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DIGITAL TWIN OF NATURE: JURISDICTIONAL CHALLENGES OF ENVIRONMENTAL MONITORING IN CYBERSPACE

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Abstract

The development of digital twin technology enables the creation of virtual representations of ecosystems such as forests, oceans, and the atmosphere for environmental monitoring and disaster mitigation. However, the storage of ecological data on foreign servers raises critical issues of jurisdiction, ownership, and data sovereignty. This study aims to analyze the challenges of national jurisdiction in regulating ecological data ownership and protection, while assessing the role of cyber law as a legal instrument to reinforce state sovereignty over digital ecological assets. Employing a normative juridical method with statutory, conceptual, and comparative approaches, the research draws on primary legal sources, secondary literature, and international reports. The findings reveal a legal vacuum concerning ecological data protection, potential domination by foreign entities, and weak national regulatory capacity. Consequently, strengthening cyber law is essential to expand legal jurisdiction into cyberspace, safeguard eco-digital sovereignty, and promote international cooperation in protecting strategic environmental data.

Keywords: Cyber law; Cyber sovereignty; Digital twin; Ecological data; Jurisdiction.

Abstrak

Perkembangan teknologi digital twin memungkinkan penciptaan representasi virtual ekosistem seperti hutan, laut, dan atmosfer untuk pemantauan lingkungan serta mitigasi bencana. Namun, penyimpanan data ekologi digital yang umumnya berada pada server asing menimbulkan persoalan yurisdiksi, kepemilikan, dan kedaulatan data. Penelitian ini bertujuan menganalisis tantangan yurisdiksi nasional dalam pengaturan kepemilikan serta perlindungan data ekologi, sekaligus menilai peran cyber law sebagai instrumen penguatan kedaulatan negara atas data ekologi digital. Metode yang digunakan adalah penelitian yuridis-normatif dengan pendekatan perundang-undangan, konseptual, dan komparatif, menggunakan bahan hukum primer, sekunder, serta laporan internasional. Hasil penelitian menunjukkan adanya kekosongan hukum terkait perlindungan data ekologi digital, risiko dominasi pihak asing, serta lemahnya kapasitas regulasi nasional. Oleh karena itu, pengembangan cyber law diperlukan sebagai upaya memperluas yurisdiksi hukum ke ranah siber, memperkuat eco-digital sovereignty, dan membangun kerja sama internasional dalam melindungi data lingkungan strategis.

Kata Kunci: Hukum siber; Kedaulatan siber; Digital twin; Ekologi data; Yurisdiksi.

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Alauddin Law Development Journal (ALDEV)
Vol. 7, No. 3, 2025

INTRODUCTION

The rapid advancement of digital technologies has fundamentally reshaped how states, institutions, and societies understand and govern their natural environments (Peng 2022). In recent years, the integration of ecological monitoring with digital infrastructures has produced new opportunities for sustainable development and environmental protection (Fowdur et al. 2022). However, these opportunities are accompanied by significant legal, political, and jurisdictional challenges, particularly when ecological data transcends national borders (Kirchner et al. 2022). This paper seeks to explore the emerging legal complexities surrounding the governance of ecological data in cyberspace, with a particular focus on the rise of digital twin technologies.

The concept of a digital twin refers to a virtual replica of physical systems, including ecosystems such as forests, oceans, and the atmosphere (Nativi et al. 2021). Through advanced sensors, satellite imagery, and Internet of Things (IoT) devices, ecological processes can now be mapped, simulated, and monitored in real time (Chen et al. 2023). Digital twins of nature are increasingly employed to predict climate change impacts, optimize natural resource management, and mitigate ecological disasters (Sahu and Upadhyay 2024). These technologies represent a paradigm shift in environmental governance, providing states and international organizations with unprecedented insight into the dynamics of natural ecosystems (Henriksen et al. 2022).

Ecological data has become one of the most strategic assets in the twenty-first century (Maxwell et al. 2020). Information about biodiversity, forest density, ocean conditions, and carbon emissions is central not only to scientific research but also to the formulation of global climate policies and sustainable development strategies (Maxwell et al. 2020). Governments and private actors alike recognize the value of such data for carbon markets, conservation efforts, and environmental diplomacy (Maxwell et al. 2020). In this sense, ecological data functions as a form of "digital natural capital," shaping both national policies and global negotiations (Fleming et al. 2022).

