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THE EFFECT OF SUPPLY CHAIN INTEGRATION DIGITALIZATION AND CIRCULAR PRODUCTION ON OPERATIONAL EFFICIENCY THROUGH GREEN INNOVATION AND ITS IMPLICATIONS FOR PUBLIC POLICY AND SUSTAINABILITY GOVERNANCE IN THE OIL AND GAS AND ENERGY SECTOR IN INDONESIA (SECONDARY DATA ANALYSIS OF ANNUAL REPORTS AND SUSTAINABILITY REPORTS 2020–2024)

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ABSTRACT
The oil and gas sector is the backbone of national energy, yet it faces challenges in maintaining operational efficiency amidst the pressure of transitioning toward Net Zero Emission (NZE) 2060. This study analyzes the impact of Digital Supply Chain Integration (DSCI) and Circular Production (CP) on Operational Efficiency (OE) with Green Innovation (GI) as a mediating variable. The research focuses on Indonesian oil, gas, and energy companies from 2020 to 2024. The method is quantitative, using path analysis on secondary data from Annual Reports and Sustainability Reports. Results show that Digital Supply Chain Integration has no significant effect on Green Innovation or Operational Efficiency, indicating digital investments are not yet optimized for ecological and cost-efficiency goals. Circular Production also has no direct significant effect on Green Innovation. Conversely, Circular Production has a significant negative effect on Operational Efficiency, demonstrating that circular practices reduce operational costs through primary input savings. Further, Operational Efficiency has a significant positive effect on Green Innovation, positioning it as a key enabler of green innovation development. The mediation test confirms that Green Innovation significantly mediates the relationship between Circular Production and Operational Efficiency via eco-design-based innovation, though it does not mediate the relationship between Digital Supply Chain Integration and Operational Efficiency. These findings highlight efficiency as an essential foundation for energy companies to achieve sustainable green innovation.

INTRODUCTIONS

The oil and gas sector remains the backbone of global energy supply, with total conventional hydrocarbon reserves reaching 11,434.9 × 10^8 tons of oil equivalent (TOE) (Tong et al., 2023) Despite a 6% decline in production

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among Oil and Gas Climate Initiative (OGCI) member companies during the 2017–2024 period, this sector still supplies approximately 55% of global energy demand and maintains high levels of upstream investment to meet the needs of developing countries (Wang et al., 2022). On the other hand, global pressure for decarbonization is driving the adoption of low-carbon technologies such as Carbon Capture and Storage (CCS), with a capture capacity reaching 49 million tons of CO_2 per year (Hu et al., 2023). The energy transition is also progressing, as seen in the increased contribution of solar and wind energy to global electricity supply from 10% in 2021 to 12% in 2022, while modern renewable energy contributes approximately 13.4% to global total final energy consumption (TFEC) (Adib, 2023; Ember Energy, 2023).

In the Indonesian context, national energy security remains heavily influenced by global oil price fluctuations, increasing domestic demand, and limited domestic production (Ministry of Energy and Mineral Resources, 2024). Indonesia's oil production stands at approximately 605 MBOPD and gas at 5,321 MMSCFD, still below the national targets of 635 MBOPD and 6,160 MMSCFD. An oil energy balance deficit persists, with imports reaching 132.4 million barrels far exceeding exports of 21.3 million barrels. Domestic energy consumption increased to 1,276 million BOE, a rise of 4.53% from the previous year, dominated by the industrial sector (45.94%) and transportation sector (36.11%). The industrial energy consumption structure remains dominated by fossil fuels such as coal (58.45%), natural gas (14.65%), and electricity (12.45%), indicating significant challenges in the transition toward low-carbon energy, as well as the urgent need to improve production efficiency and diversify energy sources to support the Net Zero Emission 2060 target (Ministry of Energy and Mineral Resources, 2024).

Although Indonesia has significant renewable energy potential, with projected output reaching 132.74 TWh by 2030 (Irena, 2023), its utilization remains limited. Fossil fuel-based power plants still dominated the energy mix in 2021, accounting for 81%, with coal contributing around 62% (Bagaskara et al., 2024) In the national energy consumption structure, the industrial sector is the largest consumer of natural gas, while the transportation sector accounts for the majority of liquid fuel consumption at 45.76% (Hasan et al., 2025; Setyawati et al., 2024; Pambudi et al., 2023). These conditions make clear that Indonesia's energy transition requires not only infrastructure investment but also a fundamental shift toward more efficient and sustainable operational systems and energy supply chains.

