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Articles

From carbon invisibility to the urgency of thirst: Environmental pedagogy and the materiality of climate change

Dall'invisibilità del carbonio all'urgenza della sete: pedagogia ambientale e materialità del cambiamento climatico

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Abstract

Faced with the asymmetry between the abstract perception of global warming and water scarcity, this study proposes a reorientation in environmental management and education. While hegemonic climate discourse focuses on invisible decarbonization, the water crisis imposes an immediate existential risk. Integrating the sociology of technology and sanitation economics, this paper analyzes the paradox of resource-rich municipalities that fail to guarantee basic sanitation due to institutional barriers and conflicts of interest. The article proposes the implementation of decentralized water management systems supported by digital auditing mechanisms. This framework demonstrates how technology applied to civic auditing can activate sustainability competencies and transform scarcity into a lever for participatory governance.

Keywords: water scarcity; digital auditing; decentralized water management; environmental governance; environmental pedagogy.

Sintesi

Di fronte all'asimmetria tra la percezione astratta del riscaldamento globale e della scarsità d'acqua, questo studio propone un riorientamento della gestione e dell'educazione ambientale. Mentre il discorso climatico egemonico si concentra sull'invisibile decarbonizzazione, la crisi idrica impone un rischio esistenziale immediato. Integrando la sociologia della tecnologia e l'economia dei servizi igienico-sanitari, questo articolo analizza il paradosso dei comuni ricchi di risorse che non riescono a garantire i servizi igienico-sanitari di base a causa di barriere istituzionali e conflitti di interesse. L'articolo propone l'implementazione di sistemi di gestione decentralizzata dell'acqua supportati da meccanismi di auditing digitale. Questo quadro dimostra come la tecnologia applicata all'auditing civico possa attivare competenze di sostenibilità e trasformare la scarsità in una leva per la governance partecipativa.

Parole chiave scarsità d'acqua; auditing digitale; gestione decentralizzata dell'acqua; governance ambientale; pedagogia ambientale.

1. Introduction

Human biological resilience presents an immediate paradox in the face of the climate crisis: while the organism is capable of tolerating gradual temperature variations, survival is impossible after only a few days without access to water. However, in contemporary public debate, “Global Warming” is often perceived as a polarized political dispute or a statistic projected into the distant future, while the “Water Crisis” imposes itself as a pressing and unavoidable biological survival issue.

This proposal seeks to reorient the pedagogical use of technology by integrating carbon measurement — an element fundamental to global climate monitoring, yet often abstract to the common citizen — with water tracking. By elevating water tracking to a level of significance equal to carbon measurement, we can tangibly materialize climate urgency. In this sense, water monitoring does not replace the carbon agenda, but rather complements it by providing a vital and immediate metric that connects global climate goals with local human survival.

In this context of necessary reconnection with reality, environmental education assumes a central role. Righettini (2024) reflects deeply on the ability of environmental pedagogy to connect ecological transition with the formation of solid sustainability skills. The author argues for the imperative need to unite material and immaterial dimensions in pedagogical discourse, valuing places of education and educating communities as privileged spaces to promote long-term well-being for both people and the planet. This pedagogical approach suggests that technology should not be an end in itself, but a means to reveal the material dynamics that sustain life.

To understand the gravity of the scenario and structure an effective educational and technological response, precise conceptual distinctions are fundamental. As highlighted by Pinotti (2025), although terms are often used interchangeably in media discourse, they are not technical synonyms. “Global Warming” refers strictly to long-term average temperature increases driven by the burning of fossil fuels and the greenhouse effect. Conversely, “Climate Change” encompasses this thermal rise and all its resulting systemic impacts, such as extreme weather events, prolonged droughts, severe flooding, and sea-level rise. The United Nations Brazil (n.d.) reinforces that, as Earth is an interconnected system, temperature alteration acts merely as the initial trigger for the collapse of other vital subsystems, identifying water scarcity as one of the most severe, immediate, and socially destabilizing consequences.