The digitalization of ecological systems has relocated vast amounts of environmental data into cyberspace (Luke 2001). Information gathered from satellites, drones, and sensors is often processed, stored, and analyzed through cloud infrastructures and artificial intelligence systems that operate across multiple jurisdictions (Berman 2018). This transnational character of digital data undermines the traditional reliance on territorial boundaries as the primary determinant of legal authority (Berman 2020). As a result, questions of ownership, control, and access to ecological data are no longer confined to the physical domain but are instead contested within a borderless digital environment (Turnbull et al. 2023).

For states, the displacement of environmental data into foreign-controlled digital infrastructures presents a profound challenge to national sovereignty (Li 2025). When critical ecological information is stored on servers outside a country's territorial borders, governments risk losing effective control over resources that are vital for both environmental governance and national security (Abd Al Ghaffar 2024). This situation raises urgent legal questions: who holds legitimate ownership over ecological data in cyberspace, and how should such ownership be protected under national and international law? Without clear legal frameworks, the risk of foreign domination over environmental knowledge becomes a serious threat to eco-digital sovereignty.

The global digital twin market has demonstrated remarkable expansion in recent years, underpinned by advances in simulation technologies and the integration of data-driven design processes

(Fortune Business Insights 2023, 2019–2030). In 2022, the global market was valued at USD 8.60 billion, and it is projected to reach USD 137.67 billion by 2030, reflecting a compound annual growth rate (CAGR) of 42.6% during the 2023–2030 period (Fortune Business Insights 2023, 2019–2030). Within this trajectory, North America alone accounted for USD 2.94 billion in 2022, highlighting its leading role in the adoption of digital twin technologies (Fortune Business Insights 2023, 2019–2030). From a regional perspective, Asia Pacific and the rest of the world contributed 33.7% and 66.3% respectively, underscoring the growing diversification of market opportunities beyond traditional technology hubs. A key driver of this expansion is the increasing adoption of 3D simulation and 3D printing software, which not only accelerates innovation cycles but also enhances sustainability practices across industries.

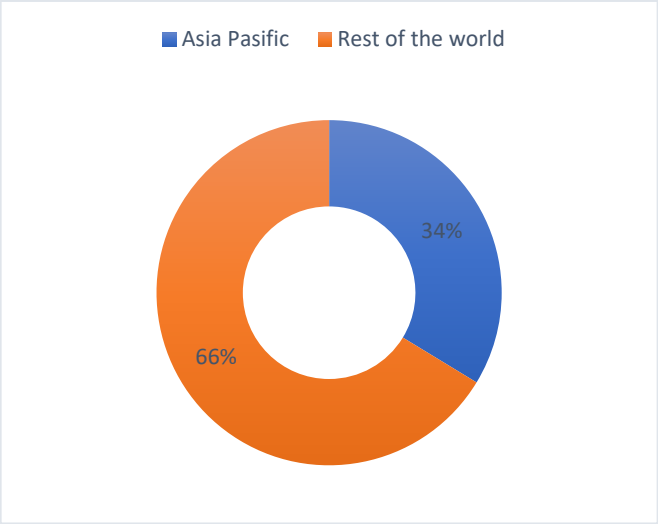

Figure 1. Geographical Breakdown of the Global Digital Twin Market, 2022.

Source: Fortune Business Insights (2023).

Recent market data further underscores the transformative impact of generative AI on the cloud computing industry (Reno 2025). According to the Synergy Research Group, global enterprise spending on cloud infrastructure services reached $91 billion in Q4 2024, marking a 22% increase compared to the same period in 2023 (Reno 2025). Overall, the market expanded to $330 billion in 2024, representing a $60 billion rise from 2023 and a $102 billion surge since 2022. Crucially, generative AI has driven nearly half of this growth over the past two years by fueling demand for GenAI platforms, GPU-as-a-service offerings, and enhancements across diverse cloud-based solutions. In terms of competitive dynamics, Amazon continues to lead with a 30% market share, while Microsoft and Google followed with 21% and 12% respectively, both experiencing faster growth than the market leader.

