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Research Article

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Downstream Policy in Indonesia: Does it Support Energy Security?

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Abstract

The downstream policy in the mining sector aims to enhance the added value and competitiveness of national industries in a dynamic global market. This policy also impacts domestic energy security. Our study explores the effects of down streaming on energy security in Indonesia using panel data from 34 provinces from 2017 to 2022. Down streaming is measured by the added value in the mining sector, while energy security is assessed through an index developed using Principal Component Analysis (PCA), covering Availability, Accessibility, Affordability, and Acceptability. By employing the Panel Least Squares method, our findings indicate that the downstream policy positively affects energy security in Indonesia. The policy significantly improves the availability, accessibility, affordability, and acceptability of energy, thereby boosting overall energy production. However, our results also reveal that the implementation of downstream leads to higher energy prices. This indicates that while the downstream policy enhances energy security by increasing energy supply and improving its distribution, it simultaneously raises the cost of energy in the domestic market. Thus, careful consideration is needed to balance these outcomes for sustainable energy policy development in Indonesia.

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1. Introduction

In the past decade, Indonesia has proactively implemented downstream policies, particularly in the mining sector. Downstream can enhance the added value and competitiveness of national industries in an increasingly dynamic global market (Franco & Marin, 2017; Barizi & Triarda, 2020; Magno & Guzman, 2021). This policy seeks to leverage Indonesia's rich mineral resources, such as nickel, which are crucial for new technologies like battery production and nuclear energy. With Indonesia's nickel reserves reaching 2.6 billion tons (the largest in the world), the downstream policy in the mining sector also has the potential to strengthen national energy security.

Downstream policies bolster energy security through various means. Saigaparova et al. (2014) explain that the expansion of the downstream mining sector can enhance energy security by utilizing alternative energy sources such as renewable energy. Energy diversification minimizes the risk of supply disruptions and energy price shocks (Chuang & Ma, 2013). Additionally, the growth of the downstream sector can stimulate technological advancements and the adoption of energy-saving practices, further contributing to energy security (Franco & Marin, 2017). Advanced technology drives productivity and energy efficiency, even promoting clean energy (Abdelaziz et al., 2011). In other words, technological innovation can be seen in improved energy efficiency.

Studies on the impact of the downstream mining sector on energy security are still limited. Previous studies have focused more on the determinants of energy security (Erdal, 2015; Ningi et al., 2020; Pimonenko et al., 2022). Some studies indicate key factors of energy security such as economic and political factors (Tichý, 2020; Balitskiy et al., 2014); finance (Pimonenko, 2022), geopolitics and global factors (Bucka et al., 2011); and technological advancements (Valentine, 2011; Azzuni & Breyer, 2018). Studies focusing on downstream exploration tend to review its impact on economic factors such as industrial added value, exports, and economic growth (Baghebo & Beauty, 2015; Balitskiy et al., 2014; Blonigen, 2016). Therefore, this study aims to examine the impact of downstream policies in the context of energy security in Indonesia.

Understanding the impact of downstream on energy security is crucial for several reasons. First, energy security is fundamental to national security. Reliable energy supply is essential for industrial activities, household needs, and the broader economy (Phoumin & Kimura, 2019; Rodionova, et al., 2017). Indonesia's energy security index, with a score of 6.64 in 2023, falls below the ideal score of 7 or even 10. By examining how downstream affects energy security, this research provides insights into strategies for enhancing national energy resilience and sustainability.

This research is highly relevant in the context of global energy transition and climate change. As the shift towards cleaner and more sustainable energy sources intensifies, Indonesia's ability to harness its mineral wealth for green technologies, such as electric vehicle batteries, becomes increasingly important. Downstream can strengthen global supply chains and contribute to global efforts to address climate change while also driving domestic economic benefits (Singer & Donoso, 2008; Baghebo & Beauty, 2015; Siudek & Zawojska, 2022). This dual advantage underscores the importance of downstream policies both in national and global contexts.

The structure of this research is as follows. Section 2 discusses the literature on downstream and energy security. Section 3 outlines the data and methodology. Section 4 presents and discusses the results of our main analysis, which includes estimates of the impact of down streaming on aggregate energy security and its indicators. Section 5 provides conclusions and policy recommendations.

2. Literature Review

2.1 Conceptual Framework effect of Downstream on Energy security

Energy security is a crucial aspect for society and industry. In this context, Kumar et al. (2022) explains that downstream activities in the energy and mining sectors play a vital role in maintaining the stability and efficiency of energy supply. The implementation of downstream policies strengthens national energy resilience by enhancing industry performance (Yuan et al., 2020). Downstreaming increases the added value of industries, which is beneficial for their growth (Kaplinsky & Morris, 2000; Bam & De Bruyne, 2017). Furthermore, it attracts more investment into related sectors, thereby reinforcing the industrial foundation (Magno & Guzman, 2021). The result is a significant increase in output and energy supply, as reported by various studies such as Hasheminejad et al. (2011) and Franco & Marin (2017) and energy research institutions like Deloitte (2022). Through this approach, energy resilience in terms of energy availability is significantly enhanced.

