recycling facilities in India".

[95] Kostyantyn Pivnenko. *Towards a Circular Economy for the Electronics Sector in Africa: Overview, Actions and Recommendations.* Tech. rep. United Nations Environment Programme, 2021.

[96] Yang et al., "Waste management, informal recycling, environmental pollution and public health".

[97] Ibid.

[98] Pivnenko, *Towards a Circular Economy for the Electronics Sector in Africa: Overview, Actions and Recommendations.*

spread of infectious diseases like malaria, cholera, and typhoid.[99]

Global Flows

But how did all this electronic waste arrive in countries such as India, China, or Ghana? What are the main global flows around the world? And how is this injustice perpetrated?

The electronics supply chain suffers from a concerning lack of transparency and harmonized waste definitions, creating a regulatory gap that facilitates the illegal trade of e-waste, often disguised as used equipment to bypass travel bans, particularly in the flow of waste from the Global North to Africa and Asia.[100]

To evade tightening enforcement in hubs like Hong Kong, due to formal import bans established by China in the year 2000, smugglers utilize backdoor routes through Vietnam, where e-waste is ferried across river borders in concealed boats. Such operations frequently utilize layering techniques, placing functional electronics at the front of containers to satisfy visual inspections while hiding hazardous waste in the back, and are increasingly infiltrated by organized crime groups attracted by the high profit margins.[101]

The economic incentive is massive, as illegal disposal is four times cheaper than legal treatment, generating roughly \$12 billion in annual revenue for criminal networks. This illicit trade flows predominantly from the European Union, Japan, and the United States, where legitimate firms often engage in fraudulent subcontracting, collecting recycling fees while illegally selling toxic waste overseas instead of to authorized facilities. This hidden flow of approximately 12 million tons annually, which represents the discrepancy

[99] Yang et al., "Waste management, informal recycling, environmental pollution and public health".

[100] Pivnenko, *Towards a Circular Economy for the Electronics Sector in Africa: Overview, Actions and Recommendations.*

[101] *Transnational Organized Crime Threat Assessment - East Asia and the Pacific.* Tech. rep. United Nations Office on Drugs and Crime, United Nations Environment Programme, 2010. Chap. Chapter 9 - Illicit trade in electrical and electronic waste (e-waste) from the world to the region.

between generated and accounted-for waste, remains largely untracked.[102]

International Treaties

Reading this can be quite discomforting if you think about the fact that regulatory frameworks were already signed and ratified more than three decades ago to tackle the issue.

In fact, the global management of e-waste is governed by a framework of international and regional agreements for hazardous waste, designed to prevent environmental exploitation and the NIMBY (Not In My Back Yard) syndrome. The Basel Convention (1989) was established following public indignation over toxic waste dumping in the developing world, driven by rising disposal costs and tightening regulations in industrialized countries. It aims to protect human health and the environment by regulating transboundary movements and ensuring a regulatory system for permissible cases adhering to environmentally sound management.[103]

Recognizing Basel's initial limitations in prohibiting trade to less developed countries, African nations adopted the Bamako Convention (1991). This treaty was triggered by the need for a total ban on importing hazardous and radioactive wastes into Africa, also aiming to minimize transboundary movements within the continent, prohibit ocean dumping, and promote cleaner production.[104]

Circular Economy

With all this information in mind, it's clear that governments need to step up and finally enforce the agreements they signed off, ensuring that instead of travelling across the world, electronic

[102] *Transnational Organized Crime Threat Assessment - East Asia and the Pacific.*

[103] Basel Convention. *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.* `https://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx`. 2026.

[104] Bamako Convention. *Basel Convention Against Illegal Dumping of Hazardous Wastes.* 2026.

waste follows the formal recycling chain in the country where it was generated.

However, at the same time, the informal recycling sector represents a significant opportunity to move toward a circular economy by demonstrating the value in e-waste through practical urban mining. In hubs like Agbogbloshie, Ghana, scrap dealers treat electronics as sources of rare earths and working components that supply repair shops nationwide. Their practical knowledge enables the up-cycling of everything from mobile phones to welding machines, proving that a landfill is a site where things are taken apart to make something new rather than just a dump.[105] However, as previously described, in most of the developing world, these activities still occur in unsafe conditions. We should learn from their experience and formalize these processes for extracting value while tackling all the social, environmental and health concerns.[106]

To achieve this practically, the whole electronics sector must globally adopt a hierarchical 9Rs framework (quite a step up from the 3Rs I learned about as a kid!). Circularity begins by *Reducing* raw material use at the design phase, ensuring products are easier to reprocess and free from toxic components. Then, users and businesses must *Refuse*, *Reduce*, or *Reuse* products to signal market demand for sustainability, while technical interventions like *Repair*, *Refurbish*, and *Remanufacture* restore performance or return items to as-new condition through standardized industrial processes, delaying the transition to waste. When a product reaches the end of its original utility, discarded components are adapted for new functions or reprocessed into secondary substances through *Repurposing* and *Recycling*.This approach is illustrated in the infographic in Figure 17.[107]

[105] DK Osseo-Asare. *What a scrapyard in Ghana can teach us about innovation.* `https://www.ted.com/talks/dk_osseo_asare_what_a_scrapyard_in_ghana_can_teach_us_about_innovation`. 2017.

