Nomos:
Jurnal Penelitian Ilmu Hukum
Vol. 5 No. 4 Tahun 2025 | Hal. 944 – 956

Redefining Regional Supervisory Authority: Smart Eco Supervision as a Preventive Administrative Sanction Instrument

Abdul Madjid Podungge [a, 1*], Risti Ristianingsih Badu [a, 2], Abdul Wahab Podungge [a, 3], Robby Hunawa [a, 4]
[a] Universitas Nahdlatul Ulama Gorontalo, Indonesia
[1] abdulmadjidpodungge@unugo.ac.id*
*korespondensi penulis

Informasi artikel :
Received: 2 December 2025;
Revised: 18 December 2025;
Accepted: 27 December 2025.
Keywords:
Administrative Law Reform;
Environmental Supervision;
Gold Mining;
Smart Eco Supervision;
Gorontalo.

ABSTRAK

This study investigates the critical development paradox in Gorontalo, where a 6.07% extractive-driven economic growth inversely correlates with extreme mercury contamination (Igeo) and severe environmental degradation in river basins. This systemic issue stems from acute regulatory discord caused by centralized licensing under the Minerba and Job Creation Laws, creating a supervisory authority vacuum that effectively paralyzes regional oversight mechanisms. Adopting a constructive socio-legal approach triangulated with hybrid spatial data (NDVI/SAR), this article proposes the Smart Eco Supervision model to bridge the critical gap between technical surveillance and legal enforcement. This model integrates high-precision geospatial detection to provide indisputable objective evidence for State Administrative Officers (TUN). Furthermore, it legally reconstructs sanctions into Restorative Administrative Sanctions, mandating scientifically quantifiable restoration methods like phytoremediation instead of mere financial fines. Grounded in *Salus Populi Suprema Lex Esto*, this framework redefines regional authority by prioritizing citizens' ecological safety as the supreme law, ensuring substantive environmental justice for impacted communities.

Kata-kata kunci:
Reformasi Hukum Administratif;
Pengawasan Lingkungan;
Pertambangan Emas;
Smart Eco Supervision;
Gorontalo.

ABSTRACT

Mendefinisikan Ulang Kewenangan Pengawasan Daerah: Smart Eco Supervision sebagai Instrumen Sanksi Administratif Preventif. *Penelitian ini mengkaji paradoks pembangunan kritis di Gorontalo, di mana pertumbuhan ekonomi 6,07% berbasis ekstraktif berbanding terbalik dengan kontaminasi merkuri ekstrem (Igeo) dan degradasi lingkungan parah di daerah aliran sungai. Masalah sistemik ini berakar pada disharmoni regulasi akut akibat sentralisasi perizinan di bawah UU Minerba dan UU Cipta Kerja, yang menciptakan kekosongan kewenangan pengawasan yang secara efektif melumpuhkan mekanisme kontrol daerah. Mengadopsi pendekatan socio-legal konstruktif yang ditriangulasi dengan data spasial hibrida (NDVI/SAR), artikel ini mengusulkan model Smart Eco Supervision untuk menjembatani kesenjangan kritis antara pengawasan teknis dan penegakan hukum. Model ini mengintegrasikan deteksi geospasial presisi tinggi untuk menyediakan bukti objektif tak terbantahkan bagi Pejabat Tata Usaha Negara (TUN). Selanjutnya, model ini merekonstruksi sanksi secara yuridis menjadi Sanksi Administratif Restoratif, yang mewajibkan metode pemulihan terukur secara ilmiah seperti fitoremediasi, bukan sekadar denda finansial. Berlandaskan Salus Populi Suprema Lex Esto, kerangka kerja ini mendefinisikan ulang kewenangan daerah dengan memprioritaskan keselamatan ekologis warga sebagai hukum tertinggi, menjamin keadilan lingkungan substantif bagi masyarakat terdampak.*

How to Cite : Podungge, A. M., Badu, R. R. ., Podungge, A. W., & Hunawa, R. (2025). Redefining Regional Supervisory Authority: Smart Eco Supervision as a Preventive Administrative Sanction Instrument. *Nomos : Jurnal Penelitian Ilmu Hukum*, *5*(4), 944–956. https://doi.org/10.56393/nomos.v5i4.3827

Introduction

The governance of natural resources in Gorontalo Province is currently confronting a critical juridical paradox. Ideally, economic growth should align with public welfare, yet empirical evidence reveals a diametrical opposition: the extractive sector's notable economic growth of 6.07% (Badan Pusat Statistik [BPS], 2025) correlates directly with severe ecological degradation. Strictly from a State Administrative Law (*Hukum Administrasi Negara*) perspective, this phenomenon indicates a failure in the state's function to guarantee the "Right to a Healthy Environment." Uncontrolled amalgamation activities have caused massive mercury (Hg) contamination in river sediments (Basir et al., 2022), proving that the increase in regional income is essentially *pseudo-growth*. This empirical reality falsifies the Environmental Kuznets Curve hypothesis in the context of Gorontalo (Mencho, 2022; Pradana et al., 2024; Werner et al., 2023; Y. Zou et al., 2025), as the damage has systematically infiltrated agricultural sectors (Halid, 2023a, 2023b) and violated the core conservation zones of the Bumi Panua Nature Reserve (Demak et al., 2023; Nawu, 2025).

The fundamental cause of this ecological failure is not merely technical, but stems from a systemic regulatory conflict resulting in the breakdown of law enforcement at the regional level (Cakranegara et al., 2023; Swari & Cahyani, 2022). The centralization of licensing authority via Law No. 3 of 2020 (Minerba Law) and Law No. 11 of 2020 (Job Creation Law) has resulted in "regulatory disarray," legally diminishing the preventive authority previously possessed by the regional government. Consequently, Gorontalo endures a "supervisory vacuum" where the central government holds authority but lacks reach, while the regional government holds the territory but lacks power. This vulnerability is intensified by the risk-based licensing framework (OSS-RBA) which prioritizes business facilitation over ecological sustainability (Zildjianda et al., 2023). Furthermore, the existing enforcement approach, which relies on the intermittent application of criminal law (*ultimum remedium*) against field-level perpetrators (*dader*), has proven ineffective in preventing systemic harm (Pakaya & Wijaya, 2022).