Downstream policies in the energy and mining sectors not only strengthen national energy resilience but also promote energy diversification. According to the Australian Institute of Petroleum (2020), this energy diversification is achieved by optimizing various local energy resources, such as minerals and raw materials that were previously exported in their raw form. This is supported by studies by Gitelman et al. (2023) and Leonowicz & Burgio (2022), which found that energy diversification reduces dependence on a single energy source, enhances supply stability, and strengthens overall energy resilience.

Downstream policies in the energy and mining sectors significantly impact energy resilience through the resulting technology transfer. Downstream activities encourage industries to develop more advanced processing technologies (Magno & Guzman, 2021) and enable more efficient use of renewable and non-conventional energy (Liu & Liang, 2013). The growth of the downstream sector can stimulate technological advancements and the implementation of energy-saving practices, which further contribute to energy resilience (Valentine, 2011; Azzuni & Breyer, 2018). These advanced technologies enhance productivity and energy efficiency and promote the use of clean energy (Hache, 2018).

In other words, technological innovations emerging from the downstreaming of the energy and mining sectors can be seen in the overall improvement of energy efficiency.

In the aspect of downstream activities, including in the energy and mining sectors, there are several stages, namely refining, distribution, marketing and storage. These activities play a significant role in ensuring a stable and efficient energy supply and contribute to the three main dimensions of energy security. According to research by Elgowainy et al. (2014)., efficient refining contributes to sustainable energy availability by ensuring consistent product supply. In addition, advanced refining technology and adequate infrastructure minimize operational disruptions, ultimately increasing the reliability of energy supply. Cost-effective refining also plays a role in lowering production costs, which can make energy products more affordable for consumers (Morrow et al., 2015).

Effective distribution is critical in ensuring energy products reach various regions and consumers. According to Bouffard & Kirschen (2008), a strong distribution system increases energy availability by reducing the risk of supply shortages. Reliable distribution infrastructure also reduces the risk of disruptions in the supply chain, increasing reliability. In addition, strategic marketing ensures energy products can be easily accessed by consumers, thereby contributing to energy availability and affordability (Das, et al).

Intervening variables such as regulations, technological advances, market dynamics, geopolitical factors, and environmental policies greatly influence the effectiveness of downstream activities in increasing energy security (Bucka & Zechowska, 2011; Balitskiy et al., 2014; Tichý, 2020; Pimonenko, 2022). Supportive regulations can strengthen the efficiency of downstream operations, while technological advances in refining, distribution and storage improve operational efficiency and resilience. Market dynamics, with fluctuations in supply and demand, influence energy availability and prices, while geopolitical stability ensures uninterrupted energy flows. Environmental policies ensure that downstream activities comply with sustainability goals. All these factors need to be managed effectively to optimize the contribution of downstream activities to energy security.

2.2 Downstream and Energy Security

Empirical studies on downstream activities and energy security reveal a complex interaction between various factors that affect a country's energy stability. For instance, Turkey's focus on oil and natural gas exploration, while beneficial for energy supply security, increases dependence on fossil fuels, thereby undermining climate change efforts (Dogan et al., 2023). Similarly, Pakistan's sustainable energy security has experienced a decline due to substantial import dependence and inefficiencies in the electricity sector, highlighting the need for a balanced approach to energy management (Abdullah et al., 2022). In the Middle East, energy security risks negatively impact economic growth, underscoring the importance of secure trade routes and diverse energy policies (Kartal, 2022).

Empirical studies indirectly discuss the relationship between downstreaming activities and energy security. The impact of downstreaming on energy security can be explained through the goals of downstreaming, such as increasing value-added and industrial performance. Pimonenko et al. (2022) study found that financial factors are crucial for national energy security, in addition to institutional, ecological, and behavioral factors. These factors support the operation of the energy industry, modernization, technology implementation, and research and development.

Previous studies also indicate that downstreaming policies are intended to strengthen the dynamic geopolitical conditions of a country (Franco & Marin, 2017). Correljé & Van der Linde (2006) found that a country's political conditions can influence energy security by affecting strategic partnerships, stakeholder engagement, and management systems. Conversely, Kim & Urpelainen (2016) noted that political decisions, such as promoting fossil fuels over renewable energy sources, can hinder efforts to enhance energy security. Additionally, political instability and geopolitical risks can pose significant challenges to energy security, as seen in the case of Thailand facing energy security risks due to economic downturns and external factors such as Russia's invasion of Ukraine (Hart & Breitner, 2022). Hart & Breitner (2022) also added that decision-making processes in complex systems are often influenced by political complexities and differing risk perspectives, which can impede the development of resilient energy systems.

Global climate change significantly impacts energy security by posing risks to various energy systems (King & Gulledge, 2014). Hughes & de Jong (2021) found that extreme weather events caused by climate change threaten reliable electricity supply by affecting transformers, transmission networks, and generators dependent on water supply, as highlighted in a study focusing on the electricity supply in Western Canada. Goodarzi et al. (2020) noted that the vulnerability of hydropower plants to climate change is evident, with projections showing decreased energy production due to changing hydrological variables, such as increased temperatures and decreased rainfall. Overall, the various studies above demonstrate that downstreaming policies are important as they promote technology transfer within industries (Magno & Guzman, 2021) and impact energy supply by encouraging the creation of clean energy that can help address climate.