Operational efficiency has become a strategic issue, given that more than 85% of Indonesia's primary energy supply still comes from fossil fuels (Ministry of Energy and Mineral Resources, 2024). International studies show that digital integration in supply chains can improve energy distribution efficiency by 15–25% and reduce logistical energy losses, while circular production approaches can lower production emission intensity by up to 30% and extend resource life cycles (Zhou, 2023; Ghazanfari, 2023). This suggests that operational inefficiency is one of the factors reinforcing fossil fuel dominance. Measuring and improving operational efficiency is therefore key to boosting productivity while supporting the energy transition (Sisdwinugraha et al., 2024)

Conceptually, operational efficiency reflects a firm's ability to maximize output with minimal input through technology, asset management, and production process optimization (Awow et al., 2025; and Abdoos et al., 2025). Operational digitalization enables real-time monitoring, predictive analytics, and more accurate decision-making (Zhang & Wang, 2023) Supply chain integration improves stakeholder coordination, reduces lead times, and lowers operational costs (Freije, 2022; Wang & Hao, 2025) Meanwhile, circular production encourages waste reduction, material optimization, and carbon emission cuts through sustainable process design (Jusoh et al., 2021; Vogiantzi & Tserpes, 2023; Lindahl et al., 2023).

However, prior studies indicate that digital supply chain integration and circular production do not always directly improve operational efficiency without green innovation acting as a mediating variable (Li et al., 2025; Ali et al., 2024). Green innovation plays a key role in translating digital and circular strategies into tangible operational performance through environmentally friendly product, process, and business model innovations (Chen et al., 2024; Cheng et al., 2024; Khanra et al., 2022). Yet, some studies suggest that green innovation does not always yield significant short-term effects, particularly in high-cost industries such as the energy sector (Hendrawan & Suhartini, 2025). Conversely, other investigation emphasizes that green innovation serves as a strategic bridge linking supply chain and circular production strategies to the achievement of higher operational efficiency (Younes et al., 2025); (Javed et al., 2024); (Ogiemwonyi et al., 2023).

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Digitalization in the supply chain plays an important role in accelerating green innovation through data integration, real-time monitoring, and enhanced analytical capabilities. Digital-based supply chain integration has been shown to strengthen green innovation by improving information flow efficiency, enabling digital coordination, and leveraging real-time data and digital monitoring systems (Li et al., 2025; Zhang et al., 2025;Tan & Li, 2025). Further, digitalization also serves as a foundation for developing renewable energy projects, increasing research and development investment, and implementing green technologies. On the other hand, circular production also drives green innovation through waste reduction, material reuse, and improved environmental efficiency which is factors shown to enhance business sustainability and resource efficiency (Andrea et al., 2025; Baca-neglia et al., 2025; Setyadi & Pawirosumarto, 2025).

Digital supply chain integration has been shown to improve operational efficiency through information integration, process automation, and data-driven control, all of which enhance system visibility, reduce lead times, and lower operational costs (Ali & Mahmood, 2024; Hejazi & Habani, 2024; Tan & Li, 2025). Circular production also contributes to operational efficiency by optimizing material use, reducing waste-related costs, and reusing production components, factors that directly improve firm productivity and energy efficiency (Alabdullah & Kanaan-Jebna, 2023; Andrea et al., 2025; Govind et al., 2025; Koval et al., 2025). In addition, green innovation has been found to enhance operational efficiency through the development of low-emission technologies, reduced energy consumption, and more sustainable production processes (Atieh & Abushaega, 2025; Koval et al., 2025; Liu & Wang, 2022).

Nevertheless, recent studies reveal that the impact of digital supply chain integration and circular production on operational efficiency is not always direct, but rather mediated by green innovation. Digital supply chain integration has been shown to strengthen green innovation capabilities, which in turn reduce energy intensity and production costs. Similarly, circular production creates demand for green technological innovation, ultimately improving firms' operational efficiency (Baca-neglia et al., 2025; Govind et al., 2025). Accordingly, green innovation is positioned as a strategic mediating mechanism in the relationship between digital supply chain integration, circular production, and operational efficiency in the energy sector.

Based on this context, this study aims to examine the effect of digitalized supply chain integration and circular production on operational efficiency, with green innovation as a mediating variable, among oil, gas, and energy sector companies in Indonesia using secondary data from Annual Reports and Sustainability Reports for the 2020–2024 period. This research offers novelty in the form of an empirical model that integrates digital strategy, circular production, and green innovation to enhance operational efficiency in the national energy sector which contributing to the advancement of sustainable and low-carbon energy transition policies.

Overall, previous research findings show a consistent pattern that supply chain integration digitalization and circular production significantly influence improving operational efficiency, with green innovation functioning as a mediating variable. Based on the theoretical framework explained previously, the relationships among variables in this study can be seen in the following conceptual research model:

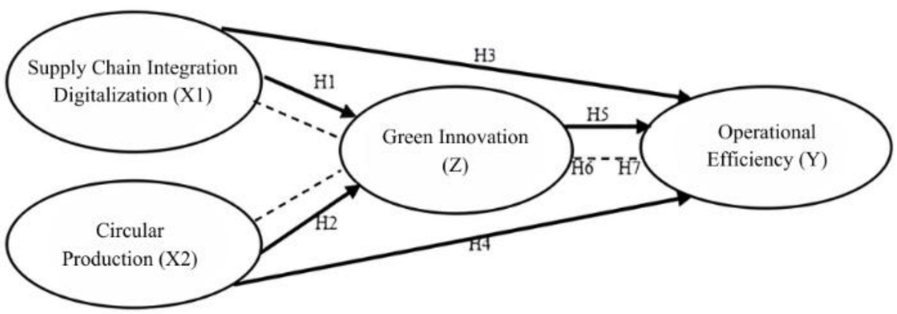

Figure 1. Research Conceptual Model
Source: Author, 2026

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METHODS

This study employs a quantitative approach to analyze the effect of Supply Chain Integration Digitalization and Circular Production on Operational Efficiency through Green Innovation in the oil, gas, and energy sector in Indonesia. The independent variables are Supply Chain Integration Digitalization (X1) and Circular Production (X2), the dependent variable is Operational Efficiency (Y), and Green Innovation (Z) serves as a mediating variable explaining the causal relationship between the independent and dependent variables. The population includes all oil, gas, energy, and coal sector companies in Indonesia that publish Annual Reports and Sustainability Reports. The sample consists of 12 companies selected using purposive sampling techniques, based on the following criteria: companies operating during the 2020–2024 period, publicly listed or state-owned (Persero), publishing complete and consecutive annual and sustainability reports, and providing complete data for all research variables. This study utilizes secondary data in the form of Annual Reports and Sustainability Reports for the 2020-2024 period, obtained from each company's official website. The data used is panel data, combining both time-series and cross-sectional dimensions to enable more comprehensive analysis. Data collection was performed by documentation methods and literature reviews of journals, books, and other supporting documents. Data processing and analysis were conducted quantitatively using Microsoft Excel and E-Views version 13. The analysis technique employed is path analysis using multiple linear regression to examine both direct and indirect effects among the research variables.

RESULTS

Classical Assumption Test Results

To confirm that the regression model is unbiased and adheres to the Best Linear Unbiased Estimator (BLUE) criteria, classical assumption testing was performed. The results are presented below:

Table 1. Summary of Classical Assumption Tests

No.	Classical Assumption Tests	Equation Model I		Equation Model II	
		p-Value	Decision	p-Value	Decision
1	Normality (Jarque-Bera)	0,3078 > 0,05	Normal Residual Distribution	0,0001 > 0,05	Residuals are normally distributed (Number of Data Points 60 > 30)
2	Heteroscedasticity (Breusch-Pagan-Godfrey)	0.0612 > 0,05	No Heteroscedasticity Issues	0.1091 > 0,05	No Heteroscedasticity Issues
3	Autocorrelation (Durbin Watson) + Generalized Method of Moments	0.2432 > 0,05	No Autocorrelation Problems	0.0909 > 0,05	No Autocorrelation Problems

No.	Classical Assumption Tests	Variable	VIF Value	Decision
		Equation Model I		
4	Multicollinearity (Variance Inflation Factors)	DSCI_X1	1,040575 < 10	No multicollinearity occurred
		CP_X2	1,040575 < 10	No multicollinearity occurred
		Equation Model II		
		Variable	**VIF Value**	**Decision**
		DSCI_X1	1,074944 < 10	No multicollinearity occurred
		CP_X2	1,105940 < 10	No multicollinearity occurred
		EO_Y	1,118452 < 10	No multicollinearity occurred
		GI_Z	1.048672 < 10	No multicollinearity occurred

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Source: E-Views 13 Processing Results, 2026

Multiple Linear Regression Estimation Results

In this study, this analysis is used to test the relationship between Supply Chain Integration Digitalization (DSCI) and Circular Production (CP) on Operational Efficiency (EO) in equation model I. Furthermore, in equation model II, the analysis is conducted to test the influence of Supply Chain Integration Digitalization (DSCI), Circular Production (CP), and Operational Efficiency (EO) on Green Innovation (GI). The estimation model used in this study is panel data regression with the Least Square method. The use of this method is based on the results of classical assumption tests that show that equation model I and equation model II meet the Best Linear Unbiased Estimator (BLUE) criteria. The following are the results of multiple regression estimation in equation model I and equation II:

Table 2. Multiple Linear Regression Estimation Results for Equation Model I with Operational Efficiency Dependent Variable

Before Trimming				
Variable	**Standardized Beta**	**t-Statistic**	**p-Value**	**Decision**
C	0,652001	8,783665	0,00000	
DSCI_X1	-0,324966	-1,372087	0,17540	> 0,05 H0 Accepted
CP_X2	-2,47743	-1,892222	0,00635	< 0,05 H0 Rejected
R-squared		0,105907		
Adjusted R-squared		0,074535		
F-Statistic		3,375879		
p-Value (F-Statistic)		0,041153		
After Trimming				
Variable	**Standardized Beta**	**t-Statistic**	**p-Value**	**Decision**
C	0,596812	9,494403	0,00000	
CP_X2	-2,83217	-2,190011	0,03260	< 0,05 H0 Rejected
R-squared		0,076376		
Adjusted R-squared		0,060452		
F-Statistic		4,796149		
p-Value (F-Statistic)		0,032558		

Source: E-Views 13 Processing Results, 2026

The test results in Table 2 indicate that Digital Supply Chain Integration (DSCI_X1) has no statistically significant effect on Operational Efficiency (EO_Y), with a standardized beta coefficient of -0.325 and a p-value of 0.175 (> 0.05). Therefore, the null hypothesis (H0) is accepted. In contrast, Circular Production (CP_X2) demonstrates a significant and negative influence on Operational Efficiency, evidenced by a coefficient of -2.477 and a p-value of 0.006 (< 0.05). This leads to the rejection of H0, confirming a significant negative relationship.

