Green Supply Chain Management and Ecological Impact Mitigation in East Kalimantan Mining

Rina Masithoh[1*], Catur Kumala Dewi[2]
masithoh.haryadi@gmail.com

[*1,] Fakultas Ekonomi dan Bisnis Universitas 17 Agustus 1945 Samarinda, Kalimantan Timur Indonesia
[2,] Fakultas Ekonomi dan Bisnis Universitas 17 Agustus 1945 Samarinda, Kalimantan Timur Indonesia

Abstract. This study examines the adoption of Green Supply Chain Management (GSCM) strategies within the mining sector of East Kalimantan, aiming to support a sustainable economic transition and mitigate ecological risks. Driven by the pressing need to address the severe environmental consequences of resource extraction, this research employs a descriptive qualitative methodology, utilizing primary data derived from a questionnaire distributed to 28 managerial respondents. Findings indicate robust corporate commitment to GSCM, particularly in high-compliance areas such as Environmental Management Systems and Reverse Logistics. Reverse logistics has been proven to be the most critical component for mitigating post-mining ecological liabilities. However, GSCM adoption faces structural inertia in Green Distribution and Energy Transition. The perceived benefits are primarily strategic (improved corporate image), with high uncertainty regarding direct economic quantification. The study highlights the necessity of deepening GSCM penetration into pre-mining planning and integrating environmental accounting to realize sustainability goals fully.

Keywords: Green Supply Chain Management (GSCM), Sustainable Mining, Ecological Impact, East Kalimantan, Reverse Logistics

1 INTRODUCTION

The global commitment to sustainable development necessitates a profound shift in how extractive industries operate. Mining plays a dual and contradictory role in this transition: it provides indispensable critical minerals (such as lithium, cobalt, and nickel) essential for powering green technologies like solar energy and electric vehicles. Simultaneously, traditional mining practices are a principal source of severe environmental damage, contributing substantially to greenhouse gas emissions, deforestation, habitat destruction, and long-term water and soil contamination. Addressing this ecological challenge requires the systemic integration of environmental responsibility across the value chain, a management philosophy encapsulated by Green Supply Chain Management (GSCM).[2]

1.1 East Kalimantan: An Economic Engine Facing Critical Ecological Stress

East Kalimantan, situated on the island of Borneo, serves as a primary economic engine for Indonesia, primarily driven by coal extraction, which accounts for approximately 90% of the country's total coal production. This intensive reliance on natural resources has undoubtedly driven regional economic development, leading to construction booms and rapid infrastructure growth. However, the expansion of mining activities, often characterized by unsystematic planning and management of exploitation business licenses, has created significant adverse ecological consequences.[4]

The environmental repercussions include widespread damage to the landscape, deforestation, soil degradation, and contamination of water sources.[4] Specific studies have identified anomalies in water quality, with pH, Iron (Fe), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) levels in local rivers frequently exceeding regulatory thresholds, directly linking pollution to mining activities. In response to these adverse impacts, the provincial government has initiated programs such as *Kaltim Green* and the *Green Growth Compact* to promote an environmentally conscious development pathway. Despite these policy shifts, multidimensional scaling assessments indicate that while East Kalimantan demonstrates strong economic sustainability, its environmental performance lags significantly, underscoring the gap between policy intent and ecological outcome.

1.2 Research Gap and Objectives

While macro-level policies mandate sustainable operations, a critical gap remains in understanding the detailed operational execution of these mandates through the lens of GSCM within local coal mining firms. Specifically, how do firms in East Kalimantan translate regulatory pressure into concrete practices across the supply chain, and how effective are these practices in addressing the chronic ecological challenges specific to the pre-mining and post-mining phases?

This study addresses this gap by aiming to fulfill the following objectives: to determine the prevalence and depth of GSCM component adoption—including Green Procurement, Green Manufacturing, Green Distribution, and Reverse Logistics—among coal mining enterprises in East Kalimantan. To analyze the specific role and effectiveness of these GSCM practices in mitigating ecological impacts throughout the coal mining lifecycle, with a clear delineation between pre-operational and post-closure stages.