[106] Pivnenko, *Towards a Circular Economy for the Electronics Sector in Africa: Overview, Actions and Recommendations.*

[107] Ibid.

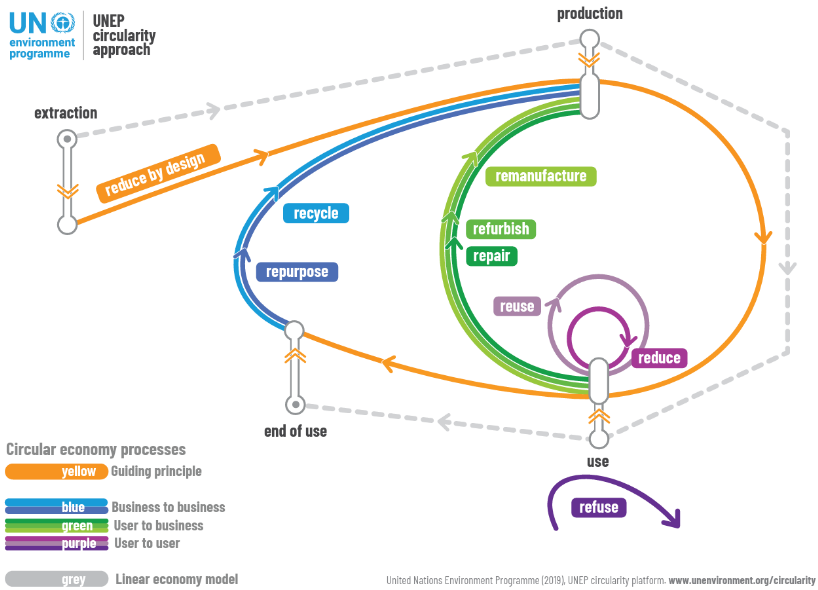

Figure 17: The UNEP circularity approach[108]

On the research front, there exist academic efforts investigating how to recover precious materials from complex electronic circuits. For example, using microwave-assisted carbo-thermal reduction, Tantalum and Manganese can efficiently be recovered from capacitors in a way that can be easily scaled-up.[109]

At the same time, policies such as the 2012 EU WEEE Directive and its 2024 amendment we discussed about above contribute to the transition away from a linear disposal model, mandating producers to finance the collection, treatment, and environmentally sound disposal of products, while collaborating with recyclers to design equipment that is easily dismantled or recovered.[110]

[108]Pivnenko, *Towards a Circular Economy for the Electronics Sector in Africa: Overview, Actions and Recommendations.*

[109]Ansan Pokharel et al. “Microwave-assisted recycling of tantalum and manganese from end-of-life tantalum capacitors”. In: *Scientific Reports* 15.1 (Apr. 2025), p. 12366.

[110]EUR-Lex, *Making the most of waste electrical and electronic equipment.*

Simply investing in sufficient formal collection and recycling infrastructure globally could yield $38 billion in annual economic benefits by 2030, while simultaneously saving on the $78 billion in estimated externalized costs to human health and the environment caused each year by poor electronic waste management. This is to say that the shift toward circularity is as necessary as it is possible: we must implement diverse measures that incentivize businesses to innovate while facilitating the right of consumers to repair and refurbish their electronics, keeping them away from landfills as long as possible.[111]

[111] UNEP Environment Program. *As electronic waste surges, countries look for answers*. https://www.unep.org/news-and-stories/story/electronic-waste-surges-countries-look-answers. 2024.

Within the Limit, Towards Biological Times

The essay *"Historical Times, Biological Times"* by Enzo Tiezzi,[112] one of the fathers of Italian environmentalism and the concept of sustainable development, begins by recalling an old story that perhaps someone will know from Vecchioni's song:

A soldier of an ancient and remote kingdom, full of fear, went to his king and told him: "Save me, sovereign, let me flee from here. I met Death dressed in black, who looked at me with malice. Lend me your horse so that I can ride to Samarkand. I fear for my life staying here." – "Give him the best steed," said the sovereign, "son of lightning, worthy of a king."

Later the king met Death in the city and said to her: "My soldier was very frightened. He told me that he met you today at the market and that you looked at him with malice." – "Oh no," replied Death, "mine was merely an astonished look, because I didn't know what he was doing here today, given that I was expecting him tonight in Samarkand. This morning he was very far from it."

Technology can be our horse to Samarkand: its frenetic acceleration deludes us into thinking we can flee from our problems, but it pushes us ever faster toward the biophysical limits of our planet.

