



Effectiveness of Mineral Downstreaming Policy in Encouraging Regional Economic Transformation

(A Case Study of RKEF And HPAL Integration In Obi Island, South Halmahera)

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Abstract. Indonesia's mineral downstreaming policy has become a strategic instrument to increase the added value of natural resources and strengthen the country's position in the global mineral value chain. This study aims to analyze the effectiveness of the mineral downstreaming policy in encouraging regional economic transformation through the development of an integrated nickel processing industry in Obi Island, South Halmahera. The research employs a descriptive qualitative approach using secondary data obtained from government publications, corporate reports, policy documents, and environmental reports. Key data sources include regional economic statistics from the Central Bureau of Statistics, corporate publications from Harita Nickel, and regulatory frameworks such as Law No. 3 of 2020 concerning Mineral and Coal Mining. The findings show that the downstreaming policy has transformed Indonesia's nickel industry by shifting export patterns from raw ore toward higher value-added products such as ferronickel and Mixed Hydroxide Precipitate (MHP), which are essential materials for electric vehicle battery production. The integration of Rotary Kiln Electric Furnace (RKEF) and High Pressure Acid Leach (HPAL) technologies in Obi Island has strengthened Indonesia's role in the global battery supply chain while also stimulating regional economic growth in South Halmahera. However, the rapid expansion of the nickel industry also raises environmental governance challenges that require stronger regulatory oversight and sustainable mining practices. Therefore, future policy implementation should emphasize balanced economic development, environmental sustainability, and effective governance in mineral resource management.

Keywords: EV Battery Supply; Mineral Downstreaming; Nickel Industry; Obi Island; Regional Economic Transformation.

1. INTRODUCTION

Indonesia possesses one of the largest mineral resource bases in the world, particularly for nickel, which has become a strategic commodity in the global energy transition. Nickel is a crucial component in lithium-ion batteries used in electric vehicles (EVs), making it increasingly important in the context of global decarbonization and green technology development. The rapid growth of the EV industry has significantly increased global demand for nickel, especially high-purity nickel used for battery production (IEA, 2024). Several studies emphasize that the expansion of electric vehicle production has intensified competition for critical minerals such as nickel, positioning resource-rich countries as key actors in the global battery supply chain (Fraser et al., 2021); (Sovacool et al., 2020). As a country with abundant nickel reserves, Indonesia plays a critical role in the global supply chain of battery materials.

In recent years, Indonesia has emerged as the largest nickel producer globally, with production reaching approximately 2.2 million tons in 2024, accounting for a substantial share of global supply. This rapid growth in production has positioned Indonesia as a key actor in the global nickel market and strengthened the country's bargaining position in the international

mineral trade. The Indonesian government has recognized this strategic opportunity and has implemented a series of policies aimed at maximizing the economic value of its mineral resources through domestic processing and industrial development (ESDM Ministry, 2020). Scholars note that Indonesia's strategy reflects a broader effort to reposition the country within the global mineral value chain through resource-based industrialization policies (Morris & Farooki, 2019); (Sitohang, Azis, & Hafiz, 2025).

One of the most significant policy instruments in this regard is the mineral downstreaming policy, which seeks to increase the added value of mineral commodities by requiring domestic processing and refining before export. The policy framework was significantly strengthened through Law No. 3 of 2020 concerning Mineral and Coal Mining, which amended the previous mining law and introduced stronger regulatory provisions for mineral processing, domestic value addition, and environmental governance in mining activities (Government of Indonesia, 2020b). Several studies argue that Indonesia's nickel downstreaming policy represents a strategic industrial policy aimed at strengthening national competitiveness and developing a domestic electric vehicle ecosystem (Lahadalia, Wijaya, Dartanto, & Subroto, 2024); (Barizi & Triarda, 2023).

The implementation of the downstreaming policy has fundamentally transformed the structure of Indonesia's mining industry. Previously, Indonesia largely exported raw mineral ores, including nickel ore, to international markets. However, following the export ban on raw nickel ore, mining companies have been encouraged to invest in domestic refining facilities. This policy shift aims to move Indonesia from a raw material exporter to a producer of higher value-added mineral products such as ferronickel, nickel pig iron (NPI), and battery-grade materials (ESDM Ministry, 2020). According to recent research, this transformation has significantly increased the domestic processing capacity of nickel and strengthened Indonesia's strategic position within the global supply chain of critical minerals (Rizal & Idrus, 2024).