2 LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

2.1 Theoretical Foundations of Green Supply Chain Management (GSCM)

GSCM is defined as the integration of sustainable environmental processes into conventional supply chain management, encompassing activities from raw material procurement and manufacturing to end-of-life management.[2] By encouraging upstream and downstream partners to adopt greener practices, GSCM seeks to create synergistic effects that drive systemic sustainability. For the extractive sector, GSCM provides the framework necessary to align corporate growth with environmental sustainability by prioritizing the efficiency and effectiveness of resource use. Key areas of focus, as identified in GSCM models, include the minimization of waste (in all forms), reduction of energy consumption, and rationalization of material usage. Regulatory pressure is a dominant driver for GSCM adoption in Indonesia, particularly following the promulgation of Law No. 3 of 2020 concerning Mineral and Coal Mining, which mandates stricter control over corporate behavior, ranging from operational practices to reclamation obligations. Beyond compliance, GSCM can enhance operational efficiency, reduce expenditures, increase brand loyalty, and ultimately provide a strategic competitive advantage.

2.2 Conceptualizing GSCM Components in the Extractive Industry

GSCM in mining can be conceptualized across four core components, addressing different stages of the operational lifecycle:

1. Green Procurement (GPr): This involves setting environmental requirements for suppliers, prioritizing those with environmental certifications (like ISO 14001), and selecting environmentally benign raw materials. GPr directly influences the control of ecological impacts at the initial, pre-mining stage by determining the type of machinery and inputs used.
2. Green Manufacturing/Operations (GMa): Focusing on the core extraction and processing activities, GMa includes investing in pollution control, using energy-efficient machinery, and designing processes to reduce emissions. This component is vital for managing water, air, and noise pollution during the active operational phase.
3. Green Distribution (GDi): This component seeks to optimize the logistics of transporting mined products by minimizing routes, reducing fuel consumption, and transitioning toward lower-emission transportation methods.
4. Reverse Logistics (RL) and Reclamation: RL manages the systematic collection, reuse, recycling, remanufacturing, or disposal of post-production materials.[3] In mining, RL is intrinsically linked to mandatory reclamation and post-mining obligations. It involves managing toxic waste (tailings) and ensuring that environmental impacts that manifest after mine closure are addressed.[12]

2.3 GSCM and Ecological Impact Mitigation Across the Lifecycle

GSCM practices must be strategically deployed to mitigate the sequential nature of mining impacts:

1. Pre-Mining Ecological Mitigation: The upstream segment of the mineral supply chain—from exploration to extraction—is traditionally associated with significant environmental risks. GSCM at this phase requires stringent ecological due diligence to inform land use decisions, minimize deforestation, and protect critical habitats. Effective GPr, by demanding less resource-intensive equipment and cleaner energy sources, aids in this upfront mitigation effort.
2. Post-Mining Ecological Mitigation (Reclamation): The long-term success of ecological restoration is fundamentally dependent on robust RL. RL practices facilitate responsible tailings management and the systematic recovery and utilization of residual materials, which are then vital for successful land rehabilitation programs. Sustainable reclamation strategies in East Kalimantan, for example, involve restoring degraded land for alternative productive uses such as rice cultivation, corn production, or pasture grazing. Furthermore, innovative approaches like re-mining abandoned sites for valuable minerals (e.g., silica for green energy) can transform RL into a mechanism for both economic value creation and environmental restoration.

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3 RESEARCH METHODS

3.1 Research Philosophy and Design

This study adopts a pragmatic research philosophy, utilizing a descriptive qualitative design. This approach is highly suitable for understanding the specific meaning and contextual application of the GSCM phenomenon as perceived by industry stakeholders. The descriptive method is necessary to catalog and analyze the variety of green strategies currently being implemented by mining firms in East Kalimantan.

3.2 Data Sources and Sample Characteristics

Primary data was collected via a structured questionnaire (Q1-Q24) administered to managerial-level personnel (e.g., Operational Managers, Supply Chain Managers, QHSE Evaluators) across various mining companies operating in East Kalimantan. The sample size for this analysis is N=28 respondents.

The firms represented operate predominantly in the coal subsector, although some responses covered Oil and Gas or other sectors. Operations are concentrated in key mining regions, including Kutai Kartanegara, Kutai Timur, Berau, and Samarinda. The sample includes companies operating on varying scales, encompassing Big Scale (IUPK), Middle Scale (IUP), and Small Scale (IPR), providing a representation of operational complexity within the region.