Furthermore, tier-two providers such as CoreWeave, Oracle, Snowflake, Cloudflare, and Databricks exhibited notable year-on-year growth, with CoreWeave achieving a breakthrough by entering the top twenty global cloud providers owing to its specialization in AI and GPU services. This trajectory highlights how generative AI is not only reshaping service models but also redistributing competitive advantages within the cloud ecosystem.

Alauddin Law Development Journal (ALDEV)
Vol. 7, No. 3, 2025

Table 1. Cloud Infrastructure Services Market Growth and Competitive Dynamics (2022–2024)

Indicator	2022	2023	2024	Notes
Market Size (USD Billion)	228	270	330	Growth of $102B since 2022
Q4 Spending (USD Billion)	–	74	91	Q4 2024 up 22% YoY
Market Growth Driver	–	GenAI adoption begins (post-ChatGPT)	GenAI drives ~50% of growth	Includes GenAI platforms, GPU-as-a-service
Market Share (Q4 2024)	–	–	Amazon 30%, Microsoft 21%, Google 12%	Amazon leads, but Microsoft & Google grow faster
Emerging High-Growth Providers	–	–	CoreWeave, Oracle, Snowflake, Cloudflare, Databricks	CoreWeave enters global Top 20

The exponential growth of cloud infrastructure and the pervasive influence of generative AI introduce profound legal and regulatory challenges (Reno 2025). As a handful of major corporations, Amazon, Microsoft, and Google, dominate the market with a combined majority share, concerns about antitrust and monopolistic practices become increasingly pronounced. This concentration of power raises questions regarding fair competition, access, and sovereignty over critical digital infrastructure (Reno 2025). Furthermore, the integration of generative AI within cloud services heightens regulatory concerns over data security, accountability, and liability, particularly when AI-driven processes manage sensitive or strategic data (Reno 2025). The lack of harmonized global regulations creates a fragmented legal environment where states struggle to safeguard their digital sovereignty while remaining dependent on transnational service providers. Thus, the convergence of cloud market dynamics and AI adoption necessitates more robust legal frameworks that balance innovation with equitable governance and protection of national interests.

Despite the growing strategic importance of ecological data, most national legal systems , including Indonesia's, lack comprehensive frameworks to govern digital environmental assets (Rohmy and Nihayaty 2023). Current regulations, such as the Personal Data Protection Act (UU PDP), primarily focus on safeguarding individual privacy and personal data (Sofia Roselin and Moody Rizqy Syailendra Putra 2025). However, ecological data falls outside this scope, leaving a significant legal vacuum regarding ownership, stewardship, and cross-border use of environmental information in cyberspace (Khan 2025). This absence of explicit legal recognition exposes ecological data to risks of foreign control, commercial exploitation, and jurisdictional disputes, thereby undermining national sovereignty and the ability to enact sustainable policies based on reliable and secure data governance.

The emerging concept of eco-digital sovereignty underscores the necessity for developing cyber laws that explicitly protect digital environmental assets (Oulad Benaissa et al. 2025). Safeguarding ecological data is not merely a technical issue but a matter of intergenerational justice, as control over environmental information directly impacts the ability of current and future generations to enjoy a healthy and sustainable environment (Skillington 2019). By embedding ecological data within the scope of cyber law, states can establish clear jurisdictional authority, prevent foreign domination, and promote equitable access to environmental knowledge. In this sense, cyber law evolves from a defensive

Alauddin Law Development Journal (ALDEV)
Vol. 7, No. 3, 2025

mechanism to a proactive framework ensuring the preservation of environmental sovereignty in the digital age.

Previous research demonstrates that digital twin technology has been increasingly applied to environmental monitoring systems, yet this trend introduces novel jurisdictional and legal complexities. Potapov et al. (2023) illustrate the capacity of digital twins to integrate data collection, storage, and analysis in the coal industry, showing their potential for real-time monitoring of environmental impacts (ПотаповВ.П. et al. 2023). However, Akremi (2025) highlights critical forensic challenges, noting that evidence derived from digital twin environments faces issues of admissibility in legal proceedings and proposing architectural solutions for forensically sound design (Akremi 2025). Similarly, Hollenbeck and Chen (2022) explore the application of digital twin frameworks for environmental sensing, specifically using unmanned aerial systems to enhance spatial monitoring techniques (Hollenbeck and Chen 2022). Beyond technical and forensic dimensions, Epstein (2025) critically evaluates the shortcomings of EU environmental law, arguing that current disclosure-based models fail to adequately regulate the intersection of digitalization and sustainability (Epstein 2025). Collectively, these studies expose a gap between technological advancements and regulatory adaptation, where the legal infrastructure lags the transformative pace of environmental digitalization.