However, the institutional approach to mitigating these problems faces significant structural barriers. Technology, which in theory should serve to empower communities, is often co-opted to sustain “Smart Cities” narratives that mask social and environmental inequalities. Viana da Silva (2025c) critically points out that the technocratic use of digital tools can widen the “democratic deficit”, creating a scenario where innovation serves surveillance mechanisms rather than solving basic infrastructure and resource access problems.

The implementation of decentralized water harvesting models, therefore, cannot be viewed merely as a technical or economic adjustment to sanitation services. It implies a profound structural change in government and governance models. Such a transition requires shifting from a centralized, top-down bureaucratic command to a distributed governance architecture. This change challenges the traditional monopoly of sanitation utilities and demands new regulatory frameworks that recognize and integrate community-led infrastructure into the formal urban fabric.

This disconnection between technological promise and scarce material reality is aggravated by direct, often hidden, economic conflicts. The implementation of decentralized rainwater harvesting systems — an evident technical solution to increase urban climate resilience — collides head-on with the traditional business model of sanitation utilities. As demonstrated by Viana da Silva (2024a), there is a systemic "conflict of interest": consumer water efficiency and autonomy through rainwater use represent, paradoxically, a revenue loss for utilities and decreased tax collection for the State.

However, this tension transcends the microeconomics of sanitation services, affecting overall economic policy. The massive adoption of decentralized models challenges the fiscal logic of large-scale centralized infrastructures and traditional public-private financial arrangements. Therefore, the transition to such a model is not a simple technical swap; it implies profound structural changes to both government and governance models. It requires a shift toward a "polycentric governance" where the State no longer acts as the sole provider, but as a regulator of a distributed, community-based network.

Given this complex landscape intertwining pedagogy, climate science, and political economy, the path toward water security becomes a challenge of institutional redesign. To address this, this work proposes a disruptive intervention: the use of the Internet of Things (IoT) and Blockchain technology not as tools of technocracy or control of people, but as instruments of public audit and active citizenship. The goal is to highlight water as the central verifiable indicator of the crisis, forcing problem visibility. Through independent and immutable verification mechanisms, the aim is to ensure that water availability and management are prioritized over convenient political narratives or interests, returning control over the narrative and survival management to the educating community and civil society.

2. Methodology

This research adopts a qualitative approach of a critical-propositional nature, structured through the transdisciplinary intersection of sociology of technology, sanitation economics, and systems engineering. The methodological design was conceived to articulate the diagnosis of educational and material barriers with the proposition of a technological architecture capable of overcoming them.

In the first phase, the methodological path begins with the critical deconstruction of the role of technology in contemporary urban planning. Using bibliographic review as an analytical tool, the thesis that digital innovation is not intrinsically neutral, but often acts as an instrument of power maintenance and hegemonic narrative construction, is investigated. Based on Behr's (2021) analysis of technocracy and the "democratic deficit", we examine how centralized solutions are implemented to create an "aesthetic of modernity" — embodied in "Smart Cities" narratives. This stage aims to demonstrate how such narratives, in practice, tend to mask the absence of basic sanitation services and distance citizen participation from crucial decisions regarding vital infrastructure.

Subsequently, the methodology incorporates a diagnostic analysis of the educational context, which is fundamental to understanding the receptivity and implementation capacity of sustainability projects in schools. To this end, data from the Cives research (Bornatici & Vacchelli, 2021), which examined the implementation of Law no. 92/2019 regarding the reintroduction of Civic Education in Italy, were re-analyzed. This

methodological stage revealed deep heterogeneity in the interpretation and application of the legislation, identifying four critical disparities that our proposal aims to mitigate. Firstly, regarding the level of teacher preparation, a significant variation in prior knowledge of Agenda 2030 was detected, oscillating between advanced groups and others lacking basic concepts. Secondly, concerning curriculum interpretation, a dichotomy was observed between schools that treated the subject in a "content-based" manner (focused on the letter of the law) and those that interpreted it as a practice of "active citizenship" and experiential projects. Additionally, the issue of fragmentation vs. transversality revealed that teacher "co-ownership" generated, in many cases, confusion and unequal applications, resulting in a bureaucratic division of hours rather than real integration. Finally, a dispersion in the thematic approach was verified, with isolated focuses sometimes on digital education, sometimes on environmental sustainability, failing to consolidate a vision of integral ecology.