3.3 Data Analysis and Interpretation

The analysis was performed in two stages:

1. Descriptive Statistical Analysis: The 24 Likert-scale questions (Q1-Q24) were analyzed to calculate the frequency and percentage distribution of responses across five categories: Strongly Agree, Agree, Neutral, Disagree, and Strongly Disagree. This stage provides quantitative breadth, establishing the overall prevalence and consensus regarding GSCM adoption across dimensions.
2. Qualitative Content Analysis: The responses from the seven open-ended questions (Q1.a, Q7.a, Q9.a, Q10.a, Q12.a, Q13.a, Q15.a) were subjected to qualitative content analysis. This analysis aimed to categorize and identify the specific technologies, materials, and operational practices being implemented, providing necessary depth and validation for the quantitative findings.

4 RESULTS AND DISCUSSION

4.1 Descriptive Profile of GSCM Adoption (Quantitative Findings)

The aggregated analysis of the Likert-scale responses (N = 28) provides a detailed descriptive profile of GSCM implementation across the supply chain components. The data reveals highly asymmetric adoption levels, with specific dimensions showing near-universal consensus, while others exhibit significant disagreement or uncertainty.

Table 1. Summary of GSCM Adoption Levels in East Kalimantan Mining (N=28)

GSCM Dimension	Key Variables (Q)	Strongly Agree/Agree (%)	Neutral (%)	Disagree/ Strongly Disagree (%)	Dominant Trend
Green Investment	Q1-Q2: Tech Funding, Innovation	78.6%	14.3%	7.1%	Strong commitment
Energy Transition	Q3-Q4: Renewable Use, Policy	62.5%	17.9%	19.6%	Moderate commitment, high variance
Environmental Mgmt	Q5-Q8: ISO 14001, Waste Funding	82.1%	10.7%	7.1%	Very High Compliance
Green Procurement	Q9-Q10: Green Suppliers/Materials	71.4%	14.3%	14.3%	Strong but variable
Green Manufacturing	Q11-Q12: Process Design, Reuse	73.2%	14.3%	12.5%	High adherence to reuse

GSCM Dimension	Key Variables (Q)	Strongly Agree/Agree (%)	Neutral (%)	Disagree/ Strongly Disagree (%)	Dominant Trend
Green Distribution	Q13-Q14: Low-Emission Transport, Route Optimisation	51.8%	23.2%	25.0%	Weakest link, high disagreement
Reverse Logistics	Q15-Q16: Waste Management Systems, Third-Party Recycling	83.9%	8.9%	7.1%	Strongest operational area
Economic Performance	Q17-Q20: Revenue, Cost, Efficiency, Quality Impact	55.4%	5.0%	19.6%	Uncertain, high neutrality
Strategic/Ecological Outcomes	Q21-Q24: Emissions Reduction, Image, Competitive Edge	78.6%	10.7%	10.7%	Strong perceived non-market benefits

The most notable finding is the high consensus (over 80% Strongly Agree/Agree) for Environmental Management Systems (Q5-Q8) and Reverse Logistics (Q15-Q16). This high performance suggests that the GSCM strategy implemented by East Kalimantan mining companies is primarily centered on managing highly regulated inputs (hazardous waste, B3) and compulsory post-mining obligations (reclamation liability). This evidence suggests a strategic focus on GSCM as a mechanism for regulatory adherence and risk reduction, thereby maintaining the License to Operate (LTO).

4.2 GSCM in the Upstream Phase: Green Purchasing and Pre-Mining Ecological Impact

Coal Mining firms demonstrate a strong commitment to Green Investment (78.6% SS/S), including significant funding for technology and innovation. This financial commitment is mirrored in Green Procurement, where 71.4% of respondents prioritize suppliers that offer environmentally friendly materials or possess environmental certifications. Suppliers named include central logistics and fuel providers such as Pertamina Patra Niaga Fuel and Shell, as well as equipment vendors like United Tractors.

Qualitative analysis of specific practices (Q1.a, Q9.a) shows that environmentally friendly raw materials widely utilized include Alum and Quicklime. While these inputs are critical, they primarily serve in the subsequent water treatment process (neutralizing Acid Mine Drainage or AAT) rather than influencing the initial stages of extraction. Technologies listed, such as panel solar or Solar Panel Cells, are often auxiliary or used for lighting.