In academic discussions, resolutions to this supervisory deadlock remain disjointed. The first pole focuses on litigation, often criticized as "Environmental Justice Light" due to its reactive nature and inability to achieve significant repair (Bertram, 2022). The second pole offers partial solutions, such as Enforcement Undertakings or the technical use of Earth Observation Data (satellite evidence) (Al Farisi, 2021; Smentek et al., 2025). However, a thorough examination of the literature uncovers a notable disjunction: technological research on remote sensing and legal analyses on administrative sanctions frequently function independently. No research has effectively integrated satellite-based early detection technology with administrative recovery sanctions into a unified, preventive supervision framework suitable for local governments. The illustration of this research gap is depicted in Figure 1 below:

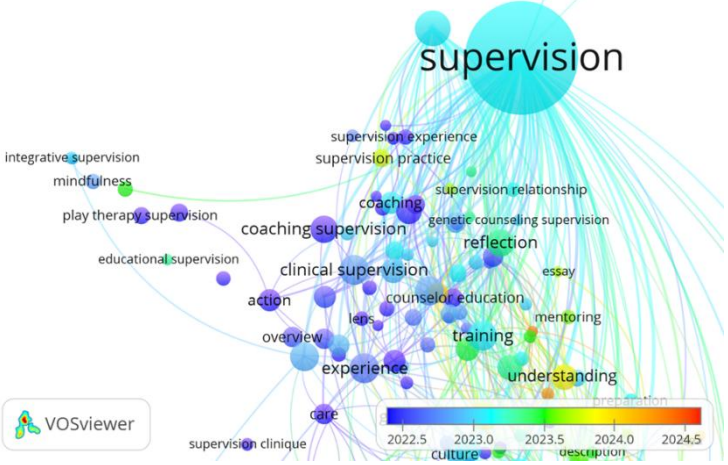

Figure 1. Research Gap Map and Novelty Position of the Smart Eco Supervision Model.
Source: Synthetic Literature Review VOSviewer was processed by the researcher using data from Scopus, Semantic Scholar, and Crossref.

As analytically shown in Figure 1, there is a scarcity of studies linking digital surveillance directly with administrative law enforcement. Addressing this theoretical and practical gap, this research introduces an innovative, multidisciplinary supervision model called "Smart Eco Supervision." This hybrid strategy employs high-precision geospatial data-driven early detection techniques, notably satellite indices like NDVI/SAR and Artificial Intelligence (AI), to furnish incontrovertible legal proof. Furthermore, it transforms the sanctions paradigm from punitive fines to Restorative Administrative Sanctions, mandating scientific recovery actions like phytoremediation. This framework is fundamentally based on the philosophical premise of *Salus Populi Suprema Lex Esto* (the primacy of ecological rights) and the tenets of *Maqashid Syariah* (the preservation of life and the environment) (Sanawiah et al., 2023).

Consequently, the specific objectives of this study are structured to address the formulated legal problems: 1) To analyze the implications of centralized regulatory disharmony on the failure of environmental law enforcement in Gorontalo; 2) To construct the legal-administrative framework of the *Smart Eco Supervision* model as an instrument for the Regional Government to exercise preventive control; and 3) To operationalize the principle of *Salus Populi Suprema Lex Esto* as the ethical and philosophical foundation for enforcing restorative administrative sanctions. By answering these objectives, this article seeks to offer a holistic solution to the paradox of mining governance in archipelagic regions.

Method

This study employs a constructive socio-legal research method that integrates doctrinal legal analysis with empirical socio-environmental inquiry, viewing law not as an autonomous system but as a social phenomenon interacting with ecological variables. The methodological structure begins with a statutory approach to examine primary legal materials, specifically Law Number 3 of 2020 regarding Mineral and Coal Mining and Law Number 11 of 2020 regarding Job Creation, to identify vertical disharmony regarding licensing authority and supervisory norms. To verify the effectiveness of these regulations, this study utilizes non-legal empirical evidence through a *Hybrid Data Triangulation* protocol, aggregating economic growth statistics (BPS) and ecological degradation data derived from Earth Observation Data. Specifically, satellite imagery indices Normalized Difference Vegetation Index (NDVI) and Normalized Difference Turbidity Index (NDTI) derived from Sentinel-2 and Landsat-8 are used to provide objective evidence of supervisory failure. All collected materials are analyzed qualitatively using Regulatory Impact Analysis (RIA) to dissect the disconnect between normative commands and empirical realities. Furthermore, the proposed *Smart Eco Supervision* solution is constructed based on the *Bestuursdwang* (government coercion) theory and justified ethically using the *Salus Populi Suprema Lex Esto* maxim to formulate the concept of Restorative Administrative Sanctions.

Result and Discussion

Before delving into the specific legal analysis, it is imperative to examine the anomalous development data in Gorontalo Province, which establishes a critical "development paradox." The region's economic performance exhibits a pronounced acceleration trend following 2024, primarily driven by the mining and manufacturing sectors. To illustrate this increase, here is a graph of GRDP growth derived from data provided by the Gorontalo Provincial Statistics Agency (Badan Pusat Statistik [BPS], 2025). According to Figure 2, Gorontalo's economic growth rate attained 6.07% (year-on-year) in the first quarter of 2025.

However, from a State Administrative Law perspective, this statistical success presents a diametrical opposition to the qualitative mandate of the *Welfare State* principle. The legitimacy of these welfare assertions disintegrated immediately upon the juxtaposition of economic data with

environmental quality data. According to a study by (Basir et al., 2022), the Geoaccumulation Index (Igeo) in river sediments from gold mining areas shows that heavy metals like mercury (Hg) and arsenic (As) are present in very high amounts. This elevated Igeo value indicates severe conditions for the aquatic ecosystem. These metals infiltrate the environment via chemical transport, leading to the formation of the highly toxic compound methylmercury.