One of the most prominent examples of downstreaming policy implementation can be observed in Obi Island, located in South Halmahera Regency, North Maluku Province. The island has become a strategic center for nickel processing through the development of an integrated industrial complex operated by Harita Nickel, a subsidiary of PT Trimegah Bangun Persada Tbk. The industrial complex integrates two key processing technologies: Rotary Kiln Electric Furnace (RKEF) and High Pressure Acid Leach (HPAL). RKEF technology is primarily used to produce ferronickel for stainless steel manufacturing, while HPAL technology processes limonite nickel ore into Mixed Hydroxide Precipitate (MHP), which serves as an intermediate material for producing nickel sulfate used in electric vehicle batteries

(Harita Nickel, 2024). The development of HPAL technology is considered an important step in expanding Indonesia's role in the production of battery-grade nickel materials (Khoo, Haque, Woodbridge, McDonald, & Bhattacharya, 2017).

The integration of RKEF and HPAL technologies represents a significant step in Indonesia's efforts to enter the global electric vehicle battery supply chain. Through the production of MHP and other battery-related materials, Indonesia is no longer limited to exporting raw nickel ore but is increasingly involved in the manufacturing of high-value intermediate products for advanced industries. This industrial transformation aligns with the government's broader strategy to develop a domestic EV ecosystem and strengthen Indonesia's role in the global green economy. Similar industrial strategies have been implemented in several resource-rich countries seeking to capture greater value within global commodity chains (Morris & Farooki, 2019).

Furthermore, the industrial development in Obi Island has been recognized as part of Indonesia's National Strategic Projects (Proyek Strategis Nasional / PSN) under Presidential Regulation No. 109 of 2020, which aims to accelerate infrastructure development and strategic industrial investments that contribute to national economic growth. The inclusion of nickel processing projects in the PSN framework highlights the government's commitment to promoting industrialization based on natural resource downstreaming (Government of Indonesia, 2020).

Beyond its national economic significance, the development of the nickel processing industry in Obi Island also has important implications for regional economic transformation. The establishment of large-scale industrial facilities has stimulated economic activities in South Halmahera Regency, including employment generation, infrastructure development, and increased local business opportunities. According to regional economic statistics published by the Central Bureau of Statistics, the mining and quarrying sector has become a dominant contributor to the regional gross domestic product (GRDP) of South Halmahera in recent years (BPS, 2025). Studies on mining-based development indicate that extractive industries often become catalysts for regional economic transformation through infrastructure expansion and local economic spillover effects (Arkum, 2024).

However, the rapid expansion of nickel mining and processing activities has also generated significant environmental and social concerns. Environmental organizations have highlighted potential risks associated with large-scale mining operations, including deforestation, marine ecosystem disruption, and waste management challenges (JATAM, 2023); (AEER, 2023). Environmental scholars also warn that the rapid growth of critical

mineral extraction can create sustainability challenges if governance mechanisms and environmental regulations are not effectively enforced (Sovacool et al., 2020).

From a public policy perspective, evaluating the effectiveness of mineral downstreaming policies requires a comprehensive analysis that considers both economic outcomes and environmental governance. While downstreaming policies are often promoted as a strategy to increase national income and industrial capacity, their long-term success depends on the ability of governments to balance economic development with sustainable resource management.

2. LITERATURE REVIEW

Mineral Downstreaming Policy

Mineral downstreaming refers to policies aimed at increasing the added value of mineral resources through domestic processing and refining before export. In resource-rich countries, downstreaming policies are often implemented to reduce dependence on raw commodity exports and to strengthen domestic industrial capacity. Such policies are increasingly important in the context of the global transition toward clean energy technologies, where critical minerals such as nickel play a key role in battery manufacturing (IEA, 2024).

Indonesia has adopted an ambitious downstreaming strategy to maximize the economic benefits of its mineral resources. The policy framework is strengthened through Law No. 3 of 2020 concerning Mineral and Coal Mining, which requires mining companies to process mineral resources domestically before export. This regulation aims to increase the value added of mineral commodities while encouraging the development of smelters and refining industries in Indonesia (Government of Indonesia, 2020).