While existing scholarship underscores the technological potential of digital twins and the forensic or regulatory dilemmas they entail, limited attention has been paid to the sovereignty dimension of ecological data in cyberspace. Few studies have systematically examined the jurisdictional challenges arising from cross-border storage and management of environmental information, nor have they explicitly connected these issues with the development of cyber law. This paper addresses that gap by advancing the concept of eco-digital sovereignty and analyzing how national jurisdictions can assert authority over ecological data in a globalized digital infrastructure. The novelty of this research lies in framing ecological data not only as a technical or environmental resource but as a strategic legal asset requiring explicit protection under cyber law to safeguard national and intergenerational rights.

Table 2. Research Gap and Novelty of the Present Study

Aspect	Findings in Previous Studies	Identified Gap	Novelty of This Paper
Technological Application	Digital twins applied for monitoring in industries (Potapov et al., 2023).	Limited analysis of ecological sovereignty implications.	Positions ecological data as a strategic national asset.
Forensic Challenges	Issues of evidence admissibility from digital twins (Akremi, 2025).	Lack of focus on sovereignty and data ownership.	Expands forensic debates to include eco-digital sovereignty.
Environmental Monitoring	Digital twin frameworks for sensing & spatial interpolation (Hollenbeck & Chen, 2022).	No jurisdictional or legal sovereignty focus.	Bridges environmental monitoring with jurisdictional cyber law analysis.
Regulatory Analysis	EU environmental law inadequacies for digitalization (Epstein, 2025).	Absence of analysis on ecological data governance in cyberspace.	Proposes cyber law framework for protecting eco-digital sovereignty.

Alauddin Law Development Journal (ALDEV)
Vol. 7, No. 3, 2025

This study is guided by two central research questions: (1) How can national jurisdictions regulate ownership and protection of ecological data in digital twin environments when such data are stored across borders? and (2) What role can cyber law play in ensuring national sovereignty over ecological data against foreign domination? The objective of this paper is to analyze the jurisdictional challenges posed by cross-border ecological data management and to explore the legal mechanisms necessary to safeguard eco-digital sovereignty. By addressing these questions, this research contributes both theoretically and practically: it advances legal scholarship by conceptualizing ecological data as a protected category within cyber law, and it offers policy-relevant insights to strengthen national resilience in the governance of digital environmental assets.

METHOD

This study employs a juridical-normative research method, which focuses on examining legal norms and doctrines as the primary analytical foundation (Bhat 2019). The normative approach is essential in understanding how legal instruments regulate the intersection of data protection, environmental sustainability, and digital governance (Achjar et al. 2023). The method enables a systematic analysis of statutory regulations, legal principles, and jurisprudence to assess the adequacy of existing laws in responding to the challenges of digital environmental data management. Through this approach, the research situates legal texts not only as prescriptive rules but also as frameworks for realizing eco-digital sovereignty.

The study adopts multiple complementary approaches. First, the statutory approach is employed by analyzing Indonesia's Personal Data Protection Law (UU PDP), the European Union's General Data Protection Regulation (GDPR), and relevant international environmental regulations. Second, the conceptual approach is utilized to explore key theoretical underpinnings such as cyber law, data sovereignty, and eco-digital sovereignty, thereby providing a robust framework for interpretation. Third, a comparative approach is applied by examining regulatory practices in other jurisdictions, particularly the European Union and the United States, which offer contrasting yet instructive models in governing digital environmental data (Taekema 2021). These combined approaches ensure a multidimensional analysis that captures both normative foundations and practical implementations.

The legal materials used in this study are categorized into three layers. Primary sources consist of binding legal instruments, including national legislation, international conventions, and regional regulatory frameworks. Secondary sources include academic literature, scholarly articles, and legal commentaries in the domains of cyber law, environmental law, and jurisdictional governance. Tertiary sources consist of policy reports and institutional documents such as those published by the United Nations Environment Programme (UNEP) and the World Economic Forum (WEF). By triangulating these sources, the research builds a comprehensive understanding of the normative landscape and policy discourses, enabling critical evaluation of the future trajectory of eco-digital sovereignty (Natow 2020).