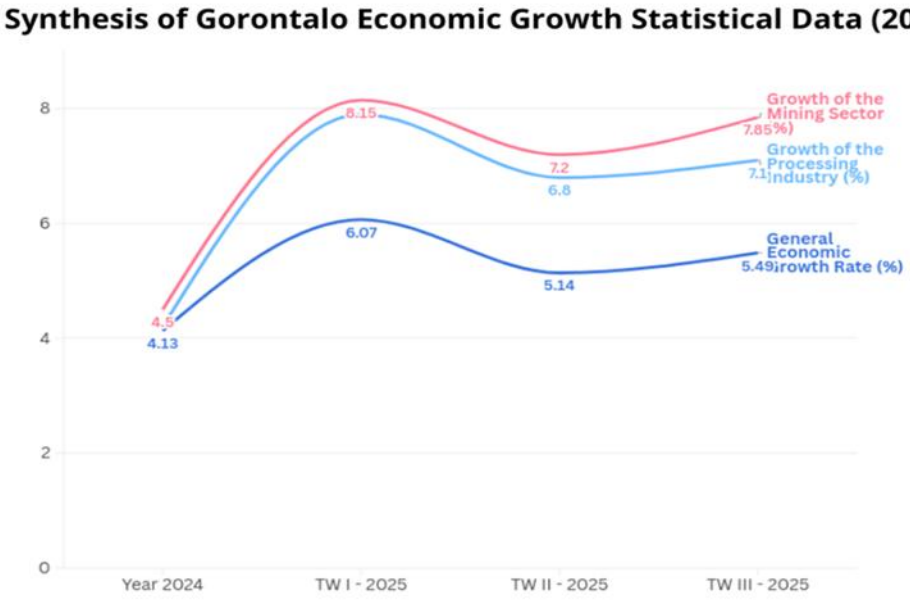

Figure 2. Economic Growth Chart of Gorontalo Province Based on BPS Data (TW I - 2025).
Source: Processed by the researcher from Gorontalo Province BPS Data (2025)

The correlation between these two datasets substantiates a legal paradox: the increase in Gorontalo's GDP is a misleading statistic (*pseudo-growth*) that conceals the truth of ecological injustice. This study demonstrates that in Gorontalo, economic growth is inversely related to environmental quality, empirically validating the Environmental Kuznets Curve hypothesis which is not universally applicable (Adry et al., 2023). Unsustainable mining results in land degradation and water contamination (Mencho, 2022; Tang & Werner, 2023), which legally necessitates a thorough analysis of the governance frameworks that influence these socio-economic outcomes (Hassan et al., 2025; Prasetya & Tsai, 2025; Zaehringer et al., 2024; C. Zou et al., 2025).

The ramifications of this paradox directly impact the fundamental rights of society. The turbid river water in Marisa, Pohuwato Regency, has a severe impact on the agricultural community because mining effluents have contaminated the irrigation system, which has led farmers to lament their inability to grow rice (Halid, 2023a). From a human rights perspective, the harm endured by the community cannot be justified by regional revenue, as the damage to the mercury-contaminated water ecosystem jeopardizes livelihoods. Consequently, the gold mining issue in Gorontalo should not be perceived merely as a statistical or administrative matter but as a systemic "supervisory maladministration" necessitating technological intervention and quantifiable environmental risks. This phenomenon underpins the assertion that the local government's oversight function has inadequately failed to prevent such damage.

However, this failure to manage environmental impacts does not occur in a vacuum; it stems from a disordered legal framework resulting from the centralization of authority due to alterations in national regulations. Following the implementation of Law Number 3 of 2020 regarding Mineral and Coal Mining and the Job Creation Law, a significant paradigm shift has occurred from decentralization to complete centralization. The significant retraction of licensing authority has caused severe normative discord between central sector regulations and the requirements of regional autonomy. A comparison

of local government authority before and after the implementation of the new Mineral and Coal Law is illustrated in Table 1 below to elucidate the specific nature of this disharmony.

Table 1. Comparison of Regional Government Authority in the Mining Sector Post-Law 3/2020 on Mineral and Coal.

Type of Authority	Before Minerba Law No. 3/2020 (Based on Law No. 23/2014)	After Minerba Law No. 3/2020	Impact on Gorontalo Regional Government (Pemda)
Issuance of Permits (IUP)	Authority was divided (District/City and Provincial Governments).	Absolutely withdrawn to the Central Government (Article 8 of Law 3/2020).	Loss of the main investment control instrument.
Field Supervision	Full Supervision Authority (State Administrative Law / HAN).	Significantly reduced, becoming merely a coordination/reporting function.	Weakening of compelling force (*Bestuursdwang*) and preventive enforcement authority.
Administrative Sanctions	Regional Government was authorized to suspend/revoke permits for environmental violations.	Authority for suspension/revocation only held by the Central Government.	Gorontalo Regional Government becomes a "spectator" over the damage in its territory.
Environmental Management	Full Autonomy (UU PPLH and UU Pemda).	UU PPLH norms are contested by the pro-investment norms of the Job Creation Law.	Loss of strict environmental protection standards.

Source: Processed by the researcher from Law 23/2014, Law 3/2020 and Cakranegara (2023)

According to Table 1, the effective delegation of IUP authority to the Central Government has "amputated" the role of regional government responsibilities previously guaranteed by Law Number 23 of 2014. This unfairness leads to a major jurisdictional problem, the Gorontalo Regional Government has to deal with environmental damage and social unrest, but lacks the *Bestuursdwang* (government coercion) authority to suspend or revoke the operating permits of violators. Consequently, the role of local supervision was diminished to a purely passive administrative reporting function lacking sufficient coercive authority. This vulnerability is systemic, as centralization policies frequently overlook local contexts and regional oversight capabilities, resulting in critical deficiencies in regulatory execution (Oh et al., 2023).

A legislative framework that does not adequately address the complexities of contemporary mining operations exacerbates this conflict (Adu-Baffour et al., 2021). This leads to a disjointed strategy for environmental protection, wherein local authorities are deprived of the autonomy to oversee environmental standards, especially concerning the extraction of critical minerals essential for the global energy transition (Wang & Azam, 2024). This gap between national policies and practical implementation in affected areas (Kinyondo & Huggins, 2021) renders artisanal mining governance (PESK) less effective, highlighting the urgency for localized adaptive management strategies (Kazapoe et al., 2023; Seccatore et al., 2025). This scenario fosters an environment where mining operations are

associated with significant ecological destruction and health risks, including mercury exposure (Finn et al., 2024; Mensah, 2021; Teku, 2025). To tackle these complex challenges, a shift towards intelligent eco-supervision is essential, utilizing advanced technologies like remote sensing and geospatial analytics not just as technical tools, but as instruments of legal evidence to alleviate environmental risks (Pavloudakis et al., 2024; Pouresmaieli et al., 2023).

The urgency of this transition is underscored by the fact that currently, the consequences of regulatory disharmony are evident in the empirical failure of law enforcement at the grassroots level. Evaluations show that conventional supervision relying on physical inspections is no longer effective. Socio-legal study (Pakaya & Wijaya, 2022) proves that law enforcement against Illegal Gold Mining (PETI) in Pohuwato has experienced structural failure (Meutia et al., 2022). The expansion of mining into the core conservation zone of the Bumi Panua Nature Reserve has worsened illegal activities (Demak et al., 2023). This failure is due to a weak regulatory framework and a lack of interagency coordination (Adu-Baffour et al., 2021), while high global demand for gold further incentivizes this unregulated activity (Fritz & Schmidt, 2025; Nursamsi et al., 2024).

