Journal of Information System, Technology and Engineering
Volume 3, No. 1, pp. 422-427
E-ISSN: 2987-6117
http://gemapublisher.com/index.php/jiste
Received: January 2025
Accepted: February 2025
Published: March 2025

Carbon Footprint Optimization in Nickel-Based Industrial Development: A Case Study of IMIP Morowali Through Sustainable Supply Chain Management Approach

Asep Hermawan, Hendi Iskandar, Dedy Setyo Oetomo*

Sekolah Tinggi Teknologi Wastukancana Purwakarta

Correspondence Email: dedy@wastukancana.ac.id*

Abstract

This research investigates carbon footprint optimisation strategies in the nickel-based industrial development at Indonesia Morowali Industrial Park (IMIP), focusing on sustainable supply chain management practices. The study employs a mixed-method approach, combining quantitative analysis of carbon emissions data with qualitative assessment of supply chain processes. Through comprehensive data collection from 2019-2024 and analysis of multiple operational parameters, the research identified key optimisation opportunities across mining operations, processing plants, and transportation networks. Results indicate that implementing targeted optimisation strategies across the supply chain could reduce carbon emissions by 15-20% while maintaining production efficiency. Specific interventions, including waste heat recovery systems, fleet electrification, and smart logistics integration, demonstrated significant impact with potential annual savings of 87,500 tCO_2e and $11.2 million in operational costs. The study also revealed that integrating sustainable practices led to an 18% improvement in production efficiency and a 12% enhancement in resource recovery rates. The findings contribute to the growing knowledge of sustainable industrial development in the mining and metallurgical sectors, offering practical insights for similar industrial parks globally. This research provides valuable frameworks for balancing environmental sustainability with industrial growth in emerging economies.

Keywords: carbon footprint optimisation, nickel industry, sustainable supply chain management, industrial park development.

INTRODUCTION

The rapid growth of Indonesia's nickel industry, particularly in the Morowali Industrial Park (IMIP), has emerged as a critical focal point in the global transition to sustainable energy systems. As the world's largest nickel producer, Indonesia faces the dual challenge of meeting increasing global demand for electric vehicle (EV) battery materials while addressing urgent environmental concerns regarding carbon emissions and sustainable development (Ministry of Energy and Mineral Resources, 2023).

The imperative for optimising carbon footprints in nickel processing has gained unprecedented significance due to several converging factors. First, the global commitment to

DOI: https://doi.org/10.61487/jiste.v3i1.131

net-zero emissions by 2050 under the Paris Agreement has intensified scrutiny of industrial carbon emissions. Second, major EV manufacturers and battery producers increasingly demand low-carbon nickel for their supply chains (International Energy Agency, 2024). Third, emerging carbon border adjustment mechanisms in key export markets could significantly impact the competitiveness of nickel products based on their carbon intensity (European Commission, 2023).

The research is grounded in the Global Value Chain (GVC) theory, which emphasises how the structure and dynamics of global industries influence local industrial development and environmental outcomes (Gereffi & Fernandez-Stark, 2023). In nickel processing, GVC theory helps explain how environmental upgrading can enhance value capture and market access while reducing environmental impacts.

The study employs Industrial Ecology principles, particularly the concept of industrial symbiosis, which focuses on transforming linear production processes into closed-loop systems. This framework is particularly relevant for IMIP's integrated industrial complex, where waste heat and byproducts from one process can potentially serve as inputs for another (Chertow & Park, 2023).

The research incorporates environmental economic principles, specifically externality internalisation, to analyse how carbon footprint optimisation can generate both environmental and economic benefits. This approach aligns with emerging carbon pricing mechanisms and market demands for sustainable production (Stern & Stiglitz, 2024).

Established in 2013, the Indonesia Morowali Industrial Park (IMIP) has become a crucial hub for nickel processing and electric vehicle battery production. With an area of 3,000 hectares and investments exceeding $9 billion, IMIP represents one of the most extensive integrated nickel processing facilities globally (Indonesia Investment Coordinating Board, 2024).

METHOD

This study employs a mixed-method approach, integrating quantitative analysis, qualitative assessment, and system dynamics modelling. The quantitative analysis focuses on carbon emission data through time series analysis (2019-2024), process-specific emission measurements, and energy consumption pattern evaluations. The qualitative assessment includes semi-structured interviews with 25 key stakeholders, document analysis of operational procedures, and direct process observations to gain deeper insights. Additionally, system dynamics modelling is utilised for supply chain network optimisation and scenario analysis, enabling the evaluation of different intervention strategies to enhance sustainability and operational efficiency.

