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Assessing the Impact of Sustainable Finance Regulation on Bank Risk: Evidence from Indonesia using a Difference-in-Differences Approach

Ahmad Sutanto[1]*, Wita Juwita Ermawati[1], Lukytawati Anggraeni[2]
[1] Department of Management, Faculty of Economics and Management, IPB University, Bogor, Indonesia
[2] Department of Economics, Faculty of Economics and Management, IPB University, Bogor, Indonesia

ORCIDs:
First AUTHOR : https://orcid.org/0009-0004-6821-861X
Second AUTHOR : https://orcid.org/0000-0002-8032-0826
Third AUTHOR : https://orcid.org/0000-0003-3212-4756

*Corresponding author email: ahmadsutanto@apps.ipb.ac.id

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ABSTRACT

Purpose: The purpose of this study is to examine the impact of the Financial Services Authority Regulation POJK 51/2017 about Sustainable Finance implementation on bank risk in Indonesia. The regulation mandates all commercial banks to integrate environmental, social, and governance principles into their strategic and operational frameworks. However, empirical evidence regarding how this policy affects financial stability remains limited. This research addresses that gap by analysing both the direct and indirect effects of the regulation on bank risk.

Method: This study employs a quantitative method with a difference-in-differences approach to analyse the causal impact of implementing POJK 51/2017 on bank risk. The data used is a panel of 22 banks for the period from 2015 to 2024. In addition, a mechanism test is conducted to explore transmission channels through green credit and cost efficiency, as well as a heterogeneity test to measure differences in impact across bank size and ownership type.

Findings: The research found that the implementation of POJK 51/2017 increased banking risk. Furthermore, a mechanism analysis showed that the green credit ratio serves as a transmission channel through which regulations influence risk, while the operational efficiency ratio does not. Furthermore, the impact is greater for small banks and state-owned banks.

Implications: Banks must adopt risk-based green lending, especially for MSME-oriented projects that have higher information risks, while the Financial Services Authority should strengthen risk-based supervision by assessing the risk profile of green exposures rather than solely focusing on green credit volume.

Novelty/Value: This study offers new empirical evidence by applying a difference-in-differences design to capture the causal impact of POJK 51/2017 on bank risk. It also identifies the green credit ratio as a main transmission channel and reveals differential risk effects across bank size and ownership, providing new insights into how institutional capacity shapes sustainable finance regulatory outcomes in Indonesia.

Keywords: Bank Risk, Difference-in-Differences, Green Credit, Operational Efficiency, Sustainable Finance.

INTRODUCTION

The banking sector is an important part of a country's economic and financial system. Banks, as intermediary institutions that manage public funds, face various risks in their business fields (Bessis, 2015) such as credit risk, market risk, liquidity risk and operational risk. In recent years, however, the banking sector has faced a change in risk perception which is caused by the number of important global changes in the risk environment, which is due to the increasing global climate crisis. Climate change causes systemic shocks that are no longer seen as simply external factors but has been seen as a structural factor that can lead to meaningfully disrupt financial stability (UN. ESCAP, 2020).

The Asian Development Bank states that Indonesia is one of the countries that is very susceptible to climate change impacts. The same report states that if Indonesia does nothing, the result by the year 2100 will be a 61.1% decrease in Gross Domestic Product (GDP) at the RCP 8.5 levels are (Campagnolo et al., 2025). The Long-term forecasts made in connection with the Low Carbon Development Indonesia (LCDI) project will also indicate that the economic losses which Indonesia has in the event of non-implementation of climate change consequences, the consequences will not only be negative with respect of the environment but will directly have harmful implications for Indonesia's long-term economic resistance. If Indonesia can make development according to climate factors (LCDI High Scenario), it is believed that it can bring an additional output of US$5.4 trillion in GDP by 2045 (Bappenas, 2019).

Due to the various challenges banks face in response to climate change, they are required to consider climate risk factors in every investment decision-making and lending process. Climate risk dimensions are divided into physical risks and transition risks (Pozdyshev et al., 2025). Physical risks include property damage, trade disruptions due to various natural disasters, and productivity losses due to rising average temperatures (FSB, 2020), while transition risks arise from the transition to a low-carbon economy, including changes in how society allocates resources, the use of technology, and regulatory changes that require companies to revalue assets, create stranded assets such as fossil fuel deposits or coal reserves, and pose a risk of systemic devaluation for the global financial industry (Swiss Re Institute, 2021).

To achieve net-zero emissions by 2060, Indonesia has developed a low-carbon development strategy as part of its long-term national development plan to mitigate various climate risks, with a primary focus on reducing greenhouse gas emissions from business activities in the energy, transportation, and land use sector (Bappenas, 2021;Minister of Environment and Forestry, 2021) Carbon emission reduction efforts are not merely seen as a commitment to various international agreements such as the Paris Agreement. Indonesia has committed to a sustainable development transition as an adaptive strategy to maintain national economic resilience. To implement this strategy, Indonesia requires large-scale and sustainable financing (UNCC, 2021). To achieve net-zero emissions, Indonesia requires an average of USD 150-200 billion per year from 2021 to 2030 (Bappenas, 2021);. The role of financial institutions and the banking sector is key in supporting the distribution of funds for environmentally sound projects (OJK, 2021).

Indonesia has initiated financial regulation measures through the Financial Service Authority to response the global demand and the high level of national vulnerability to the impact of climate change. This effort is realised through the launch of the Sustainable Finance Roadmap and the issuance of OJK Regulation No. 51/POJK.03/2017 concerning the Implementation of Sustainable Finance (POJK 51/2017). The implementation of POJK 51/2017 is being implemented in stages and will only enter its full implementation phase in 2025 (OJK, 2018). This regulation will be mandatory for BUKU 3 and 4 banks starting in 2019, BUKU 1 and 2 banks starting in 2021, and all banks will be required to prepare a Sustainable Finance Action Plan and a Sustainability Report in the 2022–2025 period. This means that the empirical impact of the new policy will be observable in the next few years. G20 IHLEG (2024) emphasizes that evaluation of sustainable finance policies should be conducted in the early implementation period because the regulatory transition phase usually gives rise to new risks due to adjustments to portfolios and governance systems.

