

Economic Evaluation of Cobalt and Iron Pricing in Lateritic Nickel Ore Sales Based on Forecasted Benchmark Mineral Prices (Period II April-Period II July 2026)

Original Article

Marwan Zam Mili^{1*}, Muhammad Ilham Kadar²

^{1,2}Department of Mining Engineering, Faculty of Mathematics and Natural Sciences, Universitas Halu Oleo, Indonesia

Email: ¹⁾ marwanzm@uho.ac.id

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Abstract

The pricing of lateritic nickel ore in Indonesia has traditionally been based on nickel (Ni) content alone, neglecting associated elements such as cobalt (Co) and iron (Fe), which may lead to undervaluation. This study aims to evaluate the economic impact of incorporating cobalt and iron in lateritic nickel ore pricing based on forecasted Benchmark Mineral Prices (HPM). Secondary data comprising Benchmark Mineral Reference Prices (HMA) for nickel, cobalt, and iron from Period I of May 2025 to Period I of April 2026 were utilized. Price forecasting employed the Moving Average method of order 2, selected based on the lowest Mean Squared Error (MSE), projecting prices from Period II of April to Period II of July 2026. A comparative approach between existing and proposed pricing schemes was applied. Results show that incorporating cobalt and iron significantly increases ore value, with the limonite layer rising from \$21/ton to \$85/ton and the saprolite layer from \$47/ton to \$70-75/ton. Based on volumes of 3.8 million wmt (limonite) and 3.62 million wmt (saprolite), nickel's economic potential reaches USD 60,211,426 (IDR 957,537,484,403) and USD 103,792,752 (IDR 1,650,607,831,636) respectively, while cobalt contributes USD 19,550,965 (IDR 310,917,430,537) and USD 1,978,843 (IDR 31,469,375,560). These findings confirm that a comprehensive pricing scheme encompassing all mineral constituents is essential for improving valuation accuracy and supporting equitable mineral pricing policies.

Keywords: Cobalt, Economic Evaluation, Iron, Lateritic Nickel Ore.

1. Introduction

Indonesia is one of the world's largest nickel producers, with abundant laterite nickel ore reserves, particularly in the Sulawesi and Maluku regions (Tamehe et al., 2024). In current sales practices, laterite nickel ore is generally valued based on its nickel (Ni) content as the primary commodity, referring to the Mineral Benchmark Price (*Harga Patokan Mineral/HPM*) mechanism established by the Ministry of Energy and Mineral Resources (KESDM, 2020). However, laterite nickel ore also contains associated elements with significant economic value, such as cobalt (Co) and iron (Fe), which have not yet been fully incorporated into the existing pricing scheme. Therefore, the integration of by-product minerals into the HPM framework is vital from a policy perspective, as emphasized by the Organization for Economic Co-operation and Development and the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (OECD & IGF, 2024), which state that government revenue depends on accurate pricing and measurement of mineral products, highlighting the importance of transparent and comprehensive mineral valuation.



In terms of utilization, cobalt is a strategic mineral that plays a crucial role in the development of the electric vehicle battery industry (Arif, 2018), particularly as a key material in lithium-ion battery cathodes. Meanwhile, nickel and iron also play important roles in the base metals industry, especially in the production of stainless steel, batteries, and corrosion-resistant alloys that form the backbone of various manufacturing sectors (UNCTAD, 2004). According to the International Energy Agency (2022), the rapid growth of the electric vehicle industry has significantly increased demand for critical minerals, including nickel and cobalt. The U.S. Geological Survey (2023) further emphasizes Indonesia's position as the world's largest nickel producer, indicating that optimizing the valuation of all associated elements, including iron, is increasingly important to maximize the economic value of mineral resources. The failure to account for Co and Fe in nickel ore transactions may lead to undervaluation, where the selling price does not reflect the total mineral content. This highlights a gap between current pricing practices and the actual economic potential of laterite nickel ore.

On the other hand, fluctuations in mineral commodity prices in global markets require an analytical approach to price forecasting as a basis for economic decision-making. Regression and moving average methods are among the approaches that can be used to predict price trends based on historical data, with accuracy evaluated using the Mean Squared Error (MSE) indicator (Gujarati & Porter, 2009). Through this approach, price forecasts for nickel, cobalt, and iron can serve as a basis for evaluating the implementation of a more comprehensive pricing scheme.

Based on these conditions, this study addresses several key questions: how the forecasted prices of nickel, cobalt, and iron will behave in the upcoming period, the accuracy level of the applied model, and the extent to which the inclusion of cobalt and iron pricing affects the selling value of laterite nickel ore. Therefore, this research is directed at evaluating the economic feasibility of incorporating cobalt and iron pricing in laterite nickel ore sales, based on Mineral Benchmark Price (HPM) forecasts for Period II of April to Period II of July 2026. This study aims to analyze price forecasts for each commodity using regression and moving average methods, evaluate model accuracy, and assess changes in the selling value per ton of laterite nickel ore before and after the inclusion of cobalt and iron pricing. Thus, the results of this study are expected to provide a quantitative assessment of the potential increase in the economic value of nickel ore, as well as serve as a basis for developing a fairer, more transparent, and more comprehensive pricing policy that reflects the full mineral content of laterite nickel ore.

