



Beyond data silos: federated governance as legal response to planetary ecological collapse

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Abstract

This article examines the concept of data federalization as an innovative legal mechanism designed to enhance ecosystem protection through the integration of global computational systems. As the world faces increasing environmental degradation, there is a pressing need for effective legal frameworks that leverage technology. The article explores the regulatory and social challenges associated with data federalization, including issues of jurisdiction, data privacy, power dynamics, and the harmonization of international laws. By investigating these challenges, the article highlights their significant impact on existing environmental law, underscoring the necessity for adaptable legal strategies that can address contemporary ecological threats. Furthermore, it discusses the potential benefits of implementing a data federalization framework, such as improved data sharing among nations, enhanced monitoring of biodiversity, and more effective response strategies to environmental crises. Through a comprehensive exploration of these themes, the article aims to propose elements for a future International Treaty as well as contribute to the ongoing discussion about the intersection of law, technology, and environmental stewardship, advocating for stronger legal solutions to safeguard our planet's ecosystems.

Keywords Data federalization · Ecosystem protection · Environmental law · Planetary computational systems · Global governance

1 Introduction: data federalization and the imperative for planetary-scale legal innovation

The accelerating collapse of Earth's ecosystems, evidenced by the loss of 69% of global vertebrate populations since 1970 (UN WCMC, 2022), the breaching of six out of nine planetary boundaries, including biosphere integrity and climate change (Richardson et al., 2023), added to the imminent extinction of one million species (UN, 2019) has thrust humanity into

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an era of unprecedented ecological precarity. It is in this context that planetary computational systems emerge as a paradigm shift in confronting ecological collapse. These systems integrate artificial intelligence with globally distributed data networks, drawing on satellite imagery, environmental sensors, and machine learning architectures that can operate across multiple data sources simultaneously. Their promise lies in the ability to synthesize real-time data across biomes, political borders, and scales, enabling not only hyperlocal monitoring of deforestation, biodiversity loss, and carbon fluxes but also predictive modeling of cascading ecological tipping points (Bratton, 2023; Dakos et al., 2024; Morton, 2013).

Yet their efficacy is undermined by a structural paradox: while ecological threats are intrinsically transnational, the legal frameworks governing data remain bound to territorial sovereignty and narrowly anthropocentric conceptions of rights. This tension constitutes the central obstacle that data federalization for planetary computation seeks to overcome. Addressing this challenge requires an integrated approach that is simultaneously technological and legal.

From a technological perspective, data federalization represents a paradigm shift away from centralized data aggregation towards a distributed, cooperative model (Bratton, 2016). Rather than consolidating raw data into a single repository, this approach enables large-scale computation and analysis across vast, heterogeneous datasets generated globally, from climate sensors and satellite networks to urban infrastructure and personal devices. The core technological challenge lies in designing architectures that facilitate interoperability across disparate, geographically dispersed data silos governed by different entities, something that today is possible thanks to enabling technologies that include; federated learning, which allows an AI model to be trained across multiple datasets (such as hospital records from different countries) without any raw data ever leaving its original location; secure multi-party computation (SMPC), which enables multiple parties to jointly compute a result without revealing their individual inputs; and differential privacy, which adds statistical noise to queries to protect individual data points. These technologies allow insights to be derived collaboratively while fundamentally respecting the autonomy, locality, and security constraints of data originators and jurisdictions.

From a legal perspective, data federalization addresses the profound challenge of governing data flows and computational processes that inherently transcend national borders (Fahey, 2022). It seeks to establish a framework where data sovereignty, the principle that data is subject to the laws and governance structures of the nation or region where it is collected, can be maintained while still enabling beneficial global-scale computation. The legal problem manifests in navigating the complex, often conflicting mosaic of international, regional, and national regulations concerning data privacy (e.g., GDPR, CCPA), security, intellectual property, cross-border data transfer restrictions, and national security mandates. A key challenge is defining governance models that establish trust and accountability in a decentralized system, which requires creating contractual and technical frameworks for data sharing agreements that specify permissible uses, liability, auditability, and compliance verification mechanisms across participating entities operating under different legal regimes. The legal aim is to provide a predictable, rights-respecting foundation that enables technological federation without undermining the diverse legal principles and protections established within different sovereign territories.

The integration of technological and legal approaches in data federalization for planetary systems reveals their deep interdependence. Technological solutions provide the *means* to

comply with legal requirements for data localization and minimization by design, minimizing exposure and cross-border data transfer. Conversely, legal frameworks must evolve to recognize and validate these novel technical approaches as compliant mechanisms, moving beyond traditional compliance models built around physical data location and centralized control. Effective data federalization requires co-design: legal principles must inform the technical architecture's requirements for transparency, auditability, and enforceability of data usage policies, while the capabilities and limitations of technology shape what is legally feasible. Data federalization, therefore, offers a path to overcome the current fragmentation that epitomizes the failure of legal regimes to reconcile national data sovereignty with planetary ecological urgencies.

At the heart of this crisis lies a governance vacuum. Existing frameworks like the UN's *Global Biodiversity Framework* (UNCTAD, 2022) prioritize symbolic commitments over enforceable data-sharing mechanisms, while regional initiatives such as the EU's *Data Governance Act* (European Commission, 2024) restrict cross-border flows to nations with "adequate" privacy laws, a standard that excludes biodiverse but legally weak states like Indonesia and the Democratic Republic of Congo. Meanwhile, AI-driven conservation tools, such as the Wildlife Insights platform (Google, 2021), which processes 12 million camera-trap images annually to track endangered species, face legal paralysis when data intersects with incompatible jurisdictions. For instance, Mexico's jaguar monitoring data managed through Huawei Cloud Technology (EFE, 2023), becomes inaccessible to Central American researchers under U.S.-controlled AI algorithms. These disconnects amplify what the IPCC terms the "governance gap" which allows us to identify that a relevant number of climate adaptation projects fail due to data incompatibility across borders (Dellmuth & Gustafsson, 2023; IPCC, 2023).

Furthermore, Indigenous communities, who steward a big part of Earth's biodiversity, (Fernández-Llamazares et al., 2024), increasingly resist centralized data systems over fears of biopiracy and dispossession. As planetary boundaries fracture, the push to digitize Earth's remaining biodiversity has intensified, framed as a necessary response to ecological collapse. Blockchain-based platforms, AI-driven bioprospecting, and synthetic biology are increasingly marketed as tools to "save" nature through its computational codification. Yet these systems risk accelerating the very crises they claim to mitigate by reducing complex ecosystems to extractable data points and enabling new forms of algorithmic biopiracy. Allowing us to understand that the stakes transcend environmental metrics; they imply foundational questions of equity and justice.

The Nagoya Protocol's shortcomings in preventing biopiracy now manifest in digital dimensions (The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing, 2014). Pharmaceutical corporations, partnering with AI startups, mine Indigenous ethnobotanical knowledge through datasets scraped from anthropological archives or "voluntarily" uploaded to conservation apps. Today, many patents for AI-generated medicinal compounds trace their training data to uncredited Indigenous knowledge systems, representing cases of digital biopiracy (Raven et al., 2024) Blockchain's ecological footprint further exposes the hypocrisy of "green" techno-fixes. Bitcoin mining alone consumes more electricity than Sweden (*Cambridge Blockchain Network Sustainability Index: CBECI*, 2025; Huang et al., 2021); with server farms disproportionately located in the Global South to exploit cheap energy and lax regulations. This creates what can be classified as thermodynamic colonialism, where the Global South bears the energy costs of sustaining Northern

digital infrastructures. This dynamic intersects with data colonialism, a concept articulated by Nick Couldry and Ulises A. Mejias (Mejías & Couldry, 2019), who argue that modern data extraction mirrors historical colonial patterns, with powerful entities monetizing data from marginalized communities while excluding them from governance or benefits. These systems exemplify what Howson calls crypto-colonialism, where blockchain’s “decentralized” rhetoric masks extractive practices that deepen North-South inequities (Howson, 2020).