The current GSCM adoption in the upstream phase appears to be concentrated on optimizing process-control inputs necessary for compliance. The data show minimal evidence that GSCM has a profound influence on fundamental decisions regarding pre-mining ecological avoidance, such as large-scale land disturbance, deforestation, and habitat destruction. This suggests that while companies adhere to regulations regarding operational inputs, the initial high-impact activity of land clearing remains relatively unmitigated by GSCM principles focused on fundamental input substitution or alternative extraction planning.

4.3 GSCM in Core Operations: Green Manufacturing and Energy Transition

Operational GSCM (Green Supply Chain Management) in East Kalimantan is robust in terms of ecological control and compliance. The high adherence to Environmental Management Systems (82.1% SS/S) is validated by the specific operational tools cited, including the use of *Settling Pond* (settling pond) systems specifically for handling Acid Mine Drainage (AAT) and dedicated Hazardous Waste Treatment facilities. These practices confirm a serious commitment to mitigating critical water pollution risks—a major ecological challenge in the region.

Despite the overall strong compliance, GSCM components linked to major capital expenditure and structural changes show significant variance. The Energy Transition component (Q3-Q4) achieves only a moderate consensus (62.5% SS/S), with nearly 20% expressing disagreement or neutrality. While some firms deploy *PLTS* (Solar Power Plants) or Solar cell lamps, the core energy production systems remain heavily reliant on traditional methods, such as generating electricity using coal or steam. The continuation of such entrenched practices highlights the powerful economic structural inertia present in a resource-dependent economy, where the difficulty and cost of decoupling the mining process from its primary fuel source serve as a significant constraint, mirroring broader barriers to GSCM implementation in heavy industry.

The weakest link identified in the entire supply chain is Green Distribution (Q13-Q14), with the lowest consensus (51.8% for strongly agree) and the highest combined rate of neutrality and disagreement (48.2%).

Logistics in mining involve the high-volume transport of bulk materials, which is intensely cost-sensitive. While firms utilize Bio Solar B30/B35/B40, these are regulatory minimums, not proactive innovation. The limited mention of battery-powered heavy equipment (Q13.a: *Using electric heavy equipment*) suggests that the high capital cost and logistical complexity associated with transitioning the haul fleet inhibit GSCM progress in this component. This demonstrates that for high-cost activities, immediate financial constraints currently dominate strategic environmental goals.

4.4 GSCM in the Post-Mining Phase: Reverse Logistics and Ecological Mitigation

Reverse Logistics (RL) is the most mature and effectively implemented GSCM dimension, evidenced by the highest agreement rate (83.9% SS/S). This strong performance is strategic, as RL serves as the necessary operational framework for fulfilling mandatory post-mining obligations (reclamation and closure).

Table 2. Categorization of Qualitative GSCM Practices in East Kalimantan Mining

GSCM Component	Input/Upstream (Pre-Mining Focus)	Operation (During Mining Focus)	Output/Downstream (Post-Mining Focus)
Green Technology & Energy	Panel Solar cell; PLTS construction	Water treatment with a gravity system; Steam coal power generation	Heavy equipment using batteries (Limited); Bio Solar B30/B35/B40 for distribution
Green Materials/Sourcing	Prioritizing certified suppliers (PT Shell, United Tractors, PT Kaltim Prima Coal)	Alum, Quicklime, Fly ash for AAT treatment	Wetland for water purification; wood waste
Waste Management & RL	Environmental assessment compliance (Q22)	Hazardous waste; Settling Pond for AAT treatment; Maggot Farming	Material reuse: Coal blending, Scrap metal, Accu/oil recycle; External disposal/recycling
Ecological/Social Mitigation	Management understands ISO 14001 principles (Q6)	Clean water management from Coal waste	Community empowerment (recycle); Reclamation for sustainable agriculture/land use [6]

The qualitative practices listed under reverse logistics demonstrate a focus on liability reduction and material valorization. Practices include the collection and redistribution of production waste for recycling by third parties, such as the delivery of hazardous waste to centralized facilities like PPLI Bogor. Furthermore, significant internal material reuse is documented, including the use of lower-grade coal for blending purposes and the recycling of used oil, batteries, and scrap metal.