Ilya Prigogine distinguishes between different levels of time: the mechanical level, described by classical or quantum mechanics, which links time to movement, and the thermodynamic level, which implies causality and introduces the notion of irreversibility.

The first level belongs to technology and the capitalist economy. Progress is measured by the speed of production; the faster nature's resources are used, the more progress advances. A concept that could be summarized by the famous phrase "time is money." In other words, the faster nature is transformed, the more time is saved.

[112] Enzo Tiezzi. "Tempi Storici Tempi Biologici". In: Donzelli Editore, 2005.

The second level belongs to natural reality, which obeys different laws than capitalist ones: the faster the world's resources and available energy are consumed, the less time remains available for our survival.

Nature operates according to the thermodynamic arrow of time: every irreversible process generates entropy (disorder, dissipated heat). The biosphere accumulates low-entropy energy over very slow times (chlorophyll photosynthesis that generates fossil biomass over millions of years); we, by burning it to power our machines, dissipate it in an instant, and an organism that consumes faster than the environment produces for its subsistence has no chance of survival.

Technological time is inversely proportional to entropic time; economic time is inversely proportional to biological time.

The Sorcerer's Apprentice Gap

There is a current of contemporary cultural production that feeds the tendency towards "technological hope" with the purpose, more or less manifest, of perpetuating the model of resource waste and aggression against the environment.

This illusion, this blind and uncritical faith in a thaumaturgical technology contributes to what the biologist Barry Commoner in his first book Science and Survival defined as "the sorcerer's apprentice gap."

While the power and impact of our technologies grow with an uncontrollable exponential curve, our knowledge of its biological and ecological interactions proceeds on a slower and more linear line. We act on the basis of dangerously incomplete knowledge, conducting a potentially irreversible experiment on our own skin.

The Machines of Entropy: Crypto and AI Bubble

To fully understand the dynamics and risks of this transformation, the bio-economic analysis traced by Howard T. Odum, particu-

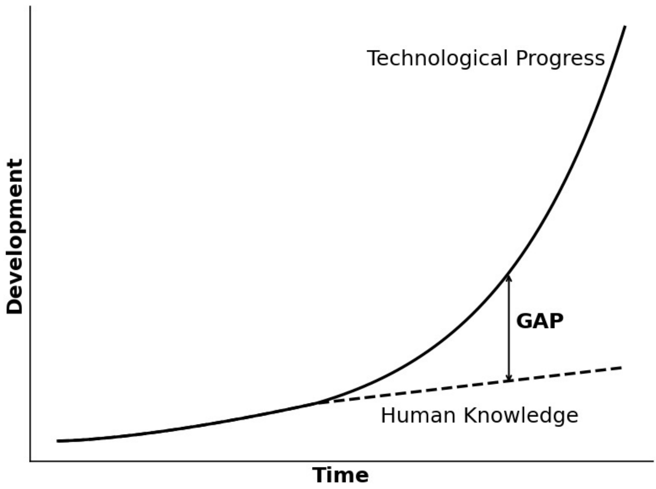

Figure 18: Graph inspired by Barry Commoner[114]

larly in his text Energy Basis for Man and Nature,[113] provides an interesting interpretive key.

The basic principle is: in a macroeconomic system, the flow of money constantly proceeds in the opposite direction to that of energy. Money can thus be seen as a symbolic representation of useful work, or rather of the low-entropy energy available to a society.

If the amount of money in circulation grows faster than the real energy flow (i.e., the energy the system can actually capture and transform into useful work), the result is inflation.

Applying this conceptual matrix by Odum, today's IT hyper-infrastructure takes on disturbing outlines. What happens to an economic system when it injects hundreds of billions of dollars into technological sectors that devour enormous quantities of real energy, but whose capacity to return useful work, at least in their current state, appears debatable or limited to purely speculative

[113] H T Odum and E C Odum. *Energy basis for man and nature*. McGraw-Hill Book Company,New York, Jan. 1976. URL: `https://www.osti.gov/biblio/7191626`.
[114] Tiezzi, "Tempi Storici Tempi Biologici".

dynamics?

We are, in essence, creating a dramatic entropic inflation: we burn real resources to sustain the illusion of infinite growth in financialised markets that do not translate into a real, tangible well-being for society, simultaneously depleting the energetic and ecological base upon which the entire economy is founded.

Cryptocurrency mining is the ultimate expression of this bio-economic short circuit. The underlying algorithm of Bitcoin is the **Proof of Work** protocol: to validate a block of transactions and mine new coins, millions of computers (miners) scattered around the world compete to solve complex cryptographic puzzles, proceeding exclusively by trial and error (brute force). The more machines participate in the network, the more the protocol automatically increases the difficulty of the mathematical puzzle. This mechanism inherently requires wasting enormous amounts of energy for the sole purpose of making the creation of new currency difficult and expensive, thus simulating an artificial digital scarcity. It is the direct conversion of useful energy into dissipated heat for pure financial speculation.

