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Financial Dynamics of Energy, Coal, and Crude Oil Prices: Pathways to Sustainability

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ABSTRACT

This study examines the effect of coal and crude oil prices on Indonesia's Energy Stock Price Index (ESPI) from February 2021 to November 2024. Utilizing econometric tools such as the Augmented Dickey-Fuller (ADF) test, Johansen cointegration test, and Vector Error Correction Model (VECM). Findings indicate a significant link between coal, crude oil, and the energy sector, with coal exerting a strong and consistent influence on the ESPI, while crude oil's impact is less pronounced in the short term. The Granger causality test reveals a one-way causal relationship from coal and crude oil to energy, emphasizing the importance of past price movements in forecasting energy price fluctuations. The study concludes that coal largely drives the ESPI, while crude oil and energy prices also contribute to its variations. These results highlight the considerable impact of coal and crude oil price shocks on energy prices, providing important insights for investors and policymakers. Future research could broaden the scope by including factors like technological advancements, environmental policies, and global economic conditions for a deeper understanding of energy market dynamics.

Keywords: Energy, Coal, Crude Oil, VECM
JEL Classifications: C13, C22, G17, Q48

1. INTRODUCTION

Energy is a core concept in physics, representing a system's capacity to perform work. It exists in multiple forms, such as kinetic energy (motion energy), potential energy (energy stored due to position), thermal energy (heat), chemical energy (energy within atomic and molecular bonds), electrical energy, and nuclear energy. A deep understanding of energy and its various types is essential for tackling global issues like climate change, energy security, and sustainable development. Transitioning to cleaner and more sustainable energy sources is vital for ensuring a sustainable future. Non-renewable energy sources, such as fossil fuels (coal, oil, and natural gas) and nuclear energy, are limited in supply and cannot be replenished within a human lifespan. These energy sources are typically extracted from the Earth.

The value of a company is influenced by several factors, including its assets, revenue, profitability, growth potential, and prevailing market conditions (Goh et al., 2024). For energy companies, specific key factors that determine their value include the size and quality of their asset base, financial performance in terms of revenue and profitability, growth opportunities, market dynamics, levels of debt and financial stability, advancements in technology, geopolitical influences, and commitment to environmental and social responsibility (Ferrer et al., 2018; Goh et al., 2024; Goh et al., 2021; Cosimato and Troisi, 2015; Khalil et al., 2024; Adamkaite et al., 2023; Zhou et al., 2022; Rheynaldi, 2023; Amalia et al., 2021; Denisova, 2020).

Phan et al. (2019), Chen et al. (2020), and Hu et al. (2023) explore the connection between oil price shocks and green innovation, emphasizing several key insights. They find that rising oil prices drive increased green patenting activities, both in terms of intensity and economic value, as firms prioritize energy efficiency and environmental controls when oil becomes a more valuable resource. Conversely, when oil supply expands and prices drop, the intensity and value of green innovation tend to decline due to weaker economic incentives to invest in alternative energy solutions. Firms with stronger access to financing and those in highly competitive industries are more responsive to oil price shocks, likely due to their ability to adapt quickly by pursuing green innovation. In contrast, oil producers, despite experiencing higher profitability during oil demand shocks, often reduce green innovation efforts. This decline may stem from a focus on short-term profits or a reduced need for green innovation when traditional oil demand is high.

The research questions are: How do changes in crude oil prices affect the market valuation of energy companies? How do fluctuations in crude oil and coal prices influence energy stock prices? The study aims to explore the impact of crude oil and coal price volatility on firm value to provide insights into economic stability and investment decisions. Crude oil prices are highly volatile, influenced by geopolitical events, supply-demand imbalances, OPEC policies, and macroeconomic factors, creating uncertainty for energy firms and affecting their revenues, costs, and market value. Despite the global shift toward cleaner energy, coal remains a significant energy source, particularly in emerging economies like China, India, and Indonesia. Rising crude oil prices can increase production and operational costs for energy firms, potentially reducing profit margins for non-integrated companies. For upstream oil companies like Pertamina, higher crude oil prices translate to increased revenues from exploration and production, boosting stock valuations. As one of the world's largest coal exporters, Indonesia hosts major players such as Adaro Energy, Bukit Asam, and Indo Tambangraya Megah. Higher global coal prices result in increased revenues for these companies, contributing to a rise in the energy stock index. The influence of crude oil and coal prices on Indonesia's Energy Stock Price Index is especially significant, given the country's heavy reliance on these fossil fuels. As a major coal exporter and a net importer of oil, Indonesia's energy sector is closely connected to global price movements of these key commodities.