Data federalization emerges as a legal-technical mechanism to harmonize fragmented governance. Defined as the equitable, coordinated stewardship of shared environmental data across jurisdictional and institutional boundaries, federalization seeks to transcend territorial silos without erasing sovereignty. Its principles can be drawn from hybrid models like the *International Treaty on Plant Genetic Resources* (FAO, 2009) which balances open access with benefit-sharing. Yet federalization remains nascent in environmental law, hindered by three interrelated barriers: Jurisdictional fragmentation, technological asymmetries and ethical voids.

As beforementioned, jurisdictional fragmentation complicates cross-border environmental governance, as overlapping legal regimes struggle to synchronize data standards or enforcement. For instance, in the Amazon Basin, nine sovereign nations operate under disparate data-sharing protocols, with Brazil’s *National Institute for Space Research* (INPE) (Gov.br, 2025) monitoring deforestation independently of Colombia’s *SINCHI* (*SINCHI*, 2025) which focus more on biodiversity, creating gaps in unified action (ACTO, 2021). Technological asymmetries further deepen inequities: high-income nations deploy AI-driven systems, while low-resource countries such as the Democratic Republic of Congo, home to the Congo Basin’s critical carbon sinks, lack bandwidth to process satellite data, perpetuating a “monitoring divide” (Mahonghol, 2024). The 2024 World Air Quality Report (IQAir, 2024) exemplified the divide, showing a clear concentration in North America and Europe, leaving Global South regions underrepresented in climate models (Fig. 1).

Finally, ethical voids, manifest in unchecked corporate data extraction, such as mineral firms using AI to map Indigenous lands without consent, as seen in Canada’s Ring of Fire mining disputes (IW, 2025), or opaque algorithms prioritizing economic interests over ecological thresholds. The absence of binding frameworks to address these issues leaves initiatives like the *UNESCO Recommendation on Open Science* toothless (UNESCO, 2023), as private entities patent biodiversity data from the Global South, evading equitable benefit-sharing under the *Nagoya Protocol*. Until these barriers are dismantled through enforceable, inclusive governance, data federalization risks replicating the power imbalances it seeks to resolve.

Therefore, our premise is that current governance architectures, fractured by competing data regimes and colonial infrastructures, risk perpetuating the very metabolic rift¹ they claim to mend. For example, lithium extraction ravaging biodiverse salt flats to fuel “green” blockchain solutions. Yet emerging models, from Indigenous-led biocultural data licenses to polycentric wildlife commons, hint at alternatives that harmonize planetary-scale interoperability with relational ontologies of care. These innovations, though nascent, challenge law to reimagine itself not as a tool of enclosure but as a scaffold for pluriversal stew-

¹ Metabolic rift refers to the disruption of the natural material cycles that sustain life, resulting from capitalist production’s tendency to treat ecosystems as extractable resources rather than as living systems requiring renewal.

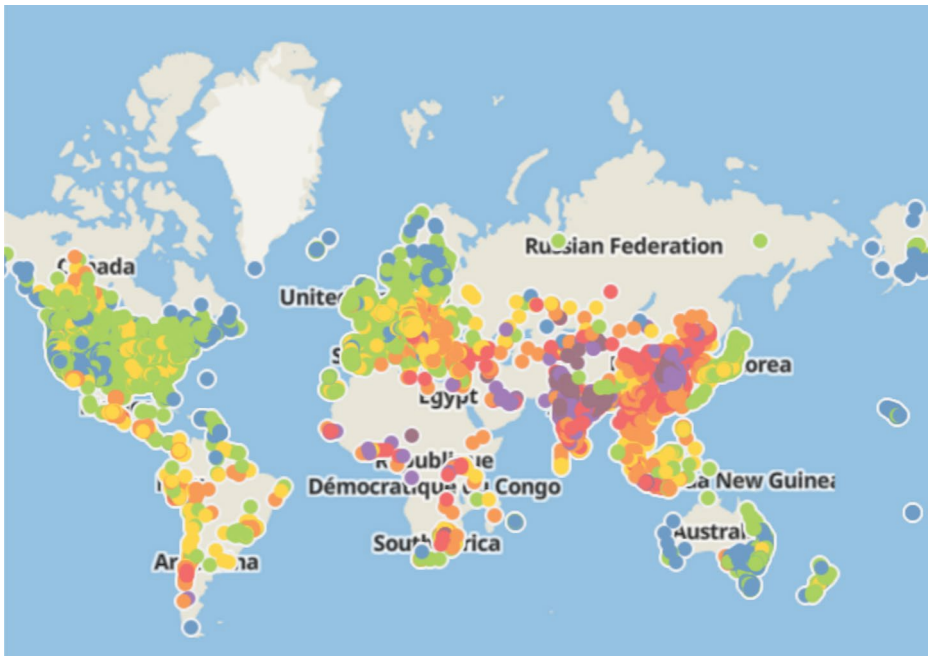


Fig. 1 Air Quality Reporting Sensors (IQAir, 2024)

ardship (Escobar, 2015, 2020), where data flows are governed by reciprocity rather than extraction, and energy sovereignty displaces thermodynamic hierarchies. The path forward requires therefore synthesizing these fragments into a cohesive jurisprudence that bridges the urgency of planetary computation with the grounded wisdom of Earth's original custodians, a task this article undertakes by interrogating the legal, technical, and epistemic foundations of data federalization as both a critique of and antidote to collapse.

2 Theoretical framework: synthesizing legal, ethical, and technical paradigms for data federalization

To develop a robust theory of data federalization, we must analyze the problem through three interlocking lenses. First, a governance and power lens examines how legal institutions and sovereign states manage (or fail to manage) cross-border data flows. Second, an epistemological and ontological lens interrogates what counts as knowledge, whose knowledge systems are validated, and how data infrastructures shape our relationship with the natural world. Third, a material and political economy lens traces the physical infrastructures underpinning digital systems, from lithium mines to server farms, and the unequal distribution of their ecological costs. Together, these lenses reveal that data federalization cannot be merely a technical fix; it must be a legally robust, ethically plural, and materially just framework for planetary-scale governance.

2.1 Governance and power lens

The governance of planetary ecological data exists at the intersection of competing sovereignties; territorial, corporate, and Indigenous. The theory of Legal Linked Data Ecosystems (Poblet et al., 2019) posits that legal interoperability requires harmonizing three pillars: semantic standards, ethical norms, and jurisdictional rules.

Semantic Standards refer to shared ontologies and vocabularies, such as the EU's SEMIC action (EC, 2025), which aligns cross-border environmental data through common specifications like DCAT-AP and Core Vocabularies (EU, 2025). Ensuring that terms like “carbon sink” or “deforestation” are uniformly interpreted across jurisdictions. However, semantic interoperability also carries deep epistemological implications: when Indigenous concepts of land stewardship are translated into Western scientific categories, meaning can be lost or distorted.

Ethical Norms encompass equitable benefit-sharing mechanisms. The Nagoya Protocol sought to address this for genetic resources, but digital-era challenges require evolution. Digital sequence information (DSI) on genetic resources can now be shared globally without physical transfer, rendering traditional access and benefit-sharing models obsolete. Proposed mechanisms like the Cali Fund (Convention on Biological Diversity, 2025) attempt to monetize DSI, yet Indigenous-led models offer alternatives. The Māori Data Sovereignty Network's biocultural licenses (Te Mana Raraunga, 2025) embed dynamic consent and reciprocity into data governance, treating data not as a commodity but as a relationship.

Jurisdictional Rules: govern cross-border enforcement. Frameworks like the Hague Judgments Convention provide templates, but planetary-scale systems demand hybrid models that can accommodate both state sovereignty and Indigenous legal orders. The metabolic rift between these pillars is stark: corporate-controlled AI tools like Wildlife Insights (Wildlife Insights, 2025) process millions of biodiversity images but often strip Indigenous context, reducing complex ecosystems to decontextualized data points. Legal interoperability thus requires not just technical alignment but governance hybridity.

Elinor Ostrom's principles of polycentric governance; decentralized, community-led stewardship operating at multiple scales, offer a foundational framework for data federalization (Ostrom, 2010). Ostrom demonstrated that common-pool resources can be sustainably managed without top-down regulation or privatization when communities develop context-specific rules, monitor compliance, and establish graduated sanctions.