From this critique of technocracy and the diagnosis of pedagogical fragmentation, the investigation advances to the diagnosis of material and economic barriers. It focuses specifically on the conflict of interest inherent in the sanitation concession model. Through documentary analysis of current legislation and tariff structures, the deductive logic presented by Viana da Silva (2024b) is applied to evidence the regulatory paradox: consumer water efficiency, obtained via rainwater harvesting, results in a direct loss of revenue for utilities and tax collection for the State. This stage is crucial to demonstrate that water scarcity in municipalities like Maricá (Brazil) is not merely a climatic or technical phenomenon, but the result of an institutional arrangement that financially disincentivizes user autonomy.

Finally, in the propositional phase, the work uses the comparative method to contrast two antagonistic resource management models: the current Centralized Model, characterized by runoff acceleration, dependence on large infrastructure, data opacity, and vulnerability to systemic failures; and the proposed Decentralized Model, which prioritizes source retention, citizen autonomy (the "Right to the Slab"), and network resilience.

The validation of this proposal is performed through the theoretical modeling of an integrated Internet of Things (IoT) and Blockchain system. This modeling demonstrates how the automation of water "Proof of Life" and the use of Smart Contracts can act as independent audit mechanisms. This technological approach aims to break the identified conflict of interest and overcome the educational fragmentation detected by Bornatici and Vacchelli (2021), transferring trust from institutional bureaucracy — subject to failures and diverse interpretations — to algorithmic, immutable, and transparent code verification.

3. Theoretical framework

Contemporary urban water management faces a structural paradox between speed engineering and the imperative need for resilience. Historically, city planning was grounded in a hygienist logic of rapid water expulsion, where efficiency was measured exclusively by the capacity to reduce concentration time — the interval necessary for water precipitated in a basin to reach its outlet point. As discussed by Viana da Silva (2025a), this artificial acceleration of runoff, promoted through sealing and channeling, generates a double environmental liability: upstream freshwater waste (which ceases to infiltrate) and the amplification of destructive downstream flood peaks. The technical

alternative lies in reversing this logic, prioritizing retention, reuse, and recycling, transforming each building into a damping microstructure capable of restoring, albeit partially, the natural hydrological cycle.

However, the non-massive implementation of these decentralized technologies, despite their proven technical efficacy, stems from political choices based on what can be designated as the "Silver Bullet Theory". Public decision-makers tend to favor large centralized infrastructure works, which offer high electoral visibility and maintain the monopoly of resource management, to the detriment of capillary solutions that confer autonomy to the citizen. This preference reinforces what Viana da Silva (2025c) identifies as a "democratic deficit" in technocracy: administrative complexity is used as justification for surveillance and social control, preventing simple and liberating technologies — like rainwater harvesting — from threatening the centrality of state and corporate power.

To break this technocratic inertia, it is fundamental to observe how higher education institutions are reformulating their own governance and sustainability strategies. Mazzaro and Morschheuser (2025), analyzing the case of the Baden-Wuerttemberg Cooperative State University (DHBW), highlight the importance of participatory processes in strategic development. The authors describe an institution characterized by "theory-practice" transfer, where sustainability strategy is not imposed top-down but built through stakeholder engagement and critical reflection on quality. This participatory approach, described in the German study, contrasts vividly with the centralized water management model criticized earlier, suggesting that the solution to the water crisis requires governance that integrates the community in defining solutions rather than excluding it.