3. Method

3.1 Data

This study explores the impact of downstream activities on energy security in Indonesia using panel data from 34 provinces over the period 2017-2022. The selection of this period was primarily based on data availability, ensuring the analysis could be conducted with the most recent and comprehensive dataset. This period is particularly significant as it captures key developments in Indonesia's energy and mining sectors, including the implementation of major policies and reforms aimed at enhancing downstream activities.

Energy security variables were constructed using the Principal Component Analysis (PCA) method, incorporating four key dimensions of energy security: Availability, Accessibility, Affordability, and Acceptability. These dimensions were based on the model developed by the Asia Pacific Energy Research Centre (APERC) using the 4 A's approach to energy security (APERC, 2007). Each dimension in this study is represented by different proxy variables, including installed capacity, electricity generation, electricity tariffs, and the percentage of electricity users. Table 1 presents the variables used to construct energy security indicators in this study.

Tabel 1. Energy Security Indicator

Variables	Symbol	Definition	Sources
Availability			
Capacity	capc	Installed Capacity of Power Plants by Province (Mega Watt)	BPS
Accessibility			
Power	pow	Electric Power Generated by Province (GWh)	BPS
Affordability			
Price	price	Average Electricity Tariff per Customer Group (Rp/kWh)	BPS
Acceptability			
Electricity	elect	Percentage of Households by Province, Region Type and PLN Electric Light Source (Percent)	BPS

Table 2 provides a summary of the proxy indicators for the energy security dimensions: availability, accessibility, affordability, and acceptability. For the availability dimension, the variable capacity, representing the installed capacity of power plants, has an average value of 1914.59 MW, with a maximum value of 13,543.39 MW recorded in Central Java Province in 2022. Additionally, the variable pow, which denotes total electricity generated, shows an average and maximum value of 8,382.29 GWh and 65,368.35 GWh, respectively. Central Java also recorded the highest pow value, corresponding with the high installed power plant capacity.

Regarding the affordability dimension, proxied by the variable *price* (which represents the average electricity tariff per customer group), the mean value is 953.71 Rp/kWh. The highest recorded value is 1311.16 in Papua Province in 2022, while the lowest value is 12.21 in the Bangka Belitung Islands in 2020. These figures indicate significant disparities in electricity tariffs, largely attributed to the limited reach of the electricity grid in eastern Indonesia.

The variable *elect*, representing the percentage of households using electricity, has a mean value of 92.89 percent. This means that, on average, approximately 93 percent of households in Indonesia rely on electricity for daily needs. The highest value recorded is 100 percent in DKI Jakarta, while the lowest is 41.61 percent in Papua. This highlights the considerable disparity in electricity access across the country, with less than half of the households in Papua having access to electricity.

Table 2. Summary Statistics of Energy Security Indicator

Variables	Capacity	Power	Price	Electricity
Mean	1914.59	8382.29	953.71	92.89
Maximum	13543.39	65368.35	1311.16	100
Minimum	0	0	12.21	41.61
Std. Dev.	2892.25	15126.6	326.73	10.78
Obs	204	204	204	204

Source: Author's data processing results

We proxy downstream activities using the added value of the mining sector, considering that all business activities in the mining industry represent a series of downstream processes that create added value for a product. The added value generated by the mining industry is derived from the process of converting raw materials into finished or semi-finished goods. These downstream mining activities are closely linked to energy security.

Furthermore, this study incorporates several control variables to account for the potential influence of other factors on energy security, and to mitigate omitted variable bias, which could lead to biased and inefficient estimates. The control variables included are labor, domestic investment, and economic growth. A competent workforce in the mining sector, particularly in renewable energy, can enhance the sector's performance by producing more efficient energy. Investment plays a key role in the development of energy infrastructure, including the adoption of advanced and environmentally friendly technologies. The penetration of renewable energy reduces dependence on conventional fuels and enhances energy security. Lastly, economic growth contributes to energy security by increasing energy demand, which in turn drives the development of new energy infrastructure and the diversification of energy sources.

Table 3. Variable Description

Variables	Symbol	Definition	Sources
Energy Security	Ensec	Energy security is constructed using the PCA method, incorporating the dimensions of Availability, Accessibility, Affordability, and Acceptability.	Statistics Indonesia (BPS)
Downstream	Downs	The added value of the mining industry	Statistics Indonesia (BPS)
Labor	Lab	Number of workforces	Statistics Indonesia (BPS)
Investment	invest	Value of domestic investment	Statistics Indonesia (BPS)

Economic Growth	Eco	Growth in Gross Domestic Product	Statistics (BPS)	Indonesia

3.2 Energy Security Construction with Principal Component Analysis (PCA)

This study employs the Principal Component Analysis (PCA) method to construct the energy security variable. PCA is a widely used technique for constructing composite indices (Lin & Kuo, 2023; Wang et al., 2023; Yaqin & Safuan, 2023). PCA captures the variation across the components or indicators used to measure energy security. Prior to applying PCA, the indicators for each dimension were standardized to account for differences in measurement units among the variables, ensuring that the measurement scales do not distort the analysis.