That this entropic inflation is an algorithmic choice, and not an inescapable necessity of the technology, was demonstrated by the recent case of Ethereum. In September 2022, with the event known as The Merge, the world's second-largest cryptocurrency by market capitalization abandoned Proof of Work to transition to **Proof of Stake**. In this system, the network is secured not by burning electricity via supercomputers, but through "validators" who lock up a portion of their own cryptocurrency as collateral (stake). By removing computational competition, the collapse in consumption was instantaneous.

The data certifies the energetic divide between the two models. While the Bitcoin network, based on PoW, continues to run on exorbitant consumption between 110 and 121 TWh per year,[115]

[115] Cambridge. *Bitcoin Electricity Consumption Index*. `https://ccaf.io/cbnsi/cbeci`. 2024.

Ethereum's transition to PoS has slashed its energy requirements by over 99.9%. The Ethereum network, in fact, went from a consumption of roughly 24 TWh per year to a mere 0.006 TWh.[116] An abyss that clearly demonstrates how environmental unsustainability is not intrinsic to the blockchain as such, but is rather the poisoned fruit of the speculative, energy-devouring, and thermo-economically absurd logic that drives Proof of Work.

To put these figures into perspective, suffice it to say that Bitcoin routinely consumes electricity in quantities comparable to entire industrialized nations: Italy's annual electricity demand is estimated by the IEA at around 300 TWh.[117] This means that a single cryptocurrency network ends up consuming the equivalent of 36-40% of the electrical energy required to run our entire country.

But it is by cross-referencing this energy expenditure with real economic output that the thermodynamic absurdity manifests in all its glaring clarity. Italy, with its 300 TWh, sustains a real economy (healthcare, agriculture, transport, manufacturing) that gives back to society an immense amount of "useful work" and subsistence goods for millions of people. Bitcoin, devouring almost half of that energy, produces no material goods and provides no essential services: its "value" is exhausted entirely in its market capitalization, a purely speculative and virtual asset. It is the tangible demonstration of entropic inflation: a colossal, irreversible expenditure of energy that, however, yields no return in terms of social utility.

Worse still, the hardware: the ASIC servers used for mining become obsolete and economically uncompetitive in about 1.5 years.[118] Unable to be reused, they instantly become trash: it is estimated that a single Bitcoin transaction generates on average the same

[116] Cambridge Centre for Alternative Finance. *Crypto Carbon Ratings Institute*. `https://ccaf.io/cbnsi/cbeci`. 2024.

[117] International Energy Agency. *Italy*. `https://www.iea.org/countries/italy/electricity`. 2026.

[118] Alex de Vries and Christian Stoll. "Bitcoin's growing e-waste problem". In: *Resources, Conservation and Recycling* 175 (Dec. 2021), p. 105901. DOI: `10.1016/j.resconrec.2021.105901`.

e-waste as two discarded smartphones.

The AI Boom and the Collapse of Productivity

Generative artificial intelligence falls into the same pattern. The obsession of techno-capitalism is to increase labour productivity, i.e., the amount of added value per working hour, by laying off personnel and replacing humans with machines and energy. We thus witness an enormous increase in labour productivity simultaneously with the collapse of capital productivity, i.e., the added value per unit of invested capital, and above all of energy productivity, i.e., the economic efficiency with which energy is transformed.

AI requires monumental infrastructures to perform actions, such as writing a text or making a summary, which the human brain (a thermodynamically perfect machine) performs consuming very few calories.

In this impasse, the debate on the **AI Bubble** takes shape. If we look at the financial mechanisms sustaining it, we realize that the tech industry is violating not only planetary boundaries but also the basic rules of the real economy.

The Silicon Valley giants, driven by pure speculative **FOMO** (Fear Of Missing Out), are injecting disproportionate capital into hardware infrastructures: just think of Project Stargate, an AI infrastructure initiative planned by Microsoft and OpenAI that aims to reach 10 gigawatts of power, requiring astronomical investments, which will start from 100 billion dollars to reach a 500 billion plan.[119] To power 10 gigawatts continuously would require 10 large traditional nuclear reactors or more than 30 small modular reactors (SMRs) dedicated exclusively to this purpose. Added to these are the hundreds of billions poured into securing highly expensive processing chips, like those produced by Nvidia.

[119] Anissa Gardizy and Amir Efrati. “Microsoft and OpenAI Plot $100 Billion Stargate AI Supercomputer”. In: *The Information* (2026). URL: `https://www.theinformation.com/articles/microsoft-and-openai-plot-100-billion-stargate-ai-supercomputer`.