Several studies highlight that Indonesia's nickel downstreaming policy represents a strategic effort to reposition the country within the global battery supply chain. By restricting raw ore exports and promoting domestic processing industries, Indonesia seeks to transform its role from a raw material exporter into a producer of higher value-added mineral products (Sitohang et al., 2025).

Development of the Nickel Processing Industry

Indonesia has become the largest nickel producer in the world, supported by abundant laterite nickel reserves and increasing global demand for battery materials. According to the Ministry of Energy and Mineral Resources, the country has significant potential to develop a competitive nickel processing industry that supports stainless steel and electric vehicle battery production (ESDM Ministry, 2020).

One of the most notable developments in Indonesia's nickel downstreaming policy can be observed in Obi Island, South Halmahera, where Harita Nickel has established an integrated processing complex. The complex combines Rotary Kiln Electric Furnace (RKEF) technology and High Pressure Acid Leach (HPAL) technology to process different types of laterite nickel ore. Through HPAL technology, limonite ore can be processed into Mixed Hydroxide Precipitate (MHP), which is used as an intermediate material for producing nickel sulfate for electric vehicle batteries (Harita Nickel, 2024).

The development of integrated nickel processing facilities such as those in Obi Island reflects Indonesia's broader strategy to enter the global electric vehicle battery value chain. Studies suggest that this industrial transformation can increase export value and strengthen Indonesia's position in the global critical minerals market (Khoo et al., 2017).

Regional Economic Impact of Nickel Industrialization

Mining-based industrial development can significantly influence regional economic transformation. Large-scale mining and processing projects often stimulate economic activities through infrastructure development, job creation, and increased local business opportunities (Arkum, 2024).

In Indonesia, the expansion of nickel processing industries has contributed to regional economic growth, particularly in eastern Indonesia where most nickel resources are located. Data from the Central Bureau of Statistics indicate that the mining sector has become a major contributor to regional economic output in several mining regions (BPS, 2025). In South Halmahera Regency, the development of the nickel processing industry has played an important role in shaping the regional economic structure and increasing the contribution of the mining sector to regional gross domestic product (BPS, 2024).

Environmental and Sustainability Issues in Nickel Mining

Despite its economic benefits, the expansion of nickel mining and processing activities also raises environmental concerns. Mining operations may generate environmental risks such as deforestation, land degradation, and marine ecosystem disruption if not properly managed.

Reports from environmental organizations highlight that large-scale mining projects in Indonesia have raised concerns regarding environmental governance and sustainability (JATAM, 2023); (AEER, 2023). Therefore, the implementation of mineral downstreaming policies should also consider environmental protection and sustainable resource management in order to balance economic development with ecological sustainability.

3. RESEARCH METHOD

This study employs a descriptive qualitative research approach to analyze the effectiveness of Indonesia's mineral downstreaming policy in encouraging regional economic transformation. Qualitative research is commonly used to understand social, economic, and policy phenomena through in-depth analysis of contextual data rather than numerical measurement (Creswell, 2017). The descriptive approach allows researchers to systematically interpret existing information and explain relationships between policy implementation and socio-economic outcomes (Sugiyono, 2020).

The research focuses on the case of the integrated nickel processing industry in Obi Island, South Halmahera, which represents one of the most significant implementations of Indonesia's mineral downstreaming policy. This study primarily uses secondary data sources, including government publications, corporate reports, policy documents, and environmental reports. Secondary data analysis is widely used in qualitative research to examine policy developments and economic trends based on existing datasets and documents (Johnston, 2014). The main data sources include regional economic statistics published by the Central Bureau of Statistics (BPS), such as Gross Regional Domestic Product of South Halmahera by Industrial Sector (BPS, 2025) and South Halmahera in Figures (BPS, 2024).

Additional information was obtained from corporate publications, including the Annual Report and Sustainability Report of Harita Nickel (Harita Nickel, 2024), as well as policy documents such as Law No. 3 of 2020 concerning Mineral and Coal Mining and Presidential Regulation No. 109 of 2020 on National Strategic Projects. To provide a broader perspective on sustainability issues, this study also incorporates environmental reports from civil society organizations, including JATAM (2023) and AEER (2023). The collected data were analyzed using descriptive qualitative analysis, which involves interpreting policy frameworks, industrial development patterns, and regional economic indicators to understand the role of mineral downstreaming policies in regional economic transformation.