2. LITERATURE REVIEW

The Energy Stock Price Index (ESPI), which tracks the performance of energy sector stocks, is influenced by a complex interplay of financial markets, investor behavior, and energy market dynamics. It reflects investor sentiment and expectations about the future profitability of energy companies, strongly affected by current and anticipated energy prices. Mukhtarov et al. (2022), Prempeh (2023,) Gnahe (2020), and Wang et al. (2021) noted that the ESPI could indirectly impact energy prices through market signaling. Investors in energy stocks often utilize financial instruments like futures and options for hedging or speculation, with ESPI movements influencing these instruments and, consequently, energy prices.

Melati et al. (2023) highlighted the close link between the ESPI and energy prices, including coal and crude oil, with the two interacting through market expectations, speculation, and macroeconomic factors. External elements such as regulatory shifts, technological advancements, and broader economic trends also shape this relationship. The ESPI's correlation with indices like the Nikkei and Dow Jones reflects broader equity market trends in Japan and the U.S., shaped by macroeconomic conditions and sectoral dynamics. Exchange rates significantly influence energy stock valuations, especially for globally active companies. While the ESPI often aligns with broader indices during economic growth, divergence may occur due to commodity price shocks, geopolitical risks, or currency volatility. Understanding these dynamics is crucial for investors and policymakers monitoring energy markets and their wider economic implications.

Adekunle (2023) examined how the growth of renewable energy could reduce long-term demand for fossil fuels, negatively affecting the stock prices of non-renewable energy companies. This dynamic may result in the ESPI underperforming if dominated by traditional energy stocks. Non-renewable energy stocks typically experience high volatility due to geopolitical risks, supply chain disruptions, and fluctuating demand, while renewable energy stocks face volatility tied to technology adoption rates, rare earth material supply chains, and project financing. In the short to medium term, both renewable and non-renewable energy sources remain essential for meeting global energy demand, with the ESPI reflecting this transitional phase. Over the long term, the index is expected to shift towards renewable energy stocks as decarbonization efforts intensify. The relationship between renewable and non-renewable energy in the ESPI is marked by competition, complementarity, and the dynamics of transition. While non-renewables have historically dominated the index, the growing influence of renewables signifies a shift towards sustainability. Over time, the ESPI is anticipated to align more closely with the performance of renewable energy companies, reflecting global sustainability goals.

Research by Guo and Zhao (2024) suggests that fluctuations in crude oil prices frequently drive changes in coal prices, primarily due to the interchangeable roles of these two energy sources, particularly in industries and power generation. Additionally, Chen et al. (2024) explored the application of multivariate models to analyze the interrelationships between energy prices, offering valuable perspectives on risk management strategies for investors in the energy market.

Wu et al. (2023) and Chen et al. (2020) examined how the relationship between the ESPI and environmental sustainability is evolving, driven by policy changes, investor preferences, and market forces. A sustainable ESPI will depend on the energy sector's ability to adopt greener technologies and practices, with a gradual weighting shift toward renewable energy stocks aligning the index with sustainability objectives.

Bekzhanova et al. (2023) and Delgado et al. (2018) explored the interconnectedness of gold prices, oil prices, and energy stock returns, revealing a multifaceted relationship shaped by macroeconomic conditions, geopolitical events, and market dynamics. While oil prices directly impact energy stock returns, gold prices serve as a broader indicator of market sentiment and economic stability.