These principles find contemporary expression in Indigenous-led forest monitoring programs. In the Peruvian Amazon, equipping 36 Indigenous communities in Loreto with satellite data and smartphones reduced deforestation by 52% in 2018 and 21% in 2019 by enabling real-time tracking of illegal activities (Slough et al., 2021). The Ka'apor people in Brazil similarly partnered with Greenpeace to combat illegal logging using camera traps and GPS trackers, documenting deforestation and pressuring authorities to act (O'Brien, 2015). These initiatives align with Ostrom's emphasis on local autonomy, shared resource management, and the importance of monitoring (Ostrom, 1994).

However, polycentric governance faces significant challenges when scaled to planetary data systems. Corporate control of environmental data platforms can undermine local agency. While initiatives like (Global Forest Watch, 2025) provide open-access deforestation alerts, proprietary systems often limit transparency and community control. In Peru's Loreto region, Indigenous monitors using drones and smartphones faced unresolved illegal

logging cases due to bureaucratic delays and litigation, despite providing actionable evidence (Alejo, 2025).

The tension between open data and Indigenous sovereignty is further illustrated by the Rainforest Foundation US's work in the Amazon (Rainforest Foundation, 2025). By training communities to use geofenced drones and satellite alerts, they achieved zero deforestation in some areas, yet long-term success depends on addressing systemic corruption and land rights disputes (Street, 2021). These challenges underscore Ostrom's warning that polycentric systems require not only local agency but also supportive legal frameworks at higher scales to prevent enclosure of shared resources (Ostrom, 2010). For data federalization, this means designing multi-level governance that empowers local communities while enabling interoperability across scales.

2.2 Epistemological and ontological lens: relational ontologies against algorithmic reductionism

The clash between Indigenous knowledge systems and extractive data regimes reflects a deeper ontological conflict. Indigenous epistemologies tend to understand knowledge as relational, embedded in specific places, and inseparable from responsibilities toward human and more-than-human communities. Algorithmic reductionism, by contrast, treats knowledge as decontextualized data points to be extracted, aggregated, and commodified.

Arturo Escobar's concept of pluriversal ontologies provides a framework for understanding this conflict (Escobar, 2015, 2020). Escobar argues that modernity's universalizing logic, which assumes one world with one set of valid knowledge practices, is giving way to recognition of multiple coexisting worlds, each with its own ontology. This aligns with Ecuador's constitutional recognition of *Buen Vivir* (Lenhardt, 2023), which enshrines the Rights of Nature (*Pachamama*) and situates humans within ecological networks rather than above them.

But, extractive data regimes replicate what Boaventura de Sousa Santos terms epistemicide: the systematic erasure of subaltern knowledge systems (Santos, 2015). Corporate-controlled conservation platforms risk perpetuating this violence by reducing Indigenous territories to decontextualized datasets. The Maya ICBG bioprospecting controversy (1999–2000) remains instructive. A project aimed at documenting Maya medicinal knowledge for pharmaceutical development faced accusations of biopiracy, collapsing after Indigenous organizations challenged its consent processes and benefit-sharing arrangements (Berlin & Berlin, 2003; Bjorkan & Qvenild, 2010). Despite the researchers stated intentions, the project revealed the difficulty of securing meaningful consent for collective knowledge and the risks of creating unrepresentative intermediary organizations.

Indigenous data sovereignty initiatives counter these extractive hierarchies through frameworks grounded in relational accountability. The Global Indigenous Data Alliance's CARE Principles (Collective Benefit, Authority to Control, Responsibility, Ethics) (Global Indigenous Data Alliance, 2025) require dynamic consent, continuous Indigenous oversight of data use, inspired by Andean *ayni* (reciprocity) and Amazonian *Buen Vivir*. These principles challenge conventional intellectual property regimes by framing data as embedded in interspecies kinship networks rather than as alienable commodities. In practice, this ethos is reflected in the Māori-led *Te Mana Raraunga* (Te Mana Raraunga, 2025), which governs data as *taonga* (treasures) requiring intergenerational custodianship. Such models contrast

sharply with platforms like (iNaturalist, n.d.) which crowdsource biodiversity data without ensuring Indigenous control or benefit-sharing. These struggles represent lived resistance to what Escobar terms the “ontological occupation” of techno-capitalism, offering pathways to governance grounded in reciprocity rather than extraction.

2.3 Material and political economy lens: lithium, AI, and the necropolitics of computation

The computational recasting of Marx’s metabolic rift theory, developed by John Bellamy Foster (1999) to describe capitalism’s severing of natural cycles, reveals a contemporary regime of necropolitical governance. Achille Mbembe’s concept of necropolitics (Mbembe, 2008) describes how political power operates not merely by disciplining life but by dictating who may live and who must die. In the computational age, the infrastructures sustaining AI-driven conservation tools systematically expose Indigenous communities and ecosystems to conditions of social and biological death.

In Chile’s Atacama Desert, lithium extraction for the renewable energy transition consumes 2.1 million liters of groundwater daily, a hydrological violence transforming ancestral Lickanantay territories into sacrifice zones (Blair et al., 2023; Earthworks, 2020). Sacred saltwater lakes are drained to sustain the Global North’s server farms and electric vehicle batteries. This continues despite Chile’s ratification of the Escazú Agreement (UNTC, 2018) its participatory mechanisms rendered meaningless by mining concessions that classify vital water sources as expendable industrial inputs rather than protected cultural rights under ILO Convention 169 (ILO, 1989).

The necropolitical calculus becomes explicit in the cobalt mines of the Democratic Republic of Congo. Amnesty International’s documentation of 40,000 children working under lethal conditions in artisanal mines (AI, 2016; Godelive et al., 2023) reveals how the rhetoric of sustainable development masks a thanatopolitical logic. Congolese youth are systematically exposed to cave-ins, toxic exposure, and premature death while EU regulations deliberately exclude informal mining sectors from oversight. The EU’s Battery Regulation (EUR-Lex, 2023) and Conflict Minerals Regulation (EC, 2017) focus on formal supply chains but fail to regulate artisanal mining effectively, creating a legal loophole that allows corporations to distance themselves from human rights violations while still sourcing cheap cobalt.

This computational metabolic rift extends its epistemic violence through the very platforms claiming to protect biodiversity. Wildlife Insights, the Google-backed conservation AI, enacts what Tuck and Yang (Tuck & Yang, 2014) theorize as data evisceration, its algorithms systematically strip Indigenous relational ontologies from captured biodiversity data. Machine vision technologies reduce complex biocultural landscapes to decontextualized pixels, enabling violations of UNDRIP Article 31 (UN, 2007) which safeguards Indigenous control over knowledge systems. This erasure finds synergy with the Inter-American Court’s condemnation of “technological assimilationism” in the *Kaliña and Lokono v. Suriname* case (CIDH, 2014), where imposed surveillance tools disrupted Indigenous sovereignty.

Three interlocking mechanisms enable computational necropolitics. First, corporate cartography as death permits: in Chile’s lithium fields, environmental impact assessments conducted by industry-contracted firms systematically erase Lickanantay sacred sites from protected zones (Barnett & Vilchez, 2023), violating the non-regression principle of inter-

national environmental law. Second, algorithmic impunity in conservation tech: the EU AI Act's exemption for conservation technologies creates a legal vacuum where machine vision operates without oversight. Platforms like WWF's SMART software (WWF, 2016) misclassify Maasai pastoralists as poachers, triggering violent evictions documented by Survival International (SI, 2022). Third, investor-state warfare via climate arbitration: the Energy Charter Treaty allows foreign investors to sue governments over environmental regulations, with 175 known ISDS cases brought against environmental measures as of 2022 (TNI, 2023). As Andreas Malm argues, this is climate warfare by other means (Malm, 2023).