To obtain the energy security variable, the values of all dimensions, weighted by their respective dimensions, were summed. The energy security variable is constructed using Equation 1.

$$Ensec_{it} = w_1 Y_{it}^{capc} + w_2 Y_{it}^{pow} + w_3 Y_{it}^{price} + w_4 Y_{it}^{elect} \quad (1)$$

Where $Ensec$ represents the composite index of energy security; w_1, w_2, w_3, w_4 are the relative weights for each dimension of energy security. Y_{it}^{capc} represents the availability dimension Y_{it}^{pow} represents the accessibility dimension, Y_{it}^{pric} represents the affordability dimension, and Y_{it}^{elect} represents the acceptability dimension.

3.3 Method for Estimating the Impact of Downstream on Energy Security

To estimate the impact of downstream activities on energy security, we apply static panel regression analysis. The use of panel regression offers several advantages, particularly by increasing the number of observations, which enhances the degrees of freedom and helps mitigate omitted variable bias that could lead to inefficient and biased estimates. The general form of the panel data regression model is expressed by the following equation (Hsiao, 2003):

$$\gamma_{it} = \alpha_{it} + \beta X_{it} + \varepsilon_{it}$$

In the panel regression models, the dependent variable is denoted by γ_{it}, representing energy security for province $i$at time t. The intercept α_{it}captures the baseline level of energy security when all independent variables are zero. The independent variables, represented by X_{it}, include factors such as downstream activities, labor, economic growth, and domestic investment, all of which are expected to influence energy security. Each independent variable has a corresponding coefficient β, which indicates the strength and direction of its relationship with energy security. The error term, ϵ_{it}, captures the unobserved factors that may also affect energy security but are not included in the model. The subscript $i$represents the cross-sectional units (provinces), and $t$represents the time dimension (years).

For this study, the research model specification is as follows:

$$ensec_{it} = \beta_0 + \beta_1 log(downs)_{it} + \beta_2 log(lab)_{it} + \beta_3 eco_{it} + \beta_4 log(invest)_{it} + \epsilon_{it} \quad (2)$$

Where $ensec$ represents the composite index of energy security, constructed using the Principal Component Analysis (PCA). log (downs)represents the log-transformed value of downstream activities. log(lab) represents the log-transformed value of labor (workforce in the mining sector). Eco represents economic growth (GDP), log (Invest)represents domestic investment and $\epsilon_{it}$is the error term. The coefficient $\beta_1$is expected to be positive, indicating that downstream activities are anticipated to positively influence energy security in Indonesia.

Additionally, this study examines the impact of downstream activities on the individual dimensions of energy security. These dimensions include installed capacity, electric power generation, electricity tariffs, and the percentage of electricity users. The estimation for these dimensions is based on the following research models:

$$capc_{it} = \gamma_0 + \gamma_1 log(downs)_{it} + \gamma_2 log(lab)_{it} + \gamma_3 eco_{it} + \gamma_4 log(invest)_{it} + \epsilon_{it} \quad (3)$$

$$pow_{it} = \delta_0 + \delta_1 log\ (downs)_{it} + \delta_2 log\ (lab)_t + \delta_3 eco_{it} + \delta_4 log\ (invest)_{it} + \epsilon_{it} \quad (4)$$

$$price_{it} = \vartheta_0 + \vartheta_1 log\ (downs)_{it} + \vartheta_2 log\ (lab)_t + \vartheta_3 eco_{it} + \vartheta_4 log\ (invest)_{it} + \epsilon_{it} \quad (5)$$

$$elect_{it} = \rho_0 + \rho_1 log\ (downs)_{it} + \rho_2 log\ (lab)_t + \rho_3 eco_{it} + \rho_4 log\ (invest)_{it} + \epsilon_{it} \quad (6)$$

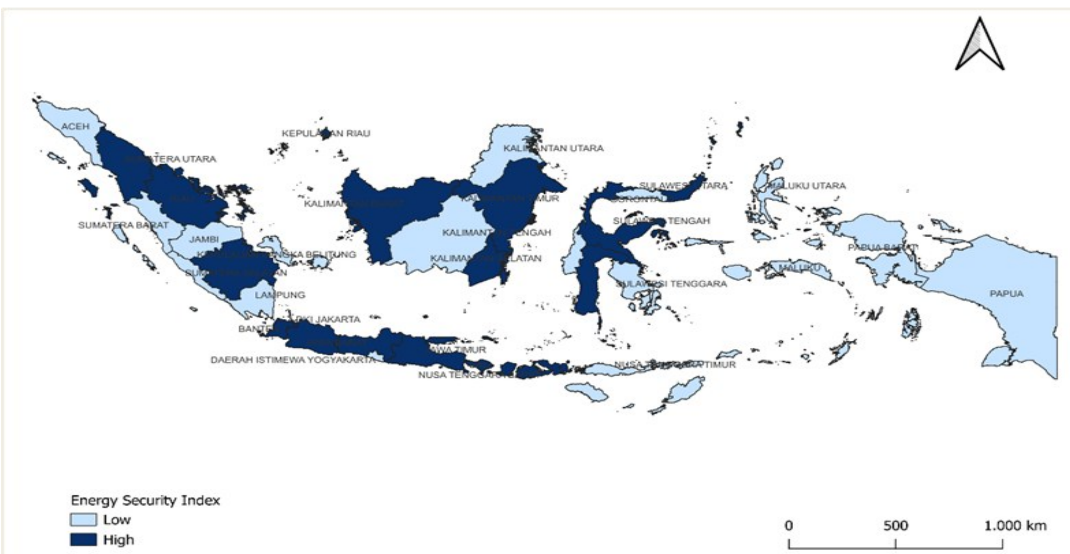
Where *capc* represents the availability dimension (installed capacity of power plants), *pow* represents the accessibility dimension (electric power generated), *price* crepresents the affordability dimension (electricity tariffs), and *elect* represents the acceptability dimension (percentage of households with access to electricity). Each of these models assesses the relationship between downstream activities and the individual dimensions of energy security. The coefficients γ_1, δ_1, ϑ_1, and $\rho_1$are expected to be positive, reflecting the anticipated positive impact of downstream activities on energy security indicators.

