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The Environmental Toll of Digital Technologies

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This study delves into the complex connection between digital technologies and environmental sustainability in the face of the worsening climate crisis. It presents two different stories: one praises digitalization for its improved efficiency and less waste, while the other cautions about the environmental impact of energy-consuming data centers and growing electronic waste. As temperatures increase worldwide, the need for immediate action becomes more pressing. Despite being seen as abstract, digital technologies depend greatly on physical infrastructures, which have a substantial impact on the environment. Thinkers such as Guillaume Pitron, Kate Crawford, and Benedetta Brevini question the positive perceptions of technology by exposing how misinformation conceals its impact on the environment. The paper underscores the importance of informed public discussion and working together to tackle the environmental challenges of digitalization, highlighting the significance of evaluating the ecological effects of digital technologies for a truly sustainable tomorrow.

Keywords: digital technologies – climate emergency – environmental impact – agnotology – sustainability

Introduction

The discourse on digital transition currently stands at a critical juncture, where technological advancements intersect with escalating environmental concerns. With global temperatures surpassing pre-industrial levels, the urgency to address climate change intensifies, contrasting with pervasive optimism about digital technologies' potential for sustainability. While these innovations promise efficiency and dematerialization, their material impact – including energy-intensive data centers and electronic waste – remains significant. This dichotomy underscores the need for an assessment of how digital technologies can either exacerbate or mitigate environmental degradation, highlighting the complexities inherent in pursuing a green digital transformation amidst mounting ecological challenges.

This study aims to critically examine these dual narratives, exploring how digital technologies contribute to both environmental harm and potential solutions. Section one establishes the context by emphasizing the urgency of addressing climate change. Section two explores how digital technologies have evolved and integrated into society and the economy, discussing their sustainability benefits and environmental consequences. Section three examines the dual nature of digital technologies as both immaterial tools and physical entities, challenging perceptions of dematerialization and discussing their material footprint. The final section investigates how agnotological stratagems obscure the environmental impact of digital technologies, revealing their true ecological costs amid global climate challenges.

I. On the Current State of Our Planet

Since assuming office in 2017, UN Secretary-General António Guterres has been a leading voice on the global climate crisis. He warned early on about the crucial "link between climate change and the devastation we are witnessing is clear, and there is a collective responsibility of the international community to stop this suicidal development" (Guterres 2017). His speeches have since adopted an increasingly urgent and catastrophic tone, describing humanity as being on the brink of disaster. This evolving rhetoric underscores his deepening concern about the climate emergency and the urgent need for decisive action.

To understand why this shift from a climate crisis to a climate emergency has occurred, it is important to consider the potential consequences of temperatures surpassing pre-industrial levels. Mark Lynas's framework in *Our Final Warning* (2020, esp. chap. 7), summarized below (table 1), is useful for grasping the escalating severity of the situation:

Temperature	What to Expect
1º C	The Earth's current average surface temperature exceeds that of the late 19th century pre-industrial levels, resulting in melting glaciers, rising sea levels, more heatwaves, altered rainfall patterns, and significant stress on ecosystems and species.
2°C	A 2°C temperature increase marks a critical point for dangerous climate change, leading to harsher droughts, more extreme weather events, coral reef degradation, agricultural disruptions, and widespread food insecurity.
The "threshold for carbon-cycle feedback" is a critical point in Earth's carbon cycle where rising carbon dioxide levels intensify processes. This triggers feedback loops such as permafrost thawing and increased ocean CO_2 release, worsening climate change impacts.	
3º C	At 3°C, the impacts worsen significantly. Feedback loops such as methane release from permafrost and melting ice sheets in Greenland and West Antarctica accelerate sea level rise. More frequent and intense extreme weather events cause widespread devastation and larger-scale displacement of populations.
The "threshold for Siberian methane feedback" is a critical point in Siberia's permafrost thawing, leading to increased methane emissions that worsen climate change by causing additional warming.	
4º C	This level of warming poses a catastrophic scenario with severe and irreversible outcomes. Coastal cities will be flooded due to rising sea levels, displacing millions. Extensive heatwaves, droughts, and wildfires will render vast regions uninhabitable. Ecosystem collapse will accelerate, causing significant biodiversity loss and the depletion of essential services crucial for human survival.
5º C	At this warming level, Earth experiences profound climate shifts with frequent and intense extreme weather events like hurricanes, storms, and floods. Agricultural systems collapse in many regions, sparking widespread famine and social upheaval, threatening the survival of human civilization.
6º C	This envisions Earth entering a hothouse state, where the climate becomes hostile to human civilization with widespread desertification, biodiversity loss, and ecosystem collapse, resembling ancient conditions.