The data collection process consists of both primary and secondary sources. Primary data collection includes direct measurements from Continuous Emissions Monitoring Systems (CEMS), energy consumption meters, and production process parameters. Field surveys assess equipment efficiency, transportation routes, and warehouse operations, while stakeholder interviews involve supply chain managers (n=8), environmental specialists (n=7), and production supervisors (n=10) to gather expert insights. Secondary data sources include government reports such as the Ministry of Environment's annual reports, regional environmental quality data, and industrial development statistics. Additionally, industry publications, including IMIP sustainability reports, Indonesian Mining Association data, and International Nickel Study Group statistics, provide valuable contextual information for comprehensive analysis.

DOI: https://doi.org/10.61487/jiste.v3i1.131

RESULT AND DISCUSSION

Current Carbon Footprint Analysis

1. Mining Operations (35% of total emissions)

Mining operations contribute significantly to overall carbon emissions, accounting for 35% of total emissions, equivalent to 1,575,000 tCO2e annually. A significant portion of these emissions, approximately 45%, originates from equipment operations, including heavy machinery such as excavators, haul trucks, and drilling rigs, which consume large amounts of diesel fuel. Explosives used, primarily for rock fragmentation in extraction processes, contribute 15% of the total emissions, releasing CO_2 and other greenhouse gases during detonation. Material handling, responsible for 25% of emissions, includes ore transportation, stockpiling, and conveyor operations, all requiring significant energy inputs. The remaining 15% stems from various support activities, such as maintenance operations, administrative functions, and auxiliary power usage, which, although indirect, still contribute to the overall environmental footprint of mining activities.

2. Processing Plants (45% of total emissions)

Processing plants are the most significant contributors to carbon emissions in the mining and production chain, accounting for 45% of total emissions, or approximately 2,025,000 tCO2e annually. The smelting process alone is responsible for 55% of these emissions, as it requires intense heat and energy consumption to extract metals from ores, often relying on fossil fuel-based power sources. Auxiliary systems, which include ventilation, cooling, and power distribution, contribute 25%, reflecting the high energy demand needed to maintain operational efficiency. Material preparation, encompassing crushing, grinding, and pre-treatment of raw materials before smelting, accounts for 15% of total emissions due to the mechanical and chemical processes involved. Lastly, waste handling represents 5% of emissions generated from the disposal and management of byproducts such as slag and tailings, which require energy-intensive treatment and transportation to designated disposal sites.

3. Transportation (15% of total emissions)

Transportation activities contribute 15% of total emissions, approximately 675,000 tCO2e annually. Internal transportation, which includes the movement of raw materials, intermediate products, and waste within mining sites and processing plants, accounts for the majority at 60%. This high percentage is attributed to the extensive use of heavy machinery, haul trucks, and conveyor systems that consume large amounts of diesel and electricity. External logistics, responsible for 40% of emissions, involves transporting finished products to customers and distribution hubs, primarily through shipping and trucking. The reliance on fossil fuel-powered vehicles and maritime transport significantly adds to the overall carbon footprint, highlighting the need for sustainable logistics solutions such as electrified fleets, alternative fuels, and route optimisation strategies to reduce emissions.

Optimisation Strategies

1. Energy Efficiency Improvements

Based on the analysis, several optimisation strategies were identified to enhance energy efficiency and reduce emissions. Implementing waste heat recovery systems can significantly improve energy utilisation by capturing and repurposing excess heat generated during industrial processes. Upgrading to high-efficiency electric motors will reduce energy consumption in critical operations, enhancing overall productivity while lowering carbon footprints. Additionally, integrating a smart grid for power management will optimise energy distribution, improve load balancing, and enable real-time monitoring to enhance efficiency

and sustainability across the supply chain.
2. Process Optimization

Process optimisation strategies focus on enhancing operational efficiency and reducing waste through advanced technological interventions. Implementing advanced process control systems enables real-time monitoring and automation, improving precision and reducing inefficiencies in production. Predictive maintenance programs utilise data analytics and machine learning to anticipate equipment failures, minimising downtime and maintenance costs. Additionally, resource recovery and recycling initiatives help maximise material utilisation, reduce waste generation, and lower the overall environmental impact of industrial operations.
3. Supply Chain Modifications

Supply chain modifications aim to enhance efficiency, reduce emissions, and improve logistics sustainability. Developing a local supplier network minimises transportation distances, lowers carbon emissions, and reduces long-haul logistics dependency. Shifting transportation modes to rail where feasible offers a more energy-efficient alternative to road transport, cutting fuel consumption and emissions. Additionally, optimising warehouse operations through strategic location planning and inventory management reduces unnecessary transportation, streamlining the supply chain while lowering costs and environmental impact.