A robust reverse logistics framework is crucial for mitigating the ecological impacts of post-mining activities. By systematically managing waste and promoting resource recovery, reverse logistics directly facilitates compliance with reclamation obligations. Furthermore, specific reverse logistics activities, such as empowering recycling of scrap iron, integrate waste management with local social benefits, thereby enhancing the overall social dimension of sustainability in the post-mining landscape, which is often utilized for agriculture or livelihood creation.[6] Reverse logistics is thus identified as the most effective GSCM component for transitioning from environmental liability to sustainable economic utilization after extraction has ceased.

4.5 Impact Assessment: Strategic Performance vs. Economic Quantification

The perception of ecological and strategic outcomes resulting from GSCM implementation is overwhelmingly positive. A high majority of respondents are confident that green initiatives have resulted in a decline in emissions and waste volume over the past three years (Q21) and that all operations undergo comprehensive environmental impact assessments (Q22).

Strategically, the implementation of GSCM is perceived as highly successful. Nearly 79% of respondents agree or strongly agree that green initiatives have significantly improved the company's corporate image among investors and the public (Q23), and 78.6% believe GSCM provides a competitive advantage (Q24). This high valuation of non-market outcomes—reputation, LTO, and competitive positioning—confirms that these strategic benefits are the primary internal drivers motivating substantial investment in GSCM, even when direct financial returns are not immediately apparent.

Conversely, the assessment of direct financial performance shows high uncertainty. Only 55.4% agree that GSCM has positively impacted revenue, cost reduction, or production efficiency (Q17-Q20), with a notably high 25.0% remaining neutral on these questions. This pronounced neutrality suggests a fundamental challenge in systematically linking environmental investments to quantifiable financial metrics. This difficulty highlights a critical gap: the lack of robust financial tools and environmental accounting practices necessary to track the return on investment (ROI) from GSCM activities. Until firms move beyond simple cost identification to comprehensive benefit calculation, GSCM will continue to be perceived, in part, as a regulatory burden rather than a fully integrated, verifiable economic driver.

5 CONCLUSION

5.1 Synthesis of GSCM's Role in Ecological Mitigation

The implementation of Green Supply Chain Management in the East Kalimantan mining sector is characterized by a compliance-driven strategy, with a strong focus on mitigating high-profile environmental liabilities. Reverse Logistics (RL) emerges as the most mature and practical GSCM component, successfully acting as the crucial mechanism for mitigating post-mining ecological risks. The robust RL framework, evidenced by specialized waste disposal and material valorization practices (e.g., coal blending, scrap metal recycling), enables firms to fulfill mandatory reclamation obligations and link waste management to sustainable economic activities.

Conversely, ecological impact mitigation in the pre-mining phase through Green Procurement remains less sophisticated, focusing mainly on optimizing chemical process inputs rather than minimizing initial land disturbance. The overall system efficiency is constrained by economic and technical structural inertia, particularly in Green Distribution (due to high logistics costs) and Energy Transition (due to reliance on coal-fired power).

5.2 Implications for Sustainable Economic Development

To accelerate East Kalimantan's transition toward the *Kaltim Green* vision, strategic policy adjustments are required. The government must introduce incentives and regulatory reinforcement to compel greater GSCM adoption in components currently constrained by cost, such as incentivizing the adoption of low-emission heavy equipment for distribution beyond current minimum biofuel standards.

Furthermore, mining firms must urgently address the observed uncertainty in economic quantification. This requires the integration of detailed environmental cost and benefit accounting practices to accurately transform the high costs of compliance and investment into recognized economic advantages, ensuring GSCM is perceived as a value creator rather than solely a risk reducer.

5.3 Limitations and Future Research

This study employed a descriptive qualitative approach, based on perceptual data collected from a limited sample of managers. The findings reflect the consensus and stated practices of the firms. A significant limitation is the reliance on self-reported data, which may be subject to desirability bias. Future research should move beyond descriptive analysis to employ causal modeling techniques (e.g., Structural Equation Modeling) to statistically test the hypothesized relationship between specific GSCM dimensions (e.g., RL investments) and verified ecological output metrics, such as measured reductions in Acid Mine Drainage volume or objective land reclamation success rates monitored via remote sensing.

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