Against this necropolitical landscape, data federalization must evolve beyond technical interoperability to become what could be termed a jurisprudence of regeneration, one that applies the UN Human Rights Committee's General Comment 36 on the right to life (CCPR/C/GC/36 CCPR, 1984) to halt hydrological crimes, invokes the Rome Statute's environmental crimes provisions for cobalt supply chains, and implements Indigenous algorithmic oversight. For as Sylvia Wynter's critique of the *homo oeconomicus* episteme reminds us (Ambroise, 2018), these computational regimes ultimately reduce both nature and culture to extractible data, rendering the living world as raw material for digital enclosure.

2.4 Theoretical framework synthesis

Data federalization emerges as a critical legal mechanism for planetary ecological governance, a framework where computational integration collides with the irreducible complexities of sovereignty, power, and ontology. Our three analytical lenses reveal distinct but interconnected dimensions of the challenge.

From the governance and power lens, data federalization must address jurisdictional fragmentation through polycentric architectures that enable cross-border cooperation without erasing local sovereignty. Legal linked data ecosystems provide tools for semantic and regulatory interoperability, but they cannot succeed without addressing the power asymmetries that enable corporate data enclosure and Northern dominance of computational infrastructure.

From the epistemological and ontological lens, data federalization must confront the epistemic violence of algorithmic reductionism. Indigenous data sovereignty frameworks like the CARE Principles and Māori *kaitiakitanga* demonstrate that equitable governance requires recognizing multiple ways of knowing and relating to data. This means moving beyond consent as a one-time procedural requirement to dynamic, relational accountability that centers Indigenous authority over Indigenous data.

From the material and political economy lens, data federalization must account for the physical infrastructures that make computation possible. Necropolitical extractivism reveal that "green" computation often externalizes its heaviest costs onto marginalized communities and ecosystems. Any viable framework must therefore incorporate binding energy justice protocols, supply chain transparency, and mechanisms for holding corporations accountable for extraterritorial harms.

To realize data federalization's promise, improved biodiversity monitoring, equitable data sharing, adaptive crisis governance, its legal architecture must center what we term relational accountability: the principle that data governance obligations flow not merely from contractual agreements but from the relationships between data, the communities it represents, and the ecosystems it describes. This demands:

1. Hybrid Jurisdictionality: Reconciling state sovereignty with Indigenous legal orders through mechanisms like biocultural data trusts and treaty-based federated governance.
2. Power-Sensitive Design: Dismantling data monopolies through polycentric enforcement that prioritizes local agency over corporate or state control.
3. Ethical Computation: Legally binding frameworks to audit and decarbonize tech infrastructures, ensuring planetary tools do not perpetuate sacrifice zones.

Ultimately, data federalization must evolve beyond a technical fix into an adaptive legal philosophy—one that treats environmental data not as a commodity but as a commons of reciprocity. By embedding jurisdictional agility, epistemic pluralism, and thermodynamic justice into its core, it can reframe global environmental law as a dynamic, living system: responsive to ecological urgency yet rooted in the protection of both human and more-than-human lifeworlds.

3 Legal-tech hybrids for relational stewardship

The commodification of ecological data under late capitalism demands transformative legal frameworks capable of reconciling two seemingly contradictory imperatives: sovereign control over data and decentralized, democratized access to knowledge. Without radical legal innovations that integrate jurisdictional enforcement with decentralized systems, we risk exacerbating ecological crises through fragmented, profit-driven data regimes. This section develops interrelated legal-technical mechanisms designed to operationalize the principles of relational accountability developed earlier aiming to provide building blocks for an international treaty.

3.1 Data's ontological duality and the limits of property

Any governance proposal must first contend with data's peculiar ontology. Data constitutes the operational substrate of artificial intelligence and algorithmic governance, yet its nature as both a non-rival economic good; capable of unlimited replication, and a rival legal good; through its linkage to privacy and sovereignty rights, places it in an unprecedented regulatory paradigm. Understanding this duality is essential for designing mechanisms that neither over-privatize nor under-protect ecological information.

Data produced through organic human-nature interactions, from satellite imagery of deforestation to biometric records of endangered species, possesses strategic value derived from its epistemic authenticity: it reflects unique ecological and social patterns that cannot be simply recreated. Yet its exploitation faces asymptotic limits. Massive data collection encounters diminishing returns in data mining, as the marginal cost of obtaining novel information increases exponentially once accessible datasets are exhausted. This phenomenon, familiar from the economics of open-access resources, is exacerbated by legal constraints. The GDPR and similar regimes empower individuals and communities to control data use, transforming data into a scarce resource through regulatory design rather than physical limitation (Álvarez, 2025).

This practical scarcity creates a collective action dilemma. Technology companies treat data as a privatizable commodity under intellectual property regimes, while states and Indig-

enous communities increasingly advocate for its status as a public good or commons. The tension demands governance mechanisms that transcend absolute territorial sovereignty. Data federalization offers a path forward, but it requires resolving how to enable cross-border flows without eroding privacy safeguards or falling into data colonialism.

Synthetic data, in the other hand, generated through generative adversarial networks and large language models, presents itself as a post-scarcity alternative. By emulating statistical distributions of real data without containing identifiable information, it promises to resolve the trilemma between privacy, utility, and access. Yet synthetic data lacks ontological autonomy, operating as a meta-resource dependent on the quality and diversity of original training data. Additionally, the mirroring problem means that biases in source data are not merely replicated but amplified. Moreover, synthetic data inhabits a regulatory void: the EU Copyright Directive does not recognize non-human authorship, leaving ownership uncertain. This gap, analyzable through Heller's theory of fragmented property rights, risks creating a tragedy of the anticommons where overlapping claims prevent efficient exploitation. Without clear legal frameworks, both organic and synthetic data may remain trapped in silo, hoarded by corporate actors or rendered unusable by legal uncertainty (Heller, 1998). The mechanisms proposed below resolve this impasse by embedding data within fiduciary relationships rather than exclusive property rights.

3.2 Biocultural data trusts as fiduciary structures

Traditional data governance models, whether open-access platforms like the Global Biodiversity Information Facility or proprietary systems like IBM's Geospatial Analytics, tend to reduce ecosystems to inert resources. Scholars have critiqued this as digital *terra nullius*, a logic that treats Indigenous territories and biodiverse landscapes as empty spaces awaiting data extraction. Biocultural Data Trusts counter this by redefining environmental data as a fiduciary resource held in stewardship for more-than-human communities. Drawing from the Māori concept of *kaitiakitanga* and the common law tradition of the trust, these legal structures oblige trustees to prioritize ecological and cultural integrity over profit (Ruckstuhl, 2023).

The legal architecture of a Biocultural Data Trust rests on three components. First, the trust is established by Indigenous nations, local communities, or conservation organizations for the benefit of designated beneficiaries. Crucially, beneficiaries may include not only present and future human communities but also the ecosystems themselves; rivers, forests, species. Whose interests are represented by human trustees with enforceable fiduciary duties. This extends the emerging field of rights of nature into the data governance context. Second, the trust property consists of data assets: biodiversity datasets, geospatial information, traditional knowledge records, and related metadata. These assets are held in trust rather than owned outright, meaning they cannot be alienated or exploited without beneficiary consent. A trust instrument specifies permissible uses, access conditions, and benefit-sharing arrangements. Third, trustees owe enforceable duties of loyalty and care. The duty of loyalty requires acting solely in the interests of beneficiaries, prohibiting self-dealing or extraction for commercial gain without explicit authorization. The duty of care requires reasonable prudence in managing data assets, including protection from unauthorized access.

Several initiatives already embody aspects of this model. The Centre for Indigenous Conservation and Development Alternatives in the Americas has pioneered collaborative

approaches integrating Indigenous knowledge systems with modern technology. Its community mapping projects enable Indigenous partners to document and manage lands using GIS technology, with data governed under OCAP principles; Ownership, Control, Access, Possession, ensuring First Nations retain authority over how genetic and geographic information is used. The Atateken Declaration formalizes this approach, advocating for legal recognition of Indigenous data sovereignty in natural resource management, including protocols for co-managing geospatial data on sacred sites (CBD, 2019). These mapping projects have directly informed land restitution claims in Quebec, where Innu Nation leaders used community-generated data to halt mining projects impacting caribou migration routes.