RESULT AND DISCUSSION

1. National Jurisdictional Challenges of Environmental Digital Twins

Environmental data processed within digital twin systems frequently transcends national borders, thereby challenging the traditional territorial basis of jurisdiction in international law (McInerney, 2022). Unlike physical resources, digital data flows seamlessly across servers, cloud networks, and distributed storage systems without regard to state boundaries. This transnational character complicates the attribution of legal authority, as multiple states may claim jurisdiction over the same data depending

Alauddin Law Development Journal (ALDEV)
Vol. 7, No. 3, 2025

on where it is stored, transmitted, or utilized (Gao 2023). Consequently, reliance on classical territorial principles becomes insufficient, necessitating new legal frameworks to address the unique challenges of data-driven environmental governance.

Many countries, including Indonesia, remain heavily reliant on foreign-owned server infrastructure and cloud technologies for the storage and management of environmental data (Hawkins et al. 2025). This dependency significantly reduces their ability to exercise full sovereignty over ecological information, as the technical and operational control rests with external providers (Stürmer et al. 2021). The asymmetry in infrastructure ownership not only creates vulnerabilities in terms of access and data governance but also exposes states to potential disruptions or restrictions imposed by foreign entities. Such reliance underscores the urgent need for domestic investment in digital infrastructure to safeguard ecological sovereignty.

Environmental data constitutes a strategic national asset, as it encompasses critical information on natural resources, biodiversity, and ecosystem health (Anderson 2025). Without adequate legal protections, this sensitive data is highly susceptible to unauthorized access, exploitation, or commercial misuse by foreign actors health (Anderson 2025). For example, ecological datasets could be used to inform corporate extraction strategies or influence global climate negotiations in ways that disadvantage resource-owning states. The absence of strict regulatory safeguards thus creates both economic and environmental risks, highlighting the necessity of establishing robust legal regimes to protect ecological data from exploitation.

The management of environmental digital twins often generates conflicts of interest between data-owning states and foreign technology providers who control the underlying digital infrastructure (Fischli 2024). Satellite operators, cloud service companies, and AI-driven data analytics firms frequently assert control over the storage and processing of ecological data, creating tensions regarding ownership and usage rights (Van Der Vlist et al. 2024). These conflicting interests raise complex questions about whether data sovereignty should rest with the territorial state that owns the environment or with the entity that enables the digital infrastructure. Resolving such disputes will require international consensus and carefully negotiated legal mechanisms to balance competing claims.

Global regulations governing the management of environmental digital data remain fragmented, with no comprehensive framework addressing cross-border jurisdictional issues (Khan 2025). While certain instruments regulate data protection or environmental governance separately, there is no unified regime that integrates both dimensions in the context of digital twin technologies (Jørgensen and Ma 2025). This regulatory gap fosters legal uncertainty, leaving states and corporations to operate in a grey area that is vulnerable to disputes and exploitation. A coherent international standard is therefore essential to provide clarity, consistency, and enforceability in managing ecological data across borders.

Developing countries often face significant challenges in establishing the technological infrastructure necessary for independent digital twin development and management (Yu and He 2022). These limitations leave them more vulnerable to dependency on advanced economies that dominate both the technological and legal architectures of environmental data governance. The imbalance creates a hierarchy in which powerful states and corporations dictate standards and practices, potentially marginalizing the interests of weaker jurisdictions. Bridging this capacity gap is thus vital, not only for achieving environmental justice but also for ensuring equitable participation in global digital ecosystems.

Alauddin Law Development Journal (ALDEV)
Vol. 7, No. 3, 2025

Efforts to harmonize national legislation with global regulatory practices often encounter obstacles rooted in divergent legal principles and policy priorities (Abbott and Snidal 2021). While some states prioritize sovereignty and strict control over environmental data, others emphasize openness, data-sharing, and transnational collaboration. These differences complicate the creation of a common framework that respects both national autonomy and global environmental imperatives. The difficulty of harmonization underscores the need for innovative legal models that reconcile domestic regulatory objectives with international obligations, thereby safeguarding both ecological interests and digital sovereignty.