Table 1. Mark Lynas' 6-degrees framework

Where do we stand now? In 2023, NASA reported Earth's average surface temperature had risen by 1.36 degrees Celsius compared to the late 19th century average (1850 – 1900), marking the highest recorded since 1880 (NASA 2023). The latest IPCC Sixth Assessment Report (AR6), published in March 2023 (IPCC 2023), indicates a greater than 50% likelihood of global temperatures reaching or exceeding a 1.5 degrees Celsius rise by 2040 without significant policy changes or effective mitigation measures. By 2100, temperatures could potentially increase by 3.3 to 5.7 degrees Celsius, emphasizing the urgent need for decisive climate action.

II. The Digital Transition Narrative

The term "digital transition" originally referred to the shift from analog to digital television systems in the late 20th century. Today, its meaning has evolved from "digital transformation," introduced by Capgemini and MIT in 2011. Initially aimed at using technology to boost business performance, it is now crucial in the strategic plans of numerous organizations (e.g., KPMG 2023).

With the escalating climate crisis, the term's scope has expanded beyond television technology and business to include broader societal, economic, daily life, and climate-related aspects. The anticipation of digital transition predates the term, marked by milestones like the emergence of computers in the 1940s – 1950s, mainframe and minicomputers in the 1960s – 1970s, personal computers in the 1980s, the internet and World Wide Web in the 1990s, mobile technology and social media in the 2000s, and cloud computing and big data since the 2010s (Schwab 2017, 11).

It now involves integrating digital technologies into virtually every aspect of human life. This process primarily substitutes the material with the immaterial and the tangible with the virtual.

In this nuanced view of digital transition lies the potential for these technologies to significantly impact the climate emergency. This has sparked a sort of utopian narrative blending technology, politics, and economics, focusing on the ecological benefits of digital transition. It emphasizes how digital technologies can dematerialize our lifestyles and decouple economic growth from physical resource consumption.

A thorough analysis is pending yet consider the EU Ministerial Declaration of 2021 on the intertwined green and digital transition. Here, the EU emphasizes the critical role of environmental sustainability ("green") and digitalization ("digital") in fostering economic growth, innovation, and societal advancement. The declaration's opening paragraph underscores this symbiotic relationship, suggesting digital technologies can greatly contribute to addressing the climate crisis:

> Smart use of clean digital technologies can serve as a key enabler for climate action, environmental sustainability, and reaching the UN Sustainable Development Goals….Our goal is to accelerate and take the global lead on the green digital transformation… (European Union 2021).

The terms "clean," "green," and "sustainable" linked with "digital technologies" aim for rhetorical impact. Yet, they are part of a widespread narrative that subtly suggests digital technologies inherently support ecological benefits and environmental friendliness. This narrative diverts attention from potential risks, such as exacerbating ecological issues or perpetuating unsustainable consumption and production patterns.

In the Declaration's list of sixteen objectives, this narrative is reinforced, particularly in the first objective highlighted here:

> Accelerate the development and deployment of digital technologies…as key solutions to ensure the impact of climate adaptation and mitigation policies, decrease pollution, optimise energy and resource efficiency, develop a circular

economy, promote precision farming and helping to combat the loss of biodiversity (European Union 2021).

Digital technologies are heralded as essential solutions for urgent climate, ecological, energy, and economic challenges. However, the document overlooks potential unintended negative environmental impacts that may arise from these technologies.

This Declaration backs the European Green Digital Coalition, formed in 2020 to promote the Green and Digital Transformation of the EU. Initially led by 26 CEOs, it now includes 37 ICT companies.[1] It raises questions about whether the EU, possibly due to excessive optimism, is unintentionally contributing to the greenwashing practices it condemns.