The absence of surveillance technology in the current system leads to empirical evidence of real losses directly experienced by the public. The complaints of farmers in Marisa whose rice fields "cannot grow rice" due to mining waste (Halid, 2023b) are clear evidence of the violation of economic rights and the right to a healthy environment (Rusydi et al., 2023). Because the apparatus's response, which is predominately repressive (Nawu, 2025), only targeted field-level offenders without ending the systemic damage, it proved ineffective. Therefore, this empirical failure serves as the primary justification for reconstructing the supervision model, demanding a total paradigm shift from passive-repressive supervision to active-preventive supervision based on geospatial technology.

The application of multispectral and radar imaging datasets has proven instrumental in characterizing and monitoring environmental changes (Basir et al., 2022; Kimijima et al., 2021; Ngom et al., 2022; Obodai et al., 2023). This advanced geospatial technique enables comprehensive monitoring, providing critical data for evidence-based regulatory interventions. Studies in Ghana show how satellite imagery (Landsat, Sentinel-2) is effective in monitoring land use changes (Obodai et al., 2023). Additionally, machine learning methods used on Sentinel-2 images were able to spot changes related to mining, which is crucial because artisanal mining is highly informal (Alessi et al., 2023; Çamalan et al., 2022; Fonseca et al., 2024). Furthermore, the use of Synthetic Aperture Radar (SAR) data enhances detection capabilities in cloud-covered tropical regions (van Rensburg & Kemp, 2022), offering a scientific, timely, and cost-effective method for evaluating mining operations (Narciso & Principe, 2024).

This technological integration facilitates the creation of a Smart Eco Supervision framework that employs real-time data for adaptive management. Unlike traditional bureaucratic oversight, this model utilizes U-Net convolutional neural networks and deep learning models to precisely identify mining disturbances (Malik et al., 2021). In the context of Administrative Law, this method promotes the creation of predictive models that allow State Administrative Officials to take proactive measures shifting the legal paradigm from "repressive-responsive" to "preventive-anticipatory" (MacDonald et al., 2023). Furthermore, the integration of remote sensing data with ecological literacy initiatives transcends mere technical utility, enabling local stakeholders to engage in participatory monitoring (Pouresmaieli et al., 2023). The operational framework of this system is illustrated in Figure 3 below, depicting the logic flow of the Smart Eco Supervision model.

As visualized in the workflow above, the monitoring mechanism initiates with Geospatial Monitoring. Upon the detection of a land change anomaly (e.g., deforestation outside the permit area), the algorithm initiates the issuance of an "Administrative Preliminary Alert." Legally, this instrument functions as a preventive administrative act (*beschikking*), enabling the administrative officer to mandate a temporary cessation (suspension) of activities based on the *Precautionary Principle*, without

awaiting a lengthy physical inspection. If this alert is disregarded, the mechanism advances to the imposition of restorative administrative sanctions, with criminal penalties serving only as an *ultimum remedium*. This approach renders supervision more quantifiable, expedient, and concentrated on averting irreversible harm.

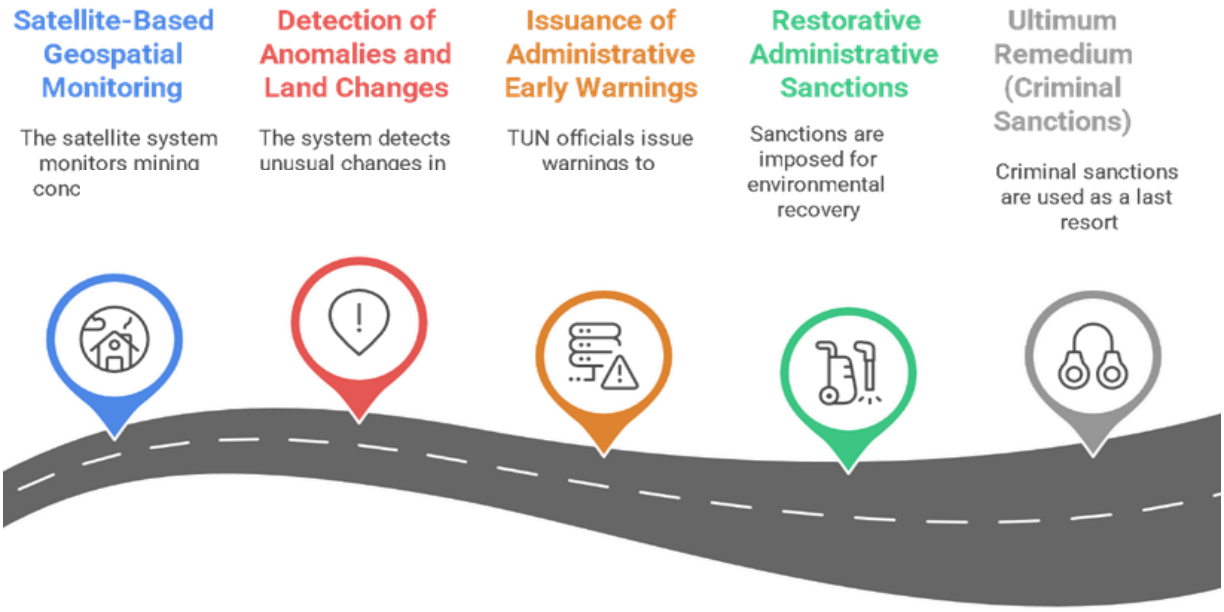

Figure 3. Smart Eco Supervision Model Workflow Mechanism.
Source: Researcher's Construction Results (2025)

Nevertheless, the implementation of such a sophisticated technical model is not a standalone solution, it necessitates a simultaneous reconfiguration of legal instruments. A primary critique of the existing administrative sanctions framework is its inefficacy in recouping actual losses. Fines frequently contribute to Non-Tax State Revenue (PNBP), resulting in a "zero-sum scenario" where the state gains financially, yet the impacted community continues to endure an impaired ecosystem. Addressing this injustice, this research introduces innovation by transforming the sanctions paradigm into Restorative Administrative Sanctions, emphasizing "restoring the victim and the environment" rather than merely "punishing the perpetrator" (Rusydi et al., 2023). The essential legal distinction between the conventional approach and this proposed model is comparatively illustrated in Table 2 below :