2. The Role of Cyber Law in Ensuring the Sovereignty of Digital Ecological Data

Cyber law serves as a crucial instrument for safeguarding digital environmental data from illegal access, manipulation, and exploitation by both foreign and private actors (Ministry of Defence, Govt of India. et al. 2024). The strategic nature of ecological data, ranging from biodiversity mapping to carbon storage, requires strong legal safeguards to ensure that such information is not commodified without state oversight (Ives et al. 2015). In this regard, cyber law establishes the normative framework through which the integrity, confidentiality, and lawful use of digital environmental information can be guaranteed. Without such protections, ecological data risks becoming a vulnerable resource that can be appropriated in ways detrimental to national sovereignty and environmental sustainability.

In the Indonesian context, the Personal Data Protection Law (UU PDP) provides an important normative foundation, even though its scope is primarily directed toward individual and personal information (Widiatedja and Mishra 2023). However, through legal interpretation, this framework can be extended to cover digital environmental data, thereby broadening its protective capacity. Such contextualization is critical in recognizing that environmental information constitutes a collective good whose misuse may harm both present and future generations. Incorporating ecological data within the ambit of the PDP framework would mark a significant step toward recognizing data ecosystems as part of the broader domain of national sovereignty.

The European Union's General Data Protection Regulation (GDPR) provides a valuable reference point for strengthening environmental data protection. GDPR sets strict standards for data transfers across borders, emphasizing accountability, transparency, and user consent (Natamiharja and Setiawan 2024). Although originally developed for personal data, its stringent transnational requirements can inspire Indonesia in crafting robust regulatory mechanisms for ecological datasets (Puananndini et al. 2025). By drawing lessons from the GDPR, Indonesia and other developing nations could mitigate the risks of asymmetrical dependency on foreign servers and ensure a higher level of control over their environmental data sovereignty.

The notion of eco-digital sovereignty underscores the necessity of recognizing environmental data as a strategic national asset equivalent in importance to physical natural resources (Aydın and Bensghir 2019). This approach highlights the responsibility of the state to safeguard its ecological data against external dominance while ensuring its use serves the national interest (Aydın and Bensghir 2019). Conceptualizing digital environmental information in this way elevates its legal and political status, thereby requiring protective measures similar to those applied to critical infrastructure and natural wealth. Such a framework reframes environmental data governance as an issue of sovereignty, security, and intergenerational equity.

Despite the significance of ecological data, existing regulations remain fragmented and insufficient in addressing its protection in cyberspace (Utegenov Ongarbay Dariyabayevichc 2023).

Alauddin Law Development Journal (ALDEV)
Vol. 7, No. 3, 2025

Current legal systems tend to focus on privacy or trade aspects of data, leaving a regulatory vacuum for environmental datasets (Epstein 2025). This gap necessitates the formulation of a dedicated legal framework that clearly defines ecological data as a strategic object of law. Such a framework would not only strengthen national sovereignty but also ensure legal certainty for stakeholders, including researchers, policymakers, and private actors, who rely on digital twin technologies.

National laws alone are insufficient to guarantee ecological digital sovereignty, particularly given the inherently transboundary nature of data flows (Nugraha et al. 2015). International cooperation is therefore essential to develop a cyber law regime specific to environmental governance (Fauzi et al. 2024). Such collaboration could include binding agreements on data sharing, safeguards against monopolization, and common standards for ecological data use. Without this multilateral dimension, states risk facing imbalances of power where technologically advanced actors dictate the terms of environmental data governance, leaving weaker nations at a structural disadvantage.

Table 3. The Role of Cyber Law in Ensuring Digital Ecological Data Sovereignty

Aspect	Key Points
Legal Protection	Cyber law secures environmental digital data from misuse and exploitation.
Comparative Framework	Indonesia's PDP Law vs. EU's GDPR highlights gaps and best practices.
Eco-Digital Sovereignty	States must treat ecological data as a strategic legal asset.
International Cooperation	Global collaboration is urgent to establish a cyber environmental legal regime.
Regulatory Gap	Lack of specific laws on ecological digital data management.
Risk Mitigation	Cyber law reduces dependency on foreign servers and prevents data colonialism.
Future Direction	Integrating cyber law with environmental law to ensure sustainable digital governance.