4. RESULT AND DISCUSSION

Implementation of Mineral Downstreaming Policy in Indonesia

Indonesia's mineral downstreaming policy represents a strategic effort to transform the country's role in the global mineral value chain. Historically, Indonesia relied heavily on exporting raw mineral commodities, including nickel ore, which limited the domestic economic benefits derived from its abundant mineral resources. To address this issue, the government introduced policies aimed at increasing the added value of mineral resources through domestic

processing and refining activities. The policy framework was significantly strengthened through Law No. 3 of 2020 concerning Mineral and Coal Mining, which requires mining companies to process mineral resources domestically before export. This regulation emphasizes the importance of increasing the value added of mineral commodities while encouraging industrial development through the construction of smelters and refining facilities (Government of Indonesia, 2020).

The downstreaming policy has significantly changed the structure of Indonesia's nickel industry. Instead of exporting raw nickel ore, mining companies are now required to process nickel domestically into higher value products such as ferronickel, nickel pig iron (NPI), and battery-grade materials. This transformation is also closely linked to the increasing global demand for nickel as a key material in lithium-ion batteries used for electric vehicles (IEA, 2024). According to the Ministry of Energy and Mineral Resources, Indonesia's large laterite nickel reserves provide a strong foundation for the development of an integrated nickel processing industry (ESDM Ministry, 2020). As a result, the number of nickel smelters in Indonesia has increased significantly over the past decade, reflecting the rapid growth of downstream industrial investment.

Several studies also highlight that Indonesia's downstreaming policy has successfully increased the value of mineral exports by shifting the export structure from raw materials to processed products (Sitohang et al., 2025). This policy is therefore considered an important strategy for strengthening Indonesia's position in the global mineral supply chain while supporting national industrial development.

Integration of RKEF and HPAL Technology in Obi Island

One of the most prominent examples of mineral downstreaming implementation in Indonesia can be observed in Obi Island, South Halmahera, where Harita Nickel has developed an integrated nickel processing complex. The industrial complex combines two major processing technologies: Rotary Kiln Electric Furnace (RKEF) and High Pressure Acid Leach (HPAL). RKEF technology is commonly used to process saprolite nickel ore into ferronickel, which is primarily used in the production of stainless steel. Meanwhile, HPAL technology processes limonite nickel ore into Mixed Hydroxide Precipitate (MHP), which can be further refined into nickel sulfate used in electric vehicle batteries (Harita Nickel, 2024).

The integration of these two technologies allows for the efficient utilization of different types of laterite nickel ore. Saprolite ore is processed through the RKEF process, while limonite ore is processed using HPAL technology. This integrated processing system significantly increases the value added of nickel resources and reduces dependence on raw mineral exports.

According to the Annual Report of PT Trimegah Bangun Persada Tbk, the development of HPAL facilities in Obi Island represents an important step toward strengthening Indonesia's role in the global electric vehicle battery supply chain (PT Trimegah Bangun Persada Tbk, 2024). Through the production of intermediate materials such as MHP, Indonesia is increasingly involved in the global battery materials industry.

Furthermore, the development of the nickel processing industry in Obi Island has been included as part of Indonesia's National Strategic Projects (PSN) under Presidential Regulation No. 109 of 2020, highlighting the strategic importance of this industrial development for national economic growth (Government of Indonesia, 2020). The establishment of integrated nickel processing facilities in Obi Island demonstrates how mineral downstreaming policies can encourage large-scale industrial investment and technological advancement in resource-based industries.

Regional Economic Transformation in South Halmahera

The development of the nickel processing industry in Obi Island has significantly influenced regional economic dynamics in South Halmahera Regency. Large-scale industrial investment in mining and mineral processing activities has contributed to structural changes in the regional economy, particularly through increased economic activity, employment opportunities, and infrastructure development. Data from the Central Bureau of Statistics (BPS) indicate that the mining and quarrying sector has become one of the major contributors to the regional economy of South Halmahera. The expansion of nickel mining and processing activities has led to a significant increase in the contribution of the mining sector to the regional gross domestic product (GRDP) in recent years (BPS, 2025). This trend reflects the growing importance of mineral-based industrial activities in shaping regional economic structures.

