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Sekolah Pascasarjana Universitas Airlangga
Jalan Airlangga No. 4-6, Surabaya - 60286
Telp. : (031) 5041566, 5041536
Email : adj@journal.unair.ac.id
Website : https://e-journal.unair.ac.id/ADJ

IDEAL ENVIRONMENTAL RECOVERY MODEL FOR B3 ALUMINIUM SLAG WASTE IN JOMBANG

Jainul Arifin
Dinas Kehutanan
happy.23419@yahoo.co.id

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ABSTRACT
The problem of B3 (hazardous and toxic) aluminium slag waste in Jombang Regency has persisted for over four decades, accumulating more than 100 million tons of hazardous residues on open land, agricultural fields, and riverbanks. This study employs a normative juridical method to examine national and regional legal frameworks, law enforcement practices, and judicial experiences in pollution cases, then formulates an ideal environmental recovery model for Jombang. The findings indicate that although Regional Regulation No. 8/2017 and Law No. 32/2009 provide a basis for remediation and recovery, implementation in the field remains hindered by limited institutional capacity, outdated industrial data, and low awareness among residents and business actors. The proposed recovery model includes: (1) formation of a "Aluminium Slag Recovery Task Force" comprising local government, Ministry of Environment and Forestry, Bappeda, Public Works Agency, small and medium aluminium industries (IKM), local cooperatives, and law enforcement; (2) execution of technical stages in accordance with Article 54 of Law No. 32/2009 (source cessation, remediation, rehabilitation, and restoration) using solidification/stabilization and phytoremediation techniques; (3) financing mechanisms based on the "polluter pays" and "strict liability" principles through environmental guarantee funds and incentives for compliant IKM; and (4) progressive law enforcement and capacity building of Jombang's Environmental Office in monitoring, education, and public participation via a GIS dashboard and village-level forums. Implementing this model is expected to accelerate ecosystem function recovery, generate economic value from properly treated slag, and ensure accountability and transparency in B3 waste management across Jombang.
Keywords: *B3 Aluminium Slag Waste; Environmental Recovery; Jombang;*

INTRODUCTION

The issue of environmental pollution caused by hazardous and toxic waste (B3 waste), particularly aluminium slag waste, has become a critical concern in Jombang Regency, East Java. For over four decades, the practice of disposing and stockpiling B3 waste has occurred on a massive scale at various locations, ranging from open lands, rice fields, plantations, residential areas, to riverbank irrigation zones. This condition is closely linked to the activities of small and medium-scale industries (IKM) engaged in aluminium waste processing, which have proliferated significantly in the region, particularly in Kesamben and Sumobito sub-districts. According to data from the Environmental Agency of East Java Province, there are at least 88 IKMs involved in this activity. As a result, more than 100 million tons of aluminium slag waste have polluted the surrounding environment, causing cumulative negative impacts on soil, water, and public health.

Uncontrolled disposal of aluminium slag waste poses not only a local threat but also has the potential for transboundary effects through river water contamination. This waste is generated from the process of smelting and recycling aluminium, which is often carried out informally by the community to produce various household items or aluminium ingots.

Unfortunately, such processes are not accompanied by adequate waste management systems. As stated by Ecoton Executive Director, Prigi Arisandi, the indiscriminate dumping of aluminium slag waste contains toxic compounds that can contaminate ecosystems and directly endanger human health. In practice, this waste has even been used to patch river embankments, such as in the case of the DAM Yani levee, despite the fact that the flowing water can dissolve hazardous compounds from the waste.[1]

In response to the escalation of this issue, the government, through various agencies, has begun to take legal enforcement actions. A concrete example is the exposure of illegal B3 waste transfer cases by the Environmental and Forestry Law Enforcement Agency (Gakkum KLHK) in 2022, involving a company director in Sumobito District. However, legal enforcement alone is insufficient. Major challenges remain, particularly in terms of supervision and raising awareness among the community and industry players to manage B3 waste responsibly. Sustainable waste management requires an integrative approach encompassing education, adequate treatment facilities, and a continuous environmental monitoring system.[2]

Indonesia's regulatory framework has, in fact, provided for the management of B3 waste through various regulations, such as Government Regulation No. 18 of 1999 and Law No. 32 of 2009 concerning Environmental Protection and Management (PPLH Law). These regulations cover the handling, storage, and disposal of hazardous waste. Nevertheless, the effectiveness of legal enforcement has faced new challenges following the enactment of Law No. 11 of 2020 on Job Creation, which eliminated several criminal provisions in the PPLH Law, including Article 102 concerning sanctions for unlicensed B3 waste management. This raises concerns about a potential surge in illegal waste management activities, which could further aggravate environmental degradation.