Utilizing a Vector Error Correction Model (VECM) to study the effects of crude oil and coal prices on Indonesia's ESPI offers insights into both short-term dynamics and long-term relationships. Researchers have widely used VECM for similar analyses. For instance, Derouez et al. (2024) studied energy, technology, and economic growth in Saudi Arabia using VECM and Autoregressive Distributed Lag (ARDL) models to capture the long-term equilibrium and short-term dynamics between energy sources, technological progress, foreign investment, and carbon emissions. Similarly, Tao et al. (2023) investigated the link between renewable energy adoption and CO_2 emissions, employing Bounds Testing and VECM to assess renewable energy's role in reducing emissions.

Khurshid (2023) analyzed Pakistan's sustainability challenges, including energy dependence, geopolitical risks, and trade policies, using VECM to explore causal relationships and dynamics, offering insights to align policies with sustainability objectives. Aboul Ela (2023) studied Egypt's rising energy demand and greenhouse gas emissions, applying VECM and ARIMAX to examine the short- and long-term relationships among CO_2 emissions, CH4 emissions, and energy consumption, providing forecasts to inform policy for sustainable development.

Aboul Ela (2023), was investigating the rapid economic growth and urbanization, leading to rising energy demand and greenhouse gas (GHG) emissions in Egypt. Understanding the dynamics between carbon dioxide (CO_2) emissions, methane (CH_4) emissions, and energy consumption is essential for policy development to ensure sustainable growth. By applying the Vector Error Correction Model (VECM) and Autoregressive Integrated Moving Average with Exogenous Variables (ARIMAX), this study aims to analyze the short-term and long-term relationships among CO_2 emissions, CH_4 emissions, and energy consumption and forecast future trends for these variables to guide policy decisions.

3. DATA AND METHODOLOGY

We examined the influence of coal and crude oil prices on the Energy Stock Price Index (ESPI) by analyzing data from the Indonesia Stock Exchange Energy Index for ESPI, crude oil prices from Investing.com, and coal prices from Trading Economics, covering the period from February 2021 to November 2024. To assess the stationarity of the variables, we conducted the Augmented Dickey-Fuller (ADF) test. When variables were found to be non-stationary but integrated of the same order (I(1)), we proceeded with cointegration testing. Using the Johansen Cointegration Test, we identified long-term relationships among the variables. Since cointegration was confirmed, we employed the Vector Error Correction Model (VECM), which effectively captures both short-term dynamics and long-term equilibrium relationships.

$$\Delta Y_t = \alpha(\beta' X_{t-1}) + i = 1\sum p\Gamma_i \Delta X_{t-i} + \epsilon_t$$

Where:

Y_t: Energy Stock Price Index (dependent variable),

X_t: Vector of independent variables (Coal Price and Crude Oil Price)

β: Long-term equilibrium coefficients,

α: Speed of adjustment to long-term equilibrium

Γ_i: Short-term dynamics coefficients.

We perform the estimation the long-term relationship.

$ESPI = \beta_1 CP + \beta_2 COP + \epsilon$

Then, we include an Error Correction Term (ECT) to account for short-term deviations

$$\Delta ESPI_t = \lambda ECT_{t-1} + \sum_{i=1}^{p} \phi_i \Delta CP_{t-i} + \sum_{j=1}^{q} \phi_j \Delta CP_{t-j} + \epsilon_t$$

4. RESULTS AND DISCUSSION

Descriptive statistics highlight the essential characteristics of a dataset, offering valuable insights into the behavior and relationships of the variables being analyzed (Table 1). In studying the effect of crude oil and coal prices on the energy stock price index, descriptive statistics generally encompass:

The descriptive statistics reveal the behavior of three variables: crude oil, coal, and energy. Crude oil has an average price of 76.61 with a standard deviation of 12.26, indicating moderate price variability. Its price range, spanning from 53.55 to 123.7, reflects a moderate spread. The skewness of 1.09 indicates a right-skewed distribution, suggesting that higher price values occur less frequently. A kurtosis value of 4.41 points to a leptokurtic distribution, characterized by a sharp peak and fatter tails, indicating occasional extreme values.