According to the legal comparison in Table 2, the Restorative model's comparative advantage lies in its assured recovery, consistent with a functional interpretation of the "polluter pays" principle (Obodai et al., 2023). This model promotes a shift from monetary sanctions to mandatory technical rehabilitation measures. For instance, upon the detection of heavy metal contamination, the administrative order must specifically mandate remediation measures, such as a stabilization program for settling ponds or phytoremediation. The law must explicitly require the use of hyperaccumulator plants like *Vetiveria zizanioides* and *Amaranthus hypochondriacus*, which are proficient in absorbing mercury and arsenic (Amri & Adifa, 2025; Putri Oktariani et al., 2024; Surya Husada, 2022). Emphasizing these remedial sanctions is essential, as it guarantees the systematic resolution of the damage (Pouresmaieli et al., 2023; Zhu et al., 2023). The efficacy of the recovery is then assessed not by the payment of fines, but by the attainment of environmental quality parameters that comply with Environmental Quality Standards (BML).

This restorative measure necessitates the establishment of a comprehensive data-driven framework to assess ecological recovery. Consistent oversight of the restoration process is crucial for maintaining the traceability of mine land rehabilitation efforts and attaining genuine ecological recovery (Kourouma et al., 2023; Manero et al., 2021). This implies using advanced monitoring tools, like remote

sensing data (Gastauer et al., 2021; MacDonald et al., 2023) and cutting-edge tools like drones, genomics, and eDNA bacterial community analysis (Gwenzi, 2021; Liddicoat et al., 2022). This study makes a unique scientific contribution by formulating sanctions that are both legally binding and technically measurable. Consequently, administrative sanctions are converted into a mechanism of ecological justice that responsibly, quantifiably, and scientifically reinstates environmental carrying capacity.

Table 2. Comparative Analysis of Effectiveness of Conventional Sanctions vs. Restorative Administrative Sanctions.

Indicator of Effectiveness	Conventional Sanctions (Status Quo / Ineffective)	Restorative Administrative Sanctions (Proposed Novelty)
Sanction Fund Flow Mechanism	Fines deposited into the Central State Treasury (PNBP). No guarantee of funds returning to the region.	Funds must be allocated directly for restoration costs at the incident site (*Direct Investment*).
Impact on the Environment	Often minimal/none. Perpetrator pays the fine, but the damage (mining pits/pollution) is left abandoned.	Measurable. Perpetrator is obliged to conduct soil/water remediation until environmental quality standards (BML) are met.
Impact on Affected Community	Community continues to suffer due to murky water/skin issues. Social conflict persists.	Concrete. Perpetrator is obliged to provide *Community Benefits* (e.g., building clean water facilities or village health facilities).
Basis of Legitimacy	*Legality* (Mere procedural compliance).	*Social License to Operate* (Social acceptance and substantive justice).
Role of Regional Government	Passive (Only a reporter/administrative supervisor).	Active (Executor of Government Compulsion / *Bestuursdwang*) to ensure restoration is carried out.

Source: Researcher's synthesis based on HAN Perspective (Rusydi, 2023)

Ultimately, however, the successful implementation of this ecological justice mechanism depends on the ethical foundation of the bureaucracy. All the technical structures (Smart Eco Supervision) and legal instruments (Restorative Sanctions) proposed above are merely "tools" that function effectively only when underpinned by a strong ethical imperative. Therefore, this study asserts that the principle of *Salus Populi Suprema Lex Esto* (the safety of the people is the supreme law) must be re-actualized as the highest norm in mining governance in Gorontalo. This principle should be interpreted progressively to encompass the Safety of Ecological Rights, prioritizing environmental integrity over immediate economic benefits. This value aligns closely with the principles of *Maqashid Syariah*, which prioritize the preservation of life (*hifz an-nafs*) and the safeguarding of the environment (*hifz al-bi'ah*) (Sanawiah et al., 2023). The regulatory framework must actively endorse restorative justice, in accordance with the "Nature Positive" paradigm (Victurine et al., 2024), ensuring that mining operations foster biodiversity (Ballesteros et al., 2025) and utilize adaptive management strategies (Manero et al., 2021).

Putting this ethical framework into action requires using high-tech monitoring tools, like Light Detection and Ranging (LiDAR) drones and satellite imagery (Bayat et al., 2023), to verify that mining

companies fulfill their reclamation obligations (Listiyani et al., 2023; Victurine et al., 2024). The legal framework must establish explicit criteria for mine rehabilitation, integrating ecological, social, and economic considerations (Listiyani et al., 2023; Manero et al., 2021). It is essential that the notion of ecological literacy is integrated into this framework, allowing all stakeholders to comprehend the intricate connection between mining and ecosystem health (Pouresmaieli et al., 2023), thereby securing a social license to operate (Leung et al., 2023). Clear communication and collaborative engagement are essential for fostering trust and ensuring socially equitable protection (Pouresmaieli et al., 2023; Søndergaard & Mosbech, 2021).

Notwithstanding the comprehensive potential of this proposed framework, this research candidly recognizes the methodological limitations, especially concerning model construction, which remains at Technology Readiness Level (TRL) 1 to 3. The *Smart Eco Supervision* model is still in the conceptual policy framework stage. It has not yet been rigorously field-tested to validate the accuracy of the satellite index algorithm (NDVI/SAR) under specific Gorontalo weather conditions, nor has the efficacy of specific phytoremediation plants been tested on the soil in Marisa. However, this research significantly contributes to science through Extend, which recontextualizes Earth Observation Data from a tool for litigation evidence to an instrument for preventive administrative oversight, and Challenges the centralistic and passive doctrine of administrative law by illustrating that centralization without technological instruments leads to ecological failure. The immediate future research agenda necessitates interdisciplinary collaboration among law, IT, and environmental engineering to create an application prototype and perform a fiscal feasibility analysis (cost-benefit analysis) to facilitate the adoption of this system as a permanent policy.