In a global context, several countries have implemented stricter and more comprehensive legal systems and enforcement mechanisms. The European Union, for example, enforces Directive 2008/98/EC, which emphasizes that waste management, including B3 waste, must be carried out without endangering human health and the environment. In the United States, the Resource Conservation and Recovery Act (RCRA) grants authority to the Environmental Protection Agency (EPA) to regulate and take action against violations in hazardous waste management. Meanwhile in Japan, the Waste Management and Public Cleansing Law regulates a rigorous licensing and monitoring system, accompanied by strict sanctions for violators. These international experiences demonstrate the importance of coherence between strong regulation, reliable enforcement capacity, and active participation from both the public and industry stakeholders.

Against this backdrop, this article aims to thoroughly examine the issue of B3 waste management, particularly aluminium slag in Jombang Regency, and to assess the effectiveness of existing legal instruments, both at the national level and from a comparative legal perspective. This study is expected to contribute to the strengthening of environmental policy in Indonesia and encourage more adaptive legal reforms in facing the challenges of B3 waste management in the era of sustainable development.

METHOD

[1] Kompas Regional. (2018). *Ketika Limbah Abu Aluminium Menjadi Material Pengurug Jalan*. Retrieved from https://regional.kompas.com/read/2018/08/31/22043611/ketika-limbah-abu-alumunium-menjadi-material-pengurug-jalan.

[2] APKASI. (2022). *Menteri LH Dampingi Pj Bupati Jombang Tinjau Pengolahan Limbah Tahu dan Slag Aluminium*. Retrieved from https://apkasi.org/berita-kabupaten/menteri-lh-dampingi-pj-bupati-jombang-tinjau-pengolahan-limbah-tahu-dan-slag-alumunium.

According to Sugiyono, research methodology is essentially a scientific way to obtain data for specific purposes and uses.[3] Based on this, there are four key elements to consider: scientific method, data, objectives, and usefulness. The scientific method means that research activities are based on scientific characteristics, namely rationality, empiricism, and systematic procedures. *Rational* means that the research is conducted in a logical manner, within the bounds of human reasoning. *Empirical* means that the methods used can be observed by human senses, allowing others to examine and understand the processes involved. *Systematic* implies that the research process follows certain logical steps.[4]

This study employs normative juridical research. This refers to an approach that seeks to resolve legal issues by examining and analyzing positive legal norms using the law in books concept, primarily through a literature study.

DISCUSSION

1. Kerangka Hukum Pengelolaan Limbah B3 di Indonesia Legal Framework for Hazardous and Toxic Waste (B3 Waste) Management in Indonesia

The primary legal basis for the management of hazardous and toxic waste (B3 waste) in Indonesia is Law Number 32 of 2009 concerning Environmental Protection and Management (referred to as the Environmental Law). This law stipulates that every individual or business entity that generates B3 waste is obligated to manage it responsibly to prevent harm to human health and the environment. Such management encompasses stages including reduction, storage, transportation, utilization, treatment, and final disposal. The Environmental Law also emphasizes the application of the **precautionary principle** and **strict liability** in environmental protection.

Furthermore, Government Regulation Number 22 of 2021 on the Implementation of Environmental Protection and Management provides technical elaboration on environmental approvals, as well as the management of water, air, marine quality, and B3 and non-B3 waste. This regulation underscores that an environmental approval is a mandatory requirement for any business activity that has the potential to cause environmental impact.

In addition, several derivative regulations support the management of B3 waste, including:

- Government Regulation Number 18 of 1999 on the Management of B3 Waste; and
- Regulation of the Minister of Environment and Forestry Number P.12/MENLHK/SETJEN/PLB.3/2018 on the Management of B3 Waste.

Within Indonesia's environmental legal framework, there are several fundamental principles that serve as the foundation for B3 waste management, namely:[5]

1. Preventive Principle: B3 waste handling must prioritize preventive measures to avoid pollution or environmental degradation.
2. Polluter Pays Principle: The waste generator bears full responsibility for its management, including the costs of mitigating any resulting impacts.
3. Strict Liability Principle: Business actors are held liable for damage caused by B3 waste without the need to prove fault.