Coal prices have an average of 165.75 and a standard deviation of 87.38, highlighting significant variability relative to the mean. The range of coal prices, from 63.75 to 439, underscores notable fluctuations. A positive skewness of 1.29 also points to a right-skewed distribution. With a kurtosis of 3.48, the coal price distribution is relatively balanced, closer to a normal distribution but still somewhat heavy-tailed.

Energy prices have an average of 1740.35 and the highest standard deviation at 602.55, indicating substantial variability in absolute terms. Its range, from 691.64 to 2812.35, is the

Table 1: Descriptive statistics

Variable	Mean	Standard deviation	Min	Max	Skewness	Kurtosis
Crude	76.61	12.26	53.55	123.7	1.09	4.41
Coal	165.75	87.38	63.75	439	1.29	3.48
Energy	1740.35	602.55	691.64	2812.35	−0.42	2.06

Source: Authors' own

widest among the variables. However, the skewness of −0.42 suggests a slightly left-skewed distribution, with lower price values occurring more frequently. The kurtosis of 2.06 denotes a platykurtic distribution, which is flatter and less peaked compared to the others.

These observations indicate that coal prices exhibit the greatest volatility due to their high relative variability, while crude oil prices are the most stable, having the lowest standard deviation (Graph 1). Energy prices, although displaying considerable variability, appear more balanced and less skewed than coal and crude. The higher skewness and kurtosis of crude oil and coal prices suggest less predictability and susceptibility to occasional extreme values, likely driven by market dynamics or external shocks. Conversely, energy prices show greater stability and a more consistent distribution. These patterns highlight the potential for coal and crude price volatility to significantly influence energy prices, warranting further analysis to understand their interrelationships.

The results of the Augmented Dickey-Fuller (ADF) unit root test reveal the stationarity characteristics of coal, crude, and energy. For coal, the test statistic at the level I(0) is −2.13, which is not significant, indicating that coal prices are non-stationary at the level (Table 2). However, after first differencing (I(1)), the test statistic improves to −22.62 and is significant at the 1% level, showing that coal becomes stationary after differencing. Similarly, energy prices are non-stationary at the level, with a test statistic of −0.94 that is not significant at the 1% level, but they achieve stationarity at I(1), with a significant test statistic of −29.73 at the 1% level.

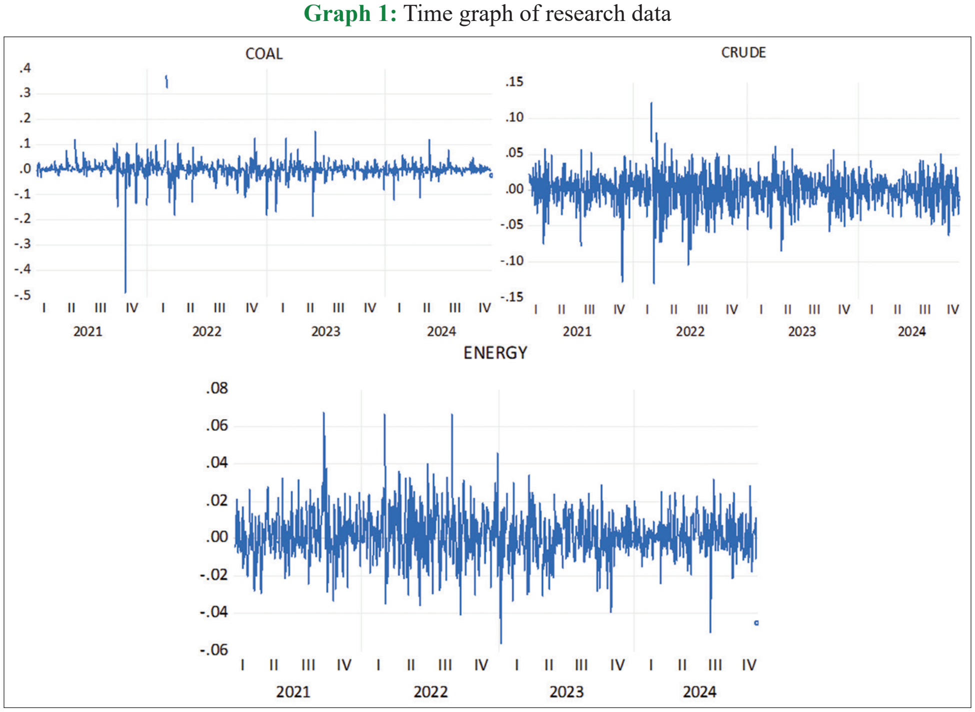
In contrast, crude prices are stationary at level I(0), as indicated by a test statistic of −2.94, which is significant at the 5% level. This means that crude prices do not require differencing to achieve stationarity. These findings demonstrate that coal and energy are integrated of order one, I(1), while crude is integrated of order zero, I(0). This mixture of integration orders makes a standard VAR model unsuitable for analysis. Instead, the Vector Error Correction Model (VECM) is applied, as it is specifically designed to examine long-term relationships between variables with different integration orders while accounting for short-term dynamics.