2. Literature Review

Mineral pricing constitutes a strategic instrument in mining sector governance, as it directly determines government revenue and the efficiency of resource utilization. OECD and IGF emphasize that the accuracy of mineral pricing and measurement is critical, as government revenue depends heavily on properly valued and quantified mineral production (OECD & IGF, 2024). In the Indonesian context, the Mineral Benchmark Price (HPM) policy is regulated under Law No. 3 of 2020 and Minister of Energy and Mineral Resources Regulation No. 11 of 2020, which mandate that mineral pricing should be based on market mechanisms and measurable parameters. However, current HPM implementation primarily focuses on main commodities such as nickel and does not explicitly incorporate the economic value of by-product minerals such as cobalt (Co) and iron (Fe).

From a geological and metallurgical perspective, laterite nickel ore is a multi-component system containing several economically valuable elements. Studies by Dalvi et al. (2004) and

Crundwell et al. (2011) demonstrate that, in addition to nickel, Fe and Co contents significantly influence both the economic value of the ore and processing performance. Cobalt, in particular, has become increasingly strategic due to the growing global demand for electric vehicle batteries. Research by Dias et al. (2018) and Msumange et al. (2026) highlights that cobalt is classified as a critical mineral with high price volatility and a crucial role in the global energy transition. Therefore, excluding cobalt from pricing frameworks such as HPM may lead to economic value distortion. On the other hand, iron (Fe), which dominates the limonite zone, is often treated as a non-economic component in ore transactions, despite its substantial role in processing, particularly in High Pressure Acid Leaching (HPAL) technology. Crundwell et al. (2011) show that iron content affects process efficiency and metal distribution in final products. This indicates that iron possesses implicit economic value that has not been fully internalized in ore pricing mechanisms.

From a mineral economics perspective, Mudd (2010) argues that resource value optimization must consider all valuable components within a deposit rather than focusing solely on the primary commodity. This aligns with the concepts of resource efficiency and sustainable mining, which emphasize comprehensive resource utilization. Consequently, the exclusion of by-product minerals from pricing systems such as HPM may result in undervaluation and lost potential government revenue. Furthermore, the high volatility of global mineral prices necessitates adaptive and predictive pricing approaches. Humphreys (2010) and Tilton & Guzmán (2016) stress that mineral pricing policies must account for global market fluctuations to maintain competitiveness and revenue stability. In this regard, price forecasting plays a crucial role. Scarciuffolo & Etienne (2021) demonstrate that time series and machine learning approaches can significantly improve the accuracy of commodity price predictions. However, most existing studies focus on primary commodities and do not integrate by-product minerals into valuation models.

The research gap identified lies in the absence of a comprehensive approach that integrates the economic value of by-product minerals such as Fe and Co into official pricing frameworks like HPM, particularly based on short-term price forecasting. In addition, empirical studies evaluating the economic impact of pricing by-product minerals in laterite nickel ore transactions remain limited, especially in the context of Indonesia as one of the world's largest nickel producers. Hence, this study is essential to address this gap by evaluating the economic implications of imposing prices on cobalt and iron in laterite nickel ore sales based on the predicted Mineral Benchmark Price for the period from the second half of April to the second half of July 2026. This approach is expected to contribute to the development of a more comprehensive, transparent, and value-optimized mineral pricing policy.

3. Methods

This research is a quantitative study with a descriptive-analytical approach aimed at evaluating the economic feasibility of imposing cobalt and iron prices in laterite nickel ore sales. The quantitative approach is used to process commodity price data and conduct price forecasting using regression and moving average methods, while the descriptive approach is used to describe the existing conditions of nickel ore price determination and evaluate changes in selling value resulting from the imposition of by-product element prices.

The data used in this research is secondary data in the form of Metal Mineral Reference Prices (*Harga Mineral Acuan/HMA*) for nickel, cobalt, and iron commodities established by the Ministry of Energy and Mineral Resources (ESDM). HMA is an indicator of metal mineral prices compiled periodically based on developments in international market prices, and is

used as a basis for establishing the Mineral Benchmark Price (HPM) which serves as a reference in metal mineral sales transactions in Indonesia (Ministry of ESDM, 2020). The determination of HMA refers to the average price from various global references such as the London Metal Exchange (LME), London Bullion Market Association (LBMA), and Asian Metal, thereby reflecting actual international market conditions (USGS, 2023).

The price data used covers Period I and II of May 2025 through Period I of April 2026, and was accessed through the official publication of the Ministry of ESDM on April 11, 2026. This data range was selected to capture the most recent relevant price trends as a basis for the price forecasting process for Period II of April through Period II of July 2026. This research does not use production data because the analysis is focused on the selling value of laterite nickel ore in units per ton.