Conclusion

This study concludes that the "development paradox" in Gorontalo where economic growth correlates with ecological degradation is a direct legal consequence of supervisory maladministration. The vertical regulatory disharmony caused by the centralization of authority under the Minerba Law and Job Creation Law has created a "supervisory vacuum," stripping the Regional Government of its preventive power while the Central Government remains empirically absent. The *Hybrid Data Triangulation* proves that this vacuum has led to unchecked deforestation and mercury contamination, violating the *Welfare State* mandate. To resolve this, the current manual and passive supervision model must be reconstructed into the Smart Eco Supervision model. This model utilizes Earth Observation Data (Satellite Imagery/NDVI) not merely as technical information, but as legally binding objective evidence for State Administrative Officials to exercise *Bestuursdwang* (government coercion). Furthermore, administrative sanctions must be transformed from punitive-financial fines into Restorative Administrative Sanctions. This implies that violators are legally obligated to perform scientific ecological recovery (such as phytoremediation) as a primary requirement. Ultimately, this reconstruction reaffirms that in mining governance, the safety of the people and ecological integrity (*Salus Populi Suprema Lex Esto*) must serve as the supreme law, overriding investment flexibility.

Reference

Adry, M. R., Putri, D. Z., & Hernanda, T. A. P. (2023). Apakah pertumbuhan ekonomi mampu berjalan beriringan dengan keberlanjutan lingkungan? *Jurnal Ecogen, 6*(3), 351–360. https://doi.org/10.24036/jmpe.v6i3.14870

Adu-Baffour, F., Daum, T., & Birner, R. (2021). Governance challenges of small-scale gold mining in Ghana: Insights from a process net-map study. *Land Use Policy, 102*, 105271. https://doi.org/10.1016/j.landusepol.2020.105271

Al Farisi, M. S. (2021). Desentralisasi kewenangan pada urusan pertambangan mineral dan batubara

dalam Undang-Undang Nomor 3 Tahun 2020. *Jurnal Ilmiah Ecosystem, 21*(1), 20–31. https://doi.org/10.35965/eco.v21i1.699

Alessi, M. A., Chirico, P. G., & Millones, M. (2023). Artisanal mining river dredge detection using SAR: A method comparison. *Remote Sensing, 15*(24), 5701. https://doi.org/10.3390/rs15245701

Amri, K., & Adifa, F. (2025). Peran fitoremediasi dalam pemulihan tanah tercemar logam berat: Tinjauan mekanisme dan aplikasi. *Jurnal Greenation Ilmu Teknik, 3*(2), 58–65. https://doi.org/10.38035/jgit.v3i2.309

Badan Pusat Statistik. (2025). *Pertumbuhan ekonomi triwulan I 2025 Provinsi Gorontalo* [Infografik]. BPS Provinsi Gorontalo. https://gorontalo.bps.go.id/id/infographic?id=469

Ballesteros, M., Řehounková, K., Decleer, K., Martínez-Ruiz, C., Alday, J. G., Gentili, R., … Prach, K. (2025). Maximising biodiversity potential in Europe's mines and quarries: A key role for EU Nature Restoration Regulation targets. *AMBIO*. https://doi.org/10.1007/s13280-025-02235-4

Basir, Kimijima, S., Sakakibara, M., Pateda, S. M., & Sera, K. (2022). Contamination level in geo-accumulation index of river sediments at artisanal and small-scale gold mining area in Gorontalo Province, Indonesia. *International Journal of Environmental Research and Public Health, 19*(10), 6094. https://doi.org/10.3390/ijerph19106094

Bayat, A. A., Heydari, M., & Albadvi, A. (2023). Analysis of insect–plant interactions affected by mining operations: A graph mining approach. *arXiv*. https://doi.org/10.48550/arXiv.2308.04464

Bertram, D. (2022). Environmental justice light? Transnational tort litigation in the corporate Anthropocene. *German Law Journal, 23*(5), 738–755. https://doi.org/10.1017/glj.2022.45

Cakranegara, P. A., Rahadi, D. R., & Susilowati, E. (2023). Distribution of authority for mining business permits between the central government and regional governments after the enactment of the Minerba Law Number 4 of 2009. *Journal of Progressive Law and Legal Studies, 1*(2), 88–96. https://doi.org/10.59653/jplls.v1i02.46

Çamalan, S., Cui, K., Pauca, V. P., Alqahtani, S., Silman, M. R., Chan, R. H., … Lutz, D. A. (2022). Change detection of Amazonian alluvial gold mining using deep learning and Sentinel-2 imagery. *Remote Sensing, 14*(7), 1746. https://doi.org/10.3390/rs14071746

Demak, N. K., Smail, D. E., Rahim, E. I., & Ahmad, A. (2023). Law enforcement against illegal gold mining in the Bumi Panua Nature Reserve, Pohuwato Regency. *International Journal of Research Publication and Reviews, 4*(5), 5809–5815. https://doi.org/10.55248/gengpi.4.523.43249

Finn, B. M., Simon, A. C., & Newell, J. (2024). Decarbonization and social justice: The case for artisanal and small-scale mining. *Energy Research & Social Science, 117*, 103733. https://doi.org/10.1016/j.erss.2024.103733

Fonseca, A., Marshall, M., & Salama, M. S. (2024). Enhanced detection of artisanal small-scale mining with spectral and textural segmentation of Landsat time series. *Remote Sensing, 16*(10), 1749. https://doi.org/10.3390/rs16101749

Fritz, B., & Schmidt, M. (2025). Climate change vs. circular economy: Challenges of the most common route for recycling gold from WEEE. *Sustainability, 17*(5), 2086. https://doi.org/10.3390/su17052086

Gastauer, M., Nascimento, W. R., Caldeira, C. F., Ramos, S. J., Souza Filho, P. W. M., & Féret, J. (2021). Spectral diversity allows remote detection of the rehabilitation status in an Amazonian iron mining complex. *International Journal of Applied Earth Observation and Geoinformation, 106*, 102653. https://doi.org/10.1016/j.jag.2021.102653

Gwenzi, W. (2021). Rethinking restoration indicators and end-points for post-mining landscapes in light of novel ecosystems. *Geoderma, 387*, 114944. https://doi.org/10.1016/j.geoderma.2021.114944

Halid, R. (2023a, December 4). *Petani Marisa Pohuwato keluhkan limbah tambang, tak bisa tanam padi*. Tribun Gorontalo. https://gorontalo.tribunnews.com/2023/12/04/petani-marisa-pohuwato-keluhkan-limbah-tambang-tak-bisa-tanam-padi

Halid, R. (2023b, October 28). *Warga Marisa Gorontalo keluhkan air sungai keruh akibat pertambangan*. Tribun Gorontalo. https://gorontalo.tribunnews.com/2023/10/28/warga-marisa-gorontalo-keluhkan-air-sungai-keruh-akibat-pertambangan