The management of B3 waste is a strategic aspect of environmental protection and public

[3] Sugiyono, *Metode Penelitian Kuantitatif, Kualitatif, dan R&D,* Alfabeta, Bandung, 2017, h. 2.
[4] Peter Mahmud Marzuki, *Penelitian Hukum*, Kencana Prenada Media Group, Jakarta, 2010, h.93.
[5] Siahaan, N. H. (2020). *Hukum Lingkungan dan Pengelolaan Limbah di Indonesia.* Jakarta: Gramedia, h. 78.

health. According to Government Regulation Number 22 of 2021, B3 waste management involves several key stages that must be fulfilled by businesses and industries.

The initial stage involves the identification and classification of B3 waste based on its characteristics and potential hazards. The regulation classifies B3 waste into three categories:

1. B3 waste from specific sources, such as waste originating from particular industrial sectors including oil and gas, mining, or heavy chemicals.
2. B3 waste from non-specific sources, such as waste produced in general production processes including manufacturing, laboratories, and hospitals.
3. B3 waste from expired products or leftover materials, including spills of hazardous substances, chemical residues, and expired medicines.

Next, waste reduction efforts are made through the substitution of hazardous raw materials, increased production efficiency, and the application of environmentally friendly technologies. B3 waste storage must meet strict safety standards to prevent leaks and harmful exposure to workers and surrounding communities.

Following storage, B3 waste must be transported and treated in accordance with regulations. Transport may only be conducted by licensed parties using vehicles that meet the standards established by the Ministry of Environment and Forestry. Treatment methods for B3 waste include:[6]

1. Physico-chemical treatment, which alters the waste properties to become more stable.
2. Biological treatment, using microorganisms to break down hazardous compounds.
3. Incineration, or high-temperature burning to destroy toxic substances.
4. Solidification and stabilization, which involves mixing the waste with binding agents like cement to make it safer for disposal.

2. Implementation of Legal Enforcement on Hazardous Waste (B3) of Aluminum Slag in Jombang

The implementation of legal enforcement regarding the management of hazardous and toxic waste (B3), particularly aluminum slag in Jombang Regency, reflects the complexity of environmental issues intertwined with technical, legal, and industrial governance aspects. Jombang Regency, as one of the regions with a significant aluminum smelting center, faces serious challenges in controlling the environmental impact of such industrial activities.[7] One of the dominant types of waste produced from the smelting process is aluminum slag—a grayish-black residue containing hazardous chemical compounds and classified as B3 waste with code B313-2 according to Government Regulation No. 101 of 2014.[8]

Improper disposal practices of aluminum slag, such as dumping it in open areas near residential zones, remain rampant on the ground. This condition is highly concerning, as such waste can contaminate soil and groundwater, potentially posing health risks to surrounding communities. It is estimated that the accumulation of illegally dumped waste in this area has

[6] Siregar, D. (2019). *Manajemen Limbah Industri.* Yogyakarta: Deepublis, h. 34.

[7] Balqis Ramadhani, "Pemanfaatan Limbah Slag Aluminium sebagai Subtitusi Semen Dalam Pembuatan Beton Normal (Studi Kasus : Kawasan Home Industry Kecamatan Sumobito)", *Jurnal Teknik Lingkungan*, Politeknik Perkapalan Negeri Surabaya, h. 75.

[8] Peraturan Menteri Lingkungan Hidup dan Kehutanan RI, "Formulir Permohonan Persetujuan Teknis Di Bidang Pengelolaan Limbah B3 Untuk Kegiatan Pengelolaan Limbah B3 (Pengumpulan, Pemanfaatan, Pengolahan, Dan Penimbunan Limbah B3)," *Menteri Lingkungan Hidup Dan Kehutanan Republik Indonesia* 7, no. 2 (2014): 107–15.

exceeded 100 million tons, a figure that reflects a systemic failure in regulatory oversight and environmental law enforcement.