Data collection was carried out through literature study and documentation methods, namely by examining various reference sources such as government regulations, official reports, and scientific literature relevant to the research topic. The collected data was then processed for quantitative analysis purposes. The analytical methods in this research include price forecasting, model accuracy testing, selling price determination, and economic analysis. Price forecasting for nickel, cobalt, and iron was conducted using regression and moving average methods. The regression or moving average method is capable of systematically describing price change trends and providing price estimates for future periods (Gujarati & Porter, 2009). The forecasting results are used to predict prices for Period II of April through Period II of July 2026.

To measure the accuracy level of the regression and moving average models used, testing was conducted using the Mean Squared Error (MSE) indicator, which shows the average squared difference between actual and predicted values. A smaller MSE value indicates a lower error rate and better model accuracy (Gujarati & Porter, 2009). The price prediction results were then used as a basis for determining the selling price of each commodity with reference to the Mineral Benchmark Price (HPM) mechanism. The selling price is calculated in units per ton for each commodity, namely nickel, cobalt, and iron, so that it can be used in comparative economic value analysis.

Economic analysis was done by comparing two laterite nickel ore sales scenarios, namely the existing scenario and the proposed scenario. In the existing scenario, the price of nickel ore is only based on nickel content, while in the proposed scenario, the price of nickel ore is calculated by considering the content of nickel, cobalt, and iron. Evaluation was performed by comparing the selling value per ton of ore before and after the imposition of cobalt and iron prices. The resulting difference in selling value becomes the main indicator in assessing the increase in economic value resulting from the application of an in-depth pricing model.

To maintain focus and consistency of analysis, this research has several limitations, namely it only covers the commodities of nickel, cobalt, and iron, does not consider aspects of production, processing, or transportation costs, and only focuses on the selling value of ore in units per ton. In addition, the forecasting methods used are limited to regression and moving average with historical data within the determined time range. Overall, the research stages begin with the identification of problems related to the unaccounted value of cobalt and iron in nickel ore price determination, followed by price data collection and processing, price forecasting using regression and moving average, model accuracy testing, selling price determination based on HPM, and economic analysis through selling value comparison. The final stage of the research is the drawing of conclusions and formulation of recommendations that are expected to contribute to the development of mineral pricing policies that are fairer and reflect resource content comprehensively.

The equations used in determining the Mineral Benchmark Price (HPM) use the following equations (Directorate General of Minerals and Coal, 2017):

$$HPM\ Cobalt = \% Co \times CF \times HMA\ Cobalt \dots\dots\dots (1)$$

Description:

- HPM Cobalt = cobalt mineral benchmark price (US\$/DMT)
- % Co = cobalt grade (%)
- CF = corrective factor (%)
- HMA Cobalt = cobalt mineral reference price

For the determination of HPM nickel based on the equation:

$$HPM\ Nickel = \% Ni \times CF \times HMA\ Nickel \dots\dots\dots (2)$$

Description:

- HPM Nickel = nickel mineral benchmark price (US\$/DMT)
- % Ni = nickel grade (%)
- CF = corrective factor (%)
- HMA Nickel = nickel mineral reference price
- MC = moisture content (%)

$$HPM\ Iron\ Ore = \% Fe \times CF \times HMA\ Iron \dots\dots\dots (3)$$

Description:

- HPM Iron = iron mineral benchmark price (US\$/DMT)
- % Fe = iron grade (%)
- CF = corrective factor (%)
- HMA Iron = iron mineral reference price
- MC = moisture content (%)

The research flowchart is presented in Figure 1.

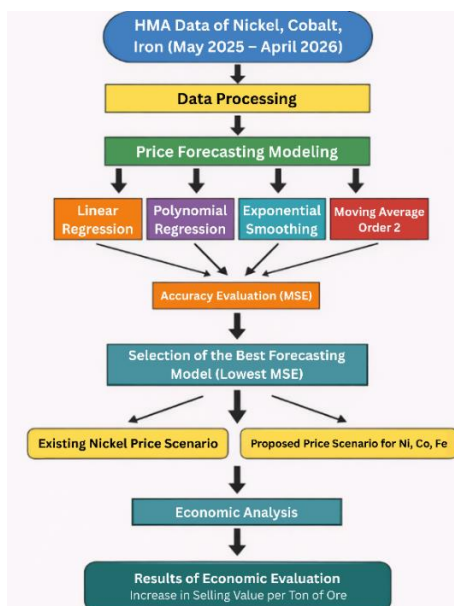


Figure 1. Research Flow Diagram
Source: Author (2026)

The research flowchart as in figure 1 illustrates the stages of evaluating the economic impact of incorporating cobalt (Co) and iron (Fe) pricing in lateritic nickel ore based on forecasted Benchmark Mineral Prices (HPM). The study begins with the collection of Benchmark Mineral Reference Price (HMA) data for nickel, cobalt, and iron from May 2025 to April 2026, followed by data processing through validation and time series preparation. Price forecasting is then conducted using several methods, including linear regression, polynomial regression, exponential smoothing, and moving average (order 2). The accuracy of each model is evaluated using Mean Squared Error (MSE), and the model with the lowest MSE is selected as the best model to predict prices for the period from Period II April to Period II July 2026. The forecasted prices are then used to determine the HPM, which serves as the basis for calculating the economic value of the ore based on the contribution of Ni, Co, and Fe in the limonite and saprolite layers. The final stage involves discussion and drawing conclusions regarding the increase in the economic value of lateritic nickel ore.