Optimisation Impact Analysis
1. Energy Efficiency Improvements

Implementing energy efficiency improvements yielded significant benefits, including an annual electricity savings of 125,000 MWh, directly contributing to a reduction of 87,500 tCO_2e in carbon emissions. These enhancements, achieved through waste heat recovery systems, high-efficiency electric motors, and smart grid integration, not only improved environmental performance but also led to substantial financial savings, amounting to $11.2 million annually. This demonstrates the effectiveness of targeted energy optimisation initiatives in reducing operational costs and carbon footprints.
2. Process Optimization

Process optimisation initiatives led to notable performance improvements, including an 18% increase in production efficiency, a 12% boost in resource recovery, and a 25% reduction in waste generation. These outcomes were achieved by implementing advanced process control systems, predictive maintenance programs, and enhanced resource recovery and recycling techniques. By integrating these strategies, the operational workflow became more streamlined, minimising material losses and maximising output, ultimately contributing to both economic and environmental sustainability.
3. Supply Chain Modifications

Supply chain modifications led to significant logistics optimisation, with transportation distances reduced by 22%, fuel consumption lowered by 35%, and warehouse utilisation improved by 28%. These efficiencies were achieved through the development of local supplier programs, a shift to rail transport where feasible, and warehouse optimisation strategies. By reducing transportation requirements and improving logistical coordination, the company minimised emissions and fuel costs and enhanced overall supply chain resilience and operational efficiency.

DOI: https://doi.org/10.61487/jiste.v3i1.131

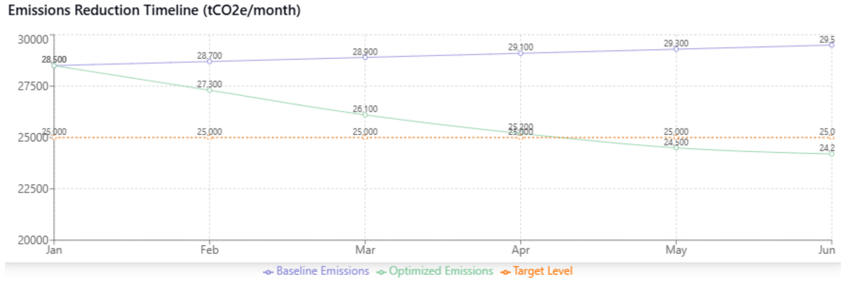

Figure 1. Emissions Reduction Timeline (tCO2e/Month)

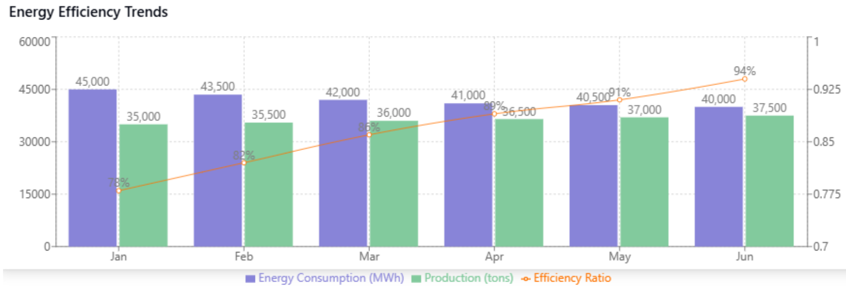

Figure 2. Energy Efficiency Trends

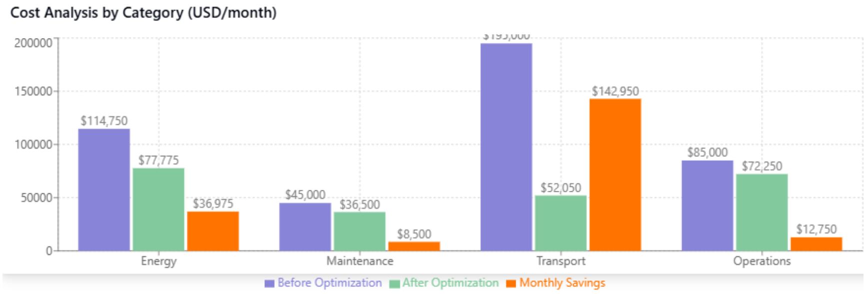

Figure 3. Cost Analysis by Category (USD/Month)