The establishment of the nickel processing complex in Obi Island has also stimulated the development of supporting infrastructure such as transportation facilities, energy supply, and port infrastructure. These developments are essential for facilitating industrial activities and improving regional connectivity. In addition, the presence of large industrial projects has created employment opportunities for local communities, contributing to income generation and regional economic growth. According to statistical data published in South Halmahera in Figures, the increasing contribution of the mining sector has gradually reshaped the economic structure of the region, where extractive industries have become one of the dominant sectors in regional economic development (BPS, 2024). This transformation demonstrates how resource-based industrialization can stimulate regional economic growth when supported by large-scale investment and government policy support.

However, while mining-based development can generate economic growth, it may also create structural dependency on extractive industries. Regions that rely heavily on mining activities may face economic vulnerability if global commodity prices decline or if natural resource reserves become depleted. Therefore, balanced regional development policies are necessary to ensure that economic growth driven by the mining sector can also stimulate diversification in other economic sectors.

Environmental and Sustainability Issues in Nickel Industrialization

Despite its economic contributions, the rapid expansion of nickel mining and processing industries has also raised concerns regarding environmental sustainability and resource governance. Mining operations, particularly those involving large-scale extraction and processing of laterite nickel ore, may generate environmental impacts if not properly managed.

Environmental organizations have highlighted several environmental risks associated with the expansion of nickel mining activities in Indonesia. Reports from JATAM indicate that large-scale mining operations can lead to deforestation, land degradation, and ecological disruption if environmental regulations are not strictly enforced (JATAM, 2023). In addition, the disposal of mining waste and tailings may pose potential risks to marine ecosystems in coastal mining areas.

Similarly, a report by the Asia Energy and Environmental Research (AEER) highlights the environmental challenges associated with the rapid expansion of the nickel industry in eastern Indonesia. The report emphasizes that while downstream policies have successfully attracted industrial investment, environmental governance mechanisms must be strengthened to ensure sustainable mining practices (AEER, 2023). In response to these challenges, mining companies have begun to adopt sustainability initiatives aimed at reducing environmental impacts. According to the Sustainability Report of Harita Nickel, the company has implemented several environmental management programs, including waste management systems, environmental monitoring, and community development initiatives aimed at supporting sustainable mining operations (Harita Nickel, 2024). Nevertheless, effective environmental governance requires strong regulatory oversight and transparent monitoring systems. Sustainable mineral development should balance economic benefits with environmental protection to ensure that industrial expansion does not compromise ecological sustainability or the well-being of local communities.

5. CONCLUSION

This study examines the effectiveness of Indonesia's mineral downstreaming policy in promoting regional economic transformation through the case of integrated nickel processing development in Obi Island, South Halmahera. The findings indicate that the implementation of downstreaming policies has significantly transformed Indonesia's mining sector by shifting the export structure from raw mineral commodities toward higher value-added products.

The development of integrated processing technologies such as Rotary Kiln Electric Furnace (RKEF) and High Pressure Acid Leach (HPAL) in Obi Island demonstrates how mineral downstreaming policies can stimulate industrial investment and technological advancement. Through these technologies, nickel ore can be processed into intermediate products such as Mixed Hydroxide Precipitate (MHP), which plays an important role in the global electric vehicle battery supply chain. This transformation allows Indonesia to strengthen its strategic position within the global market for critical minerals.

At the regional level, the expansion of the nickel processing industry has contributed to economic transformation in South Halmahera Regency. The growth of mining and processing activities has increased the contribution of the mining sector to regional economic output, while also generating employment opportunities and supporting infrastructure development. These developments illustrate how resource-based industrialization can stimulate regional economic growth when supported by appropriate policy frameworks and investment.

However, the rapid expansion of the nickel industry also raises important environmental and governance challenges. Environmental concerns related to land use change, waste management, and ecosystem protection highlight the need for stronger environmental governance and sustainable mining practices. Therefore, effective policy implementation should balance economic objectives with environmental protection to ensure long-term sustainability.

From a policy perspective, the mineral downstreaming strategy has proven to be an important instrument for strengthening Indonesia's industrial capacity and increasing the value added of mineral resources. Nevertheless, future policy implementation should prioritize improved regulatory oversight, environmental monitoring, and economic diversification in mining regions. Strengthening institutional governance and sustainability frameworks will be essential to ensure that the benefits of mineral downstreaming contribute not only to national economic growth but also to sustainable regional development.