4. Results and Discussion

4.1. Research Results

Laterite nickel ore is the result of intensive weathering of ultramafic rocks, by the laterization process (Hasria & Septiana, 2024). The laterization process causes the leaching of easily soluble elements and the relative enrichment of certain elements such as nickel (Ni), iron (Fe), and cobalt (Co) in the laterite soil profile (Golightly, 1981). This condition makes Indonesia one of the countries with very large laterite nickel deposit potential.

Seo et al. (2016) explain that saprolite and limonite are the two main types of laterite nickel ores. Saprolite is a silicate ore characterized by high magnesia and silica content, making it suitable for pyrometallurgical processing. In contrast, limonite is an oxide ore with an iron content of more than 40% and a Si+Mg content of less than 10%, making it suitable for hydrometallurgical processing. Meanwhile, cobalt is predominantly found in the limonite zone, with a maximum content reaching 0.13% (Anbiyak & Cahyaningrum, 2021).

The distribution of these elements is influenced by geochemical processes during weathering (Figure 2). Nickel tends to mobilize and accumulate in the saprolite zone, while iron undergoes oxidation and enrichment in the limonite zone. Cobalt, which has an affinity for iron and manganese oxide minerals, tends to be adsorbed onto goethite minerals in the limonite zone (Golightly, 1981; USGS, 2023).

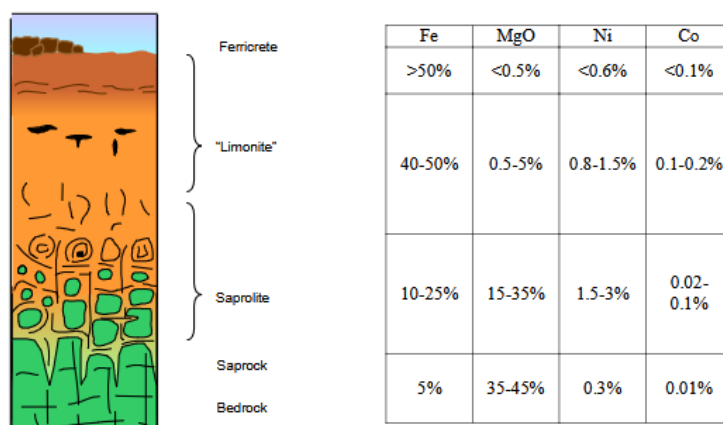


Figure 2. Schematic laterite profile formed on ultramafic rocks in a tropical climate

Source: Elias (2002)

From a mineral economics perspective, this distribution has significant implications for the valuation of laterite nickel ore. So far, the pricing of ores has primarily focused on nickel content, particularly in the saprolite zone, which serves as the main source of raw materials for pyrometallurgical industries. However, the limonite zone, rich in iron and cobalt, also holds substantial economic potential, especially with the development of hydrometallurgical technologies like High Pressure Acid Leaching (HPAL), which can process ores with nickel grades of 1.1-1.4%. This method can produce over 37% nickel and cobalt as valuable by-products (Gultom & Sianipar, 2020).

Iron in nature is generally not found in its free elemental form but occurs in combination with other elements, forming various mineral compounds such as magnetite (Fe_3O_4), hematite (Fe_2O_3), and goethite (FeOOH) (Clout & Manuel, 2022). Meanwhile, cobalt is associated with minerals such as antigorite (Wakila et al., 2024). Therefore, the characteristics and distribution of Ni, Fe, and Co contents in laterite nickel ore are highly important for developing a more comprehensive economic valuation approach. The inclusion of pricing for cobalt and iron in laterite nickel ore sales has the potential to significantly increase the ore's selling value, particularly in the limonite zone, which has so far not been optimally accounted for in conventional pricing schemes.