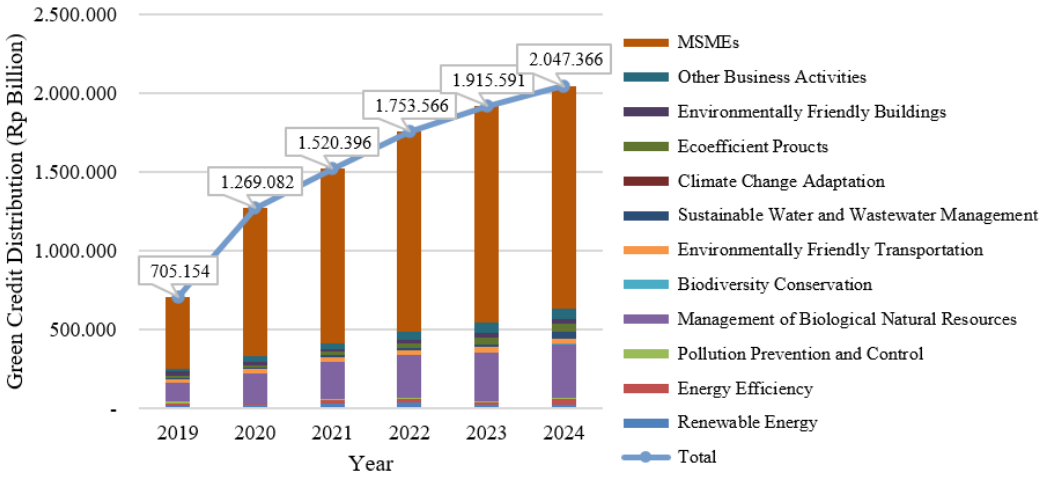

Figure 1. Bank Green Credit Portfolio in Indonesia
Source: https://keuanganberkelanjutan.ojk.go.id/keuanganberkelanjutan/id/statistik, Juni 2025

Figure 1 illustrates that the Financial Services Authority's statistical data indicate that the implementation of POJK 51/2017 has driven the growth of green credit distribution in Indonesia. The total green credit portfolio has increased more than threefold from 2019 to 2024, from IDR 705.154 billion in 2019 to IDR 2,047.366 billion in 2024. However, a closer look reveals that the dominance of Micro, Small, and Medium Enterprises (MSMEs) financing contributes the largest portion of total green credit financing, reaching 69% of the total portfolio in 2024 (IDR 1,411,974 billion). Rapid growth has also occurred in several sectors, such as Sustainable Water and Wastewater Management, which has increased by 648% since 2019, and Eco-efficient Products, which have grown by 185% in the same period. Several crucial sectors in the effort to develop a low-carbon economy have not been touched at all. The Biodiversity Conservation sector has only received 0.04% of credit disbursement, and there has been no financing in the Climate Change Adaptation sector. Challenges in assessing the feasibility of highly complex projects are a reason why the technical sector has not been able to absorb higher levels of financing. The dominance of MSME financing in credit allocation can create potential concentration risks because MSME credit is characterized by limited collateral and higher information asymmetry compared to other sectors (Y. Zhang et al., 2021).

One reason why banks have not been able to channel credit to technical sectors is the high initial operational costs required for new systems, capacity development, and human resources (Wanting, 2020). Large banks can achieve profitability in their green credit businesses with more comprehensive risk management mechanisms. Small banks are often limited by resources, and the inability to implement effective risk management mechanisms is one reason why this regulation is difficult to implement effectively. Running a green credit business is a relatively complex endeavour, with high credit risks and opportunity costs.

Statistical data on banking stability and risk in Indonesia from 2014 to 2024 published by Financial Service Authority does not directly show how sustainable financial policies shape banking risk. A strengthening trend occurred in the Capital Adequacy Ratio (CAR) indicator, from 19.57% to 26.76%. The Non-Performing Loan (NPL) indicator experienced volatility, peaking at 3.06% in 2020 before returning to 2.08% in 2024. Financial stability, as measured by the Z-Score, experienced a stable trend of 3.65 in 2019 and stagnated at 3.57-3.58 during the 2020-2024 period. The Z-score stagnation pattern coincided with the full implementation of POJK 51/2017 for BUKU 3 and 4 banks, coinciding with a period of aggressive green credit expansion.

The CAR strengthening and Z-Score stagnation indicates a potential trade-off between sustainability regulatory compliance and risk stability. This finding is consistent with X. Yin (2021) that identified tension between mandatory environmental lending and financial stability in the medium term. Portfolio transformation toward green financing has the potential to create new risk pressures that have not been fully accommodated within conventional risk management frameworks(Battiston et al., 2021). In addition, several studies show that Z-score volatility is usually higher in small banks and state-

owned banks compared to large banks and private banks. This indicates that the policy impact is heterogeneous, influenced by specific characteristics of each bank, such as bank size and ownership structure (W. Yin et al., 2021; X. Yin, 2021; Zhou et al., 2022).

Table 1. Banking Risk Indicators in Indonesia 2014-2024

Year	NPL	CAR	*Z-Score*
2014	2.16%	19.57%	3.46
2015	2.49%	21.39%	3.56
2016	2.93%	22.93%	3.61
2017	2.59%	23.18%	3.62
2018	2.37%	22.97%	3.62
2019	2.53%	23.40%	3.65
2020	3.06%	23.89%	3.57
2021	3.00%	25.66%	3.57
2022	2.44%	25.62%	3.57
2023	2.19%	27.75%	3.58
2024	2.08%	26.76%	3.58

Source: Indonesia Banking Statistic Report 2014-2024, Indonesia Financial Services Authority

Several international institutions have also warned that green finance policies could increase banking risks in the early stages of the transition IMF (2022), NGFS (2022), TCFD (2016) emphasize that regulatory pressures to increase green financing have the potential to create green asset bubbles, mispricing of transition risk, and credit misallocation, particularly when banks allocate credit to projects that lack a sufficient technological track record or feasibility. This phenomenon is consistent with the empirical findings of Y. Feng et al. (2024), Al-Qudah et al. (2023), W. Yin et al. (2021) who found that sustainable finance policies in several countries increased banking risks in the early stages of their implementation. Therefore, it remains crucial to evaluate POJK 51/2017 to prevent latent risk accumulation.