III. Ontology of the Digital Technologies

Digital technologies are often perceived as immaterial existing in a virtual realm, seemingly disconnected from the tangible world much like atoms, which are intangible and not directly observable. However, as Yuk Hui argues, digital technologies are both material and immaterial (Hui 2012). They operate with data and metadata, which the Hong Kong philosopher of technology refers to as "digital objects." These technologies generate, process, store, and manage these digital objects, but rely on physical components for their functioning. This means that data and metadata must be embodied in material supports such as electronic circuits, magnetic storage devices, and network infrastructures (Lovink – Hui 2016).

Perceiving digital technologies as ethereal reflects a false dualism, disconnecting them from their material underpinnings. Although digital objects may appear detached from physical reality, they are intricately linked to material supports. While they may not rely on a specific material medium, their existence is contingent upon materiality. Data holds substance because it is inherently situated within material supports, regardless of their specific nature.

Decoupling the digital from the material is a misconception perpetuated by the concept of digitalization as dematerialization (e.g., Devine 2015). Overlooking the inherent connection between digital technologies and the physical world prevents us from recognizing their influence through material presence.

The prevailing perception of digital technologies as immaterial often downplays their significant potential in addressing pressing global challenges,

[1] See online: https://www.greendigitalcoalition.eu

particularly the urgent issue of climate change. While they may not be immediately associated with exacerbating environmental issues, they are increasingly recognized for their pivotal role in mitigating them. Digital technologies not only facilitate the reduction of carbon emissions through innovative processes like virtualization and dematerialization but also stand as environmentally benign solutions in their own right.

However, this perception overlooks the material footprint of digital infrastructures, including data centers, manufacturing processes, and electronic waste. Digital technologies rely on physical resources and energy-intensive processes, contributing to their carbon footprint and environmental impact. While they offer opportunities for efficiency gains and sustainable practices, their material embodiment necessitates a holistic assessment of their environmental implications. Digitalization alone is not a panacea for the climate crisis; instead, it requires careful consideration of the material realities underlying digital technologies and their role in shaping sustainable futures.

IV. Unmasking the Ecoclimatic Impact of Digital Technologies

The analysis of the digital transition narrative has only recently begun. Two internationally impactful publications stand out in this context. The first is the Foresight Brief "The Growing Footprint of Digitalisation," prepared by Stefan Schwarzer and Pascal Peduzzi for the United Nations Environment Programme. It concluded, negatively, that

> the environmental footprint of the digital infrastructure poses serious threats to our planet and future generations. The demand on precious/rare metals needed for the production of and the huge consumption of energy to run the infrastructure constitute serious challenges if we want digitalization to help combat climate change and lower our environmental footprint on the planet (United Nations Environment Programme 2021, 8).

The second is the article "Digitalization and the Anthropocene" (Creutzig et al. 2022). While it acknowledges that "digitalization has historically increased environmental impacts at local and planetary scales…" (Creutzig et al. 2022, 480) and that "he indirect and systemic effects of digitalization are more profoundly reshaping the relationship between humans, technosphere and planet" (Creutzig et al. 2022, 480), it concludes that although "current trajectories suggest a contribution of digitalization to further planetary destabilization" (Creutzig et al. 2022, 500), it is nonetheless possible, through public policy, for "digitalization [to] support planetary health" (Creutzig et al. 2022, 500).

In this section, we will examine how key thinkers such as Guillaume Pitron, Kate Crawford, and Benedetta Brevini have critiqued these optimistic narratives and exposed how agnotological stratagems – deliberate ignorance creation, including spreading selective, inaccurate, or misleading scientific data (Proctor 2008) – are used to obscure the true ecoclimatic costs of digital technologies.

A. Journey to the End of the Digital Hell

French journalist and documentary maker Guillaume Pitron published the exposé *La guerre des métaux rares* (The Rare Metals War) in 2018. This work is the result of six years of research across twelve countries on four continents, focusing on, as the subtitle reveals, *La face cachée de la transition énergétique et numérique* (The dark side of clean energy and digital technologies). Of particular significance is the second chapter, which is further explored in his essay three years later, *L'enfer numérique. Voyage au bout d'un like* (The dark cloud. How the digital world is costing the earth).

His main argument is that digital technologies do not enable the fulfillment of what he metaphorically refers to as Hercules' 13th labor, namely, the implementation of the Paris Agreement reached at COP 21 in 2015 (Pitron 2018, 24). Not only do these technologies fail to effectively mitigate the global anthropogenic climate crisis, but they paradoxically exacerbate it. "The so-called happy march towards the age of dematerialization," he asserts, "is therefore nothing but a grand deception, as it actually generates an ever-increasing physical impact" (Pitron 2018, 68). According to him, we are constructing a "digital Leviathan" that feeds on coal plants, oil and gas platforms, nuclear power plants, wind farms, solar farms, and smart grids, all of whose infrastructures require rare metals (Pitron 2018, 68 – 69).