Aluminum slag itself is the by-product of further processing of dross, a solid residue formed during the primary aluminum smelting process. In addition to slag, dross is also classified as hazardous waste as it still contains 20–45% aluminum metal along with other reactive chemical compounds. The treatment of dross and slag requires special technology due to their reactivity with air and water, which can generate toxic substances if not handled carefully. One technology that can be used to reduce its impact is the solidification/stabilization (S/S) method, a treatment method that converts B3 waste into a stable solid form so that it is not easily leached into the environment and can be safely reused, for example, as construction material.[9]

Juridically, the Jombang Regency Government has enacted Regional Regulation No. 8 of 2017 concerning Environmental Protection and Management as a local legal framework for B3 waste management. This regulation adopts the fundamental principles of environmental management such as the precautionary principle, ecological justice, and the polluter pays principle. In its implementation, the regulation mandates that each business actor must store B3 waste temporarily in dedicated facilities that meet safety standards before such waste can be collected, transported, processed, or further utilized. Licensing authority, including temporary storage and collection permits, is held by the Regional Government through the Environmental Protection and Management Permit (PPLH) mechanism as stipulated in Article 19 paragraph (3) of the Regulation.

However, despite the existence of such regulations, their implementation in practice encounters significant challenges. According to data compiled by the Jombang Regency Environmental Agency (DLH), of approximately 96 aluminum smelting industries producing B3 waste, only 31 have officially obtained permits. This disparity reflects a significant gap in monitoring and operational legality, caused by several factors such as limited institutional capacity, lack of an integrated industrial database system, and fluctuations in business status—particularly among small-scale industries that often operate informally or transition into cooperatives or sole proprietorships.

Legal enforcement against violations of B3 waste management in Jombang is carried out through administrative, civil, and criminal approaches. Administratively, violators may be subject to sanctions ranging from written warnings, government coercive measures, permit suspension, to revocation of environmental permits as regulated under Article 33 of the Regulation. This approach reflects the government's effort to allow gradual correction before imposing harsher penalties. However, in practice, the effectiveness of such administrative sanctions heavily depends on the consistency of monitoring and the responsiveness of environmental law enforcement agencies at the regional level.[10]

Untuk penyelesaian sengketa lingkungan hidup, Perda juga membuka jalur perdata, baik melalui pengadilan maupun mekanisme alternatif penyelesaian di luar pengadilan. Hal ini bertujuan untuk mendorong pendekatan restoratif dan partisipatif dalam penyelesaian konflik lingkungan antara pelaku usaha, pemerintah, dan masyarakat. Namun apabila mekanisme non-litigasi tidak membuahkan hasil, gugatan lingkungan tetap dapat diajukan melalui lembaga peradilan sesuai dengan ketentuan perundang-undangan nasional.

For environmental dispute resolution, the Regulation also provides civil avenues, either

[9] Komang Ardya Putri Saraswati dan Mohammad Razif, "Potensi Pemanfaatan Slag Aluminium Sebagai Substitusi Semen Dalam Proses Stabilisasi/Solidifikasi Limbah B3 Dengan Kajian Pustaka (Studi Kasus: Pt.X Kecamatan Kesamben, Jombang)", *Jurnal Envirotek*, Vol. 12, No. 2, 2020, h. 54.

[10] Natalis Situmorang, *Buku Ajar AMDAL*, Universitas Sahid Jakarta, Jakarta, 2022, h. 52.

through the courts or alternative non-judicial mechanisms. This aims to encourage restorative and participatory approaches in resolving environmental conflicts between businesses, government, and the community. However, if non-litigation mechanisms prove ineffective, environmental lawsuits may still be filed through the judiciary in accordance with national legal provisions.

In the context of criminal enforcement, the Jombang Regional Regulation does not explicitly regulate criminal sanctions, but instead refers to the provisions in Law No. 32 of 2009 on Environmental Protection and Management. This is in line with the principle of *lex superior derogat legi inferiori*, in which criminal provisions must follow those in higher-level legislation. Therefore, acts such as disposing waste without a permit, managing B3 waste illegally, or providing false environmental data may be subject to criminal sanctions under the provisions of Law 32/2009.

The Jombang Regency Government also promotes community participation in supervising B3 waste management through provisions in Article 31 of the Regulation. The public is granted the right to obtain information, submit objections, and report violations as a form of social control that contributes to the accountability of environmental management. In support of information transparency, an environmental information system has been developed as a means of publicly disseminating data and the status of environmental management online.