The lag length selection based on the AIC reveals that different lags have varying levels of explanatory power for energy, coal, and crude (Table 3). For Energy, the AIC value for lag 3 is 9.16, which is the lowest among all lags, indicating that lag 3 provides the best fit for this variable. Similarly, for coal, lag 3 has an AIC value of 7.19, which is lower than lags 1 and 2 but slightly higher than lag 4 (7.14). For crude, both lags 3 and 4 have the same lowest AIC value (4.28), making them equally optimal. However, considering the consistency across energy and coal, lag 3 emerges as the most appropriate choice overall.

Based on these results, lag 3 was selected for the study because it minimizes the AIC and balances the model's complexity with its ability to explain the data effectively. This choice ensures a robust analysis while avoiding overfitting, allowing the model to capture both short-term and long-term dynamics of the variables under investigation.

The cointegration test results indicate the existence of long-term relationships among the variables energy, coal, and crude (Table 4). The test statistics for the hypothesized number of cointegrating equations significantly exceed the critical values at the 5% significance level. For the null hypothesis of "None," the test statistic is 411.88, far surpassing the critical value of 29.79, leading to the rejection of the null hypothesis and confirming at

Graph 1: Time graph of research data



least one cointegrating relationship. Similarly, for "At most 1," the test statistic of 187.55 exceeds the critical value of 15.49, indicating a second cointegrating equation. Finally, for "At most 2," the test statistic is 7.46, which is greater than the critical value of 3.84, confirming a third cointegrating relationship. All associated probability values are below 0.05, further reinforcing the significance of these findings. In summary, the cointegration test provides robust evidence of multiple long-term equilibrium relationships among the variables. The presence of these cointegrating equations supports the application of a Vector Error Correction Model (VECM) to account for both short-term dynamics and long-term adjustments between energy, coal, and crude.

The Granger causality test identifies significant directional relationships among crude, coal, and energy (Table 5). Both crude and coal Granger cause energy, with probabilities of 2×10^{-12} and 2×10^{-7}, respectively, but energy does not Granger cause either crude or coal. Additionally, there is bidirectional Granger causality between coal and crude, with both variables significantly influencing each other, as indicated by probabilities below 0.05. These findings suggest that past values of crude and coal can predict energy prices, while crude and coal are mutually interdependent.

For coal, the coefficient is 0.53, with a standard error of 0.15 and a t-statistic of 3.35 (Table 6). This positive and significant coefficient indicates that changes in coal prices have a notable and direct positive impact on energy prices, supporting a long-term equilibrium relationship between the two variables. For crude, the coefficient is −0.1, with a standard error of 0.06 and a t-statistic of −1.64. Since the t-statistic is not significant, it suggests that crude oil prices do not have a significant short-term effect on energy prices within this model.