Table 1. Reference Mineral Prices for Ni, Co, and Fe, Period May I 2025 - April I 2026

No.	Period	Ni (\$/ton)	Co (\$/ton)	Iron Ore (\$/ton)
1.	May 1 2025	15,049.23	33,274.62	1.43
2.	May 2 2025	15,415.00	33,260.77	1.44
3.	June 1 2025	15,405.00	33,256.79	1.45
4.	June 2 2025	15,221.00	33,235.33	1.42
5.	July 1 2025	14,942.67	32,944.00	1.36
6.	July 2 2025	14,926.00	32,896.00	1.35
7.	Aug 1 2025	15,028.33	32,894.33	1.44
8.	Aug 2 2025	15,012.67	32,893.33	1.48
9.	Sept 1 2025	14,899.64	32,894.29	1.47
10.	Sept 2 2025	15,000.33	32,897.67	1.49
11.	Oct 1 2025	15,101.67	33,307.67	1.55
12.	Oct 2 2025	15,142.00	35,151.00	1.54
13.	Nov 1 2025	15,075.33	42,283.33	1.55
14.	Nov 2 2025	14,998.67	47,571.00	1.54
15.	Dec 1 2025	14,666.67	48,139.00	1.52
16.	Dec 2 2025	14,599.33	49,112.67	1.55
17.	Jan 1 2026	14,630.00	52,145.71	1.56
18.	Jan 2 2026	16,426.54	53,440.00	1.58
19.	Feb 1 2026	17,774.00	55,537.00	1.56
20.	Feb 2 2026	17,670.31	55,838.13	1.50
21.	Mar 1 2026	17,103.67	55,859.00	1.45
22.	Mar 2 2026	17,329.23	55,857.69	1.44
23.	Apr 1 2026	17,092.67	55,848.00	1.55

Source: minerba.esdm.go.id/reference_prices_2026

Based on HMA data presented in Table 1 for Period I and II of May 2025 through Period I of April 2026, nickel prices show a fluctuating pattern with a relatively stable tendency. Nickel price movements are influenced by the balance between global demand and supply, where increased demand from the stainless steel and electric vehicle battery industries is the

main driving factor, while increased production from producing countries also exerts pressure on prices (USGS, 2023).

Meanwhile, cobalt prices show a higher level of volatility compared to nickel. This is due to cobalt's role as a critical mineral in the electric vehicle battery industry, which is highly sensitive to technological developments and global energy policies. Increasing demand for nickel-cobalt-based batteries and limited global supply causes cobalt price fluctuations to be sharper (IEA, 2022; USGS, 2023).

On the other hand, iron prices tend to be more stable compared to both commodities. This stability is influenced by the breadth of the iron market dominated by the construction and steel industry sectors, so its price movements more closely reflect global macroeconomic conditions. Nevertheless, iron prices still experience fluctuations influenced by changes in industrial demand and global economic developments (USGS, 2023).

Based on the accuracy test results using Mean Squared Error (MSE), the Moving Average (MA) order 2 model shows the best performance in predicting nickel (Ni), cobalt (Co), and iron (Fe) prices, as indicated by the smallest MSE value compared to other models. This indicates that the MA order 2 model is capable of representing relatively stable price data patterns with short-term fluctuations more accurately. The characteristics of the data that do not show a strong trend and tend to fluctuate mildly make this method effective in dampening noise and producing predictions that are closer to actual values.

Thus, the MA order 2 model was selected, this method is more effective in reducing short-term fluctuations, resulting in more stable and representative estimates of volatile mineral price patterns. In contrast, linear and polynomial methods tend to follow trends more rigidly, while exponential smoothing is more sensitive to recent data changes. Thus, the MA order 2 model was selected as the forecasting model used in this research because it provides the highest level of accuracy and more stable prediction results.

Table 2. Accuracy of Mineral Reference Price Forecasting Models

Element	Exp. Smoothing	MA Order 2	Linear	Polynomial
Ni	594,813	454,436	605,943	1,311,042
Co	12,828,425	9,015,318	14,428,115	9,904,695
Fe	0.002646979	0.002577381	0.002623609	0.091001215

Source: Data processing results, 2026

Based on the commodity price forecasting results for nickel (Ni), cobalt (Co), and iron (Fe) for Period II of April through Period II of July 2026 (Table 2), all three commodities generally show relatively stable movement patterns with very small fluctuations. This indicates that the linear regression model used produces price trends that tend to be constant in the short term.

Nickel (Ni) prices are in the range of 17,151.81-17,210.95 \$/ton, with the highest value occurring in Period II of April 2026 and experiencing a slight decline in the following period before stabilizing again through July 2026. This movement indicates that nickel prices tend to undergo a mild correction at the beginning of the period and then remain in a stable condition, reflecting the balance between demand and supply in the market.

Cobalt (Co) prices show very high stability, with a price range that is almost unchanged at around 55,850-55,853 \$/ton. This very small fluctuation indicates that in the forecasting model, cobalt prices are in a steady state or equilibrium condition, with the effect of time changes being relatively insignificant. Meanwhile, iron (Fe) prices are in the range of 1.4950-1.5225 \$/ton, with fluctuations that are slightly more visible compared to cobalt, but still within a narrow range. The highest price occurs in Period I of May 2026, while the lowest value

occurs in Period II of April 2026. After that, iron prices show a stable tendency with slight up-and-down variations.