4. Results and Discussion

4.1 Energy Security in Indonesia

Energy security in Indonesia is a critical issue that reflects the nation's ability to provide reliable, affordable, and sustainable energy for its growing population and economy. With diverse geographical, economic, and developmental conditions across its provinces, energy security in Indonesia varies significantly from one region to another. Figure 2 illustrates the Energy Security Index across various provinces in Indonesia, with dark blue regions representing higher energy security index values, and bright blue regions denoting lower index values. This spatial distribution highlights significant regional disparities in energy security within the country. Provinces such as DKI Jakarta, West Java, and East Java exhibit higher energy security, as indicated by the dark blue shading. These areas benefit from robust energy infrastructure, diversified energy sources, and substantial industrial activities, which drive investments in energy systems. For instance, Jakarta, being the capital city, has a well-developed energy infrastructure and higher economic activities, which support a reliable energy supply.

Figure 2. Energy Security Index



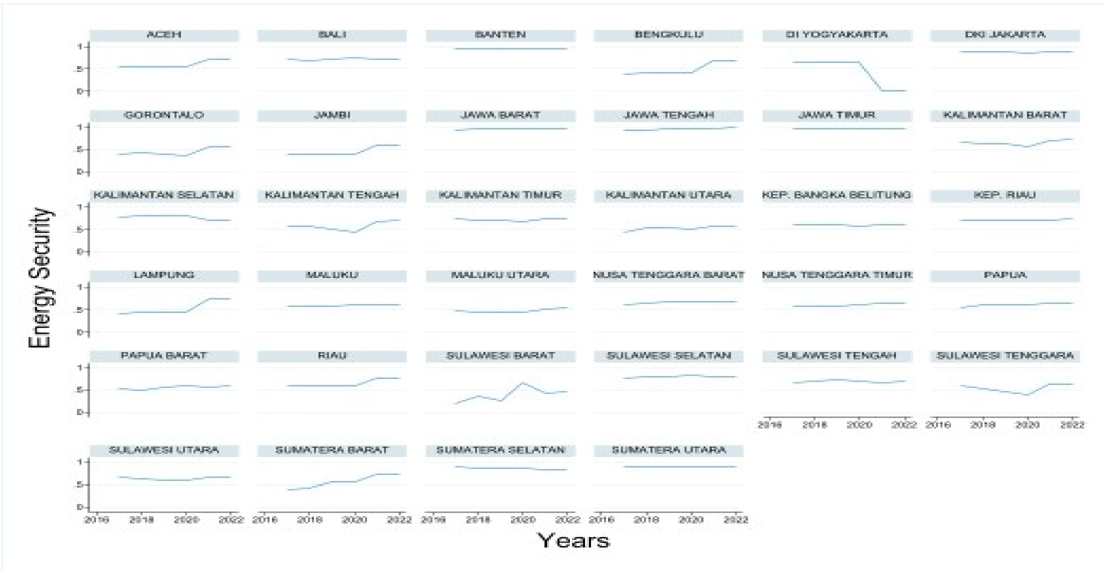
Note: Energy security is categorized as low if it is below 0.5 and high if it is above it.

Source: Author's data processing results

Conversely, provinces like Papua, West Papua, and parts of Nusa Tenggara show lower energy security, marked by the bright blue color. These regions face challenges such as inadequate energy infrastructure, limited access to energy resources, and logistical difficulties due to their geographical location. The disparity in energy security indices reflects broader economic and developmental inequalities within Indonesia, where remote and less economically developed regions struggle to achieve the same level of energy security as more industrialized and economically vibrant provinces.

From 2017 to 2022, the average energy security index for the country shows a gradual improvement. However, this positive trend is uneven across different regions. Data from the Indonesian Ministry of Energy and Mineral Resources (2022) suggest that national policies focusing on energy diversification, rural electrification, and investments in renewable energy have contributed to enhancing energy security. Nevertheless, the uneven distribution of these advancements necessitates targeted regional policies to address specific local challenges and improve energy security comprehensively.