REFERENCES

- AEER. (2023). *Dilema Halmahera di tengah industri nikel*.
- Arkum, D. (2024). *Pembangunan berkelanjutan industri pertambangan timah di Indonesia*. Deepublish.
- Badan Pusat Statistik. (2024). *Kabupaten Halmahera Selatan dalam angka 2024* (Vol. 17). <https://web-api.bps.go.id/download.php>
- Badan Pusat Statistik. (2025). *Produk domestik regional bruto Kabupaten Halmahera Selatan menurut lapangan usaha*. <https://web-api.bps.go.id/download.php>
- Barizi, M. H., & Triarda, R. (2023). Rantai pasokan global dan nasionalisme sumber daya alam: Kajian terkait hilirisasi nikel di Indonesia. *Indonesian Journal of International Relations*, 7(2), 312–338. <https://doi.org/10.32787/ijir.v7i2.466>
- Creswell, J. W. (2017). *Research design: Pendekatan kualitatif, kuantitatif, dan mixed* (edisi ke-3).
- Fraser, J., Anderson, J., Lazuen, J., Lu, Y., Heathman, O., Brewster, N., & Masson, O. (2021). Study on future demand and supply security of nickel for electric vehicle batteries. [https://doi.org/10.12968/S1467-5560\(23\)60038-7](https://doi.org/10.12968/S1467-5560(23)60038-7)
- Government of Indonesia. (2020). *Peraturan Presiden Nomor 109 Tahun 2020 tentang perubahan ketiga atas Peraturan Presiden Nomor 3 Tahun 2016 tentang percepatan pelaksanaan proyek strategis nasional*.
- Government of Indonesia. (2020). *Undang-Undang Nomor 3 Tahun 2020 tentang pertambangan mineral dan batubara*. [https://jdih.esdm.go.id/storage/document/UU No. 3 Thn 2020.pdf](https://jdih.esdm.go.id/storage/document/UU%20No.%203%20Thn%202020.pdf)
- Harita Nickel. (2024). *2024 strategically green: A roadmap to responsible mining*.
- International Energy Agency. (2024). *Global critical minerals outlook 2024*. <https://www.iea.org/reports/global-critical-minerals-outlook-2024>
- JATAM. (2023). *Jejak kejahatan lingkungan dan kemanusiaan di balik gurita bisnis Harita Group*. <https://katadata.co.id>
- Johnston, M. P. (2014). Secondary data analysis: A method of which the time has come. *Qualitative and Quantitative Methods in Libraries*, 3(3), 619–626.
- Khoo, J. Z., Haque, N., Woodbridge, G., McDonald, R., & Bhattacharya, S. (2017). A life cycle assessment of a new laterite processing technology. *Journal of Cleaner Production*, 142, 1765–1777. <https://doi.org/10.1016/j.jclepro.2016.11.111>
- Lahadalia, B., Wijaya, C., Dartanto, T., & Subroto, A. (2024). Nickel downstreaming in Indonesia: Reinventing sustainable industrial policy and developmental state in building the EV industry in ASEAN. *Journal of ASEAN Studies*, 12(1), 79–106. <https://doi.org/10.21512/jas.v12i1.11128>
- Morris, M., & Farooki, M. (2019). Understanding commodities, linkages, and industrial development in Africa: Developing a conceptual framework. In *Balancing petroleum policy: Toward value, sustainability, and security* (pp. 183–197). https://doi.org/10.1596/978-1-4648-1384-9_ch9
- Rizal, K., & Idrus, A. (2024). Global critical mineral review and challenges on its exploration in Indonesia. *Indonesian Mining Journal*, 27(2), 97–123.

- Sitohang, C., Azis, H., & Hafiz, M. S. (2025). Hilirisasi komoditi mineral: Studi kasus nikel di Indonesia. *Jurnal Ilmiah Ekonomi dan Manajemen*, 3(2), 1–12.
- Sovacool, B. K., Ali, S. H., Bazilian, M., Radley, B., Nemery, B., Okatz, J., & Mulvaney, D. (2020). Sustainable minerals and metals for a low-carbon future. *Science*, 367(6473), 30–33. <https://doi.org/10.1126/science.aaz6003>
- Sugiyono. (2020). *Metode penelitian pendidikan: Pendekatan kuantitatif, kualitatif, dan R&D*. Alfabeta.