Nevertheless, the transition to this participatory and decentralized model is halted by an economic conflict of interest intrinsic to the current sanitation concession model. As demonstrated by Viana da Silva (2024a), the current tariff structure creates a financial disincentive for efficiency: reducing potable water consumption through alternative sources (such as rain) results in a direct loss of revenue for utilities and tax collection for the State. Thus, the technology to break this barrier exists, but its adoption is blocked by an obsolete institutional architecture.

It is in this scenario of systemic complexity that education for sustainable development assumes a strategic role, not only informative but formative. Del Gobbo and colleagues (2021) argue that, to navigate these contradictions, it is necessary to develop a specific set of skills in future professionals, going beyond traditional teaching. Aligning with international frameworks such as Unece, the authors highlight essential competencies that apply directly to resolving the water conflict. Systems Thinking is fundamental for understanding that the "dry tap" is not an accident, but the result of interconnections between climate, economy, and urban regulation. Critical Thinking involves the ability to question current tariff norms and engineering practices that perpetuate scarcity. Normative and Strategic Competency refers to the skill of negotiating conflicting values (utility profit vs. right to water) and implementing innovative actions. Finally, Anticipatory Competency is the aptitude to imagine future scenarios where scarcity will be the norm, requiring immediate adaptation.

The increase and adoption of new auditing and decentralization technologies (IoT and Blockchain) thus appear not as a technical panacea, but as the operational tool for these competencies. It acts as a disruptive element capable of overcoming regulatory blockage, driven by the need for survival.

The urgency of this technological and educational transition must, finally, be read through the lens of global climate asymmetry. While Global North nations may have resources for advanced adaptation strategies — and, in some cases, economically benefit from new agricultural frontiers due to warming — the Global South faces an existential risk (Huggel et al., 2022). For these countries, the "risk of doing nothing" is immeasurably greater. While temperature changes can be managed with artificial thermal comfort in wealthy nations, the water crisis disrupts the biological basis of life and economic structure in developing countries. Thus, water sovereignty, supported by emancipatory education and verification technologies, becomes the determining factor for social stability in the coming decades.

4. Results and discussion

Integrated analysis of climate and sanitation vectors demonstrates that, although carbon emission control is fundamental for global atmospheric stability in the long term, water management plays a role of superior immediate relevance in local environmental quality and community biological survival. Water acts not only as a consumption resource but as an active atmosphere "scavenging" mechanism, removing particulate matter, and as a fundamental thermal regulator, exemplified by increased air humidity and mitigation of extreme temperatures. Thus, climate adaptation strategies that ignore the hydrological cycle in favor of purely carbon-based metrics prove insufficient to mitigate acute climate change effects perceived by the population, such as urban heat islands and the spread of pathogenic vectors.

In the pedagogical realm, this needs for connection with reality echoes the review by Falchi and Zurru (2024). The authors identified that Outdoor Education activities are crucial for promoting direct contact with nature and motivating pro-environmental attitudes. However, it is imperative to critically observe this practice: the symbolic act of "hugging trees" or sporadic park visits are not enough to develop robust sustainability skills, especially if they are isolated actions unconnected to a continuous curriculum. Forming an ecological consciousness requires constant and systemic immersion, often made impossible by the material reality of the territory where the school is located.

This mismatch between biological/pedagogical need and political management is evidenced by the "Brazilian paradox". As pointed out by Marengo (2008), Brazil holds a privileged position, housing about 12% of the world's average annual surface water flow — reaching 18% when considering transboundary rivers. However, this natural abundance collides head-on with the absence of water governance, creating scenarios of artificial scarcity amidst potential wealth.