Biocultural Data Trusts align closely with data federalization goals. By ensuring communities retain control over their data, they balance power dynamics and promote equitable participation in governance. Within federated networks, they enable inclusion of traditional ecological knowledge in environmental monitoring, establish clear access guidelines that respect Indigenous sovereignty, provide trusted nodes where data is accessible for approved purposes without compromising community control, and create legally enforceable benefit-sharing mechanisms when data contributes to commercial or scientific applications.

3.3 Proof-of-stewardship and cryptographic accountability

Proof-of-stewardship addresses the accountability gaps that emerge when data federalization lacks mechanisms to verify compliance with stewardship obligations. Grounded in stewardship theory (ALI, 2021; Davis et al., 1997; Hsu & Zhang, 2025; Steffen et al., 2011), which redefines resource management as fiduciary obligation to collective welfare rather than private gain, this framework reimagines data governance through intergenerational accountability.

Without such mechanisms, data federalism risks becoming unregulated exchange where datasets collected for climate modeling are commodified without consent. Platforms like Google Earth Engine centralize global environmental data under proprietary architecture while externalizing extraction costs onto marginalized regions, replicating colonial patterns where data harvested from the Global South fuels algorithmic governance in the Global North while bypassing local sovereignty.

Proof-of-stewardship requires entities that generate, steward, or utilize ecological data to provide cryptographically verifiable proof that their actions align with stewardship obligations. This can be implemented through several interconnected technologies. Blockchain-based transparency protocols record data provenance, access logs, and usage history in tamper-evident form. When paired with federated learning architectures, these protocols enable cryptographic audits of data flows that ensure compliance with environmental and ethical standards without revealing underlying data. A conservation AI trained on Indigenous biodiversity data could generate periodic proofs that its training processes adhered to agreed consent and usage parameters.

Smart contracts encode stewardship rules directly into data access systems. When a researcher requests access to a Biocultural Data Trust-governed dataset, a smart contract can verify credentials, enforce purpose limitations, and automatically distribute benefits to trust beneficiaries; all with full auditability. Anti-commandeering safeguards prohibit unilateral data requisition by corporations or states without reciprocal obligations such as climate reparations or resource-sharing agreements. These echo GDPR's principles of data mini-

mization and purpose limitation while scaling them to planetary exigencies, ensuring that reused satellite imagery or biodiversity datasets adhere to circular economies that reduce digital waste.

Benjamin Bratton's Stack model frames planetary computation as a layered infrastructure requiring polycentric governance to mitigate its extractive logics. Proof-of-stewardship operates across multiple Stack layers. At the Earth layer of physical infrastructure, it can verify that lithium extraction for data centers adheres to agreed environmental and human rights standards. At the Cloud layer of computational platforms, it can audit AI training processes for compliance with Indigenous data sovereignty protocols. At the User layer of interfaces and interactions, it can ensure that insights derived from ecological data benefit frontline communities rather than extracting value for distant corporations. Such frameworks reject technological neutrality, instead embedding legal accountability into computation's materiality from lithium mines to AI training datasets.

3.4 The māori model as operational blueprint

The Māori-led Te Mana Raraunga initiative offers a globally recognized blueprint. Established in 2016, it asserts Māori sovereignty over data related to their lands, waterways, and people, operationalizing the CARE Principles of Collective Benefit, Authority to Control, Responsibility, and Ethics developed by the Global Indigenous Data Alliance.

The Māori model rests on interconnected concepts from Te Ao Māori. Data is understood as *taonga*, a treasure imbued with ancestral relationships and collective rights, demanding custodianship aligned with *tikanga* or Māori customary practices. This directly challenges the *datum nullius* logic that treats data as a blank slate for extraction. *Rangatiratanga* asserts that Māori data must be governed by Māori, for Māori, within Aotearoa New Zealand, rejecting frameworks that would place Māori data under external control. *Kaitiakitanga* means that those who hold data act as guardians, not owners, with fiduciary obligations to present and future generations, aligning closely with the trust architecture proposed above. *Whanaungatanga* embeds reciprocal obligations, meaning that access to Māori data requires corresponding benefits for Māori communities.

The framework operationalizes these principles through concrete mechanisms. A Chief Māori Data Steward provides leadership and accountability across government agencies and research institutions. *Data Pou* or pillars including anti-racist practices, decentralized infrastructure, and Māori ethics review ensure implementation aligns with Māori values. The framework extends to algorithmic governance: Māori algorithmic sovereignty requires that algorithms affecting Māori communities be audited for bias, decolonized through Māori-led design, and indigenized to reflect te ao Māori.

Recent controversies illustrate the stakes. When OpenAI's Whisper model scraped te reo Māori data without consent, it exemplified the asymmetry this framework seeks to dismantle: a planetary-scale system profiting from Indigenous knowledge while externalizing harms (Mahelona & Leoni, 2023). The Māori response asserting that only Māori should decide how their language is digitized mirrors the anti-commandeering principle, demanding equitable resource-sharing or reparative justice.

The challenge for data federalization lies in scaling such place-based models. The Māori framework's insistence on data as *taonga* offers a blueprint for planetary systems that treat ecological information not as neutral inputs but as entangled lifeworlds requiring custodial

care. Applying *kotahitanga* or collective benefit to climate datasets would mean prioritizing Indigenous-led interpretation, ensuring insights serve frontline communities rather than distant corporations. Yet the Māori model's reliance on *Te Tiriti o Waitangi*² highlights the legal precarity of translating Indigenous sovereignty into planetary computation's stateless architectures, suggesting the need for treaty-based recognition at the international level.

3.5 Toward a global commons data treaty

The mechanisms examined above; Biocultural Data Trusts, proof-of-stewardship architectures, and Indigenous data sovereignty frameworks, provide essential building blocks for a coherent legal architecture. Yet their full potential depends on integration within a larger framework capable of operating at planetary scale. A Global Commons Data Treaty (GCDT) offers one possible pathway: not a monolithic, top-down regime imposed uniformly across jurisdictions, but a flexible instrument designed to enable polycentric experimentation while establishing minimum standards that safeguard against the extractive logics documented throughout this article.

3.5.1 Core elements of a GCDT

A treaty adequate to these challenges would need to address several interconnected dimensions simultaneously.

First, recognition of Indigenous data sovereignty as a non-derogable right. Building on UNDRIP Article 31, which affirms Indigenous peoples' right to maintain, control, protect, and develop their cultural heritage and traditional knowledge, a GCDT should operationalize the CARE Principles (Collective Benefit, Authority to Control, Responsibility, Ethics) as binding obligations for state parties and corporations operating within their jurisdiction (Global Indigenous Data Alliance, 2025; UN, 2007). This would move beyond aspirational declarations to enforceable duties, requiring that any use of Indigenous data, whether for conservation science, commercial AI training, or climate modeling, proceed only on terms set by Indigenous governing authorities.

Second, interoperability protocols rather than centralized repositories. The treaty should resist the temptation to create a single global database, which would concentrate power and create irresistible targets for surveillance or appropriation. Instead, it should establish technical and legal standards enabling federated querying across distributed nodes; Biocultural Data Trusts, community databases, national repositories, while ensuring that each query leaves control with data originators. This approach, inspired by the technical architecture of federated learning, would allow planetary-scale analysis (of deforestation patterns, biodiversity trends, carbon fluxes) without requiring communities to surrender their data.

Third, benefit-sharing mechanisms adapted to the digital age. The Nagoya Protocol's access and benefit-sharing framework assumed tangible transfers of genetic materials. A GCDT must address digital sequence information (DSI), which can be extracted from published databases and used commercially without any benefit flowing to source communities. Similarly, it must address AI training datasets, whose value is realized not through direct commercialization of specific data points but through the capabilities of models trained on

² Treaty of Waitangi is one of the foundational documents of Aotearoa New Zealand. It was signed in 1840 between representatives of the British Crown and many Māori Rangatira (chiefs).

them. The treaty should mandate that commercial and scientific users of ecological data, including corporations developing AI systems, contribute to a global fund supporting Indigenous-led conservation and data governance, with contributions calibrated to the scale and nature of use.