However, it so happens that this "materiality of the invisible" has been deliberately hidden. By whom? Primarily by the "prophets of the energy transition" – the American "Magnificent Seven": Apple, Microsoft, Alphabet (Google), Amazon, Meta Platforms (formerly Facebook), Nvidia, Tesla; and the BATX in China: Baidu, Alibaba, Tencent, and Xiaomi – with the continued support of their respective governments. They have woven a narrative of illusions and mystifications over decades, aimed at making the whole world believe that digital technology will enable energy sobriety (Pitron 2018, 62 – 63, 84; Pitron 2021, 129), i.e., the reduction of overall energy consumption to promote sustainability and address climate change (e.g., The Shift Project, 2019).

How? By resorting to agnotological stratagems that have proven successful but urgently need to be unraveled. Pitron identifies three in particular. One involves concealing the true ecological cost of digital technologies, preventing their connection with the physical world from being perceived. For instance, a simple "like" click on Facebook from a smartphone or laptop requires navigating a physical infrastructure with multiple layers and high energy consumption, operating 24/7 until reaching its destination (Pitron 2021, 26). In this regard, Pitron reveals Estonia as an exemplary case, having fully embraced digitalization while collectively avoiding acknowledgement of the physical, energetic, and software infrastructure that "keeps the state machine running" (Pitron 2021, 42). Additionally, there's a truncation of the perception of their complete life cycle, such as the production process of a tablet from material extraction to disposal and transformation into e-waste when it's no longer in use. These practices exemplify cases of greenwashing, where the environmental impacts of technological consumption are underestimated or obscured, undermining genuine efforts towards sustainability and environmental accountability.

Another stratagem involves deploying rhetoric that uses terms such as "green," "decarbonized," and "renewable" to portray digital technologies as environmentally beneficial and capable of facilitating a transition away from fossil fuels. However, in reality, these technologies still rely on activities that produce greenhouse gases (Pitron 2018, 80 – 81). Conversely, employing attractive terms like "circular economy," "process efficiency," and "resource productivity gains" serves to separate their material consumption from the creation of wealth (Pitron 2021, 40).

The third stratagem involves secrecy, specifically withholding official data on the true eco-climatic costs of digital technologies. This is achieved in two main ways: by deliberately creating a disconnect between perceived effects and actual impacts, either by keeping the general public and consumers uninformed or by delaying the disclosure of these impacts over time (Pitron 2021, 61 – 62); and by omitting this information in official government documents and business reports from tech giants (Pitron 2018, 103). Pitron argues that China, in particular, has adopted this stratagem, often in close cooperation with Western nations (Pitron 2018, 92, 102).

B. Environmentally Demonic Artificial Systems

In her book *Atlas of AI: Power, Politics, and the Planetary Costs of Artificial Intelligence*, Kate Crawford, a leading Australian scholar in Artificial Intelligence (AI) and its impacts, argues that AI systems, as a manifestation of digital technologies, are "neither artificial nor intelligent" (Crawford 2021, 8). AI is here understood as a subset of digital technologies. She points out that AI systems not only have physical existence, but also lack autonomy and rationality, necessitating extensive training with large datasets or predefined rules and rewards. Crawford emphasizes that "AI can seem like a spectral force – as disembodied computation – but these systems are anything but abstract. They are physical infrastructures actively reshaping the Earth" (Crawford 2021, 19).

Crawford further asserts that AI is profoundly influenced by significant political decisions, societal structures, and substantial financial investments. Consequently, AI primarily benefits powerful entities and mirrors existing power dynamics (Crawford 2021, 8). This leads many industries involved in developing AI systems to conceal the true costs of their operations. Moreover, the complexity and scale required for AI development make it challenging to fully comprehend. Legal protections related to intellectual property rights and intricate logistical and technical challenges further contribute to this lack of transparency (Crawford 2021, 49).