The results indicate that energy's own past values (lags 1, 2, and 3) do not significantly impact current energy changes, suggesting a lack of short-term autocorrelation. In contrast, coal consistently has a positive and significant effect on energy across all lags, implying that past coal prices are strong predictors of changes in energy. Crude oil has a positive and significant effect on energy only at lag 1, with no significant influence at longer lags, indicating its short-term impact. For coal, energy consistently and significantly influences it at all lags, showing a strong relationship where past energy values drive changes in coal. Coal also exhibits negative and significant autocorrelation at all lags, indicating a self-correcting mechanism where past increases in coal prices lead to reduced future changes. Crude does not significantly affect coal at lags 1 and 3, but at lag 2, it has a negative and significant effect.

For crude, neither energy nor its own past values significantly affect crude changes, indicating no notable short-term interactions (Table 7). However, coal positively and significantly affects crude at lags 2 and 3, with no significant effect at lag 1 (Table 8). This suggests that changes in coal prices have a delayed positive impact on crude. In conclusion, (1) Energy's past values do not significantly predict its current values, suggesting it may not be highly autoregressive; (2) Coal is a strong predictor of energy across all lags, showing a consistent and positive relationship; and (3) Crude has a short-term influence on energy (lag 1), but this effect diminishes at longer lags. Following this, an impulse response analysis is conducted.

The results from Table 8 show that crude has an immediate effect on energy, but this influence gradually weakens over time. Coal, on the other hand, has a positive impact initially, turns negative in the middle periods, and then returns to a positive effect in the later periods. Energy mostly stabilizes after the initial shock, suggesting that its response does not exhibit prolonged autocorrelation. These dynamics underscore the changing effects of external shocks from coal and crude on energy throughout different time periods.

The results indicate that coal shows a strong and consistent positive self-response across all periods, emphasizing its significant

Table 2: Unit root test

Variable	I (0)	I (1)
Coal	−2.13	−22.62***
Crude	−2.94**	−29.76***
Energy	−0.94	−29.73***

***Indicates significance at 1% level; **At the 5% level; *At the 10% level

Source: Authors' own

Table 3: Lag length selection

Lag length	Energy	Coal	Crude
Lag 1	9.18	7.3	4.3
Lag 2	9.16	7.2	4.3
Lag 3	9.16	7.19	4.28
Lag 4	9.21	7.14	4.28

Source: Authors' own

Table 4: Cointegration test

Hypothesized	T-statistics	Critical value
None*	411.88	29.79
At most 1*	187.55	15.49
At most 2*	7.46	3.84

*Indicates significance at 5% level

Table 5: Granger causality test

Hypothesis	F-statistics	Prob.
Crude does not granger cause energy	19.79	2×10^{-12}
Energy does not granger cause crude	1.44	0.22
Coal does not granger cause energy	11.62	2×10^{-7}
Energy does not granger cause coal	2.22	0.08
Coal does not granger cause crude	6.93	0.0001
Crude does not granger cause coal	8.55	1×10^{-5}

Source: Authors' own

Table 6: Vector error correction model

Variable	CointEq
D (Energy [−1])	1
D (Coal [−1])	0.53
	(0.15)
	[3.35]
Crude (−1)	−0.1
	(0.06)
	[−1.64]
C	6.28