Table 3. Reference Mineral Prices for Ni, Co, and Fe

Period 2026	Ni (\$/ton)	Co (\$/ton)	Fe (\$/ton)
April II	17,210.95	55,852.85	1.4950
May I	17,151.81	55,850.42	1.5225
May II	17,181.38	55,851.63	1.5088
June I	17,166.60	55,851.03	1.5156
June II	17,173.99	55,851.33	1.5122
July I	17,170.29	55,851.18	1.5139
July II	17,172.14	55,851.26	1.5130

Source: Data processing results, 2026

As a basis for determining the Ni, Co, and Fe content (Table 3), based on the feasibility study report of PT. RBP, the cobalt element grade in the limonite layer is recorded at 0.12%, while in the saprolite layer it reaches 0.04%, as can be seen in Table 4.

Table 4. Element Content of the Limonite and Saprolite Zones in Laterite Nickel Deposits

Material	Ni (%)	Fe (%)	Co (%)	SiO ₂ (%)	MgO (%)
Limonite	1.09	54.47	0.12	1.86	3.43
Saprolite	1.62	15.8	0.04	27.69	35.08

Source: PT RBP, 2022

Table 5. Economic Potential of Ni, Co, and Fe in Laterite Nickel Deposits

Period	Type	Element	%	CF (%)	HMA (\$/ton)	HPM (\$/ton)	Economic Value (\$/ton)
April II 2026	Limonite	Ni	1.09	11	17,211	21	88
		Co	0.12	100	55,853	67	
		Fe	54.47	40	1.50	0.33	
	Saprolite	Ni	1.62	17	17,211	47	70
		Co	0.04	100	55,853	22	
		Fe	15.80	22	1.50	0.05	
May I 2026	Limonite	Ni	1.09	11	17,152	21	88
		Co	0.12	100	55,850	67	
		Fe	54.5	40	1.52	0.33	
	Saprolite	Ni	1.62	17	17,152	47	75
		Co	0.04	100	55,850	22	
		Fe	15.8	22	1.52	0.05	
May II 2026	Limonite	Ni	1.09	11	17,181	21	88
		Co	0.12	100	55,852	67	
		Fe	54.5	40	1.51	0.33	
	Saprolite	Ni	1.62	17	17,181	47	75
		Co	0.04	100	55,852	22	
		Fe	15.8	22	1.51	0.05	
June I 2026	Limonite	Ni	1.09	11	17,167	21	88
		Co	0.12	100	55,851	67	
		Fe	54.5	40	1.52	0.33	
	Saprolite	Ni	1.62	17	17,167	47	75
		Co	0.04	100	55,851	22	
		Fe	15.8	22	1.51	0.05	

Period	Type	Element	%	CF (%)	HMA (\$/ton)	HPM (\$/ton)	Economic Value (\$/ton)
June II 2026	Limonite	Fe	15.8	22	1.52	0.05	
		Ni	1.09	11	17,174	21	
		Co	0.12	100	55,851	67	88
	Saprolite	Fe	54.5	40	1.51	0.33	
		Ni	1.62	17	17,174	47	
		Co	0.04	100	55,851	22	75
July I 2026	Limonite	Fe	15.8	22	1.51	0.05	
		Ni	1.09	11	17,170	21	
		Co	0.12	100	55,851	67	88
	Saprolite	Fe	54.5	40	1.51	0.33	
		Ni	1.62	17	17,170	47	
		Co	0.04	100	55,851	22	75
July II 2026	Limonite	Fe	15.8	22	1.51	5	
		Ni	1.09	11	17,172	21	
		Co	0.12	100	55,851	67	88
	Saprolite	Fe	54.5	40	1.51	0.33	
		Ni	1.62	17	17,172	47	
		Co	0.04	100	55,851	22	75
		Fe	15.8	22	1.51	0.05	

Source: Data Processing Results, 2026

Based on the simulation results in Table 5, it was found that there is a significant increase in economic value when the price determination for laterite nickel ore sales not only considers nickel (Ni) grade, but also incorporates the economic value of cobalt (Co) and iron (Fe). This indicates that the conventional pricing approach that only focuses on nickel potentially ignores the added value of by-product minerals that actually have economic contributions.

Calculation results for the period of April II 2026 through July II 2026 show that in the limonite layer, there is a fairly large increase in economic value, from approximately 21 \$/ton to 85 \$/ton. This increase is primarily influenced by the relatively higher cobalt content in the limonite zone, where cobalt has a high selling value in the global market, thus providing a significant contribution to the total ore value.

Meanwhile, in the saprolite layer, an increase in economic value also occurs, although not as large as in the limonite, namely from approximately 47 \$/ton to 70-75 \$/ton. This is due to the dominance of nickel content in the saprolite zone which from the outset already provides the main economic value, so the additional contribution from cobalt and iron is relatively smaller compared to the limonite zone. Overall, these results indicate that the imposition of prices on cobalt and iron elements is capable of significantly increasing the selling value of laterite nickel ore, particularly in the limonite zone which has tended to be undervalued in conventional sales schemes. Thus, this approach provides an overview that optimizing the utilization of all mineral content in ore can increase resource efficiency and economic value.