Similar to Pitron, Crawford underscores the significant environmental impacts of AI systems, debunking the notion of "clean technologies." She critiques the industry's disregard for the carbon footprints, fossil fuel usage, and pollution associated with advanced computation, contrasting misleading metaphors like "the cloud" with the stark realities of AI's ecological footprint (Crawford 2021, 50). The reality is that, as she says, "the carbon footprint of the world's computational infrastructure has matched that of the aviation industry at its height, and it is increasing at a faster rate" (Crawford 2021, 53) and the actual energy consumption of AI systems kept confidential, reveals how the data economy hides its environmental footprint (Crawford 2021, 42 – 43). As she stated in an interview with the Spanish newspaper *El País*, "these are systems that are very environmentally demonic" (Crawford – Vidal 2023).

Crawford criticizes agnotological stratagems employed to hide the environmental impact of digital technologies. "Just like the mines that served San Francisco in the nineteenth century," she says, "extraction for the technology sector is done by keeping the real costs out of sight" (Crawford 2021, 35). She suggests that ignorance of the supply chain is deeply embedded within capitalist systems, allowing businesses to shield themselves through third-party contractors and complex supply networks. This deliberate opacity extends to how goods are marketed and advertised, perpetuating a cycle where consumers remain unaware of the environmental and social impacts of their technological consumption. However, is this ignorance solely a product of capitalist structures, or do consumers share responsibility for seeking information about the products they purchase? While businesses may use complex supply chains to obscure their practices, emerging technologies advocate for greater transparency. This raises questions about whether opacity is an inherent characteristic of capitalism or reflects broader systemic issues like regulatory failures and consumer complacency.

The notion of "bad faith" emerges as businesses employ increasingly intricate forms of distancing, ensuring that different parts of the organization operate with limited knowledge of each other`s activities. Ultimately, this agnotological stratagem serves as a tool to maintain plausible deniability and prevent public awareness of the extensive costs – environmental degradation, exploitation of labor, and resource depletion – associated with the production and maintenance of the vast techno-digital ecosystem.

However, unlike Pitron, she also emphasizes the need to uncover other hidden truths, such as their intensive reliance on human labor:

> The massive ecosystem of AI relies on many kinds of extraction: from harvesting the data made from our daily activities and expressions, to depleting natural resources, and to exploiting labor around the globe so that this vast planetary network can be built and maintained. And AI extracts far more from us and the planet than is widely known (Crawford 2021, 32).

Resorting to the term "megamachine," coined by American historian and philosopher Lewis Mumford in his 1967 book *The Myth of the Machine*, Crawford argues that AI systems exemplify this concept. They encompass far more than databases, algorithms, and machine learning models; they represent "a set of technological approaches that depend on industrial infrastructures, global supply chains, and human labor, all of which are kept opaque" (Crawford 2021, 48). The dependence of AI systems on human labor is intentionally rendered invisible, sustaining the illusion that these technologies are free from exploitative working conditions and human intervention. This deliberate opacity concentrates power and knowledge among a few, creating an informational imbalance that prevents democratic and informed participation in AI development decisions. Opacity protects the interests of those who profit from AI while keeping the public ignorant, making awareness and contestation difficult.

C. AI's Geophagic Appetite

Italian journalist, media activist, and academic Benedetta Brevini, akin to Pitron and Crawford, has formulated a critique of the excessive consumption of data, energy, and material resources by AI systems. She initially articulated this viewpoint in Brevini (2020, 1), a relatively concise article where she "contends that public discourse on AI systematically avoids considering AI's environmental costs," and later expanded upon it in the essay *Is AI Good for the Planet?* two years later.

In Brevini (2020), it is argued that data analytics and AI have deeply infiltrated essential sectors like medicine, law enforcement, education, and cybersecurity. It signifies how these technologies have become deeply embedded and utilized within these sectors, influencing their operations and practices. This integration is driven by the growing reliance on AI's ability to process large volumes of data and perform complex computations, which are essential for advancing capabilities and efficiency in various fields of endeavor.

Brevini also critiques the environmental impact of AI and digital technologies, highlighting how the rapid expansion of AI infrastructure, including data centers and computational networks, consumes substantial energy and resources. This contributes significantly to climate change and generates electronic waste, challenging the notion that AI alone can solve global challenges. This critique underscores the importance of addressing AI's environmental impacts and ethical implications.