The trimming model is a model used to refine a path analysis structure by eliminating independent variable models that have insignificant coefficients. In equation model I, the path coefficient of the influence of Supply Chain Integration Digitalization (DSCI_X1) shows insignificant results (0.17540 > 0.05), so trimming is performed by removing this variable from the model. After trimming, the Circular Production variable (CP_X2) continues to show a significant negative influence on Operational Efficiency with an increasingly strong p-value of 0.03260 and an F-statistic value of 4.796149 (p-value 0.032558), indicating that the model is appropriate to use.

Table 3. Multiple Linear Regression Estimation Results for Equation Model II with Green Innovation Dependent Variable

Before Trimming

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Variable	Standardized Beta	t-Statistic	p-Value	Decision
C	0,157355	2,132448	0,03740	
DSCI_X1	0,019285	0,123637	0,90200	> 0,05 H0 Accepted
CP_X2	-0,087405	-0,999329	0,3219	> 0,05 H0 Accepted
EO_Y	0,198874	2,317112	0,0242	< 0,05 H0 Rejected
R-squared		0,12984		
Adjusted R-squared		0,083224		
F-Statistic		2,785328		
p-Value (F-Statistic)		0,04907		
After Trimming				
Variable	**Standardized Beta**	**t-Statistic**	**p-Value**	**Keputusan**
C	0,115916	2,590323	0,01210	
EO_Y	0,220124	2,736064	0,00820	< 0,05 H0 Rejected
R-squared		0,114315		
Adjusted R-squared		0,099045		
F-Statistic		7,486048		
p-Value (F-Statistic)		0,008238		

Source: E-Views 13 Processing Results, 2026

Based on the test results in Table 3 above, it is known that Supply Chain Integration Digitalization (DSCI_X1) has no influence on Green Innovation (GI_Z). This is indicated by a coefficient value of 0.019285 with a p-value of 0.90200 > 0.05, so H0 is accepted, meaning that Supply Chain Integration Digitalization does not affect Green Innovation. The Circular Production variable (CP_X2) has no influence on Green Innovation (GI_Z). This is indicated by the coefficient value in the table of -0.087405 with a p-value of 0.3219 > 0.05, so H0 is accepted, meaning that Circular Production does not affect Green Innovation. Furthermore, the Operational Efficiency variable (EO_Y) has a positive and significant influence on Green Innovation (GI_Z). This is indicated by the coefficient value in the table of 0.198874 with a p-value of 0.0242 < 0.05, so H0 is rejected, meaning that Operational Efficiency has a positive effect on Green Innovation. These results show that every increase of one unit in the Operational Efficiency variable, assuming other independent variables are constant, the Green Innovation value will increase by 0.198874 units and vice versa.

The trimming model is a model used to refine a path analysis structure by eliminating independent variable models that have insignificant coefficients. In this equation model II, variables DSCI_X1 and CP_X2 have p-values > 0.05, so trimming is performed by removing both variables from the model. After trimming, the Operational Efficiency variable (EO_Y) independently proved to have a positive and significant influence on Green Innovation (GI_Z) with an increased coefficient value of 0.220124 and a p-value of 0.00820. These results show that the research model after trimming is more accurate in explaining the influence of Operational Efficiency on Green Innovation in sample companies.

Path Analysis Results

The magnitude of direct influence can be seen through the standardized beta regression coefficient value, while the magnitude of indirect influence is measured by multiplying the intervening variable coefficient by the indirect coefficient. The following are the path diagram results and path coefficient values:

Table 4. Path Diagram Results for Equation Model I with
Operational Efficiency Dependent Variable Using Trimming Method

Equation I	Variable	p-value	t-statistic	Standardized Beta	R-Squared	Adj R-Squared
Before Trimming	DSCI_X1	0,1754	-1,372087	-0,324966	0,105907	0,074535

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	CP_X2	0,00635	-1,892222	-2,47743		
After Trimming	CP_X2	0,0326	-2,190011	-2,83217	0,076376	0,060452

Source: E-Views 13 Processing Results, 2026

Based on the regression results of equation model I in path analysis, it can be seen in Table 4 that the Supply Chain Integration Digitalization variable (DSCI_X1) has no significant effect. To improve a path analysis model structure, one step that can be taken is to exclude independent variables that have insignificant path coefficients from the model. Therefore, the path analysis in this study uses a trimming model, namely by recalculating path coefficients without including insignificant variables. Table 4 presents a summary of regression results for equation model I after trimming. The value of e_1, which represents the influence of other variables outside the model on Operational Efficiency (EO_Y), can be calculated using the following formula:

$$e_1 = \sqrt{1 - 0{,}076376} = 0{,}961053$$

Based on the analysis results in equation model I after trimming, the path coefficient value of Circular Production (CP_X2) on Operational Efficiency (EO_Y) is -2.83217. The path diagram for equation model I after trimming is presented in the following figure:

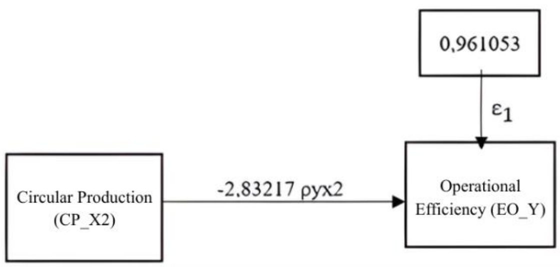

Figure 2. Path Diagram Results for Equation Model I

Based on Figure 2, the path diagram results in equation model I yield the following path model equation:

EO_Y = ρyx2 CP + ρyε1

EO_Y = -2,83217CP_X2 + 0,961053ε1

Table 5. Path Diagram Results for Equation Model II with
Green Innovation Dependent Variable Using Trimming Method

Equation I	Variable	p-value	t-statistic	Standardized Beta	R-Squared	Adj R-Squared
	DSCI_X1	0,902	0,123637	0,019285		
Before Trimming	CP_X2	0,3219	-0,999329	-0,087405	0,12984	0,083224
	EO_Y	0,0242	2,317112	0,198874		
After Trimming	EO_Y	0,0082	2,736064	0,220124	0,114315	0,099045

Source: E-Views 13 Processing Results, 2026

Table 5 presents a summary of regression results for equation model II after trimming. Based on the analysis results in equation model II after trimming, it is known that the Operational Efficiency variable (EO_Y) has a path coefficient value (Standardized Beta) of 0.220124. The value of e_2 represents the influence of other variables outside the model on Green Innovation (GI_Z), which can be calculated using the following formula:

$$\varepsilon_2 = \sqrt{1 - 0{,}114315} = 0{,}941108$$

This value shows that the contribution of other variables outside the model in explaining Green Innovation is still quite large. The following presents the path diagram results in equation model II:

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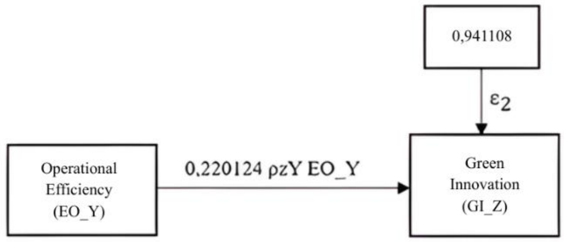

Figure 3. Path Diagram Results for Equation Model II

Based on Figure 3, the path diagram results in equation model II yield the following path model:

GI_Z = ρzY EP + ε2

GI_Z = 0,220124 EO_Y + 0,961053ε_2

Below are the results of the structural model path diagram, as follows:

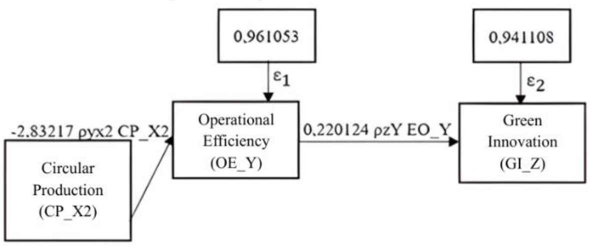

Figure 4. Path Diagram Results for Circular Production and Operational Efficiency on Green Innovation

The following is a summary of the calculation results of direct and indirect path coefficients, as well as total effects:

Table 6. Summary of Direct and Indirect Path Coefficient Results, and Total Effects

No.	Variable Influence	Causal Influence		
		Direct	Indirect	Total
1	DSCI_X1 on EO_Y	-	-	-
2	DSCI (X1) on GI_Z	-	-	-
3	CP_X2 on EO_Y	-2,83217	-	-2,83217
4	CP_X2 on GI_Z	-	-0,623428	-0,623428
5	EO_Y on GI_Z	0,220124	-	0,220124
6	ε1 on EO_Y	0,961053	-	0,923624
7	ε2 on GI_Z	0,941108	-	0,885685
8	Adjusted R-Squared	-	-	0,099045

Source: E-Views 13 Processing Results, 2026

Based on Table 6, it is known that the Supply Chain Integration Digitalization variable (DSCI_X1) has no direct or indirect influence on Green Innovation (GI_Z). This is because in the first and second trimming model stages, variable DSCI_X1 was removed from the model due to having p-values of 0.1754 and 0.902, which are greater than the significance level of 0.05. Therefore, it can be concluded that Operational Efficiency (EO_Y) does not mediate the influence of Supply Chain Integration Digitalization on Green Innovation in Indonesian oil and gas and energy sector companies. The Circular Production variable (CP_X2) has an indirect influence on Green Innovation (GI_Z) of -0.623428. The magnitude of indirect influence is measured using the multiplication formula of the path coefficient of Circular Production on Operational Efficiency multiplied by the coefficient of Operational Efficiency on Green Innovation: -2.83217×0.220124=-0.623428. These results show that Operational Efficiency significantly mediates the influence of Circular Production on Green Innovation.