Fourth, independent oversight with Indigenous representation. Compliance monitoring cannot be left to state parties alone, particularly where states themselves may be implicated in extracting data from Indigenous territories. A GCDT should establish a permanent oversight body with substantial Indigenous representation, empowered to receive complaints, conduct investigations, and issue findings. Dispute resolution mechanisms must be accessible to communities lacking resources for international litigation, potentially through simplified procedures, legal aid funds, or regional ombudspersons.

Fifth, supply chain transparency and material justice protocols. Data governance cannot be divorced from the physical infrastructures that make computation possible. A GCDT should impose binding obligations on data infrastructure operators, cloud providers, data center operators, AI companies, to disclose their supply chains for minerals, energy sources, and manufacturing. It should require demonstrable evidence of community consent for resource extraction in sacrifice zones, and mandate contributions to just transition funds in affected regions. These provisions would operationalize the principle of thermodynamic colonialism developed in Sect. 2, ensuring that the costs of planetary computation are borne equitably rather than concentrated on marginalized communities.

3.5.2 Pathways to feasibility: from unilateralism to multilateralism

Acknowledging the profound political obstacles to any new international treaty, particularly one addressing sensitive issues of data sovereignty and technology governance, a realistic pathway must begin not with universal consensus but with coalitions of the willing. The treaty could be initiated as a unilateral agreement among states hosting critical biomes: the Amazon Basin countries, the Congo Basin nations, Southeast Asian archipelagic states, together with their international partners. These are the regions where biodiversity is concentrated, where Indigenous data sovereignty is most urgently at stake, and where the costs of extractive data regimes are most directly felt.

This approach mirrors the historical development of international environmental law. The Convention on Biological Diversity itself built on earlier regional conservation agreements; the Ramsar Convention on Wetlands began with a handful of signatories before achieving near-universal membership (RAMSAR, 1971). A unilateral GCDT would create a *de facto* standard, technically, legally, and ethically, that other states and corporations would find increasingly costly to ignore. Major technology companies seeking access to biodiversity data from treaty members would need to comply with its terms, creating pressure for their home states to join or negotiate accommodations.

3.5.3 Operationalizing reciprocity

The treaty's transformative potential lies in its capacity to operationalize reciprocity. Under current arrangements, data flows from biodiversity-rich but technologically less powerful states to AI developers in the Global North, with benefits accruing almost entirely to the latter. A GCDT would invert this logic: access to ecological data would be conditional on

reciprocal transfers of computational capacity, technology transfer, and financial resources. High-income states and corporations would share supercomputing access, satellite bandwidth, and AI expertise with treaty partners, enabling them to participate in planetary-scale analysis rather than merely supplying raw data.

This reciprocity transforms data federalization from a one-way extractive flow into genuine partnership. It acknowledges that the value of ecological data is co-produced: the data itself comes from particular places and communities, while the computational capacity to analyze it at scale is concentrated elsewhere. Neither is inherently more valuable; both are necessary. A treaty that requires their equitable combination would not only redress historical asymmetries but also produce better science, as Indigenous-led interpretation enriches the insights derived from global datasets.

4 Conclusions: epistemic humility and legal innovation, foundations for just environmental transitions

The accelerating disintegration of Earth's ecosystems demands a reconfiguration of environmental governance that transcends territorial sovereignty without replicating the extractive logics of technological solutionism. This article has shown that data federalization; the equitable, coordinated stewardship of ecological data across jurisdictional and ontological boundaries, offers a critical framework for addressing the metabolic rifts between planetary-scale computation and localized ecological survival. However, its efficacy hinges on integrating legal innovation with epistemic pluralism, ensuring that global interoperability does not eclipse Indigenous sovereignty or deepen thermodynamic colonialism.

The analysis reveals four irreducible tensions shaping data federalization's potential:

1. **Jurisdictional Fragmentation vs. Ecological Interdependence:** Fractured monitoring regimes exemplify how territorial data silos enable transnational environmental crimes, while centralized systems risk algorithmic imperialism. Effective governance requires hybrid models, such as polycentric federated networks, that balance shared standards with place-based sovereignty.
2. **Technological Asymmetries vs. Relational Ontologies:** AI-driven tools, while advancing biodiversity monitoring, often reduce Indigenous territories to decontextualized datasets, perpetuating epistemicide. Bridging this divide necessitates legal frameworks that embed principle such those exemplified by CARE into computational infrastructures, prioritizing dynamic consent and biocultural reciprocity.
3. **Green Techno-Utopianism vs. Necropolitical Realities:** Technologies promise of decentralized transparency collides with its necropolitical footprint, as lithium extraction for "sustainable" computation drains Indigenous aquifers. Mitigating this demands binding energy justice protocols, decarbonizing infrastructures while centering frontline communities in tech governance.
4. **Global Integration vs. Local Autonomy:** Planetary-scale data systems require interoperability and shared standards, yet effective stewardship depends on place-based governance and community control. Data federalization must navigate this tension through polycentric architectures that enable global coordination without erasing local decision-making authority.

Within this landscape, the theoretical proposal of a Global Common Data Treaty (GCDT) emerges not as a panacea but as one component of a broader pluriversal approach. Rather than imposing monolithic frameworks, the Treaty could catalyze coalitions, nations and Indigenous alliances adopting federated data pools for critical biomes under shared stewardship principles. Its value lies in operationalizing reciprocity: requiring high-income states to share computational capacity in exchange for biodiversity data access, while mandating decolonial audits of AI training sets.

However, the success of such a model depends on parallel shifts: dismantling investor-state arbitration systems that privilege extraction over ecology, recognizing Indigenous data sovereignty as a non-derogable right under international law, and reorienting metrics of success from GDP-adjusted emissions to biocultural health indices. The Māori concept of *kaitiakitanga* (guardianship) and Zapatista autonomous governance models underscore that data federalization must evolve as a *relational practice*, one that harmonizes planetary monitoring with place-based care.

For scholars and policymakers, this underscores an urgent mandate: environmental law must abandon its anthropocentric fetishization of data as a commodity and instead reimagine it as a commons of interdependence. This requires moving beyond regulatory tinkering to embrace epistemic humility, recognizing that the computational infrastructures we build today will either deepen Earth's metabolic rifts or seed the juridical-ethical foundations for a just transition. The path forward is not open data for open data's sake, but closed loops of accountability, where every byte of ecological data flows back to nourish the lifeworlds it represents.

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References

ACTO (2021). *Amazon Assessment Report 2021 - Conservation measures to counter the main threats to Amazonian biodiversity - Chap. 27*. Amazon Cooperation Treaty Organization. <https://otca.org/en/project/amazon-assessment-report-2021/>