Projections on resource consumption are at the very least alarming. The International Energy Agency[120] estimates that AI and data center consumption could double by 2026, exceeding 1,000 global TWh (as much as all of Japan). At the hardware level, a study in Nature Computational Science[121] sounds a dramatic alarm: in 2023, AI-related servers produced approximately 2,600 tons of e-waste. By 2030, this number is projected at 2.5 million tons annually. This is an increase of nearly 1,000 times in just seven years: the exact representation of an exponential and potentially uncontrollable curve. Regarding water impact, it is estimated that withdrawal to cool data centers will reach between 4.2 and 6.6 billion cubic meters by 2027, half the consumption of the United Kingdom.[122]

Yet, against this colossal expenditure of capital and energy, the economic return remains profoundly disproportionate. OpenAI, the symbolic company of this race, continues to burn capital at a pace unprecedented in the history of computing: 2025 balance sheets indicate that, despite reaching revenues of about 13 billion dollars, the company recorded estimated net losses of around 9 billion dollars. Weighing heavily are the unsustainable operational and training costs, so much so that internal projections estimate a further worsening, with losses expected at a whopping 14 billion dollars for 2026.[123] Broadening the view to the entire industry, the Sequoia Capital fund calculated a financial deficit of about 600 billion dollars between the capital spent globally to build hardware infrastructures and the revenues, insufficient so far, generated by the AI ecosystem.[124]

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[120] *World Energy Outlook 2024*. Tech. rep. `https://www.iea.org/reports/world-energy-outlook-2024`. International Energy Agency, 2024.

[121] Peng Wang et al. "E-waste challenges of generative artificial intelligence". In: *Nature Computational Science* 4.11 (Nov. 2024), pp. 818–823.

[122] Pengfei Li et al. "Making AI less "thirsty"". In: *Communications of the ACM* 68.7 (June 2025), pp. 54–61. DOI: `10.1145/3724499`.

[123] Cory Weinberg. "OpenAI Projections Imply Losses Tripling to $14 Billion in 2026". In: *The Information* (2026). URL: `https://www.theinformation.com/articles/openai-projections-imply-losses-tripling-to-14-billion-in-2026`.

[124] David Cahn. "AI's $600B Question". In: *Sequoia* (2024). URL: `https://sequoiacap.com/article/ais-600b-question/`.

How to explain this haemorrhage of energy and capital without a corresponding increase in real wealth? The commercial implementation of AI is currently blocked by a sequence of four structural bottlenecks acting as a funnel, throttling its productivity:

1. **The cognitive bottleneck**: The techno-capitalist narrative assumes universal automation of work, but the mathematical reality is quite different. The study by Nobel Laureate Daron Acemoglu demonstrates that current generative AI is profitable only on purely digital and repetitive tasks, limiting its real impact to just 4.6% of the economy's total tasks over the next decade. For over 95% of corporate tasks, which require complex contexts and physical or social interactions, using AI is not yet economically advantageous compared to the enormous energy and technological costs necessary to run it.[125]

2. **The structural bottleneck**: Even in the limited cases where speed gains are recorded at the micro level, the macro impact on Total Factor Productivity (TFP) remains flat due to profoundly asymmetrical adoption. While 52% of large enterprises have started experimenting with AI, a mere 17.4% of Small and Medium Enterprises (SMEs) manage to integrate it due to a lack of capital, skills, and structured data.[126] Without widespread diffusion in the productive fabric, the enormous energy consumption of the IT infrastructure does not translate into collective wealth.

3. **The organizational bottleneck**: AI is a GPT - General Purpose Technology, like electricity for example. Currently, companies merely integrate algorithms into old production processes. Redesigning corporate architectures requires massive investments in what economists call "complementary

[125] Daron Acemoglu. "The simple macroeconomics of AI". in: *Economic Policy* 40 (Aug. 2024). DOI: 10.1093/epolic/eiae042.

[126] Flavio Calvino et al. *AI adoption by small and medium-sized enterprises: OECD discussion paper for the G7.* Tech. rep. OECD, 2025. DOI: 10.1787/426399c1-en.

assets" or "intangible capital": staff training, work reorganization, and new business models.[127] This organizational friction generates what economic literature defines as the "Productivity J-Curve": in a primary phase of technological adoption, measured productivity (TFP) remains flat or even drops, because capital, time, and human resources are temporarily diverted to build this invisible organizational capital.[128] Developing these complementary assets requires human adaptation time that is physiologically much slower compared to the exponential computing speed of processors.

4. **The thermodynamic bottleneck**: According to the Italian physicist and mathematician Pierluigi Contucci, this colossal inefficiency is not an anomaly, but the typical characteristic of a "pre-scientific revolution." Exactly as happened with the first steam engines before Carnot and Kelvin formalized the laws of thermodynamics, technological invention preceded physical understanding. Today, Artificial Intelligence is a black-box: we are forcing an immature technology to absorb massive amounts of energy to transform it into information, without yet having developed an efficiency theory for it. It is, precisely, a "pre-scientific" technology that compensates for the lack of theoretical elegance with computational, and therefore energetic, brute force. It is no coincidence that, just like in early industrial England, the EPE (Economic Productivity of Energy) tied to these new infrastructures, i.e., the wealth generated for each consumed kWh, is dropping due to the intrinsic waste of the first rudimentary systemic adoption attempts. Which, unsurprisingly, did not happen with the electrical revolution or

[127] Erik Brynjolfsson, Daniel Rock, and Chad Syverson. *Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics*. Working Paper 24001. National Bureau of Economic Research, Nov. 2017. DOI: 10.3386/w24001. URL: http://www.nber.org/papers/w24001.