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The Circular Production variable (CP_X2) also has a direct influence on Operational Efficiency (EO_Y) with a coefficient of -2.83217. Although the direction of influence is negative, this value is proven significant with p-value $0.0326 < 0.05$. Meanwhile, the direct influence of CP_X2 on Green Innovation (GI_Z) is stated as insignificant because the p-value is $0.3219 > 0.05$, so this direct path is removed in the trimming model. Finally, the Operational Efficiency variable (EO_Y) is proven to have a direct and positive influence on Green Innovation (GI_Z), indicated by a path coefficient value of 0.220124 and a significance value of $0.0082 < 0.05$. This confirms that improvement in operational efficiency is a key driving factor for the creation of green innovation in Indonesian oil and gas and energy sector companies.

Model Goodness of Fit Testing

The goodness of fit test aims to test whether the model used in the study has a good fit with the data or not.

Statistical Testing:

The multiple coefficients of determination for the proposed model from this study's path diagram obtained the following coefficient of determination values:

$R_1^2 = 0{,}076376$

$R_2^2 = 0{,}114315$

The calculation of the multiple coefficients of determination (Rm^2) is performed using the formula:

$Rm^2 = 1 − ((1 − R_1^2) × (1 − R_2^2))$

Thus obtained:

$Rm^2 = 1 − ((1 − 0{,}076376) × (1 − 0{,}114315))$

$Rm^2 = 1 − (0{,}923624 × 0{,}885685)$

$Rm^2 = 1 − 0{,}818206$

$Rm^2 = 0{,}181794$

The Rm^2 value of 0.181794 indicates that the model's variables collectively explain 18.18% of the variation in the path analysis relationships. The remaining 81.82% is accounted for by factors outside the model. Following the elimination of insignificant paths, the adjusted coefficient of determination for the trimmed model is as follows:

R_1^2 (after trimming) = 0,076376

Then the M value is determined as follows:

M = Rm^2 after trimming

$M = 1 − (1 − 0{,}076376)$

$M = 1 − 0{,}923624$

$M = 0{,}076376$

Furthermore, model goodness of fit testing is conducted using the Q coefficient with the formula:

$Q = (1 − Rm^2) / (1 − M)$

$Q = (1 − 0{,}181794) / (1 − 0{,}076376)$

$Q = 0{,}818206 / 0{,}923624$

$Q = 0{,}885863$

The Q value of 0.885863 (< 1) shows that the model is classified as a not perfect fit model, so to ensure model feasibility, further testing is conducted using the W statistic. The W statistic calculation is performed using the formula:

$W = − (n − d) \ln Q$

With the number of observations (n) = 60 and the number of eliminated paths (d) = 2, the following is obtained:

$W = −(60 − 2) \ln (0{,}885863)$

$W = −58 × (−0{,}121006)$

$W = 7{,}018348$

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The W statistic value of 7.018348 is then compared with the Chi-Square (χ^2) table value at a significance level of 5% with degrees of freedom (df) = 2, which is 5.9915. Because the calculated W value > χ^2 table (7.018348 > 5.9915), H_0 is rejected. This shows that the formed path analysis model is significant and appropriate to use. Therefore, it can be concluded that the structural equation model in this study has good capability in explaining the relationships among Supply Chain Integration Digitalization, Circular Production, Operational Efficiency, and Green Innovation in Indonesian oil and gas and energy sector companies.

Coefficient of Determination

This study uses more than two independent variables, so in determining the coefficient of determination, adjusted R square can be used as in the table 7 below:

Table 7. Coefficient of Determination Results

No.	Variable		Adjusted R-Squared	Interpretation
	Independent	Dependent		
1	DSCI_X1 and CP_X2	EO_Y	0,074535	The influence of the independent variables (DSCI_X1 and CP_X2) on the dependent variable (EO_Y) is 7.45%, while the remaining 92.55% is influenced by other factors.
2	DSCI_X1, CP_X2 and EO_Y	GI_Z	0,083224	The influence of the independent variables (DSCI_X1, CP_X2, and EO_Y) on the dependent variable (GI_Z) is 8.32%, while the remaining 91.68% is influenced by other factors.

Source: E-Views 13 Processing Results, 2026

DISCUSSION

The Influence of Supply Chain Integration Digitalization on Green Innovation in Indonesian Oil and Gas and Energy Sector Companies 2020-2024

Based on research results showing that there is no influence between Supply Chain Integration Digitalization and Green Innovation, it is not consistent with the theory proposed by Li et al., (2025), which explains that digitalization in supply chains should be able to accelerate the green innovation process through improved data integration, real-time monitoring, and better analytical capabilities. Companies with high levels of digital integration in their supply chains can theoretically create a foundation for the emergence of renewable energy projects, increased Research and Development (R&D) investment, and more effective green technology implementation.