4.2. Discussion

Based on the smallest Mean Square Error (MSE) obtained, the second-order moving average method is selected as the best model for forecasting benchmark mineral prices. This method demonstrates superior performance in reducing short-term fluctuations, resulting in more stable trend estimations. Compared to regression approaches, the second-order moving average is more effective in capturing dynamic price patterns over shorter time scales. This

finding is consistent with Arianos et al. (2011), who stated that higher-order moving averages exhibit self-similarity properties, enabling consistent smoothing behavior across different time scales and producing more stable representations of volatile time-series data.

In the context of mineral economic valuation, such an approach becomes particularly relevant when applied to laterite nickel ores with complex mineralogical characteristics. Dalvi et al. (2004) and Crundwell et al. (2011) emphasize that the economic value of laterite ores is not determined solely by nickel (Ni) grade, but is also significantly influenced by the presence of associated elements such as iron (Fe) and cobalt (Co), which contribute substantial economic value. Therefore, a valuation approach based solely on nickel content may lead to the undervaluation of the total economic value of the ore.

Currently, the Mineral Benchmark Price (HPM) scheme established by the Ministry of Energy and Mineral Resources primarily focuses on nickel grade, and thus does not fully reflect the total economic value of all minerals contained in laterite ore. This indicates limitations in the conventional valuation approach and reinforces the urgency of developing a multi-commodity value-based pricing model that integrates the economic contributions of Ni, Fe, and Co simultaneously.

Such an adjustment can be normatively accommodated through the revision of Minister of Energy and Mineral Resources Regulation No. 11 of 2020, ensuring that mineral pricing systems more accurately, transparently, and comprehensively reflect actual economic value. Accordingly, optimizing the economic value of nickel along with its associated elements such as cobalt and iron not only improves valuation accuracy but also supports sustainable and equitable mineral resource governance.

Furthermore, the economic value of Ni, Fe, and Co is dynamic and highly influenced by global market fluctuations, particularly through changes in industrial demand that significantly drive price volatility (Gocht et al., 1988). In addition, external factors such as global oil prices also affect production cost structures and global supply chains, further contributing to mineral price dynamics (Jiang et al., 2025). In the context of the global energy transition, cobalt and nickel are critical minerals with strategic importance in the development of electric vehicles and renewable energy systems, with demand projected to increase by 3 to 42 times by 2040 compared to 2020 (Du & Thakur, 2025). This further emphasizes the urgency of optimizing mineral economic value at the upstream stage through a more comprehensive valuation system.

5. Conclusion

Based on the results of the analysis and simulation, this study demonstrates that the inclusion of cobalt (Co) and iron (Fe) pricing in laterite nickel ore sales significantly increases economic value compared to the conventional method that only considers nickel grade. The highest increase in economic value is observed in the limonite layer, while the increase in the saprolite layer is relatively more moderate. These findings confirm that a pricing scheme which accounts for the full mineral content, particularly cobalt and iron, can enhance the selling value of nickel ore more optimally and better reflect its true economic value.

The application of the moving average method also indicates that commodity price forecasting can provide a sufficiently reliable quantitative basis for evaluating alternative pricing schemes. This highlights the importance of analytical approaches in supporting more accurate and data-driven economic decision-making in the mining sector.

Further, the findings underscore the need for policy refinement, particularly within the Mineral Benchmark Price (HPM) framework, toward a multi-commodity approach. Such an

approach would enable a more transparent, comprehensive, and equitable valuation of mineral resources by ensuring that all economically valuable elements are properly accounted for. Therefore, this study not only provides economic insights but also offers a practical framework that can be utilized by policymakers and industry stakeholders to improve pricing mechanisms, enhance state revenue, and promote more efficient and sustainable utilization of Indonesia's nickel resources.