The municipality of Maricá (RJ) serves as the definitive case study of this contradiction and challenges traditional categories of educational barrier analysis. Contrasting this scenario with Tino's (2024) study, a peculiar phenomenon is observed. Tino identifies "lack of financial resources", "time management", "inadequate training", and "bureaucracy" as main barriers to sustainability education. However, Maricá invalidates the financial justification. Being one of the largest beneficiaries of oil royalties in the country, the municipality does not face the fund scarcity cited by Tino. Yet, data from the Water and Sanitation Institute (Instituto Água e Saneamento, 2022) reveal that 98.82% of the population lacks access to the sewage network and 42.03% has no official water connection. This suggests that, in contexts of high revenue, barriers of "resistance to

change" and "bureaucracy" supplant the financial issue, perpetuating an administrative inertia that prevents wealth from converting into basic sanitation.

Infrastructural precariousness in Maricá transcends statistics and materializes in public health crises and supply collapse, directly affecting the school community and learning capacity. The absence of sanitation and drinking water was evidenced in October 2025, when the City Hall had to issue alerts reinforcing guidelines on scabies prevention, a disease directly associated with poor hygiene conditions (Prefeitura Municipal de Maricá, 2025). Simultaneously, the seasonality of the water crisis was confirmed again in December 2025, when the population faced water shortages once more, evidencing that billionaire revenue did not convert into water security or infrastructure capable of supporting peak demand (Maricá Info, 2025).

While the case of Maricá provides a critical laboratory for high-revenue municipalities with low sanitation coverage, the proposed framework does not claim universal validity; its application in other contexts requires verification of local regulatory and economic architectures.

This local inefficiency reflects a macropolicy of wasted opportunities. Brazil repeats the error of the 2016 Olympic legacy, where promises of environmental transformation resulted in unaudited liabilities. Oil income management follows this circular logic: according to the Institute for Socioeconomic Studies (Inesc, 2025), only 0.16% of oil resources were allocated to the environmental and climate agenda. Furthermore, funding for innovation is incipient, with only 1% of oil revenue directed to the Ministry of Science, Technology and Innovation (MCTI) via the National Fund for Scientific and Technological Development (Fndct). Paradoxically, this fund is mostly reinvested in the oil and gas chain itself, perpetuating the extractive model instead of financing the transition to water sustainability technologies.

Critical analysis suggests, therefore, that short-term water urgency must be understood in articulation with long-term goals, but stripped of naivety. Insistence on recurrent and unfulfilled government promises — exemplified by the "eternal" depollution of Guanabara Bay, promised since 2007 and now rescheduled to 2031 — demonstrates the failure of the centralized management model based exclusively on political discourse. Ecological and social efficiency thus depends not on new narratives, but on the implementation of decentralized verification technologies (such as IoT and Blockchain) that expose the raw reality of data. Only by forcing problem visibility through algorithmic proof will it be possible to ensure rational resource allocation, preventing the population, ironically surrounded by millionaire royalties, from remaining vulnerable to thirst and avoidable diseases.

5. Conclusions

The analysis of climate and hydrological scenarios indicates that the severity of future impacts will not be defined solely by the physical magnitude of extreme events, but fundamentally by the response time of institutions and civil society. Human behavioral inertia in the face of "slow dangers" and cumulative risks — like global warming, psychologically analogous to chronic conditions like obesity or smoking — requires a radical strategic shift in communication and problem management. It is necessary to instrumentalize water scarcity, an imminent and tangible danger, to activate the immediate survival instinct that the abstract concept of "invisible carbon" fails to awaken.

To mitigate this fatal latency between announced disaster and corrective action, it is imperative to establish a regime of total visibility, where measuring, monitoring, and reacting to real conditions becomes the basic premise of governance.

This visibility must operate systemically, starting from the technical dimension and advancing to the financial one. The implementation of soil moisture sensors and cistern level monitors eliminates convenient political management subjectivity, replacing the imprecise narrative of "I think it rained little" with the irrefutable data of a sensor recording the absence of water. This metric certainty grounds financial visibility, enabled by Smart Contracts and Escrow mechanisms, where public or private resources are only released upon physical proof of water existence. Thus, a water "Proof of Life" is established: if water runs out, financial flow ceases. This mechanism forces the manager to prioritize water security through a direct economic imperative, overcoming administrative negligence through responsibility automation.