Figure 3. The Trend of Energy Security Index by Provinces



Source: Author's data processing results

Figure 3 illustrates the trends in the energy security index across various provinces in Indonesia. Overall, most provinces show a relatively stable or slightly increasing trend in their energy security index over the years, with some regions, such as Bengkulu, Lampung, Riau, and North Sumatra, displaying more noticeable upward movements, indicating improvements in energy security. Conversely, provinces like DI Yogyakarta, South Kalimantan, and Southeast Sulawesi exhibit downward trends, suggesting challenges in maintaining or improving energy security. The general pattern reflects a diverse regional landscape, where energy security has either remained consistent or shown modest progress, with certain areas experiencing more pronounced growth, possibly due to targeted regional policies or infrastructure developments.

The spatial and trend analysis of the energy security index in Indonesia reveals significant regional disparities, with provinces on Java Island mostly showing higher energy security compared to the eastern regions of Indonesia. While national policies and programs have made strides in improving overall energy security from 2017 to 2022, addressing regional inequalities remains a critical challenge. Focused regional strategies and sustained investments are essential to ensure equitable energy security across all provinces in Indonesia.

4.2 The Estimation Results of Downstream on Energy Security

This section presents the estimation results for the impact of downstream activities on energy security. Prior to conducting the estimation, model selection was performed using the fixed effects model (FEM), random effects model (REM), and pooled least square (PLS). The selection of the best model was based on the results from several diagnostic tests: the Lagrange-multiplier (LM) test, the Chow test, and the Hausman test.

The results of the LM test indicated a probability value of 0.000, which is less than the 1%, 5%, and 10% alpha levels, suggesting that the null hypothesis should be rejected in favor of the REM model over PLS. The Chow test also showed a probability value of 0.000, indicating the rejection of the null hypothesis and favoring FEM over PLS.

Finally, the Hausman test results showed a probability value greater than the alpha level, implying that REM is preferred over FEM. Therefore, the REM model was selected as the primary model for the estimation.

Table 5 presents the estimation results, which show that downstream activities have a positive and statistically significant effect on energy security, with a coefficient of 0.0223. This suggests that a 1% increase in downstream activities leads to a 0.0223% improvement in energy security. The positive and significant coefficient indicates that the expansion of the downstream mining sector contributes to enhanced energy security in Indonesia.

In addition, the estimation results for control variables show that labor has a positive and highly significant effect on energy security, with a coefficient of 0.0972 at the 1% significance level. This implies that a larger and more skilled labor force within the downstream sector boosts energy security by increasing productivity and supporting more efficient energy usage. Furthermore, investment demonstrates a positive and significant impact on energy security at the 5% significance level. This highlights the importance of continued capital investment in developing energy infrastructure and adopting advanced technologies to strengthen energy security in Indonesia.

Tabel 5. The Estimation Results of Downstream on Energy Security

Variables	REM	FEM	PLS
$logdown$	0.0223**	0.0059	0.0177*
	(0.0217)	(0.7956)	(0.0592)
$loglab$	0.0972***	0.3357	0.08229***
	(0.0000)	(0.2293)	(0.0000)
eco	0.0000	-0.0001	0.0005
	(0.9991)	(0.9441)	(0.7480)
$loginvest$	0.0194**	0.0063	0.0355***
	(0.0185)	(0.6440)	(0.0008)
constant	-1.1108***	-4.3269	-0.9895***
	(0.0000)	(0.2600)	(0.0000)
obs	204	204	204
F-test	16.7880***	18.0733***	58.2544***
	(0.000)	(0.00000)	(0.0000)
Wald chi2			
R-Squared	0.2523	0.8011	0.5393
LM Test			137.056***
			(0.0000)
Chow Test		171.347***	
		(0.0000)	
Hausman Test	0.000		
	(1.0000)		

*Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively*

Source: Author's data processing results

The downstream mining sector can promote the diversification of energy sources, as industries in this sector often utilize a mix of energy inputs, including natural gas, electricity, and renewables, thereby reducing dependency on any single energy source. As demonstrated by Saigaparova et al (2014), the expansion of the downstream mining sector contributes to energy security in Indonesia. This diversification is crucial for energy security as it mitigates the risks associated with supply disruptions and price volatility.

The Indonesian government has encouraged increased energy supply by promoting the use of a 30% biodiesel (B30) program in 2020, which aims to enhance the use of clean energy, reduce CO2 emissions, and decrease dependence on fossil fuel imports (Saputra et al., 2021). Similarly, Zhang et al (2022) explain that the development of new energy sources can reduce reliance on conventional fuels like coal and improve the structure of energy consumption and resources to achieve more sustainable energy production and usage. This is further confirmed by findings from Sun & Chen (2022) who state that support for renewable energy usage, such as through green financing, will effectively drive adjustments in energy consumption structures towards cleaner energy consumption.