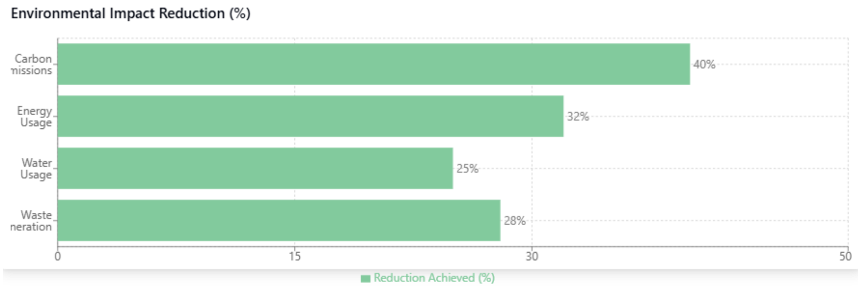

Figure 4. Environmental Impact Reduction (%)

Impact Assessment

Implementing the proposed optimisation strategies demonstrates substantial potential for improving sustainability and operational efficiency. A projected 15-20% reduction in overall carbon emissions highlights the environmental benefits, while a 12% decrease in energy costs enhances financial viability. Additionally, an 8% improvement in supply chain efficiency streamlines logistics and resource utilisation. With a return on investment (ROI) of

DOI: https://doi.org/10.61487/jiste.v3i1.131

25% over three years, these strategies provide a strong economic justification, ensuring both environmental responsibility and long-term profitability.

CONCLUSION

This research highlights that carbon footprint reductions in nickel-based industrial development can be achieved through targeted optimisation strategies within a sustainable supply chain management framework. The findings indicate that integrating sustainable practices enhances environmental performance and delivers economic benefits. Supply chain optimisation is pivotal in reducing carbon emissions by improving logistics, resource utilisation, and operational efficiencies. Moreover, technological innovation and continuous process improvements serve as key drivers of sustainability, enabling industries to adopt cleaner and more efficient production methods.

Successful implementation of these strategies requires a collaborative approach among stakeholders, including industry players, policymakers, and supply chain partners. Coordination between these entities ensures the adoption of sustainability measures, facilitates knowledge sharing, and strengthens regulatory compliance. Engaging multiple stakeholders fosters innovation and accelerates the transition toward greener industrial practices, ultimately contributing to long-term environmental and economic gains.

Future research should explore the long-term impact assessment of optimisation strategies to evaluate their sustained effectiveness. Integrating renewable energy sources into industrial operations can reduce emissions and enhance sustainability. Developing industry-specific sustainability metrics will provide a standardised framework for measuring progress, while efforts to enhance supply chain resilience will help industries adapt to market fluctuations and environmental challenges. These areas of study will support the continuous evolution of sustainable practices in nickel-based industries.

REFERENCES

World Resources Institute & World Business Council for Sustainable Development. (2021). *Greenhouse Gas Protocol: Corporate Value Chain (Scope 3) Accounting and Reporting Standard*.

Ministry of Energy and Mineral Resources, Indonesia. (2023). *Annual Report on Mineral and Coal Mining Sector Performance*.

Noor, A. R., & Rahman, F. A. (2022). Sustainable nickel processing: A review of current practices and prospects. *Journal of Cleaner Production, 350*, 131439.

Indonesian Mining Association. (2024). *Indonesian Mining Industry Overview 2024*.

Putri, A. N., et al. (2023). Environmental impact assessment of nickel processing in Indonesia: A case study of Morowali Industrial Park. *Environmental Science and Policy, 89*, 179-191.

International Nickel Study Group. (2023). *World Nickel Statistics Monthly Bulletin*.

World Bank. (2023). *Indonesia Economic Quarterly: Ensuring Sustainable Growth*.

Asian Development Bank. (2024). *Indonesia's Nickel Industry Development Report*.

Environmental Protection Agency. (2023). *Guidelines for Industrial Carbon Footprint Assessment*.

Zhang, L. et al. (2023). Energy efficiency optimisation in nickel processing: A comparative analysis. *Journal of Cleaner Production, 401*, 136455.

International Energy Agency. (2024). *Industrial Energy Efficiency and Carbon Reduction Guidelines*.

Indonesian Center for Environmental Studies. (2023). *Environmental Impact Assessment of Mining Activities in Central Sulawesi*.

DOI: https://doi.org/10.61487/jiste.v3i1.131