Theoretically, there are two opposing perspectives regarding the impact of implementing sustainable financial policies on bank risk, where stakeholder theory states that carrying out business activities by integrating environmental and social factors can improve the bank's reputation and reduce reputational and legal risks (Freeman, 2010). However, agency theory and information asymmetry theory state that green project financing often has uncertainty and limited historical data, which can increase screening and monitoring costs and adverse selection (ESRB, 2022).

POJK 51/2017 remains the primary basis for all sustainable finance transition policies in Indonesia, thus posing systemic risks to its implementation. This regulation serves as the foundation for Indonesia Green Taxonomy 2.0, Climate-Related Stress Testing Guidance, and the Sustainable Finance Roadmap Phase II. Empirical evaluation of the impact of POJK 51/2017 is essential to ensure that green portfolio expansion is aligned with financial stability. World Bank (2021) states that developing countries need evidence-based regulatory calibration to ensure that sustainability initiatives do not create new systemic risks.

Empirical research analysing the causal relationship between the implementation of POJK 51/2017 and banking risks in Indonesia remains limited. Existing research tends to be descriptive or correlational (Furqan & Sutrisno, 2024; Krisna Bayu & Novita, 2021; Paragina & Muchtar, 2021; Sutrisno et al., 2024). Therefore, this study aims to achieve three main objectives. First, to analyse the causal effect of the implementation of POJK 51/2017 on banking risk in Indonesia. Second, to test the transmission mechanism of sustainable finance policies by examining the role of the green credit ratio and operational cost efficiency. Third, to analyse the heterogeneity of the impact of POJK 51/2017 implementation on bank risk by comparing large banks vs. small banks and state-owned banks vs. private banks.

The answers to these three objectives will add to existing literature using a quasi-natural experiment (POJK 51/2017) and a difference-in-difference methodology to measure the causal effect of Sustainability Policies on Bank Risk. The use of DID is less common in Indonesia and provides a better insight into the effects of Sustainability Regulations in the Financial Sector. As such, this study extends our knowledge of how regulatory pressure may lead to agency conflict and information asymmetry in the green credit distribution process. It is expected that the results of this study will be practically useful for decision makers within the Banking Industry and Supervisory Institutions as they can provide a quantifiable insight into how POJK 51/2017 impacts bank risk. Furthermore, it will provide empirical evidence supporting governments and regulators when developing Sustainable Finance Policies with consideration of the capabilities of financial institutions. Therefore, this study has the potential to enhance both theoretical developments and the policy discourse regarding the transition to a Sustainable Financial System.

LITERATURE REVIEW

Agency Theory

Agency theory is a key concept for understanding how banks respond to new regulations, particularly when these regulations require fundamental changes in internal work patterns. According to (Jensen & Meckling, (1976) this theory demonstrates that the objectives and risk preferences of owners and managers may be partially unaligned. The banking sector is an example of when this can be especially true as bank management must respond to regulatory expectations, shareholder expectations and the pressure of the markets.

As part of the implementation of POJK 51/2017, the reporting obligation for banks not only included sustainability reports but also the changes in how banks would evaluate and manage risk and how they would allocate credit. In doing so, it placed the burden on the bank's management to establish adequate ESG risk assessments prior to making credit portfolio decisions. For many banks, this resulted in credit portfolio decision-making being driven by the need to comply with regulations, as opposed to making decisions based on careful consideration of the associated risks. As a result, management had the ability to choose strategies that would likely increase risk to show short term compliance (Yusupova et al., 2025).

Agency theory serves as a grand theory in this research because differences in capacity and orientation across bank groups, including large banks, small banks, state-owned banks, and private banks, resulted in heterogeneous responses to policy. Banks under public and political pressure, such as state-owned banks, have different incentives than private banks, which are more focused on profitability and efficiency. This asymmetry in incentives is the initial source of variations in banking risk after the policy is implemented.

Information Asymmetry Theory

Information asymmetry implies that in a business activity, one stakeholder with better information has an advantage over the less informed stakeholder, resulting in an imbalance of bargaining power (Akerlof, 1970). When information asymmetry occurs, decisions taken by one party become less than optimal and can lead to market failure. One of the factors that contributes to credit risk is the strength of information asymmetry between banks and borrowers. Banks do not always have complete information regarding the borrower's financial condition and the risks of the projects they finance. While borrowers usually have complete data and knowledge related to the projects they are running. Stiglitz and Weiss (1981) expanded this framework by introducing adverse selection and moral hazard as two critical outcomes of asymmetric information. Adverse selection occurs when banks cannot distinguish between high- and low-risk borrowers. Conversely, moral hazard arises when borrowers are encouraged to take riskier actions after obtaining credit from a bank because the bank will bear the risk. These two mechanisms become more difficult to control when banks channel credit to sectors with limited track records, such as green projects promoted by POJK 51/2017.

POJK 51/2017 requires banks to increase their exposure to green credit while implementing ESG principles in their operational activities. To achieve these goals, a strong information infrastructure is

needed to maintain bank stability. This is particularly relevant for small banks with limited resources that do not yet have a robust green risk evaluation system(Li et al., 2023). So that efforts to support sustainable development do not create the potential for new financial fragility if they are not balanced with adequate information systems and risk mitigation.

Green Banking

The concept of green banking or sustainable banking has become important in the banking sector in response to increasing awareness among stakeholders of various environmental issues arising from global industrial and economic activities. This theory proposes that financial objectives should not be separated from environmental and social responsibilities. This theory developed in the 1980s with the emergence of the Brundtland Report (1987), which defined sustainable development as meeting the needs of the present without compromising the needs of future generations. Green banking must operate by integrating environmental, social, and governance (ESG) factors into every financial decision-making process.

The green banking process involves identifying and evaluating potential environmental risks from the projects they finance, as well as developing financial products and services that support environmentally friendly economic growth (Alamri, 2023; Mumtaz & Smith, 2019). By implementing sustainable practices and financing initiatives that uphold social and environmental responsibility, banks can play a role in mitigating climate change and reducing their carbon footprint by supporting financing for renewable energy, energy efficiency, and other environmentally friendly projects (Alamri, 2023).