Additionally, the growth of the downstream sector can stimulate technological advancements and the adoption of energy-efficient practices, further contributing to energy security. Pan et al. (2019) found that technological innovation drives energy efficiency through the implementation of energy-saving technologies, indicating the need for government incentives and subsidies to encourage companies to create various technological innovations. Chen et al. (2021) concluded that technological innovation enables a country not only to transition to renewable energy but also to improve production systems to progressively reduce energy intensity. In other words, advancements in technological innovation can be seen in improvements in energy efficiency.

Furthermore, the downstream sector's growth enhances the resilience of energy systems by promoting local value addition and reducing dependence on energy imports. By processing raw materials domestically, the downstream industry helps stabilize the supply chain and mitigates risks associated with global market fluctuations and geopolitical tensions that often impact energy imports. This localized production model fosters a more self-reliant economy, reducing the vulnerability of the mining sector to external shocks. As highlighted by Yao et al. (2020), countries that prioritize domestic value addition in their resource sectors tend to experience greater stability in energy supplies, which ultimately strengthens their overall energy security.

In addition, the downstream sector's role in energy security is also linked to its potential to create jobs and spur economic growth, which further supports energy infrastructure development. Employment generated by the expansion of downstream industries increases household incomes, fostering greater domestic demand for diverse energy sources and incentivizing further investments in energy infrastructure. The study by Magno and Guzman (2021) demonstrates that countries with robust downstream sectors tend to have higher energy infrastructure investments, as increased economic activity drives demand for more reliable and efficient energy systems (Magno & Guzman, 2021). Similarly, Franco and Marin (2014) also suggest that energy taxes and downstream sector productivity spur innovation, indirectly supporting energy infrastructure development (Franco & Marin, 2014). Thus, the downstream sector contributes to a cycle of growth and development that underpins a more secure, sustainable, and resilient energy landscape.

4.3 The Estimation Results of Downstream on Energy Security Indicator

This section presents the estimation results of the impact of downstream activities on the four key dimensions of energy security: availability, accessibility, affordability, and acceptability. By using panel data and employing a regression analysis, the study evaluates how downstream activities in Indonesia, particularly in the mining sector, influence these dimensions. The results demonstrate that downstream activities play a significant role in improving energy security across different aspects, although the effects vary in magnitude and significance. While downstream activities positively impact the availability, accessibility, and acceptability of energy, their effect on energy affordability remains inconclusive, reflecting the complex cost structures and policy influences in the energy sector. The following results provide a detailed breakdown of how each dimension of energy security is affected by downstream activities, labor, economic growth, and investment.

Table 6 presents the estimation results for the impact of downstream activities on the four dimensions of energy security. The analysis reveals that downstream activities have a significant positive impact on the availability dimension, which reflects the capacity to meet energy demand. The estimated coefficient of 0.1984 implies that a one percent increase in downstream sector activities leads to a 0.1984 percent improvement in energy availability. This suggests that downstream activities are integral to ensuring energy availability. The expansion of downstream industries, such as mining and processing, increases the demand for energy infrastructure. As downstream sectors grow, energy demand rises, prompting investments in energy generation and distribution to meet industrial needs. In Indonesia, the expansion of sectors such as palm oil refining, textile mining, and automotive industries has led to increased investments in energy projects (Hallward-Driemeier & Gaurav, 2017). Thus, industrial growth contributes to the development of energy infrastructure, enhancing the availability of energy supply.

Table 6. The Estimation Results of Downstream on Energy Security Indicator

Variables	**CAPC**	**POW**	**PRIC**	**ELECT**
$logdown$	0.1984**	0.0375***	-0.0518	0.2390**
	(0.0226)	(0.0000)	(0.3006)	(0.0148)
$loglab$	0.9531***	0.1356**	-0.1174	1.0525***
	(0.0000)	(0.0167)	(0.1333)	(0.0000)
eco	0.0047	-0.0011*	0.0162	0.0199
	(0.5293)	(0.0068)	(0.3156)	(0.1604)
$loginvest$	0.1937***	0.0018	0.0667	0.2658***
	(0.0025)	(0.5503)	(0.1603)	(0.0041)
constant	-10.7316***	2.2235***	8.2111***	-12.3503***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
obs	204	204	204	204
F-test	14.3015***	20.0353***	1.2398	13.5120***
	(0.000)	(0.0000)	(0.2953)	(0.0000)
Wald chi2				
R-Squared	0.2268	0.2871	0.0243	0.2179

*Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively*

Source: Author's data processing results

The estimation results also show a significant positive effect of downstream activities on the accessibility dimension. The coefficient of 0.2390 indicates that an increase in downstream activities improves energy accessibility by 0.2390 percent. This suggests that downstream activities play a crucial role in improving energy access. The downstream sector facilitates the integration of renewable energy, promoting cost savings and energy efficiency. For example, incorporating renewable energy into downstream processes such as extraction, processing, and refining in the mining sector can enhance energy efficiency (Igogo et al., 2020). Additionally, industrial clusters in Indonesia, such as in Batam and Bekasi, have been developed with dedicated energy infrastructure, improving energy access for industries. Lis & Radzio (2023) explain that industrial clustering, where various companies and actors collaborate, can contribute to sustainable development and the advancement of energy systems.