3. Implications for Sustainable Development

The governance of digital ecological data carries profound implications for the realization of sustainable development, particularly in areas such as climate change adaptation, carbon trading mechanisms, and disaster mitigation (Meinhold et al. 2025). Ecological datasets, ranging from satellite-based environmental monitoring to climate modeling and biodiversity mapping, function as the empirical foundation upon which evidence-based policies are constructed (Ciuriak 2018). Without sovereign control and integrity over these datasets, states risk basing their sustainability strategies on incomplete, manipulated, or inaccessible information. This, in turn, undermines not only the accuracy of policy formulation but also the legitimacy of national commitments to international frameworks such as the Paris Agreement and the Sustainable Development Goals (SDGs) (Ciuriak 2018).

The issue becomes increasingly critical when digital ecological data falls under the control of foreign entities or multinational corporations (Stürmer et al. 2021). Such dependence creates what may be termed "digital ecological dependency," where states rely on external actors for access, processing, and validation of environmental information (Stürmer et al. 2021). This asymmetry not only diminishes the autonomy of national decision-making but also exposes developing countries to exploitation in global carbon markets and climate finance negotiations (Baldoni and Luna 2025). For instance, if carbon credit calculations are reliant on externally managed datasets, the bargaining power of resource-rich but digitally dependent nations becomes severely weakened. Hence, the absence of robust cyber law to secure ecological data sovereignty may deepen global inequality in climate governance.

Conversely, the establishment of comprehensive cyber law frameworks offers an avenue to reclaim ecological data sovereignty and to strengthen the role of states in global environmental governance (Utegenov Ongarbay Dariyabayevichc 2023). By protecting ecological datasets through digital security, intellectual property mechanisms, and regulated cross-border data flows, cyber law ensures that nations retain control over their strategic environmental information (Utegenov Ongarbay Dariyabayevichc 2023). Such legal safeguards not only prevent unauthorized access and misuse of data but also create trust in the accuracy, credibility, and accountability of state-driven sustainability initiatives. In this way, cyber law serves as an enabling condition for integrating ecological data into national development planning and for positioning states as equal actors in global climate negotiations (Kaya and Shahid 2025).

Ultimately, embedding cyber law in the governance of digital ecological data advances sustainable development by ensuring that data functions as a sovereign resource rather than a commodified asset vulnerable to external capture (Chinenye Obasi et al. 2024). The secure management of such data enhances resilience against climate-induced risks, provides a credible basis for carbon trading and financial instruments, and strengthens national capacity in disaster preparedness and response (Chinenye Obasi et al. 2024). At a broader level, cyber law also reinforces the normative commitment to environmental justice, where equitable access and responsible use of ecological information contribute to the shared global endeavor of sustainability (Vasile et al. 2025). In this sense, digital ecological data sovereignty represents not merely a technical or legal challenge but a decisive factor in shaping the trajectory of sustainable development in the digital age.

First, strengthening institutional and regulatory frameworks is essential to safeguard digital ecological data as a strategic national asset. This includes formulating comprehensive cyber law provisions that explicitly regulate ownership, sovereignty, and ethical use of environmental data (Utegenov Ongarbay Dariyabayevichc 2023). Moreover, the state must build robust digital infrastructure and cyber defense systems to minimize risks of cyber-attacks, data theft, and unauthorized cross-border data transfers. Such initiatives not only ensure security but also increase state capacity to use ecological data as a reliable basis for climate change adaptation, carbon trade negotiations, and disaster mitigation planning.

Second, promoting multi-stakeholder collaboration and international engagement represents another crucial strategy. Governments need to actively involve academia, civil society, and private sectors in developing transparent and participatory ecological data governance models (Linkov et al. 2018). At the international level, states must advocate for fair digital environmental governance mechanisms to avoid technological dependency on foreign entities (Uwaga Monica Adanma and Emmanuel Olurotimi Ogunbiyi 2024). This includes promoting regional alliances, knowledge-sharing networks, and open innovation models that emphasize both digital sovereignty and sustainability. Such

Alauddin Law Development Journal (ALDEV)
Vol. 7, No. 3, 2025

strategies help integrate ecological data protection into broader sustainable development goals, ensuring that environmental governance remains both inclusive and resilient.