In the transition phase, banks often face technical challenges because feasibility analysis of renewable energy projects, energy efficiency, and similar initiatives requires technical competencies that are not always available. This causes the green credit disbursement process to become highly dependent on external information such as technical consultants, technology vendors, or third-party reports. This reliance on external sources increases the potential for assessment bias, especially when banks must meet regulatory targets such as POJK 51/2017. This situation places green banking as a crucial concept in risk analysis. Inadequate credit evaluation not only impacts project success but also undermines bank stability, particularly as the green credit portfolio becomes increasingly dominant. Therefore, green banking is relevant not only as an ethical concept but also as a technical determinant of risk in current banking practices.

Green Risks

For risk managers and banking regulators, risk refers to the uncertainty of outcomes and their potential negative consequences for the firm, and both aim to increase the firm's resilience to adverse situations. As a result of their efforts, risks are better identified, assessed, and monitored, risk practices are improved, and risk models are more widely used (Bessis, 2015). Decision making involving risk, especially in a financial context, always seeks to balance between potential returns and the level of risk taken. Fundamental finance theory previously explained the risk-return trade-off. Higher risk is typically accompanied by higher returns (Markowitz, 1952) Bank management must be able to balance the potential returns from loans disbursed with the inherent uncertainty.

Green financing with its noble goals does not always have low risk. Many international institutions have recognized that the transition to a green economy creates new risks that banks have not yet fully understood. BIS (2021) highlights that transition risk arises when sudden changes in climate policy, technology, or market preferences can affect project viability. IMF (2022) and NGFS (2022) also emphasize that physical risks from climate change can directly impact nature-based projects financed by banks.

Both forms of risk increase the analytical burden for banks that previously focused solely on conventional credit and market risks. As green portfolios expand due to policy incentives, transition and physical risks become increasingly relevant. Many green projects require long-term revenue estimates that are affected by policy changes, energy prices, and technological dynamics. This uncertainty can result in higher performance volatility than conventional projects. This challenge is exacerbated by the fact that more than two-thirds of green financing is directed to the MSME sector,

which historically has higher default rates. In other words, green risk stems not only from the characteristics of green projects but also from the characteristics of the borrowers receiving the financing. This explains why several banks experienced increased risk during the initial implementation of POJK 51/2017.

Internal factors such as bank size, profitability, and leverage are also influence bank risk (Martynova et al., 2020). Larger banks tend to have lower risks due to the greater impact of potential losses (Altunbas et al., 2011; Demirgüç-Kunt & Huizinga, 2010). Banking risks are primarily reflected in credit decisions, so banks must assess the creditworthiness of customers applying for credit, evaluate potential default risks, and determine appropriate interest rates to address potential future risks. A banks risk management process includes both individual borrower risk analysis and overall portfolio risk management, including risk diversification across sectors, regions, and loan types (Hull, 2023).

Hypothesis Development

Empirical research about how applying sustainable finance policies contained in the Financial Services Authority Regulation Number 51/2017 has an influence on the riskiness of banks has not yet reached the same opinion. Although various research conducted in various countries revealed that the same policies influenced the riskiness of banks in general. The obligation to adopt principles with regard to the environment, social and corporate governance (ESG), which is supplemented by an increase in the disclosure of information contained in the sustainability report is expected to improve the implementation of risk management, the level of a good reputation of the institution, as well as reduce asymmetry of information (Hassan et al., 2024). This opinion is supported by research conducted by (Bommel, 2023), which states that a commitment to sustainability serves to narrow the information gap between banks and stakeholders. Hence the information about the sustainability as well as the risk governance of ESG will be more transparent, which will give investors and stakeholders an accurate risk profile for banks to assess. A more accurate assessment will lead the banking institution to be more precise in credit delivery, consistent with prudential principles and to maintain the stability of market confidence.

The implementation of policies requiring banks to incorporate environmental and social dimensions into their business processes is intended to strengthen prudential principles while reducing potential risks. Numerous empirical studies support this view. An et al. (2023) showed that green credit policies significantly reduced aggregate banking risk. Zhou et al. (2022) shown a similar finding for a group of large state-owned banks in China. But conflicting findings also emerged. T. Feng et al. (2023) identified that green credit policies can increase banks' risk exposure. Further research by Y. Feng et al. (2024) found that the policy impact is dynamic, reducing risk in the short term but potentially increasing it in the long term. These difference results emphasise that the impact of sustainable finance policies is dependent on the context and the readiness of the institutions implementing them. Considering that the primary objective of POJK 51/2017 is to strengthen the resilience of the national financial sector, the first hypothesis of this study is formulated as follows:

H_1: Implementing POJK 51/2017 negatively and significantly affects bank risk.

Implementing sustainable finance policies requires high operational costs, such as investing in ESG systems and training employees who can implement regulatory mandates (Wanting, 2020). In the long term, effective integration of ESG factors can improve operational cost efficiency by reducing environmental sanctions (G. Tian et al., 2023). Financial stability can be achieved if banks have strong operational efficiency (Sugiharto & Siauwijaya, 2025; Tan, 2014). Operational cost efficiency is seen as a channel for implementing POJK 51/2017 and its impact on bank risk Portfolio diversification through greater green credit can mitigate climate-related financial risks by reducing bank credit reliance on environmentally damaging sectors (Fan & Gao, 2024; Mirza, Umar, et al., 2023). Banks that allocate credit to sustainable sectors are expected to experience increased stability and reduced risk. The second and third hypotheses are proposed to assess operational efficiency and the green credit ratio as transmission channels:

H_2: The green credit ratio mediates the effect of POJK 51/2017 on bank risk.