Hassan, A., Ibrahim, R. L., Raimi, L., Omokanmi, O. J., & Senathirajah, A. R. S. (2025). Balancing growth and sustainability: Can green innovation curb the ecological impact of resource-rich economies? *Sustainability, 17*(10), 4579. https://doi.org/10.3390/su17104579

Kazapoe, R. W., Amuah, E. E. Y., Abdiwali, S. A., Dankwa, P., Nang, D. B., Kazapoe, J. P., & Kpiebaya, P. (2023). Relationship between small-scale gold mining activities and water use in Ghana: A review of policy documents aimed at protecting water bodies in mining communities. *Environmental Challenges, 12*, 100727. https://doi.org/10.1016/j.envc.2023.100727

Kimijima, S., Sakakibara, M., Nagai, M., & Gafur, N. A. (2021). Time-series assessment of camp-type artisanal and small-scale gold mining sectors with large influxes of miners using Landsat imagery. *International Journal of Environmental Research and Public Health, 18*(18), 9441. https://doi.org/10.3390/ijerph18189441

Kinyondo, A., & Huggins, C. (2021). State-led efforts to reduce environmental impacts of artisanal and small-scale mining in Tanzania: Implications for fulfilment of the sustainable development goals. *Environmental Science & Policy, 120*, 157–164. https://doi.org/10.1016/j.envsci.2021.02.017

Kourouma, J. M., Monde, C., Phiri, D., & Syampungani, S. (2023). Community-centred approach for assessing social sustainability in mining regions: A case study of Chingola district, Zambia. *Sustainable Development, 31*(4), 3102–3127. https://doi.org/10.1002/sd.2572

Leung, R., Hill, A. J., & Melkumyan, A. (2023). Automation and artificial intelligence technology in surface mining: A brief introduction to open-pit operations in the Pilbara. *IEEE Robotics & Automation Magazine*. https://doi.org/10.1109/MRA.2023.3328457

Liddicoat, C., Krauss, S. L., Bissett, A., Borrett, R. J., Ducki, L. C., Peddle, S. D., … Breed, M. F. (2022). Next generation restoration metrics: Using soil eDNA bacterial community data to measure trajectories towards rehabilitation targets. *Journal of Environmental Management, 310*, 114748. https://doi.org/10.1016/j.jenvman.2022.114748

Listiyani, N., Said, M. Y., & Khalid, A. (2023). Strengthening reclamation obligation through mining law reform: Indonesian experience. *Resources, 12*(5), 56. https://doi.org/10.3390/resources12050056

MacDonald, E., Jacoby, D., & Coady, Y. (2023). MineSegSAT: An automated system to evaluate mining disturbed area extents from Sentinel-2 imagery. *arXiv*. https://doi.org/10.48550/arXiv.2311.01676

Malik, K., Robertson, C., Braun, D. C., & Greig, C. (2021). U-Net convolutional neural network models for detecting and quantifying placer mining disturbances at watershed scales. *International Journal of Applied Earth Observation and Geoinformation, 104*, 102510. https://doi.org/10.1016/j.jag.2021.102510

Manero, A., Standish, R. J., & Young, R. (2021). Mine completion criteria defined by best-practice: A global meta-analysis and Western Australian case studies. *Journal of Environmental Management, 282*, 111912. https://doi.org/10.1016/j.jenvman.2020.111912

Mencho, B. B. (2022). Assessing the effects of gold mining on environment: A case study of Shekiso district, Guji zone, Ethiopia. *Heliyon, 8*(12), e11882. https://doi.org/10.1016/j.heliyon.2022.e11882

Mensah, L. (2021). Legal pluralism in practice: Critical reflections on the formalisation of artisanal and small-scale mining and customary land tenure in Ghana. *The Extractive Industries and Society, 8*(4), 100973. https://doi.org/10.1016/j.exis.2021.100973

Meutia, A. A., Lumowa, R., & Sakakibara, M. (2022). Indonesian artisanal and small-scale gold mining: A narrative literature review. *International Journal of Environmental Research and Public Health, 19*(7), 3955. https://doi.org/10.3390/ijerph19073955

Narciso, G. A. M., & Principe, J. A. (2024). Land cover change analysis of Carrascal, Madrid, and Cantilan mining sites in Surigao del Sur using remote sensing. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 48*(4/W8), 379–386. https://doi.org/10.5194/isprs-archives-xlviii-4-w8-2023-379-2024

Nawu, A. (2025, January 15). *3 pekerja tambang emas ilegal di Pohuwato ditangkap, 1 ekskavator disita*. Detik.com. https://www.detik.com/sulsel/hukum-dan-kriminal/d-8222303/3-pekerja-tambang-emas-ilegal-di-pohuwato-ditangkap-1-ekskavator-disita

Ngom, N. M., Baratoux, D., Bolay, M., Dessertine, A., Saley, A. A., Baratoux, L., Mbaye, M., Faye,

G., Yao, A. K., & Kouamé, K. J. (2022). Artisanal exploitation of mineral resources: Remote sensing observations of environmental consequences, social and ethical aspects. *Surveys in Geophysics, 44*(1), 225–247. https://doi.org/10.1007/s10712-022-09740-1

Nursamsi, I., Sonter, L. J., Luskin, M. S., & Phinn, S. (2024). Feasibility of multispectral and radar data fusion for mapping artisanal small-scale mining: A case study from Indonesia. *International Journal of Applied Earth Observation and Geoinformation, 132*, 104015. https://doi.org/10.1016/j.jag.2024.104015

Obodai, J., Bhagwat, S. A., & Mohan, G. (2023). Gold mining's environmental footprints, drivers, and future predictions in Ghana. *Remote Sensing Applications: Society and Environment, 33*, 101103. https://doi.org/10.1016/j.rsase.2023.101103

Oh, C. H., Shin, J., & Ho, S. S. H. (2023). Conflicts between mining companies and communities: Institutional environments and conflict resolution approaches. *Business Ethics, the Environment & Responsibility, 32*(2), 638–656. https://doi.org/10.1111/beer.12522

Pakaya, M. S., & Wijaya, A. (2022). Efektivitas penegakan hukum terhadap lingkungan hidup dalam pertambangan emas tanpa izin di Desa Popaya, Kecamatan Dengilo, Kabupaten Pohuwato. *Bol. Rev., 6*(2), 236–253. https://doi.org/10.35334/bolrev.v6i2.3246

Pavloudakis, F., Roumpos, C., & Spanidis, P.-M. (2024). Sustainable mining and processing of mineral resources. *Sustainability, 16*(19), 8393. https://doi.org/10.3390/su16198393