In this case, the lack of influence of Supply Chain Integration Digitalization on Green Innovation may be caused by companies in Indonesia's oil and gas and energy sector not necessarily optimizing the use of real-time data and digital capabilities specifically for ecological innovation purposes. Digitalization performed may still focus on routine operational or administrative efficiency, so it has not been able to directly drive the creation of green products or processes. Additionally, ineffective management in managing digital technology investments that are not properly targeted can cause data integration to not contribute significantly to the development of new renewable energy projects in companies. This is evident from causal testing results where the direct influence path of DSCI on GI does not show significant figures, so it is eliminated in the final model.

These research results are consistent with conditions where digital transformation has not yet become a main driver of green innovation in sample companies. These research results are not consistent with research conducted by Li et al., (2025), Zhang et al., (2025), and Tan and Li., (2025), which state that supply chain digitization or digital transformation positively influences the increase in green innovation through more efficient information flow and digital coordination.

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The Influence of Circular Production on Green Innovation in Indonesian Oil and Gas and Energy Sector Companies 2020-2024

Based on research results showing that there is no direct influence between Circular Production and Green Innovation, it is not consistent with the theory proposed by Andrea et al. (2025), which explains that the application of circular economy should encourage companies to increase green innovation to reduce waste and significantly improve business sustainability. Companies that apply circular operations will theoretically develop new green technologies to increase resource efficiency through industrial waste recycling and the use of renewable raw materials.

In this case, the absence of direct influence of Circular Production on Green Innovation may be caused by circular activities such as waste processing and material reuse in Indonesian oil and gas and energy sector companies not necessarily directly producing new green product or process innovations. The influence of Circular Production on Green Innovation is indirect because it must go through mediation of the Operational Efficiency variable first, indicated by an indirect influence value of -0.623428. This indicates that circular production practices in sample companies are more focused on improving internal company efficiency structures before finally being able to trigger the emergence of green innovation. Therefore, the direct path of this variable must be eliminated in the trimming model because it does not have strong significance independently.

These research results support findings that Circular Production does not automatically create green innovation without improvement in company operational efficiency. These research results are not consistent with research conducted by Baca-Neglia et al., (2025) and Setyadi and Pawirosumarto, (2025), which state that circular economy or circular operations have a close relationship and direct influence in realizing green innovation and operational sustainability.

The Influence of Supply Chain Integration Digitalization on Operational Efficiency in Indonesian Oil and Gas and Energy Sector Companies 2020-2024

Based on research results showing that there is no influence between Supply Chain Integration Digitalization and Operational Efficiency, it is not consistent with the theory proposed by Hejazi and Habani, (2024), which explains that digital-enabled supply chain integration should be able to improve operational efficiency through increased visibility and reduced lead time. Digital integration in supply chains will theoretically significantly influence process optimization, production coordination, and company operational cost reduction.

In this case, the lack of influence of Supply Chain Integration Digitalization on Operational Efficiency in Indonesian oil and gas and energy sector companies may be caused by the implementation of digital technologies such as smart monitoring not yet being comprehensively integrated into demand prediction systems or data-based control. Companies may have made digitalization investments but have not been able to provide real impact on operational cost reduction due to ineffective management in managing these digital capabilities. This is evident from data processing results where the influence path of DSCI on Operational Efficiency does not show significance (blank in the causal influence table), so this variable is eliminated through the trimming model.

These research results are consistent with empirical conditions in sample companies where digital information integration has not yet become a main determining factor in significantly improving company operational process efficiency. These research results are not consistent with research conducted by Ali and Mahmood, (2024) and Tan and Li, (2025), which state that digital transformation or digital integration in supply chains significantly influences improved operational efficiency through process optimization and better coordination.

The Influence of Circular Production on Operational Efficiency in Indonesian Oil and Gas and Energy Sector Companies 2020-2024

Based on research results showing that there is an influence between Circular Production and Operational Efficiency, it is consistent with the theory proposed by Govind et al., (2025), which explains that circular principles such as reuse and refurbishing have a direct impact on operational cost reduction. Companies that apply circular

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production principles will theoretically achieve higher efficiency through material use optimization, waste cost reduction, and production flow improvement.

In this case, the influence of Circular Production on Operational Efficiency is significantly negative, indicated by a coefficient value of -2.83217. This negative influence may be caused by the implementation of circular production in Indonesian oil and gas and energy sector companies actually being able to reduce or lower company operational cost burdens. The higher the circular activities such as utilizing organic waste for alternative energy and industrial waste recycling, the lower the primary input costs incurred, so company productivity increases through energy efficiency. This proves that circular economy initiatives effectively act as catalysts in improving production process burden structures in sample companies.

These research results are supported by previous research conducted by Koval et al., (2025), which found that circular economy initiatives increase productivity through primary input reduction. These research results are also consistent with research conducted by Andrea et al. (2025), which states that circular production plays a role in reducing process burdens and improving production flow to achieve higher operational efficiency.

The Influence of Green Innovation on Operational Efficiency in Indonesian Oil and Gas and Energy Sector Companies 2020-2024

Based on research results showing that there is an influence between Operational Efficiency and Green Innovation, it is consistent with the theory proposed by Atieh and Abushaega, (2025), which explains that process efficiency improvement can increase operational performance and company sustainability performance. Companies with good operational efficiency levels can theoretically contribute to low-emission technology development, energy consumption reduction, and sustainability-oriented production process improvement.