H_3: The operational efficiency ratio mediates the effect of POJK 51/2017 on bank risk

In practice, there are significant differences in the implementation of sustainable finance policies across bank ownership types and sizes. For example, many academics have focused their research on the differences in size between large and small banks and how these differences influence the impact of green credit (Y. Feng et al., 2024; Wanting, 2020; X. Yin, 2021; An et al., 2023; Yuan, 2024). In addition to this, scholars also explored the green credit from other diversified aspects, including ownership structure (Zhou et al., 2022; D. Feng, 2023; Yan, 2024). State-owned banks may prioritise development goals aligned with mandate, but private banks emphasise profitability and financial stability to shareholders (Sutrisno et al., 2024). These differences in managerial incentives and stakeholder expectations are likely to result in different policy outcomes. Therefore, two additional hypotheses are formulated:

H_4: The effect of POJK 51/2017 on bank risk differs between state-owned and private banks.
H_5: The effect of POJK 51/2017 on bank risk differs between large and small banks.

RESEARCH METHOD

The diagram in Figure 2 illustrates the research method, outlining the sequential steps undertaken in this study, from the literature review to managerial implications.

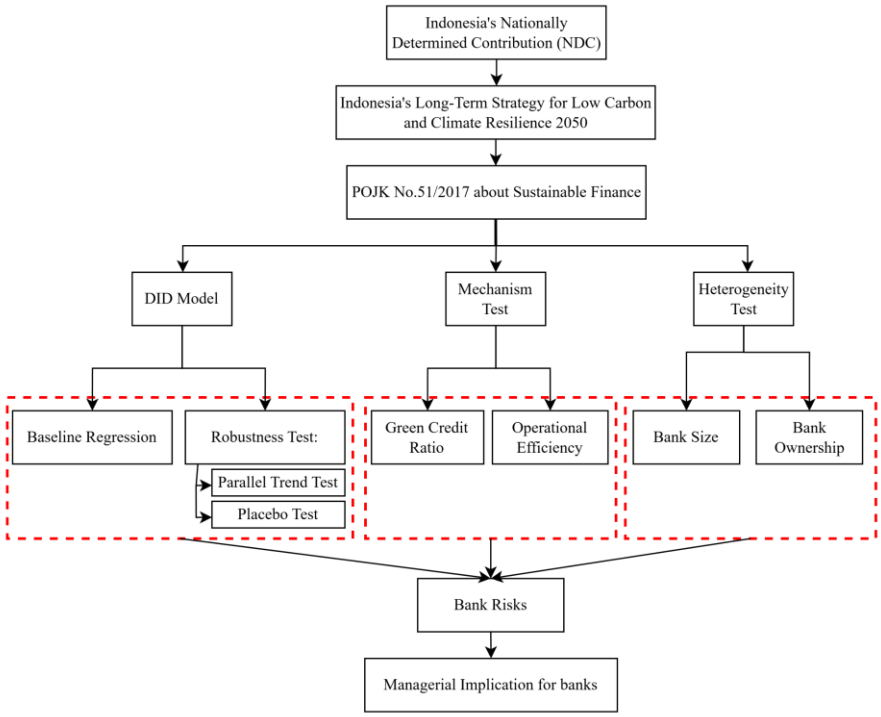

Figure 2. Research Framework
Source: Author's design

Data Types and Sources

The type of data used in this study is panel data on commercial banks operating in Indonesia from 2015 to 2024. The data is secondary and is obtained through various available sources, such as the Central Bureau of Statistics Report, the official website of the Financial Services Authority, and the Annual Report and Sustainability Report obtained through the official website of each bank.

Sampling Method

From the 105 banks registered with the Financial Services Authority in 2023, consisting of state-owned banks, foreign banks, regional development banks, and national private banks, we selected samples

using a non-probability sampling method, specifically purposive sampling. Sarker & AL-Muaalemi (2022) explain that non-probability sampling is a sampling technique that does not provide equal opportunities or chances for each member of the population. Instead, sampling is determined by specific considerations based on criteria. The criteria used in this study's sampling are as follows in Table 2. Based on these sample selection criteria, 22 commercial banks registered with the Financial Authority Service were selected for the study.

Table 2. Sample Selection

No	Criteria	Total
1	Commercial Banks registered with the Financial Services Authority	105
2	Banks classified as BUKU 3 and BUKU 4 banks in 2017	(83)
3	Commercial Banks that published consecutive annual financial reports during the research period from 2015 to 2024	-
4	Commercial Banks with complete data available for each variable required in this study from 2015 to 2024	-
	Sample Total	22

Operationalization and Measurement Variables

Table 3 summarizes the operational definitions, indicators, and measurement scales used to ensure that all variables can be observed, measured, and analyzed consistently.

Table 3. Operational Definition and Measurement

Variables	Symbol	Definition	Measurement
Dependent:			
Bank Risks	Z-score	The size of a bank's capital and profit are relative to the risks faced, which indicates banking stability.	$Z_{it} = \frac{ROA_{it} + CAR_{it}}{\sigma ROA_{it}}$
Independent:			
Implementations of POJK 51/2017	DID	Implementation of Financial Services Authority Regulation Number 51/POJK.03/2017	For a bank that implements the regulation, the value is 1; otherwise, it is 0
Mechanism:			
Green credit ratio	GCR	The proportion of credit banks providing for environmentally friendly projects of the overall credit disbursed by banks.	$GCR = \frac{Green\ credit\ total}{Credit\ Total}$
Operational efficiency ratio	OER	Operating costs to operating income measures the operational efficiency of the bank.	$OER = \frac{Operating\ Expense}{Total\ Revenue}$
Heterogeneity:			
Bank size	LN_TA	The size of a bank is measured based on total assets.	For large banks, the value is 1; for a small bank, it is 0
Type of Bank Ownership	Ownership	An entity or group that controls most shares and voting rights in a banking institution.	For state-owned banks, the value is 1; for a private bank, it is 0
Control:			
Loan-to-Deposit Ratio	LDR	Credit distribution against total funds received.	$LDR = \frac{Total\ Loans}{Total\ Deposits}$
Debt-to-Asset Ratio	DAR	The proportion of debt to total assets owned by the bank.	$DAR = \frac{Total\ Debt}{Total\ Assets}$
Revenue Growth Rate	RGR	The bank's financial performance and long-term growth potential.	$RGR = \frac{Revenue_t - Revenue_{t-1}}{Revenue_{t-1}}$
Bank Loan Balance	LN_TL	Total loans disbursed by banks.	$LN\_TL = log\ (\ total\ loans)$
Equity Multiplier	EM	Financial leverage bank.	$EM = \frac{Total\ Assets}{\text{Shareholders Equity}}$