6. References

- Anbiyak, N., & Cahyaningrum, T. (2021). Identifikasi Zona Kaya Kobalt pada Cebakan Nikel Laterit di Indonesia. *Indonesian Mining Professionals Journal*, 2(2), 103–110. <https://doi.org/10.36986/impj.v2i2.35>
- Arianos, S., Carbone, A., & Türk, C. (2011). Self-similarity of higher-order moving averages. *Physical Review E*, 84(4), 046113. <https://doi.org/10.1103/PhysRevE.84.046113>
- Arif, I. (2018). *Nikel Indonesia*. PT Gramedia Pustaka Utama.
- Clout, J. M. F., & Manuel, J. R. (2022). Mineralogical, chemical, and physical metallurgical characteristics of iron ore. In *Iron Ore* (pp. 59–108). Elsevier. <https://doi.org/10.1016/B978-0-12-820226-5.00012-4>
- Crundwell, F. K., Moats, M. S., Ramachandran, V., Robinson, T. G., & Davenport, W. G. (2011). Recycling of Nickel, Cobalt and Platinum-Group Metals. In *Extractive Metallurgy of Nickel, Cobalt and Platinum Group Metals* (pp. 537–549). Elsevier. <https://doi.org/10.1016/B978-0-08-096809-4.10038-3>
- Dalvi, A. D., Bacon, W. G., & Osborne, R. C. (2004). The Past and the Future of Nickel Laterites. *PDAC 2004 International Conference Trade Show and Investors Exchange*, 1–27.
- Dias, P. A., Blagoeva, D., Pavel, C., & Arvanitidis, N. (2018). *Cobalt: Demand-Supply Balances in the Transition to Electric Mobility*. Publications Office of the European Union. <https://doi.org/10.2760/97710>
- Du, X., & Thakur, G. C. (2025, October). The Growing Importance of Critical Minerals for the Energy Transition and U.S. Supply Chain Security. *SPE Annual Technical Conference and Exhibition*. <https://doi.org/10.2118/227895-MS>
- Elias, M. (2002). Nickel Laterite Deposits-Geological Overview, Resources and Exploitation. *Centre for Ore Deposit Research*, 205–220.
- Gocht, W. R., Zantop, H., & Eggert, R. G. (1988). *International Mineral Economics*. Springer Berlin Heidelberg. <https://doi.org/10.1007/978-3-642-73321-5>
- Golightly, J. P. (1981). Nickeliferous Laterite Deposits. In *Seventy-Fifth Anniversary Volume* (pp. 710–735). Economic Geology Publishing Company. <https://doi.org/10.5382/AV75.18>
- Gujarati, D. N., & Porter, D. C. (2009). *Basic Econometrics* (A. E. Hilbert (ed.); fifth edit). McGraw-Hill.
- Gultom, T., & Sianipar, A. (2020). High pressure acid leaching: a newly introduced technology in Indonesia. *IOP Conference Series: Earth and Environmental Science*, 413(1), 012015. <https://doi.org/10.1088/1755-1315/413/1/012015>
- Hasria, H., & Septiana, S. (2024). *Geologi Endapan Nikel Laterit*. Deepublish.
- Humphreys, D. (2010). The great metals boom: A retrospective. *Resources Policy*, 35(1), 1–13. <https://doi.org/10.1016/j.resourpol.2009.07.002>
- IEA. (2022). Global Supply Chains of EV Batteries. In *Global EV Outlook 2021*. International Energy Agency (IEA).
- Jiang, Z., Dong, X., & Yoon, S.-M. (2025). *Impact of Oil Prices on Key Energy Mineral Prices: Fresh Evidence from Quantile and Wavelet Approaches*.

- <https://doi.org/10.2139/ssrn.5093874>
- Msumange, D. A., Jampaiah, D., Tardio, J., Nilsson, M., Arandiyana, H., & Bhargava, S. K. (2026). A Review of Nickel and Cobalt from Laterite Ores: Toward Sustainable Extraction Pathways for the Battery Industry. *Journal of Sustainable Metallurgy*, 12(2), 1038–1069. <https://doi.org/10.1007/s40831-026-01439-6>
- Mudd, G. M. (2010). The Environmental sustainability of mining in Australia: key megatrends and looming constraints. *Resources Policy*, 35(2), 98–115. <https://doi.org/10.1016/j.resourpol.2009.12.001>
- OECD, & IGF. (2024). *Determining the Price of Minerals: A Transfer Pricing Framework for Lithium*. OECD.
- Scarcioffolo, A. R., & Etienne, X. (2021). Testing directional predictability between energy prices: A quantile-based analysis. *Resources Policy*, 74, 102258. <https://doi.org/10.1016/j.resourpol.2021.102258>
- Seo, J., Kim, K., Bae, I., Lee, J., & Kim, H. (2016). A Study on Classification of Limonite and Saprolite from Nickel Laterite Ores. *Journal of the Korean Institute of Resources Recycling*, 25(1), 40–47. <https://doi.org/10.7844/kirr.2016.25.1.40>
- Tamehe, L. S., Zhao, Y., Xu, W., & Gao, J. (2024). Ni(Co) Laterite Deposits of Southeast Asia: A Review and Perspective. *Minerals*, 14(2), 134. <https://doi.org/10.3390/min14020134>
- Tilton, J. E., & Guzmán, J. I. (2016). *Mineral Economics and Policy*. Routledge. <https://doi.org/10.4324/9781315733708>
- UNCTAD. (2004). *Trade and Development Report 2004: Policy Coherence, Development Strategies and Integration into the World Economy*. United Nations Conference on Trade and Development (UNCTAD).
- USGS. (2023). *Mineral commodity summaries 2023*. <https://doi.org/10.3133/mcs2023>
- Wakila, M. H., Nompo, S., Jafar, N., Thamsi, A. B., Munir, A. S., & Heriansyah, A. F. (2024). Analysis of Cobalt Distribution and Co-Ni Correlation in Nickel Laterite Zonation in Tropical Region. *The Iraqi Geological Journal*, 57(2B), 205–218. <https://doi.org/10.46717/igj.57.2B.14ms-2024-8-24>