Additionally, Brevini (2020) employs the "black box" metaphor to illuminate the opaque nature of AI algorithms and their decision-making processes. This metaphor vividly portrays how these algorithms operate as closed systems, granting corporations privileged access to personal data while shielding their methodologies from public scrutiny. This lack of transparency not only heightens societal inequalities but also presents significant ethical challenges regarding accountability and fairness.

In her 2022 essay, she continues the critique of "AI as a benevolent deity" in that "it obfuscates the materiality of the infrastructures and devices that are central to AI's functioning" (Brevini 2020, 8). According to her,

> In all its variety of forms, AI relies on large swathes of land and sea, vast arrays of technology, and greenhouse gas-emitting machines and infrastructures that deplete scarce resources through their production,

> consumption and disposal. AI requires increasing amounts of energy, water and finite resources (Brevini 2022, 8).

Brevini raises the critical question of why the negative impact of AI on the climate emergency is not being adequately discussed, especially considering that AI's massive energy consumption compromises the decarbonization plans proposed by green new deals around the world (Brevini 2022, 9).

Without mincing words, she asserts that despite claiming societal benefits, the primary purpose of AI is to maximize the profits of the large tech corporations that develop and exploit it (Brevini 2022, 25). She even caustically states that AI is "the handmaiden of neoliberalism" (Brevini 2022, 28).

Brevini introduces a crucial conceptual clarification. First, regarding the term "AI." She asserts that it should not be confused with "machine learning" – defined as "computers programmed to learn from data that are input without being continually reprogrammed" (Brevini 2022, 39) – nor with "deep learning," which refers to machines that "use different layers to learn from data and are capable of managing a larger volume of data than in machine learning" (Brevini 2022, 39). Furthermore, she argues that AI is not merely "a collection of technologies that combine data, algorithms, and computing power" (Brevini 2022, 40). This pasteurized definition of AI is designed to obscure an inconvenient reality: AI is

> a set of technologies, machines, and infrastructures that demand substantial amounts of energy to compute, analyze, and categorize. They consume scarce resources in their production, use, and disposal, exacerbating the problems of waste and pollution (Brevini 2022, 41).

Using abstract and neutral definitions is a tactic used by big tech companies as part of a bold agnotological stratagem: while developing AI, they also shape public debate on AI to influence policy outcomes (Brevini 2022, 59).

Brevini argues that the interference of these companies in shaping legal regulations, formulating moral standards, and defining academic research has become the norm. She asserts that it has become all too evident that this handful of giant digital technology firms dominate the field of AI to such an extent that they inhibit criticism of its development, while systematically avoiding a thorough discussion of the environmental costs of the technology (Brevini 2022, 61). As the author highlights, public debates on AI almost exclusively focus on its positive aspects and consistently neglect environmental considerations. This is easily observable, for instance, in various documents from the European Commission or, I might add, in the works produced by the Multistakeholder High-Level Advisory Body on Artificial Intelligence, established by the UN Secretary-General in late 2023 to advise on AI. The board includes 39 recognized figures who promote, defend, and cultivate AI, such as the Franciscan priest Paolo Benanti, whose writings on the subject are noted for their superficial critiques (Benanti 2018, 2018a, 2022).

In her 2022 essay's conclusion, Brevini advocates countering these agnotological stratagems by actively engaging in public discourse (Brevini 2022, 97 – 99), promoting unbiased and objective research (Brevini 2022, 99 – 101), calling for transparency (Brevini 2022, 101 – 105), advocating the breakup of monopolistic digital giants (Brevini 2022, 105 – 108), and fostering collaboration between environmental activists and digital technology workers to address the climate crisis.

V. Conclusion

In this paper, I undertake a critical examination of the dual nature of digital technologies in the context of the climate emergency. These technologies, despite promising dematerialization and efficiency gains, also incur significant environmental costs.

I argued that uncovering agnotological stratagems that obscure these realities necessitates increased awareness and responsible stewardship in digital innovation.

The three authors I have drawn upon illustrate how it is possible, necessary, and urgent to unmask the ecoclimatic impact of digital technologies, particularly through the critical and systematic deconstruction of the agnotological narrative perpetuated. Their critical efforts provide a valuable contribution towards initiating proactive measures to mitigate these impacts and harnessing technology as a driver of sustainable development. This nuanced understanding is crucial for navigating the intersection of digital progress and ecological resilience in the 21st century.

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