Simultaneously, technology must promote social and pedagogical visibility, realizing what Viana da Silva (2025d) terms the "Right to the Slab" (Direito à Laje) through information democratization. Instead of distant panels displaying global average temperature, installing local displays showing the community water tank level operates an inversion in Maslow's Hierarchy, placing physiological need back at the center of public attention.

However, it is essential to note that while the case of Maricá provides a laboratory for analyzing resource-rich municipalities with low sanitation coverage, this framework does not claim universal validity. The structural, regulatory, and economic architectures of urban environments vary significantly; therefore, the application of this model requires careful adaptation and verification on a case-by-case basis to ensure its effectiveness in different institutional contexts.

In this context, evaluating the effectiveness of these measures cannot follow traditional molds. Tammaro and Gragnaniello (2024) discuss the concept of Sustainable Assessment as an approach integrating teaching, learning, and evaluation, focusing not on immediate verification but on long-term impact. Transposing this concept to the water crisis, "assessment" ceases to be a test grade and becomes the community's survival and adaptation capacity. The pedagogical indicator becomes material: the sight of a plant dying of thirst in a controlled environment communicates crisis urgency more viscerally and understandably than thousands of statistical charts, preparing citizens to be lifelong learners capable of facing real transitions.

For this transition to occur, it is necessary to foster specific cognitive skills to overcome installed conflicts of interest. As proposed by Tammaro, Ferrantino and Tiso (2024), facing complex problems requires developing Divergent Thinking, characterized by four essential pillars for sustainability innovation: Fluidity, the ability to rapidly produce multiple hypotheses for water capture and management; Flexibility, the ability to leave rigid schemes (such as exclusive dependence on the public network) and adapt to new scarcity situations; Originality, the competence to find unusual solutions, such as using Blockchain for civic audit; and Elaboration, the capacity to enrich and detail these technical ideas so they are socially applicable.

This multidimensional approach fosters the creation of territorial synergies. Galeri (2021), analyzing sustainable tourism, highlights that training must empower individuals to create "relational capital". The same logic applies to water management: implementing decentralized technologies should not be an isolated action, but a motor for integral ecology, generating new employment opportunities, social innovation, and aligning urban infrastructure with green economy principles.

Therefore, we conclude that there is an inseparable logical fusion between short and long-term measures. Immediate water retention and management actions do not compete with fighting global warming; on the contrary, they constitute the material basis for any future climate strategy. Short-term measures generate the synergy necessary for long-term resilience, but their effectiveness depends on knowing and overcoming the conflicts of interest of utilities and the State, which currently profit from inefficiency. Transforming surveillance technology into survival technology and civic audit is, ultimately, the only way to ensure society does not succumb to thirst while debating the heat.

6. Future works: from local management to the geopolitics of water

As a natural unfolding of this investigation, we suggest expanding the analysis to the macroscopic sphere of natural resource geopolitics. The premise established by Viana da Silva (2025b) regarding the "rupture of the water cycle" transcends the municipal scale of Maricá; it prefigures transnational conflicts where water security tends to replace hydrocarbons as the central axis of power disputes in the 21st century.

In this sense, future research must investigate the concept of "Algorithmic Sovereignty" applied to water resources. The implementation of IoT and Blockchain systems raises a critical question regarding technological independence: if sensors and data validation infrastructure rely on hardware or servers controlled by Global North nations, the autonomy proposed for the Global South may become illusory. It is imperative to analyze how technological dependence can generate new forms of "digital colonialism," where a territory's water management is audited or conditioned by external actors.

Additionally, we propose applying the water "Proof of Life" mechanism and Smart Contracts to the context of Hydro-diplomacy in transboundary river basins. The hypothesis to be tested is whether the immutable and decentralized verification of flow in rivers shared between countries (such as the La Plata or Nile basins) could act as an automatic conflict mediation tool, ensuring compliance with international water-sharing treaties through code neutrality, thereby mitigating mutual distrust between sovereign states.

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