- AI (Amnesty International) (2016). *Democratic Republic of Congo: This is what we die for: Human rights abuses in the Democratic Republic of the Congo power the global trade in cobalt*. <https://www.amnesty.org/en/documents/afr62/3183/2016/en/>
- Alejo, I. (2025, March 12). ¿Retrosocos en el derecho de consulta previa? Una mirada desde el caso del proyecto Bellavista Mazán - Salvador - El Estrecho, en la Región Loreto. *DAR*. <https://dar.org.pe/retrosocos-en-el-derecho-de-consulta-previa-una-mirada-desde-el-caso-del-proyecto-bellavista-mazan-salvador-el-estrecho-en-la-region-loreto/>
- ALI (Ada Lovelace Institute) (2021, March 4). *Exploring legal mechanisms for data stewardship*. <https://www.adalovelaceinstitute.org/report/legal-mechanisms-data-stewardship/>
- Álvarez, J. D. R. (2025). Hacia un espacio europeo de datos: lecciones de la CECA para superar la fragmentación digital ante la emergencia de los sistemas computacionales planetarios. *Revista Española de Derecho Europeo*, 95, 57–94. https://doi.org/10.37417/rede/num95_2025_3147
- Ambrose, J. R. (2018). On Sylvia Wynter's Darwinian heresy of the Third Event. *American Quarterly*, 70(4), 847–856. <https://doi.org/10.1353/AQ.2018.0067>
- Barnett, T., & Vilchez, H. (2023, September 7). The Lickanantay: We don't want to be a sacrifice zone. *The Esperanza Project*. <https://esperanzaproject.com/cosmology-polycrisis/the-lickanantay-we-dont-want-to-be-a-sacrifice-zone/>
- Berlin, B., & Berlin, E. A. (2003). Las ONG y el proceso de consentimiento informado previo en las investigaciones de prospección biológica: El proyecto Maya ICBG en Chiapas (México). *Revista Internacional de Ciencias Sociales*, 178, 10.
- Bjorkan, M., & Qvenild, M. (2010). The biodiversity discourse: Categorisation of Indigenous people in a Mexican bio-prospecting case. *Human Ecology*. <https://www.jstor.org/stable/25652777>
- Blair, J. J. A., Balcázar, R. M., Barandiarán, J., & Maxwell, A. (2023). The 'alterlives' of green extractivism: Lithium mining and exhausted ecologies in the Atacama Desert. *Poldev*, 16. <https://doi.org/10.4000/POLDEV.5284>
- Bratton, B. (2016). *The stack: On software sovereignty*. The MIT Press.
- Bratton, B. (2023). *Antikythera*. <https://research.antikythera.org/>
- Cambridge Centre for Alternative Finance (2025, April 23). *Cambridge Blockchain Network Sustainability Index: CBECI*. <https://ccaf.io/cbnsi/cbeci>
- CBD (Convention on Biological Diversity) (2019, May 1). *Atateken Declaration*. <https://www.cbd.int/portal/s/culturaldiversity/docs/north-american-regional-declaration-on-biocultural-diversity-en.pdf>
- CCPR (UN Human Rights Committee) (1984). *General comment No. 36*. <https://docs.un.org/en/CCPR/C/GC/36>
- CIDH (Inter-American Court of Human Rights) (2014). *Kaliña and Lokono v. Suriname*.
- Convention on Biological Diversity (2025, February 14). *The Cali Fund launches in the margins of the resumed session of COP16*. <https://www.cbd.int/article/cali-fund-launch-2025>
- Dakos, V., Boulton, C. A., Buxton, J. E., Abrams, J. F., Arellano-Nava, B., Armstrong McKay, D. I., Bathiany, S., Blaschke, L., Boers, N., Dylewsky, D., López-Martínez, C., Parry, I., Ritchie, P., Van Der Bolt, B., Van Der Laan, L., Weimans, E., & Kéfi, S. (2024). Tipping point detection and early warnings in climate, ecological, and human systems. *Earth System Dynamics*, 15(4), 1117–1135. <https://doi.org/10.5194/esd-15-1117-2024>
- Davis, J. H., Schoorman, F. D., & Donaldson, L. (1997). Toward a stewardship theory of management. *Academy of Management Review*, 22(1), 20–47. <https://doi.org/10.5465/AMR.1997.9707180258>
- de Santos, B. S (2015). *Epistemologies of the South: Justice against epistemicide*. Routledge. <https://doi.org/10.4324/9781315634876>
- Dellmuth, L., & Gustafsson, M. T. (2023). Legitimacy in the trans-scalar governance of climate adaptation. *npj Climate Action*, 2(1), 1–4. <https://doi.org/10.1038/s44168-023-00036-7>
- Earthworks (2020, June 25). *Atacama, Chile*. <https://earthworks.org/blog/atacama-chile-lithium/>
- EC (European Commission) (2017). *Conflict Minerals Regulation*. https://policy.trade.ec.europa.eu/development-and-sustainability/conflict-minerals-regulation_en
- EC (European Commission) (2025). *Improving semantic interoperability in European eGovernment systems | ISA²*. https://ec.europa.eu/isa2/actions/improving-semantic-interoperability-european-egovernment-systems_en/
- EFE. (2023, May 18). Un proyecto de inteligencia artificial identifica jaguares en México. *EFE Comunica*. <https://efecomunica.efe.com/un-proyecto-de-inteligencia-artificial-identifica-jaguares-en-una-reserva-natural-de-mexico/>
- Escobar, A. (2015). Transiciones: A space for research and design for transitions to the pluriverse. *Design Philosophy Papers*, 13(1), 13–23. <https://doi.org/10.1080/14487136.2015.1085690>
- Escobar, A. (2020). *Pluriversal politics: The real and the possible*. Duke University Press.
- EU (European Union). (2025). *DCAT-AP for data portals in Europe - EU Vocabularies*. Publications Office of. <https://op.europa.eu/en/web/eu-vocabularies/dcat-ap> the European Union.

- EUR-Lex (2023). *Regulation (EU) 2023/1542 of the European Parliament and of the Council*. <https://eur-lex.europa.eu/eli/reg/2023/1542/oj/eng>
- European Commission (2024). *European Data Governance Act*. <https://digital-strategy.ec.europa.eu/en/policies/data-governance-act>
- Fahey, B. (2022). Data federalism. *Harvard Law Review*. <https://www.jstor.org/stable/27123253>
- FAO (Food and Agriculture Organization) (2009). *International Treaty on Plant Genetic Resources for Food and Agriculture*. <https://www.fao.org/plant-treaty/en/>
- Fernández-Llamazares, A., Fa, J. E., Brockington, D., Brondízio, E. S., Cariño, J., Corbera, E., Farhan Ferrari, M., Kobei, D., Márquez, G. Y. H., Molnár, Z., Tugendhat, H., & Garnett, S. T. (2024). No basis for claim that 80% of biodiversity is found in Indigenous territories. *Nature*, 633(8028), 32–35. <https://doi.org/10.1038/D41586-024-02811-W>
- Foster, J. B. (1999). Marx's theory of metabolic rift: Classical foundations for environmental sociology. *American Journal of Sociology*, 105(2), 366–405.
- Global Indigenous Data Alliance (2025). *CARE Principles*. <https://www.gida-global.org/care>
- Global Forest Watch (2025). *Forest monitoring, land use & deforestation trends*. <https://www.globalforestwatch.org/>
- Godelive, K. B., Martin, D., & Nene, M. M. B. (2023). Small-scale mining and child labour in Kolwezi, Democratic Republic of Congo. *Journal of African Studies and Development*, 15(4), 69–83. <https://doi.org/10.5897/JASD2023.0679>
- Google Sustainability (2021, March). *Technology: Wildlife Insights*. <https://sustainability.google/operating-sustainably/stories/wildlife-insights/>
- Gov.br (Instituto Nacional de Pesquisas Espaciais) (2025, March 21). *INPE*. <https://www.gov.br/inpe/pt-br>
- Heller, M. A. (1998). The tragedy of the anticommons: Property in the transition from Marx to markets. *Harvard Law Review*, 112(3), 622. <https://doi.org/10.2307/1342203>
- Howson, P. (2020). Climate crises and crypto-colonialism: Conjuring value on the blockchain frontiers of the Global South. *Frontiers in Blockchain*, 3, 479673. <https://doi.org/10.3389/FBLOC.2020.00022>
- Hsu, H. Y., & Zhang, Y. (2025). Public organizational stewardship: Conceptualization and application. *Perspectives on Public Management and Governance*, 8(1), 27–37. <https://doi.org/10.1093/PPMGOV/GVAF001>
- Huang, J., O'Neil, C., & Tabuchi, H. (2021, September 3). Bitcoin uses more electricity than many countries. How is that possible? *The New York Times*. <https://www.nytimes.com/interactive/2021/09/03/climate/bitcoin-carbon-footprint-electricity.html>
- ILO (International Labour Organization) (1989). *Convention C169 - Indigenous and Tribal Peoples Convention, 1989 (No. 169)*. https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB:12100:0::NO::P12100_ILO_CODE:C169
- iNaturalist. (n.d.). *Una comunidad para naturalistas*. Retrieved May 2 (2025). from <https://www.inaturalist.org/>
- Indigenous Watchdog (2025, January 11). *New research explores impact of Ring of Fire mining on First Nations in northern Ontario*. <https://www.indigenouwatchdog.org/update/new-research-explores-impact-of-ring-of-fire-mining-on-first-nations-in-northern-ontario/>
- IPCC (Intergovernmental Panel on Climate Change) (2023, March 19). *Synthesis report: Climate change 2023*. <https://www.ipcc.ch/report/sixth-assessment-report-cycle/>
- IQAir (2024). *2024 World Air Quality Report*. <https://www.iqair.com/world-air-quality-report>
- Lenhardt, A. (2023, June 6). *Ecuador's 2008 constitution integrates indigenous values on equality, diversity, reciprocity, and sustainability*. SDG16 Pathfinders. <https://www.sdg16.plus/policies/ecuadors-2008-constitution-integrates-indigenous-values-on-equality-diversity-reciprocity-and-sustainability/>
- Mahelona, K., & Leoni, G. (2023, January 24). *OpenAI's Whisper is another case study in colonisation*. Papareo. <https://blog.papareo.nz/whisper-is-another-case-study-in-colonisation/>
- Mahonghol, D. (2024, November 4). *The regional security imperative to protect the Congo Basin*. Africa Center for Strategic Studies. <https://africacenter.org/publication/asb44en-regional-security-imperative-protect-congo-basin/>
- Malm, A. (2023). *Fighting in a world on fire: The next generation's guide to protecting the climate and saving our future*. Verso.
- Mbembe, A. (2008). Necropolitics. In S. Morton & S. Bygrave (Eds.), *Foucault in an age of terror* (pp. 152–182). Palgrave Macmillan.
- Mejias, U. A., & Coudry, N. (2019). Colonialismo de datos: repensando la relación de los datos masivos con el sujeto contemporáneo. *Virtualis*, 10(18), 78–97. <https://doi.org/10.2123/VIRTUALIS.V10I18.289>
- Morton, T. (2013). *Hyperobjects: Philosophy and ecology after the end of the world*. University of Minnesota Press.