In contrast, downstream activities have no significant impact on the affordability dimension, as measured by electricity tariffs. This may be due to the energy cost structures in Indonesia, which are influenced by the country's archipelagic nature. Electricity generation costs in eastern Indonesia are nearly three times higher than in Java, the economic hub of the country (Wahyuni, 2022). Furthermore, energy affordability is heavily influenced by government policies, such as subsidies and pricing regulations. Ineffective subsidy policies may lead to inefficient energy consumption. Additionally, in providing renewable energy, Indonesia faces regulatory challenges related to price determination in the renewable energy sector, which can hinder investments in this market (Darrian et al., 2023).

Lastly, downstream activities have a significant positive effect on the acceptability dimension, with a coefficient of 0.0375. This indicates that a one percent increase in downstream activities improves energy acceptability by 0.0375 percent. This positive relationship suggests that downstream activities significantly support the acceptability dimension of energy security by enhancing the quality, reliability, and environmental sustainability of energy supplies. These activities help ensure that energy provided to consumers meets high standards. Moreover, downstream activities that incorporate renewable energy sources into the energy mix can contribute to the transition to cleaner and more sustainable energy systems (Igogo et al., 2020). Improving energy quality is crucial for both industrial and residential users, as it ensures a reliable and efficient energy supply.

4.5 Robustness Test

We conducted robustness tests to verify the reliability of the main estimation results. To achieve this, we applied the same estimation method (REM) used in the main analysis, gradually introducing different control variables. We created five models, each incorporating varying control variables, to assess the consistency of the coefficients reflecting the impact of downstream activities in the mining sector (logdowns) on energy security (Ensec). The estimation results are presented in Table 7.

Table 7. Robustness Test

Var	Model 1	Model 2	Model 3	Model 4	Model 5
$logdowns$	0.059***	0.059***	0.060***	0.040**	0.039**
	(0.020)	(0.020)	(0.020)	(0.016)	(0.016)
$loglab$		-0.000	0.000		0.001
		(0.002)	(0.002)		(0.002)
eco			-0.001	-0.000	
			(0.002)	(0.002)	
$loginvest$				0.037***	0.038***
				(0.009)	(0.009)
Constant	0.168	0.168	0.165	0.020	0.017
	(0.166)	(0.167)	(0.169)	(0.134)	(0.133)
Observations	204	204	204	204	204
R-squared	0.00550	0.00548	0.00587	0.0240	0.0249
Wald chi2	9.093	8.948	8.932	33.18	33.78
Prob > chi2	0.00257	0.0114	0.0302	2.94e-07	2.20e-07

*Note: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively*

Source: Author's data processing results

The estimation results across all models (Model 1 to Model 5) consistently show that downstream activities in the mining sector (logdowns) have a significant positive impact on energy security in Indonesia. This confirms that the main estimation results are robust. In each model, the coefficient for *logdowns* remains significant at the 1% to 5% levels, even as control variables such as *loglab*, *eco*, and *loginvest* are gradually introduced. For instance, in Model 1, the coefficient for *logdowns* is 0.059 with a standard error of 0.020, indicating a strong positive effect. As we move to Models 2 through 5, which include additional control variables, the positive and significant impact of *logdowns* continues, with coefficients that change only slightly.

The consistency of these results reinforces the key conclusion of the study: that downstream activities in the mining sector play an important role in enhancing energy security in Indonesia. Despite the introduction of various control variables, the positive effect of downstreaming remains significant, suggesting that downstream policies in the mining sector can be an effective strategy to strengthen national energy security. These findings imply that further investment and development in Indonesia's downstream mining sector could provide substantial benefits for energy stability.

5. Conclusions

This study investigates the impact of downstream activities in the mining sector on energy security in Indonesia, using panel regression models for estimation. The results reveal that downstream activities significantly enhance energy security, particularly in the dimensions of availability, accessibility, and acceptability. As downstream activities expand, they increase the demand for energy infrastructure, which in turn prompts greater investments in energy generation and distribution systems, thus improving the energy supply. However, the impact of downstream activities on energy affordability remains insignificant, likely due to the disparities in electricity generation costs across Indonesia, with remote regions facing much higher costs than the economic hub on Java Island. These findings highlight the critical role of industrial growth in strengthening energy security, while also pointing to the need to address cost-related challenges in the energy sector.

The findings of this study suggest that downstream activities, especially in the mining sector, are integral to enhancing national energy security. Policymakers should prioritize fostering the expansion of downstream industries as a key strategy to strengthen energy security through the development of energy infrastructure. The positive relationship between downstream activities and energy security underscores the importance of targeted investments in both conventional and renewable energy sources, particularly in regions with underdeveloped energy infrastructure. For example, policies aimed at promoting renewable energy technologies and rural electrification should be prioritized to improve energy accessibility and availability in less developed regions such as Papua and Nusa Tenggara. Additionally, addressing the structural imbalances in electricity pricing, which contribute to high energy costs in remote regions, is crucial for improving energy affordability throughout Indonesia. A comprehensive energy policy that integrates industrial growth, energy infrastructure development, and renewable energy adoption will be essential to ensuring a sustainable and equitable energy future across all regions of Indonesia.

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