In this case, the influence of Operational Efficiency on Green Innovation is significantly positive, indicated by a coefficient value of 0.220124. This positive influence shows that the higher the operational efficiency achieved by Indonesian oil and gas and energy sector companies, the greater the encouragement for those companies to conduct green innovation. Increased operational productivity enables companies to allocate available resources to create sustainability-oriented innovation capable of reducing long-term resource consumption. This proves that operational efficiency acts as an important foundation for the emergence of green innovation in sample companies.

These research results are supported by previous research conducted by Liu and Wang, (2022), which shows that efficiency directly contributes to improved green innovation and supply chain efficiency. These research results are also consistent with research conducted by Koval et al., (2025), which affirms that operational efficiency can increase productivity, thereby encouraging the creation of sustainability-oriented innovation.

The Influence of Supply Chain Integration Digitalization on Operational Efficiency Mediated by Green Innovation in Indonesian Oil and Gas and Energy Sector Companies

Based on research results showing that there is no influence of Supply Chain Integration Digitalization on Operational Efficiency through Green Innovation mediation, it is not consistent with the theory proposed by Li et al., (2025), which explains that digital integration should encourage green innovation capability that functions as a catalyst for efficiency improvement. Theoretically, digitalization capability should increase green innovation output, which then impacts energy intensity reduction and company production costs.

In this case, the absence of Green Innovation's mediating influence in the relationship between DSCI and Operational Efficiency in Indonesian oil and gas and energy sector companies is caused by the main path from DSCI to Green Innovation (H1) and to Operational Efficiency (H3) not being proven significant. This is shown in the causal influence table where the indirect influence column for the relationship of DSCI on EO through GI has no value (blank), so the DSCI variable is eliminated through the trimming model. This condition indicates that digital transformation in sample companies has not been able to increase the effectiveness of green innovation strong enough to significantly influence cost structures or energy company operations. Lack of integration between digital technology investments and green project development causes this mediation function not to work as it should.

These research results are consistent with findings that without significant direct influence from independent variables to mediating variables, Green Innovation's mediation role cannot be formed in sample companies. Inconsistent with previous work by Zhang et al., (2025) and Tan and Li, (2025), that digital transformation increases green innovation effectiveness that strengthens the impact of digitalization on company operational efficiency.

The Influence of Circular Production on Operational Efficiency Mediated by Green Innovation in Indonesian Oil and Gas and Energy Sector Companies

Based on research results showing that there is an influence between Circular Production and Operational Efficiency through Green Innovation mediation, it is consistent with the theory proposed by Govind et al., (2025), which explains that circular production creates the need for green technology innovation that then improves operational processes. Theoretically, circular supply chains will increase green innovation efficiency that directly impacts energy efficiency and company operational cost reduction.

In this case, the indirect influence of Circular Production on Operational Efficiency through Green Innovation is indicated by a mediation coefficient value of -0.623428. This negative value shows that circular production activities in Indonesian oil and gas and energy sector companies successfully encourage the emergence of eco-design-based green innovation, which ultimately effectively reduces or lowers company operational cost burdens. The utilization of industrial waste and recycled raw materials through green technology innovation has proven to facilitate companies in realizing operational sustainability while increasing resource use efficiency (Rachmat et al., 2025). This confirms that Green Innovation functions as an intermediary (mediation) that strengthens the positive impact of circular economy practices on operational productivity in sample companies.

These research results are supported by previous research conducted by Liu and Wang, (2022), which shows that circular supply chains increase efficiency through green innovation paths. These research results are also consistent with research conducted by Baca-Neglia et al., (2025), which affirms that circular economy encourages the emergence of green innovation that ultimately significantly increases company operational efficiency.

CONCLUSION

Based on the results and discussion of research on the influence of supply chain integration digitalization and circular production on operational efficiency through green innovation in Indonesia's oil and gas and energy sector for the 2020–2024 period, it can be concluded that supply chain integration digitalization and circular production have not been able to directly drive green innovation, and supply chain integration digitalization also does not significantly influence operational efficiency. However, circular production is proven to significantly influence operational efficiency with a negative direction, showing that increased circular production practices can reduce operational costs and improve resource use efficiency. Furthermore, operational efficiency has a positive and significant influence on green innovation, making it a key factor in encouraging green innovation development. Green innovation does not mediate the relationship between supply chain integration digitalization and operational efficiency but plays an important mediator role in strengthening the influence of circular production on operational efficiency. Based on these findings, further research is recommended to expand variables, objects, methods, and research periods for more comprehensive results, while companies need to strategically direct digitalization to support green innovation, strengthen the integration of circular production with green innovation, and make operational efficiency the foundation for low-emission technology development. On the other hand, investors are advised to consider the level of circular production implementation, operational efficiency, and commitment to green innovation as important indicators in assessing performance, sustainability, and long-term prospects of oil and gas and energy sector companies.

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