- Nagoya Protocol. (2014). Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from Their Utilization to the Convention on Biological Diversity (Treaty Code: 2014/283). Nagoya, Japan: Secretariat of the Convention on Biological Diversity.
- O'Brien, C. (2015, September 26). Indigenous group, Greenpeace partner to track illegal logging in the Amazon. *Mongabay*. <https://news.mongabay.com/2015/09/indigenous-group-greenpeace-partner-to-track-illegal-logging-in-the-amazon/>
- Ostrom, E. (1994). Constituting social capital and collective action. *Journal of Theoretical Politics*, 6(4), 527–562. <https://doi.org/10.1177/0951692894006004006>
- Ostrom, E. (2010). Beyond markets and states: Polycentric governance of complex economic systems. *American Economic Review*, 100(3), 641–672. <https://doi.org/10.1257/AER.100.3.641>
- Poblet, M., Casanovas, P., & Rodríguez-Doncel, V. (2019). Legal linked data ecosystems and the rule of law. In *Linked data for law* (pp. 87–126). Springer. https://doi.org/10.1007/978-3-030-13363-4_5
- Rainforest Foundation, U. S. (2025). *Rainforest Foundation US*. <https://rainforestfoundation.org/>
- RAMSAR (Convention on Wetlands) (1971). *The Convention on Wetlands*. <https://www.ramsar.org/>
- Raven, M., Gall, A., Barbara, B., & Robinson, D. (2024, June 4). Patents based on traditional knowledge are often 'biopiracy': A new international treaty will finally combat this. *UNSW Newsroom*. <https://www.unsw.edu.au/newsroom/news/2024/06/patents-based-on-traditional-knowledge-are-often-biopiracy-a-new-international-treaty-will-finally-combat-this>
- Richardson, K., Steffen, W., Lucht, W., Bendtsen, J., Cornell, S. E., Donges, J. F., Drüke, M., Fetzer, I., Bala, G., von Bloh, W., Feulner, G., Fiedler, S., Gerten, D., Gleeson, T., Hofmann, M., Huiskamp, W., Kumm, M., Mohan, C., Nogués-Bravo, D., & Rockström, J. (2023). Earth beyond six of nine planetary boundaries. *Science Advances*, 9(37). <https://doi.org/10.1126/SCIADV.ADH2458>
- Ruckstuhl, K. (2023, May 24). Data as taonga: Aotearoa New Zealand, Māori data sovereignty and implications for protection of treasures. *NYU Journal of Intellectual Property & Entertainment Law*. <https://jipel.law.nyu.edu/data-as-taonga-aotearoa-new-zealand-maori-data-sovereignty-and-implications-for-protection-of-treasures/>
- SINCHI (Instituto Amazónico de Investigaciones Científicas) (2025, March 23). *SINCHI*. <https://sinchi.org.co/>
- Slough, T., Kopas, J., & Urpelainen, J. (2021). Satellite-based deforestation alerts with training and incentives for patrolling facilitate community monitoring in the Peruvian Amazon. *Proceedings of the National Academy of Sciences*, 118(29). <https://doi.org/10.1073/PNAS.2015171118>
- Steffen, W., Persson, Å., Deutsch, L., Zalasiewicz, J., Williams, M., Richardson, K., Crumley, C., Crutzen, P., Folke, C., Gordon, L., Molina, M., Ramanathan, V., Rockström, J., Scheffer, M., Schellnhuber, H. J., & Svedin, U. (2011). The Anthropocene: From global change to planetary stewardship. *Ambio*, 40(7), 739–761. <https://doi.org/10.1007/S13280-011-0185-X>
- Street, E. (2021, March 31). Indigenous people in the Amazon use satellite data, smartphones, drones to fight illegal logging. *Yale Climate Connections*. <https://yaleclimateconnections.org/2021/03/indigenous-people-in-the-amazon-use-satellite-data-smartphones-drones-to-fight-illegal-logging/>
- Survival International (2022, June 13). *Tanzania: Thousands of Maasai flee into the bush after dozens shot and detained following evictions for trophy hunting and conservation*. <https://www.survivalinternational.org/news/13051>
- Te Mana Raraunga (2025). *Te Mana Raraunga*. <https://www.temanararaunga.maori.nz/>
- TNI (Transnational Institute) (2023, September 21). *Energy transition mythbusters: Myth #6*. <https://www.tni.org/en/article/energy-transition-mythbusters-myth-6>
- Tuck, E., & Yang, K. W. (2014). Unbecoming claims: Pedagogies of refusal in qualitative research. *Qualitative Research*, 20(6), 811–818. <https://doi.org/10.1177/1077800414530265>
- UN (United Nations) (2007). *United Nations Declaration on the Rights of Indigenous Peoples*. <https://www.un.org/development/desa/indigenouspeoples/declaration-on-the-rights-of-indigenous-peoples.html>
- UN (United Nations) (2019). *UN report: Nature's dangerous decline unprecedented; species extinction rates accelerating*. IPBES. <https://www.un.org/sustainabledevelopment/blog/2019/05/nature-decline-unprecedented-report/>
- UN WCMC (UN Environment Programme World Conservation Monitoring Centre) (2022, October). *New report reveals devastating 69% drop in wildlife populations*. <https://www.unep-wcmc.org/en/news/new-report-reveals-devastating-69-drop-in-wildlife-populations>
- UNCTAD (UN Conference on Trade and Development) (2022). *Kunming-Montreal Global Biodiversity Framework*. <https://unctad.org/topic/trade-and-environment/biotrade/kunming-montreal-global-biodiversity-framework>
- UNESCO (2023, September 1). *UNESCO Recommendation on Open Science*. <https://www.unesco.org/en/open-science/about>
- UNTC (UN Treaty Collection) (2018, March 4). *Escazú Agreement*. https://treaties.un.org/pages/viewdetails.aspx?src=treaty&mtdsg_no=xxvii-18&chapter=27&clang=en

Wildlife Insights (2025). *Wildlife Insights*. <https://www.wildlifeinsights.org/>

WWF (World Wildlife Fund) (2016, Winter 5). *Embracing new technology to tackle wildlife crime*. https://www.panda.org/wwf_news/?267751/Embracing-New-Technology-to-Tackle-Wildlife-Crime

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