Pouresmaieli, M., Ataei, M., Qarahasanlou, A. N., & Barabadi, A. (2023). Building ecological literacy in mining communities: A sustainable development perspective. *Case Studies in Chemical and Environmental Engineering, 9*, 100554. https://doi.org/10.1016/j.cscee.2023.100554

Pradana, G. W., Kuncaravita, S. A., & Alina, A. N. (2024). Policy and impact analysis of smelter development in Morowali, Sulawesi: A multidisciplinary review of social, economic, and environmental aspects. *East Asian Policy, 16*(4), 114–127. https://doi.org/10.1142/S1793930524000327

Prasetya, K. D., & Tsai, F. (2025). Multitemporal spatial analysis for monitoring and classification of coal mining and reclamation using satellite imagery. *Remote Sensing, 17*(6), 1090. https://doi.org/10.3390/rs17061090

Putri Oktariani, Suwardi, Widjaja, H., Suryaningtyas, D. T., & Putri, A. (2024). Remediation technology for heavy metal-contaminated soil on copper post-mining land reclamation. *Jurnal Pengelolaan Lingkungan Pertambangan, 1*(1), 44–54. https://doi.org/10.70191/jplp.v1i1.54692

Rusydi, J., Januri, J., & Santina, R. (2023). Tanggung jawab pemerintah dalam penegakan hukum lingkungan hidup ditinjau dari perspektif hukum administrasi negara. *Audi Et AP: Jurnal Penelitian Hukum, 2*(1), 54–63. https://doi.org/10.24967/jaeap.v2i01.2064

Sanawiah, Ramdhani, M. T., Ariyadi, Norcahyono, Aseri, A. F., Jalaluddin, Lawang, K. A., & Amruzi, M. F. A. (2023). Law politics of people's mining based on maqashid syariah. *Russian Law Journal, 11*(3S), 269–279.

Seccatore, J., Marin, T., Tarra, J. A., & Baena, Ó. J. R. (2025). Public mining governance for sustainable artisanal gold mining: Preventing mercury pollution in South America. *Sustainability, 17*(19), 8894. https://doi.org/10.3390/su17198894

Smentek, A., Kaczmarek, A., Eksert, P., & Blachowski, J. (2025). Monitoring surface water dynamics in mining areas using remote sensing indices: A review and cross-case analysis. *Water, 17*(19), 2826. https://doi.org/10.3390/w17192826

Søndergaard, J., & Mosbech, A. (2021). Mining pollution in Greenland—The lesson learned: A review of 50 years of environmental studies and monitoring. *Science of the Total Environment, 812*, 152373. https://doi.org/10.1016/j.scitotenv.2021.152373

Surya Husada, V. I. E. J. (2022). Legal policy of the Indonesian government to achieve net zero emissions. *Journal Research of Social Science, Economics, and Management, 2*(1), 128–133. https://doi.org/10.59141/jrssem.v2i1.248

Swari, N. R., & Cahyani, I. (2022). Pengaturan pengelolaan sumber daya alam dan lingkungan hidup di kawasan pertambangan mineral dan batu bara. *Inicio Legis, 3*(1), 38–51. https://doi.org/10.21107/il.v3i1.14899

Tang, L., & Werner, T. T. (2023). Global mining footprint mapped from high-resolution satellite imagery. *Communications Earth & Environment, 4*(1), Article 805.

https://doi.org/10.1038/s43247-023-00805-6

Teku, D. (2025). Geo-environmental and socio-economic impacts of artisanal and small-scale mining in Ethiopia: Challenges, opportunities, and sustainable solutions. *Frontiers in Environmental Science, 13*, Article 1505202. https://doi.org/10.3389/fenvs.2025.1505202

van Rensburg, G. J., & Kemp, J. (2022). The use of C-band and X-band SAR with machine learning for detecting small-scale mining. *Remote Sensing, 14*(4), 977. https://doi.org/10.3390/rs14040977

Victurine, R., Anstee, S., Jones, K. R., Rainey, H., DeGemmis, A., & Crowley, H. (2024). Nature positive mining: Guidance for a critical transition. *PLOS Sustainability and Transformation, 3*(12), e0000142. https://doi.org/10.1371/journal.pstr.0000142

Wang, J., & Azam, W. (2024). Natural resource scarcity, fossil fuel energy consumption, and total greenhouse gas emissions in top emitting countries. *Geoscience Frontiers, 15*(2), 101757. https://doi.org/10.1016/j.gsf.2023.101757

Werner, T. T., Toumbourou, T., Maus, V., Lukas, M. C., Sonter, L. J., Muhdar, M., Runting, R. K., & Bebbington, A. (2023). Patterns of infringement, risk, and impact driven by coal mining permits in Indonesia. *AMBIO, 53*(2), 242–256. https://doi.org/10.1007/s13280-023-01944-y

Zaehringer, J. G., Michelotti, M., Andriambalohary, M., Rajerison, F., Rakotoarinosy, A., Eckert, S., Ramamonjisoa, B., & Andriamihaja, O. R. (2024). How are large-scale extractive industries affecting progress toward the sustainable development goals in Madagascar? Perceived social-ecological impacts of mining investments. *Current Research in Environmental Sustainability, 8*, 100257. https://doi.org/10.1016/j.crsust.2024.100257

Zhu, C., Chen, Y., Wan, Z., Chen, Z., Lin, J., Chen, P., Sun, W., Hao, Y., & Zhang, Y. (2023). Cross-sensitivity analysis of land use transition and ecological service values in rare earth mining areas in southern China. *Scientific Reports, 13*(1), 49015. https://doi.org/10.1038/s41598-023-49015-2

Zildjianda, R., Muda, I., & Herlambang, D. (2023). Undang-Undang Cipta Kerja dan dampaknya terhadap masalah lingkungan. *Jurnal Ilmiah Advokasi, 11*(1), 65–75. https://doi.org/10.36987/jiad.v11i1.3379

Zou, C., Gao, W., & Ai, F. (2025). Strategic mineral policies for Indonesia: Enhancing global competitiveness, economic growth, and environmental sustainability through innovation and renewable energy. *Renewable Energy*, Article 122593. https://doi.org/10.1016/j.renene.2025.122593

Zou, Y., Wang, X., & Zhang, Q. (2025). Evolution and quantitative evaluation of China's green port policies: Evidence from text mining and text analysis. *Frontiers in Marine Science, 12*, Article 1546755. https://doi.org/10.3389/fmars.2025.1546755