Source: Authors' own

Table 7: Vector error correction model

Error Correction	D (Energy, 2)	D (Coal, 2)	D (Crude)
CointEq1	−0.91	−0.1	0.002
	(0.06)	(0.02)	(0.005)
	[−14.45]	[−4.46]	[0.54]
D (Energy [−1], 2)	−0.1	0.1	−0.007
	(0.05)	(0.02)	(0.004)
	[−1.82]	[5.11]	[−1.49]
D (Energy [−2], 2)	−0.05	0.07	−0.003
	(0.04)	(0.01)	(0.003)
	[−1.13]	[4.57]	[−0.95]
D (Energy [−3], 2)	−0.008	0.04	−0.001
	(0.03)	(0.01)	(0.002)
	[−0.25]	[3.42]	[−0.64]
D (Coal [−1], 2)	0.64	−0.46	0.01
	(0.08)	(0.03)	(0.007)
	[7.29]	[−14.04]	[1.33]
D (Coal [−2], 2)	0.58	−0.39	0.01
	(0.08)	(0.03)	(0.007)
	[6.62]	[−12.01]	[2.06]
D (Coal [−3], 2)	0.44	−0.18	0.04
	(0.08)	(0.03)	(0.007)
	[5.18]	[−5.8]	[5.46]
D (Crude [−1])	3	0.12	0.02
	(0.37)	(0.14)	(0.03)
	[7.9]	[0.88]	[0.87]
D (Crude [−2])	0.23	−0.67	−0.08
	(0.39)	(0.14)	(0.03)
	[0.59]	[−4.58]	[−2.4]
D (Crude [−3])	0.42	−0.2	0.008
	(0.39)	(0.14)	(0.03)
	[1.05]	[−1.38]	[0.23]
C	−0.2	0.006	0.01
	(0.77)	(0.28)	(0.06)
	[−0.25]	[0.02]	[0.18]

Standard error in (); t-statistics in []
Source: Authors' own

Table 8: Response of energy

Response energy			
Period	D (Energy)	D (Coal)	Crude
1	23.5	0	0
2	0.46	2.09	6.25
3	0.94	0.54	0.79
4	1.22	−0.61	0.57
5	0.47	−3.07	0.34
6	0.3	−2.15	0.26
7	0.56	−1.48	0.7
8	0.8	1.79	0.73
9	0.93	1.96	0.6
10	0.82	1.68	0.66

Source: Authors' own

autoregressive nature (Table 9). Energy has a sustained negative effect on coal, with the most pronounced impact in the mid-periods. Crude exerts a delayed negative effect on coal, which eventually stabilizes. These dynamics suggest that coal's behavior is mainly driven by its own past values, along with additional negative pressures from energy and crude over time.

The results reveal that crude's changes are primarily driven by its own past values, with energy and coal having only minor positive effects (Table 10). While energy's influence remains consistent and small, coal has a somewhat stronger impact, reaching its peak in the middle periods before stabilizing. This underscores crude's strong reliance on its own past values and its limited responsiveness to external shocks from energy and coal.

Table 9: Response of coal

Response coal			
Period	D (Energy)	D (Coal)	Crude
1	−0.65	8.74	0
2	−0.27	4.25	0.27
3	−1.04	2.47	−1.19
4	−1.5	3.14	−1.18
5	−1.99	4.07	−0.7
6	−1.43	3.17	−0.86
7	−1.46	3.07	−0.99
8	−1.55	3.41	−0.89
9	−1.53	3.5	−0.82
10	−1.45	3.31	−0.87

Source: Authors' own

Table 10: Response of crude

Response crude			
Period	D (Energy)	D (Coal)	Crude
1	0.29	0.24	2.01
2	0.2	0.35	2.07
3	0.24	0.42	1.88
4	0.26	0.69	1.89
5	0.3	0.51	1.91
6	0.26	0.45	1.86
7	0.23	0.5	1.87
8	0.22	0.52	1.88
9	0.24	0.48	1.88
10	0.24	0.48	1.87

Source: Authors' own

Table 11: Variance decomposition energy

Variance decomposition energy			
Period	D (Energy)	D (Coal)	Crude
1	100	0	0
2	92.7	0.73	6.56
3	92.56	0.78	6.64
4	92.47	0.84	6.67
5	91.03	2.37	6.58
6	90.33	3.11	6.54
7	89.94	3.45	6.59
8	89.91	3.94	6.63
9	88.82	4.52	6.64
10	88.37	4.95	6.67