Source: Previous research

Analytical Method

To achieve the first research objective, a Difference-in-Differences (DiD) approach was carried out to analyse the effect of implementing sustainable financial policies on banking risk as carried out in previous studies (Y. Feng et al., 2024; Luo et al., 2021). This research design was carried out because the policy intervention was not applied randomly but occurred exogenously at a certain point in time for an identifiable group of banks, thus creating conditions that resembled a controlled experiment. This research focuses on BUKU 3 and 4 banks, the first wave required to implement POJK 51/2017. This study will also use a more stringent definition based on verifiable evidence of compliance. The treatment group and control group will be defined as follows:

a. The treatment group consists of BUKU 3 and 4 banks that have demonstratively implemented POJK 51/2017 by providing verifiable evidence regarding Sustainable Financial Action Plan reports and Sustainability Reports as mandated by the Technical Guidelines for Banks regarding the implementation of POJK 51/2017.
b. The control group, consisting of BUKU 3 and 4 banks, based on a review of their public reports for 2019, did not provide verifiable evidence regarding the reporting of sustainable financial action plans and Sustainability Reports as mandated by the Technical Guidelines for Banks regarding the implementation of POJK 51/2017.

This method allows researchers to measure outcome changes between treatment and control groups before and after policy interventions. The DiD model used in this research refers to existing studies (Liu et al., 2021) formulated as the following equation (1):

$$Z - score_{it} = \alpha + \beta_1 DID + \beta_2 LDR_{i2} + \beta_3 DAR_{i3} + \beta_4 RGR_{i4} + \beta_5 \text{LN\_TL}_{i5} + \beta_6 EM_{i6} + u_i + \lambda_t + \varepsilon_{it} \quad \textbf{(1)}$$

Description:
Z-score : Bank Risk
DID : The policy dummy variable is obtained through the interaction between the treatment dummy variable and the time dummy variable
LDR : Loan-to-Deposit Ratio
DAR : Debt-to-Aset Ratio
RGR : Revenue Growth Rate
LN_TL : Logarithmic Natural Total Loan
EM : Equity Multiplier
u_i : Bank Fixed Effect
λ_t : Time Fixed Effect
ε_{it} : Error term

To achieve the second objective, namely the green credit ratio mechanism and cost efficiency on the influence of POJK 51/2017 implementation on risk, the Two Stage Least Squares approach was used as the approach in Shao (2024), a study was used to test whether the implementation of POJK 51/2017 can encourage banks to distribute green credit and whether it affects their operational efficiency to reduce bank risk. Equation (2) is baseline regression, Equations (3) and (4) are mechanism regression.

$$Z - score_{it} = \alpha + \beta DID_{it} + \beta LDR_{it} + \beta DAR_{it} + \beta RGR_{it} + \beta \text{LN\_TL}_{it} + \beta EM_{it} + u_{it} + \lambda_t + \varepsilon_{it} \quad \textbf{(2)}$$

$$GCR_{it} = \alpha_1 + \beta_{1t}^1 DID_{1t} + \beta_{2t}^1 LDR_{it} + \beta_{3t}^1 DAR_{it} + \beta_{4t}^1 RGR_{it} + \beta_{5t}^1 \text{LN\_TL}_{it} + \beta_{6t}^1 EM_{it} + u_{it} + \lambda_t + \varepsilon_{it} \quad \textbf{(3)}$$

$$OCR_{it} = \alpha_2 + \beta_{1t}^2 DID_{1t} + \beta_{2t}^2 LDR_{it} + \beta_{3t}^2 DAR_{it} + \beta_{4t}^2 RGR_{it} + \beta_{5t}^2 \text{LN\_TL}_{it} + \beta_{6t}^2 EM_{it} + u_{it} + \lambda_t + \varepsilon_{it} \quad \textbf{(4)}$$

Description:
GCR : Green credit ratio
OER : Operational efficiency ratio

Z-score : Bank Risk
DID : The policy dummy variable is obtained through the interaction between the treatment dummy variable and the time dummy variable
LDR : Loan-to-Deposit Ratio
DAR : Debt-to-Aset Ratio
RGR : Revenue Growth Rate
LN_TL : Logarithmic Natural Total Loan
EM : Equity Multiplier
u_i : Bank Fixed Effect
λ_t : Time Fixed Effect
ε_{it} : Error term

The third research objective is to test the heterogeneity of the influence of POJK 51 implementation based on bank characteristics (size and ownership). This research carries out regression on Equation (1) by dividing sub-samples based on bank size and type of bank ownership as done by C. Tian et al. (2022) thus, researchers can identify whether the effect of implementing POJK 51/2017 on bank risk differs significantly between bank sub-groups.

RESULTS AND DISCUSSION

Results

Descriptive Statistic

Before testing the econometric model to examine the impact of POJK 51/2017, we conducted descriptive statistics on all the main variables used in this study to obtain an overview of the characteristics of Indonesian banking data for the period 2015 - 2024. These statistics cover the dependent, independent, mediating, and control variables, combined in a difference-in-differences model.

Table 4 presents the results of descriptive statistics for all variables used in this study, including independent, dependent, mediating, and control variables, over the study period from 2015 to 2024, divided into samples before and after the implementation of POJK 51/2017, which came into effect in 2019. The average value of the DID variable (the average interaction term between treatment group and treatment time) of 0.49 reflects a balanced sample distribution between the pre- and post-policy periods. As we previously expected, the DID value was zero in the pre-policy period. It increased to 0.82 after the policy was implemented, indicating that most banks in the sample had been in the treatment group since 2019.

The average Z-score of 3.13 reflects good banking financial stability throughout the study period. The Z-score increased from 3.05 in the before policy period to 3.18 after the policy that indicating a trend toward strengthening financial stability following the implementation of POJK 51/2017. The green credit ratio (GCR) increased from 0.002 to 0.161inidicating that the policy is effective in expanding credit distribution to environmentally conscious sectors. The increase in GCR standard deviations in the after-policy period indicates that adoption rates across banks still vary, reflecting differences in capacity and implementation strategies. The average operational efficiency ratio (OER) also increased slightly from 0.83 to 0.84, possibly reflecting short-term efficiency pressures resulting from increased compliance costs and the need for investment in sustainability reporting and governance systems.