Although the legal framework is available and the regional government's commitment is relatively strong, the effectiveness of legal enforcement in Jombang still faces structural and cultural barriers. These include the lack of technically competent human resources within the DLH, the absence of standardized waste treatment facilities, and low environmental awareness among small and medium-sized enterprises. Therefore, an integrative strategy is needed involving periodic updating of industrial data, enhanced monitoring capacity, and synergy among local governments, communities, and the private sector to promote more effective and sustainable B3 waste governance.[11]

3. An Ideal Environmental Remediation Model for Hazardous Waste in the Form of Aluminum Slag in Jombang

An ideal environmental remediation model for hazardous waste in the form of aluminum slag in Jombang must begin with a normative framework that places environmental protection as a constitutional mandate. The 1945 Constitution of the Republic of Indonesia explicitly states that the right to a clean and healthy environment is part of human rights. This indicates that the state, the government, and all stakeholders have a collective responsibility to ensure the sustainability of the environment, not only for the current generation but also for future generations. Within the framework of sustainable development, the environment must not merely be a victim of industrialization processes but should serve as the main foundation for the continuity of life in Indonesia.[12]

As emphasized in Article 3 of Law Number 32 of 2009 concerning Environmental

[11] Feri Ardiansyah, "Tantangan Pengawasan dan Penegakan Hukum Lingkungan Hidup dalam Implementasi Undang-Undang Cipta Kerja", *Seminar Nasional "Pembangunan Hijau dan Perizinan: Diplomasi, Kesiapan Perangkat dan Pola Standarisasi",* Semarang, 2 Desember 2020, Sekolah Pascasarjana Universitas Diponegoro, h. 17.

[12] Wibisana A.G., "Campur Tangan Pemerintah dalam Pengelolaan Lingkungan: Sebuah Penelusuran Teoritis Berdasarkan Analisis Ekonomi atas Hukum *(Economic Analysis of Law)*", *Jurnal Hukum & Pembangunan*, Vol. 47, No. 2, 2017, h. 151-182.

Protection and Management, environmental policies are directed toward preventing pollution and/or environmental damage, ensuring public safety, maintaining ecosystem sustainability, and guaranteeing environmental rights as part of human rights. These principles place the environment in a strategic position, not merely as a resource to be exploited, but as a living system that must be managed wisely.

However, technological advancements and industrialization bring significant consequences, namely the increase of hazardous waste, including hazardous and toxic materials (B3). Although technology facilitates production and distribution activities, its uncontrolled use can create severe ecological damage. B3 waste such as aluminum slag, if not managed safely and responsibly, will pose a serious threat to human health and ecosystem stability. Many industries dispose of waste indiscriminately into environmental media such as water, soil, and air, leading to both acute and chronic pollution.

Environmental regulation through Law Number 32 of 2009 has indeed provided a legal basis for environmental protection. This law strengthens planning and legal enforcement in the environmental sector, including administrative, civil, and criminal instruments. However, weaknesses remain, particularly in the lack of strict enforcement of environmental remediation as an integral part of accountability for pollution. Yet, Article 54 of this law explicitly states that any party causing environmental pollution is obliged to restore the environmental function. Such remediation includes cessation of pollution, remediation, rehabilitation, restoration, and other methods in line with scientific and technological advancements.

This article introduces technical terms such as *remediation*, which refers to the recovery of polluted environmental quality so that environmental standards improve. *Rehabilitation* is intended to restore environmental value and function, including the protection and repair of ecosystems. Meanwhile, *restoration* aims to return the environment to its original state so that it can fully perform its ecological functions. These provisions underscore that remediation is not merely an administrative responsibility, but also a moral and constitutional obligation.

Beyond Law No. 32 of 2009, the aspect of remediation is also emphasized in Law Number 6 of 2023 concerning Job Creation, which grants authority to the Central Government to compel business actors to carry out environmental remediation, including appointing third parties at the full expense of the responsible party. This provision opens the path for the state to take an active role in ensuring environmental recovery, including in the context of aluminum slag hazardous waste in Jombang.

A review of judicial practice in handling environmental pollution highlights the need for a more explicit remediation model. In the North Jakarta District Court Decision Number 735/Pdt.G-LH/2018/PN Jkt.Utr, for example, the panel of judges declared PT. HY responsible for water pollution in the Cihujung River due to the disposal of B3 waste from its textile production process. Although the company had a wastewater treatment facility, it was found that some waste was still being discharged through a bypass channel into the river. Laboratory tests showed the waste exceeded the quality standards. The court then sentenced the company to pay compensation of more than IDR 12 billion, based on the strict liability principle.[13]

Unfortunately, even though PT. HY was ordered to pay compensation, the decision did not explicitly stipulate that the compensation had to be used for environmental remediation. This demonstrates a gap in judicial practice, where ecological remediation is often sidelined in favor of financial compensation. Therefore, strengthening legal substance and judicial practice is necessary so that every compensation for pollution is directly allocated to concrete

[13] Mahkamah Agung Republik Indonesia, *Ikhtisar Putusan Nomor 25/PUUXV/2017 Tentang Tanggung Jawab Mutlak (Strict Liability) atas Terjadinya Ancaman Serius pada Lingkungan Hidup*, Mahkamah Agung Republik Indonesia, 2017.

environmental remediation efforts.