[128] Erik Brynjolfsson, Daniel Rock, and Chad Syverson. *The Productivity J-Curve: How Intangibles Complement General Purpose Technologies*. Working Paper 25148. National Bureau of Economic Research, Oct. 2018. DOI: 10.3386/w25148. URL: http://www.nber.org/papers/w25148.

the digital internet revolution.[129]

In short, the increase in labour productivity driven by AI is currently more of a narrative promise and a hope rather than a statistical reality.

Measuring the Disaster and the Current Regulatory Delay

Measuring this waste is the first and indispensable step to curbing it. As long as consumption remains hidden inside proprietary servers, there will be no real push for change. Independent projects like the *AI Energy Score*,[130] led by researcher Sasha Luccioni, attempt to tear down this wall of opacity: testing over 100 open-source AI models, the project assigns an energy efficiency rating to allow developers and users to choose technologies based on their carbon footprint.[131] Big Tech, obviously, opposes this transparency and refuses to submit its dominant models to third-party evaluation methodologies.

Faced with this vacuum, politics is beginning to intervene. The AI Act approved by the European Union represents the first structured attempt to regulate algorithms and their systemic impacts, also introducing disclosures (albeit often voluntary) on the use of energy and physical resources by foundational models.[132]

However, Europe's push toward digital sovereignty via the GDPR itself creates a paradox. Aiming to reduce its dependence on US and Chinese cloud providers,[133] Europe is fuelling a demand for

[129] Pierluigi Contucci, Godwin Osabutey, and Filippo Zimmaro. "A New Lens on the Sustainability of the AI Revolution". In: *Energies* 19.2 (2026). ISSN: 1996-1073. DOI: 10.3390/en19020525. URL: https://www.mdpi.com/1996-1073/19/2/525.

[130] Hugging Face. *AI Energy Score*. https://huggingface.github.io/AIEnergyScore/. 2025.

[131] Sasha Luccioni. "We're doing AI all wrong. Here's how to get it right". In: *TED* (2025). URL: https://www.ted.com/talks/sasha_luccioni_we_re_doing_ai_all_wrong_here_s_how_to_get_it_right.

[132] European Data Protection Supervisor. *The EU Artificial Intelligence Act*. https://www.edps.europa.eu/artificial-intelligence/artificial-intelligence-act_en. 2024.

[133] Jan Mischke et al. "Europe's technological competitiveness". In: *World Economic*

Data Centers that the existing infrastructure cannot support. Furthermore, the absence of a dominant European cloud provider leaves the continent substantially dependent on foreign companies. In short, Europe might be forced to choose between digital sovereignty and environmental sustainability.[134]

This regulatory void doesn't just concern software opacity, but extends to the predatory management of physical resources, giving rise to energy hoarding phenomena. A disturbing trend sees Big Tech adopting approaches defined as "behind the meter." Companies purchase energy directly at the source, often nuclear plants or renewable parks, securing privileged access and bypassing the public grid.

The effect is parasitic: in the case of Pennsylvania, for example, giants like Amazon have acquired shares of nuclear energy, effectively taking them away from the community. To compensate for this loss of clean, constant energy in the civil grid, operators are forced to reactivate or keep running less efficient fossil fuel plants, causing an increase in the marginal cost of electricity that falls directly on citizens' utility bills.[135]

The IEA certifies that the explosion of data centers dedicated to AI will lead to very strong regional imbalances and direct competition for low-carbon electricity supply, confirming the risk to national climate goals.[136][137]

It is the dramatic clash between two incompatible time scales: the

Forum (Jan. 2025). URL: https://www.weforum.org/publications/europe-in-the-intelligent-age-from-ideas-to-action/.

[134] Christofer Klink, Dmitriy Genchev, and Rodolph Al Mallah. "Energy Impact of Data Centers". In: *VOYCE* (2025). URL: https://voycecommunity.eu/home/f/energy-impact-of-data-centers.

[135] Laila Kearney. "Talen asks US regulators to reject challenge to Amazon data center deal". In: *Reuters* (July 2024). URL: https://www.reuters.com/markets/deals/talen-asks-us-regulators-reject-challenge-amazon-data-center-deal-2024-07-05/.

[136] *Electricity 2024*. Tech. rep. https://www.iea.org/reports/electricity-2024. International Energy Agency, 2024.

[137] *Energy and AI*. tech. rep. https://www.iea.org/reports/energy-and-ai. International Energy Agency, 2025.

times of legislation and social awareness are slow and linear, while the times of hardware evolution and data center proliferation are violently exponential.

Return to Biological Times

Stopping the horse to Samarkand does not mean giving up on technology, but bringing it back within more "biological" times and the biophysical limits of the Earth.