The control variables in this study exhibit a relatively stable pattern, although they still provide meaningful information. The loan-to-deposit ratio (LDR) decreased from 0.99 to 0.90, indicating a conservative lending trend following the implementation of the policy. The debt-to-asset ratio (DAR) decreased from 1.40 to 0.99, indicating a strengthening of the bank's capital structure. Meanwhile, the revenue growth rate (RGR) slowed from 0.43 to -0.003, indicating a possible adjustment phase driven by changes in financing strategy and cost structure. Bank size, as measured by log total assets (LN_TA), increased moderately. At the same time, the equity multiplier (EM) decreased from 7.54 to 6.98,

indicating a tendency for banks to reduce leverage as part of efforts to maintain financial stability amidst the sustainability policy transition.

Table 4. Descriptive Statistic

Variables	Period	N	Mean	SD	Min	Max
DID	Full Sample	220	0.491	0.501	0.000	1.000
	Before Policy	88	0.000	0.000	0.000	0.000
	After Policy	132	0.818	0.387	0.000	1.000
Z-score	Full Sample	220	3.127	0.728	0.563	4.414
	Before Policy	88	3.049	0.741	0.563	4.214
	After Policy	132	3.180	0.717	0.906	4.414
GCR	Full Sample	220	0.097	0.143	0.000	0.614
	Before Policy	88	0.002	0.009	0.000	0.053
	After Policy	132	0.161	0.155	0.000	0.614
OER	Full Sample	220	0.837	0.218	0.417	2.262
	Before Policy	88	0.832	0.131	0.582	1.508
	After Policy	132	0.840	0.261	0.417	2.262
LN_TA	Full Sample	220	33.036	1.764	30.191	39.446
	Before Policy	88	32.850	1.660	30.191	39.230
	After Policy	132	33.159	1.825	30.438	39.446
Ownership	Full Sample	220	0.182	0.387	0.000	1.000
	Before Policy	88	0.182	0.388	0.000	1.000
	After Policy	132	0.182	0.387	0.000	1.000
LDR	Full Sample	220	0.933	0.220	0.553	2.320
	Before Policy	88	0.986	0.241	0.553	2.320
	After Policy	132	0.897	0.198	0.586	1.630
RGR	Full Sample	220	0.171	1.818	-10.779	13.074
	Before Policy	88	0.431	2.123	-4.438	13.074
	After Policy	132	-0.003	1.566	-10.779	6.657
DAR	Full Sample	220	1.154	1.909	0.229	14.916
	Before Policy	88	1.402	2.671	0.229	14.916
	After Policy	132	0.990	1.133	0.590	10.259
LN_TL	Full Sample	220	32.237	1.253	29.529	35.023
	Before Policy	88	32.102	1.144	29.600	34.290
	After Policy	132	32.326	1.318	29.529	35.023
EM	Full Sample	220	7.206	3.018	2.437	28.978
	Before Policy	88	7.537	2.496	3.143	15.917
	After Policy	132	6.985	3.312	2.437	28.978

Source: Data Processed – Stata17

Baseline Regression

We use the baseline regression model (DiD) in Equation (1) to investigate the causal impact of the implementation of POJK 51/2017 on banking risk, thus testing Hypothesis 1 which was tested by means of the difference-in-differences (DiD) model, which is represented in Equation 1. That said, this model works to predict the causal effect of the implementation of POJK 51/2017 on banking risk levels. The

DiD technique allows for an analysis of the comparative effect of the change in the Z-scores of the banks implementing the regulation with those not taken into account in the treatment group, in two time scales, on one hand, before the implementation of the regulation, on the other after implementation. The outcomes of this analysis will provide empirical evidence for the effect of legislation and will also permit an observation of the levels at which sustainable finance regulation coalesce with banking risk management in Indonesia.

Table 5. Baseline Regression

VARIABLES	Z-score	Z-score
DID	-0.107**	-0.102***
	(0.0499)	(0.0383)
LDR		0.114**
		(0.0571)
RGR		0.00767*
		(0.00403)
DAR		-0.0119*
		(0.00683)
LN_TL		-0.302***
		(0.0353)
EM		-0.0199***
		(0.00401)
Constant	2.979***	12.70***
	(0.0298)	(1.105)
Fixed time	Yes	Yes
Fixed individual	Yes	Yes
Control Variable	No	Yes
Observations	220	220
R-squared	0.249	0.617
Number of id	22	22

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Data Processed – Stata17

The baseline regression estimation results to test the impact of sustainable finance regulation implementation on bank risk in Table 4 show that the DID variable has a negative and significant effect on bank risk at the 1% level ($\beta = -0.102$; $p < 0.01$). Banks in the treatment group experienced a decrease in financial stability of 0.102 standard deviations of the Z-score value compared to banks in the control group. This comparison considers the influence of time and the characteristics of each bank. These findings suggest that earlier implementation of sustainable finance policies tends to put pressure on bank stability. Therefore, Hypothesis 1, which states that the implementation of POJK 51/2017 reduces bank risk, is rejected.

Other results show that the explained power of the model increased from 24.9% to 61.7% with the introduction of the control variables in the estimation. This increase indicates that differences in characteristics between the banks play a large role in explaining the effect of policy on risk. This finding is aligned with Y. Feng et al. (2024), which emphasizes that it is important to use control variables in trials since the efficiency of sustainable finance policies depends on the institutional capacity of banks.

Robustness Test

Parallel Trend Test. One of the fundamental assumptions in the Difference-in-Differences (DiD) model is the fulfilment of the parallel trend assumption, which is that before the regulation intervention, the trend of dependent variables between the treated group and the control group must move parallel. The fulfilment of this assumption ensures that any differences that arise after the intervention are really caused by policy or regulation, not by historical trends that have been different before (Gertler et al., 2016). To test these assumptions, this study adopts the average coefficient method approach as developed by Shao (2024) using an event-study model that maps the average Z-score (bank risk

indicator) change over five years before and after implementing the POJK 51/2017 regulation. The values of the pre-regulation years (t−4 to t−1) reflect the pre-intervention trend, while the post-regulation years coefficient (t to t+5) shows the post-intervention dynamics. The estimated results are shown in Figure 3 of the following parallel trend test results.