The fundamental principle of environmental remediation is to restore the function and quality of the environment to its original state. This applies to both public environments under state control and ecological areas affecting community livelihoods. Unfortunately, in practice, not all environmental damage can be fully restored. Nevertheless, the responsibility for remediation remains with the polluting party, in line with the *polluter pays principle*.

Environmental remediation, particularly concerning B3 waste such as aluminum slag, requires specific technologies and significant financial investment. In cases where the polluter is unable to finance the remediation, the state, through special mechanisms, can carry out the remediation using guarantee funds or through third parties. However, the financial burden must ultimately be charged back to the polluter. Therefore, a robust monitoring system, transparent liability tracking, and effective legal enforcement instruments are needed to ensure that environmental remediation is not just a legal ideal but a tangible reality that benefits society and the environment itself.[14]

Considering the complexity of managing B3 aluminum slag waste in Jombang, the ideal approach is to combine environmentally friendly technology-based remediation with strict law enforcement, community involvement in oversight, and affirmative policies that ensure industries are not only held accountable for pollution but also actively participate in reversing the damage they have caused. This model will ensure ecological justice and environmental sustainability for the future.[15]

CONCLUSION

First, the normative context in Indonesia—including Law No. 32 of 2009, Law No. 6 of 2023 (Job Creation Law), and Jombang Regency Regional Regulation No. 8 of 2017—emphasizes the obligation of environmental restoration by parties responsible for hazardous waste (B3) pollution. However, in practice, recovery instruments have not been optimally operationalized in Jombang. Second, key challenges on the ground include unintegrated industrial data (only 31 out of 96 aluminum slag small and medium industries [IKMs] are officially licensed), limited technical capacity and human resources at the Environmental Agency (DLH), and low public awareness and participation. Third, the case study of North Jakarta District Court Decision No. 735/Pdt.G-LH/2018/PN Jkt.Utr illustrates that compensation based on strict liability should be directed towards ecosystem restoration, rather than merely financial redress.

Fourth, the ideal recovery model in Jombang must integrate five main elements: (1) the establishment of an *Aluminum Slag Recovery Task Force* to align policy, location prioritization, and funding; (2) implementation of technical stages in accordance with Article 54 of Law No. 32 of 2009—cessation of pollutant sources, remediation (soil washing and solidification/stabilization), rehabilitation (phytoremediation and bioremediation), and restoration (riparian revegetation and monitoring for at least 12 months); (3) application of the "polluter pays" financing mechanism and placement of environmental guarantee funds in

[14] Dinas Lingkungan Hidup, *Dorong Percepatan Penyelesaian Limbah B3 Slag Aluminium di Jombang, DLH Jombang Gelar Rapat Koordinasi Pemerintah dan Dunia Usaha*, 30 April 2025, https://dlh.jombangkab.go.id/berita/dorong-percepatan-penyelesaian-limbah-b3-slag-aluminium-di-jombang-dlh-jombang-gelar-rapat-koordinasi-pemerintah-dan-dunia-usaha-12448, diakses pada 1 Mei 2025.

[15] Ainul Hafidz, *Pemerintah Beri Warning 22 Pelaku Usaha Slag Aluminium di Jombang, Jika Bandel Siap-siap Ditutup Paksa*, Radar Jombang, 3 September 2024, https://radarjombang.jawapos.com/politik-pemerintahan/665046596/pemerintah-beri-warning-22-pelaku-usaha-slag-aluminium-di-jombang-jika-bandel-siap-siap-ditutup-paksa

escrow accounts; (4) progressive law enforcement by Jombang DLH through administrative sanctions and technical assistance; and (5) public participation facilitated through the "One Map Jombang" GIS dashboard and village forums to monitor recovery progress. Fifth, incentive mechanisms (such as expedited licensing and technical subsidies) for compliant IKMs and firm sanctions for violators (including warnings and forced closure) serve as supporting instruments for environmentally sustainable business continuity. Accordingly, this model not only aims to restore degraded environmental functions but also to promote economic value from processed slag and enhance accountability in hazardous waste management governance in Jombang.

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