Source: Authors' own

Table 12: Variance decomposition coal

Variance decomposition coal			
Period	D (Energy)	D (Coal)	Crude
1	0.56	99.43	0
2	0.53	99.38	0.07
3	1.53	97.02	1.44
4	3.28	94.23	2.47
5	5.65	91.88	2.45
6	6.53	90.71	2.74
7	7.33	89.52	3.13
8	8.07	88.59	3.32
9	8.65	87.93	3.41
10	9.09	87.34	3.55

Source: Authors' own

Table 13: Variance decomposition crude

Variance decomposition crude			
Period	D (Energy)	D (Coal)	Crude
1	2.1	1.4	96.49
2	1.48	2.12	96.39
3	1.5	2.94	95.54
4	1.56	5.14	93.29
5	1.7	5.4	92.88
6	1.72	5.41	92.86
7	1.68	5.58	92.72
8	1.64	5.77	92.57
9	1.64	5.82	92.52
10	1.63	5.86	92.49

Source: Authors' own

The results indicate that energy's fluctuations are mainly driven by its own shocks, with crude providing a steady secondary influence (Table 11). Coal's impact increases gradually, though modestly, highlighting its growing role in the long-term dynamics of energy. These findings suggest that energy's behavior is largely self-determined, but is also shaped by crude and, to a lesser extent, coal.

Coal's fluctuations are mainly driven by its own shocks, but the impact of energy and crude gradually strengthens over time (Table 12). Notably, energy becomes more influential in explaining coal's variations in the long term, while crude's effect remains relatively small but shows consistent growth.

Crude's fluctuations are primarily determined by its own past values, with a small but gradually increasing influence from coal (Table 13). Energy's impact remains minimal throughout the period. These findings suggest that crude is largely self-driven, with a slight growing influence from coal over time, while energy has little effect on crude's variations.

5. CONCLUSIONS AND IMPLICATIONS

Overall, the analysis shows that while energy, coal, and crude exhibit long-term relationships and bidirectional causality, the primary drivers of each variable's fluctuations are their own past values. Coal has a significant positive effect on energy, while crude has little influence on energy. In contrast, energy and coal have a more substantial influence on crude, particularly coal, which exerts a growing impact over time. These results underscore the dominant role of self-dependence for each variable, with external influences becoming more significant for coal and crude over time. Policymakers should focus on improving coal efficiency in energy production and promoting a transition to renewable energy. Managing coal supply and diversifying the energy mix can help stabilize energy prices and reduce reliance on crude oil. Monitoring coal and crude interactions is important due to their bidirectional relationship, with further research needed. Supporting renewable energy investments will aid in reducing coal reliance and ensuring long-term sustainability. These measures will help stabilize energy markets and promote a greener future.

This study has several limitations. First, the data used in the analysis covers a specific period (February 2021-November 2024), which may not fully capture longer-term trends or cyclical fluctuations in energy, coal, and crude prices. A broader timeframe could offer a more comprehensive view of these relationships. Additionally, the focus on coal, crude, and energy prices excludes other factors that may influence energy stock prices, such as technological advancements, policy changes, and environmental factors, which could provide a more complete understanding. Although the Augmented Dickey-Fuller (ADF) test and cointegration tests suggest stationarity and long-term relationships, the linearity assumption may not capture nonlinear relationships or structural breaks in the data. Furthermore, the study is centered on Indonesia's energy market, which may not fully account for global geopolitical or economic shocks that affect energy prices in emerging markets.

For future research, extending the analysis to a longer time span or including data from other regions could help compare energy market dynamics across different countries. Incorporating additional variables such as technological innovation, environmental policies, and global energy demand would offer a more nuanced understanding of energy price fluctuations. Exploring nonlinear models or testing for structural breaks in the time series could improve model accuracy. Future studies could also examine how global economic and geopolitical factors impact energy prices, especially in developing countries like Indonesia. Lastly, as the world moves towards renewable energy, it would be beneficial to investigate the role of renewable energy sources in shaping energy markets and their interactions with traditional fossil fuels like coal and crude.

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