The Just Transition

As highlighted by reports from the International Renewable Energy Agency, the true ecological transition is structurally labour-intensive, not capital-intensive nor energy-intensive.[138] The numbers confirm it: renewable energy technologies create 2 to 3 times more jobs for every million dollars invested compared to fossil fuels.[139] This transition requires human care distributed across the territory and artisanal work to repair panels and turbines, lowering the unnecessary consumption of capital and restoring that balance between human employment and the economic productivity of energy hoped for by Tiezzi.[140]

AI for Climate and the Specter of Jevons' Paradox

Within this transition, technology retains a vital role, provided its purpose is overturned. There is a line of research and application, defined as "AI for Climate," which uses predictive models to concretely tackle the ecological crisis: optimization of smart grids, satellite monitoring to prevent deforestation, or the discovery of new materials for more efficient batteries.[141] In these spe-

[138] IRENA. *World Energy Transitions Outlook 2023*. International Renewable Energy Agency, 2023.

[139] IRENA. *Renewable Energy and Jobs - Annual Review 2022*. International Renewable Energy Agency, 2022.

[140] Tiezzi, "Tempi Storici Tempi Biologici".

[141] David Rolnick et al. "Tackling Climate Change with Machine Learning". In: *ACM Comput. Surv.* 55.2 (Feb. 2022). ISSN: 0360-0300. DOI: 10.1145/3485128. URL: https://doi.org/10.1145/3485128.

cific micro-sectors, Artificial Intelligence actually proves to be a powerful sustainability accelerator.

However, as ecological economics teaches, the environmental benefits of these applications clash with Jevons' Paradox. This establishes that the increase in technological efficiency in using a resource, by lowering its cost, paradoxically leads to an increase in the total consumption of that resource.[142]

As confirmed by recent studies, precisely because computing power becomes cheaper and more efficient, global demand explodes, creating a "rebound effect".[143] The energy savings obtained by optimizing an electrical grid are instantly devoured by the consumption generated by billions of frivolous user interactions. Hyper-efficiency, if not bound to a limit of "digital sobriety",[144] does not save the climate but accelerates the entropic consumption of the biosphere.

The Thermodynamic Lesson of the Brain

Overcoming the current paradigm, therefore, does not just pass through an attempt at hyper-efficiency of current models, but through a radical change of architecture inspired once again by biology. Geoffrey Hinton, a pioneer of Deep Learning, has recently suggested that the real frontier is not scaling raw power, but developing neural architectures that mimic as closely as possible the incredible energy frugality of the biological brain.[145] The human brain, in fact, consumes a mere 20-25 Watts of power (the equivalent of a low-energy lightbulb) to produce complex reasoning, empathy, art, and scientific discoveries, the result of a long effi-

[142] William Stanley Jevons. *The coal question:* London : Macmillan, 1865.

[143] Alex de Vries. "The growing energy footprint of artificial intelligence". In: *Joule* 7.10 (Oct. 2023), pp. 2191–2194. ISSN: 2542-4785. DOI: 10.1016/j.joule.2023.09.004. URL: https://doi.org/10.1016/j.joule.2023.09.004.

[144] The Shift Project. *Lean ICT: Towards Digital Sobriety.* 2019. URL: https://theshiftproject.org/en/article/lean-ict-our-new-report/.

[145] Geoffrey Hinton. *The Forward-Forward Algorithm: Some Preliminary Investigations.* 2022. arXiv: 2212.13345 [cs.LG]. URL: https://arxiv.org/abs/2212.13345.

ciency process lasting millions of years of biological evolution.[146]

Conversely, using a server of thousands of Watts for basic tasks represents a failure of engineering even before ecology.

The alternative to energy black holes, therefore, exists and is called digital sobriety. Instead of delegating every trivial calculation to mammoth Large Language Models locked in energy-guzzling data centers, the sustainable future looks elsewhere:

Small-LMs. Developing compacted and specific AI models drastically cuts consumption. As demonstrated by the AI Energy Score project (measured across over 100 open-source models), using a generic LLM model for simple tasks requires up to 30 times more energy compared to a task-specific model.[147] An optimized model, with "only" 135 million parameters (5,000 times smaller than commercial giants), can answer a query consuming just 0.0007 Watt-hours (Wh), which is 150 times less energy than the dominant models on the market.[148]

Edge Computing. These lightweight models allow processing at the "edges" of the network (directly on smartphones or local microcontrollers). Since transferring data via mobile networks and Wi-Fi to Cloud servers can account for up to 50-60% of the total energy cost of a digital operation,[149] processing data locally neutralizes this immense and useless waste of electricity at its root, while also guaranteeing greater privacy.