Here is an figure of strategic steps for digital ecological data governance:

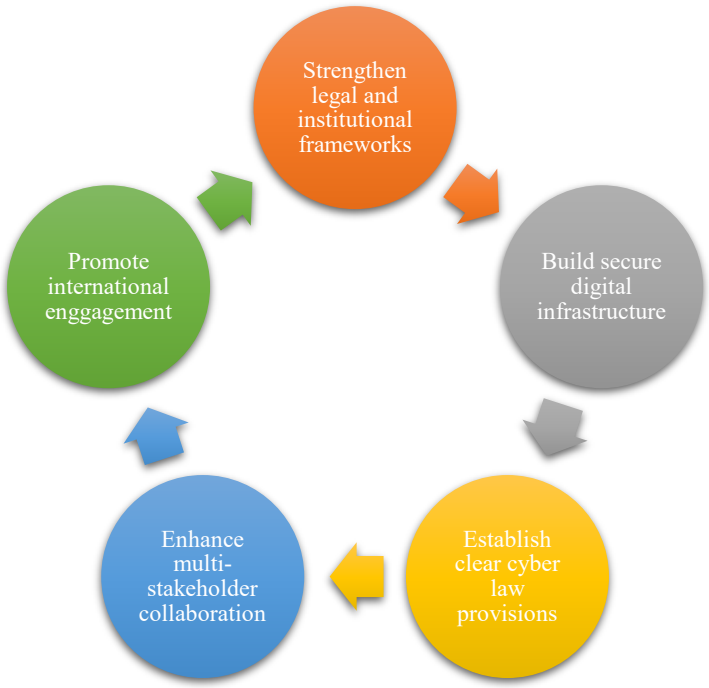

Figure 2. Strategic Steps For Digital Ecological Data Governance

CONCLUSION

This study has examined the intersection of cyber law, ecological data governance, and sustainable development, emphasizing the urgent need for legal and institutional mechanisms to safeguard digital ecological sovereignty. By analyzing challenges of jurisdiction, data protection, and global regulatory asymmetries, this research highlights how ecological data is no longer a purely technical or environmental issue but one embedded in questions of law, sovereignty, and justice. The findings demonstrate that the absence of comprehensive legal frameworks leaves ecological data vulnerable to foreign control and exploitation, undermining national sovereignty and long-term environmental sustainability. Strengthening cyber law provisions thus becomes essential to ensuring that ecological data functions as a public good serving present and future generations.

Theoretically, this research advances the understanding of ecological data governance as an extension of intergenerational justice, positioning it as a bridge between cyber law, environmental law, and family law. Much like the concept of *environcide* proposed in international legal discourse, the exploitation of ecological data without adequate legal protection can be seen as a threat to intergenerational equity. By foregrounding ecological sustainability as a central component of legal protection, this study calls for a paradigm shift in family law scholarship, expanding its scope to encompass environmental and digital dimensions that directly affect the well-being of families and communities. This perspective reconceptualizes family law not only as a mechanism for protecting interpersonal relations but also as a framework for ensuring ecological and digital security as foundations of collective survival.

Future research should explore how national legal frameworks, such as Indonesia's PDP Law or the EU's GDPR, can be adapted to incorporate ecological data as a protected category, thereby linking digital sovereignty to ecological sustainability. Comparative legal studies between jurisdictions could yield best practices for aligning national cyber law with international norms on environmental data governance. In addition, interdisciplinary collaboration between legal scholars, environmental scientists, and digital policy experts is necessary to design innovative mechanisms for monitoring, regulating, and enforcing ecological data sovereignty. Such work would deepen the theoretical and practical integration of ecological sustainability into both cyber law and family law.

Finally, this study underscores the need for empirical investigations into how ecological data governance, or its absence, affects vulnerable communities and families. The mismanagement of ecological data, particularly when dominated by foreign actors, risks exacerbating environmental harm, socio-economic inequality, and intergenerational insecurity. Conversely, legal frameworks that prioritize ecological data sovereignty can empower communities, safeguard environmental rights, and strengthen intergenerational resilience. By situating ecological data governance within the discourse of family law, this research invites a transformative rethinking of legal categories: one that connects environmental sustainability, digital sovereignty, and the protection of families as core units of society. Through this integrated approach, the scientific field of family law can evolve to embrace ecological and digital justice as central pillars of its theoretical and practical development.

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