Permacomputing. A holistic design approach, inspired by permaculture, that aims to destroy the dogma of planned obsoles-

[146] Yali Chen and Jun Zhang. "How Energy Supports Our Brain to Yield Consciousness: Insights From Neuroimaging Based on the Neuroenergetics Hypothesis". In: *Frontiers in Systems Neuroscience* Volume 15 - 2021 (2021). ISSN: 1662-5137. DOI: 10.3389/fnsys.2021.648860. URL: https://www.frontiersin.org/journals/systems-neuroscience/articles/10.3389/fnsys.2021.648860.

[147] Face, *AI Energy Score*; Alexandra Sasha Luccioni and Alex Hernandez-Garcia. *Counting Carbon: A Survey of Factors Influencing the Emissions of Machine Learning*. 2023. arXiv: 2302.08476 [cs.LG]. URL: https://arxiv.org/abs/2302.08476.

[148] Face, *AI Energy Score*.

[149] Hugues Ferreboeuf et al. *Lean ICT: Towards digital sobriety*. Tech. rep. The Shift Project, 2019.

cence. Life Cycle Assessment (LCA) data speak clearly: for computing devices (like smartphones and laptops), between 75% and 85% of the carbon footprint of the entire lifecycle is emitted even before the first power-on, during the devastating phase of mining extraction and production, the so-called embodied energy.[150] Extending the life of a machine from 3 to 6 years by developing lightweight software capable of running on "obsolete" hardware literally means halving its annual environmental impact.[151]

Planetary Limits and True Development

As ecological economist Herman Daly reminds us, echoing the warnings of the Club of Rome, there are biophysical and planetary limits to quantitative growth, but there are no limits to qualitative development. Maximizing the life of existing hardware, designing software that does not assume infinite energy is available, focusing on agile, integrated, and thermodynamically sustainable tools: this is the way to align the power of information technology to the vital slowness of the biosphere, to bring technology back within the biophysical limits of the Earth.

[150] Lotfi Belkhir and Ahmed Elmeligi. "Assessing ICT global emissions footprint: Trends to 2040 & recommendations". In: *Journal of Cleaner Production* 177 (2018), pp. 448–463. ISSN: 0959-6526. DOI: https://doi.org/10.1016/j.jclepro.2017.12.239. URL: https://www.sciencedirect.com/science/article/pii/S095965261733233X.

[151] Francisco Zuloaga et al. *Coolproducts don't cost the Earth*. Tech. rep. European Environmental Bureau, 2019. URL: https://eeb.org/en/library/coolproducts-report/.

7 Conclusion

We started this journey with a handful of minerals in your palm and ended with a soldier riding a high-tech horse toward a predictable fate in Samarkand. We've seen the red mud of Guinea, the "toxic breath" of the Congo, and the energy-devouring ghost of the AI bubble.

It's easy to feel like a small component in a very large, very broken machine. But while the system is designed to keep us in a "buy-use-discard" spiral, our e-mpact can be reduced. So, how do we actually slow down the horse?

Can We Fix It?

The most sustainable device is the one you already own. Breaking the pattern of perceived obsolescence starts in your pocket.

- *Buy Only When Necessary*

  Next time a spectacular launch event tells you that your current phone is a "museum piece," ask yourself: Is it actually broken, or did a marketing campaign just make me feel bored?

- *Choose Refurbished*

  Give tech a second life. Buying refurbished or second-hand isn't just cheaper; it saves the "embodied energy" already spent in a mine somewhere far away.

- *Support the Rebels*

  If you must buy new, look for companies like Fairphone or Framework. Support modularity, repairability, and transparent supply chains.

- *Mine Your Drawers*

  Do not let your "just in case" drawer become an electronic graveyard. Take those old phones and cables to a collection center (like the ones here at the university!).

When it comes to your cloud uses, there are also things you can do!

- *Assess your Personal Impact*

  Scan the following QR code to have access to a tools to know the carbon footprint of your use of AI.

- *Question your Use*

  Is it worth it to generate that kitten picture with an AI? And what about that high quality video that I'm only listening to? Do I really need to have the video switched on during that call?

As a Community: Amplify the Signal

Individual choices are the beginning, but systemic change requires collective actions.

- *Stay Informed*

  Don't let the supply chain stay "blurry." Keep looking behind the "window-dressing" of corporate sustainability reports.

- *Start the Conversation*

  Pass this book to a friend. Talk about the social and environmental implications of raw material mining and waste colonialism, think about digital sobriety. The more we understand the journey electronic devices make before and after our pockets and the true cost of a "free" AI query, the less we accept the status quo.

- *Demand Better Policy*

  Push for strong Right to Repair laws and stricter enforcement of the Basel and Bamako Conventions. We need to hold companies financially responsible for the "end of life" of their products, not just the "point of sale."

Technology is a tool, not a destiny. We don't have to be the sorcerer's apprentices, watching our inventions spiral out of control. The horse is fast, but we are the ones holding the reins.

P.S. If you liked the fanzine and you have any other idea on how to make the difference, or you have questions about the impact your everyday online activity has on the environment, feel free to contact us on Instagram @resilient_gap and join our community!

The online sources were accessed in April 2026.