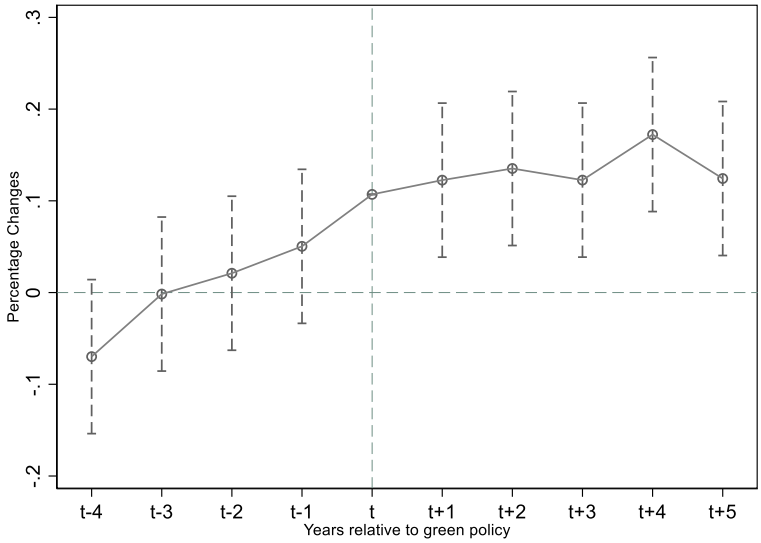

Figure 3. Parallel Trend Test Result
Source: Data Processed – Stata17

Based on Figure 3 of the trend of parallel test results, in the pre-regulation period (t-4 to t-1), the change in the average Z-score relative to the base year (t=0) fluctuated around zero values with overlapping confidence intervals. This shows no significant trend difference between the treated and control groups before the regulation is implemented, so the assumption of parallel trends is fulfilled. Thus, the DiD approach can be used in this study methodologically valid to estimate the causal influence of the POJK 51/2017 regulation on banking risk.

After the regulation year ($t \geq 0$), there is a gradual shift in the trend of the Z-score in a positive direction. Starting from a moderate increase in the year of implementation (t+1), then continuing to increase around t+4, before a decline in t+5/ this pattern suggests that banking stability (Z-score) tends to increase gradually after the regulation is implemented, which means that banking risks decrease in the medium-long term. This tendency indicates that the negative effects of policies that occur at baseline regression, where the negative DiD coefficient is significant, are short-term and transitional. At the beginning of implementation, POJK 51/2017 regulation increased risks due to additional compliance costs and portfolio structure adjustments, then the risks gradually decreased after banks began to reap the benefits of stability by implementing sustainable finance principles.

These results illustrate the process of banks' strategic adaptation to the new regulation. In the early implementation phase (t-1 to t), financial institutions faced implementation costs, technology investment requirements, and challenges in integrating ESG aspects into their risk management frameworks, which disrupted banking stability in the short term (Celestin & Sujatha, 2024). Over time (t+1 to t+4), POJK 51/2017 regulations encourage improved governance structures, increased transparency, and more selective credit distribution to low-risk green sectors (T. Feng et al., 2023; Mirza, Afzal, et al., 2023). Sustainable finance integration regulations tend to reduce the likelihood of default and strengthen systemic stability after the initial transition phase.

Placebo Test. The placebo test was conducted to ensure that the results of the DiD model estimate truly reflect the causal effects of the implementation of the POJK 51/2017 regulation, not solely because of random factors or trends unrelated to the regulation. Methodologically, the placebo test evaluates the external validity and robustness of the main results. Referring to the approach used by Z. Zhang et al. (2025), the placebo test was conducted by randomly generating experimental groups or re-randomizing

treatment groups. In other words, the identities of banks considered to receive the regulation (treated banks) are randomized, while the DiD model estimation is still run using the same time structure. This process is repeated 500 times to distribute the estimated coefficients (placebo coefficients) empirically. A simulation distribution was obtained from the test results that described the distribution of the coefficient values of the placebo results, which were then compared with the absolute coefficient values of the main estimation results. A visualization of the results is shown in Figure 4.

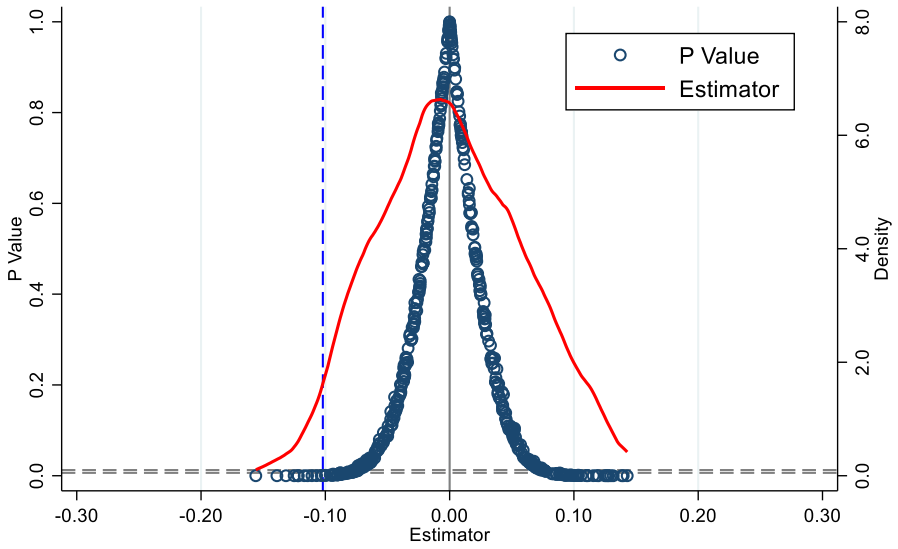

Figure 4. Placebo Test Results
Source: Data Processed – Stata17

Figure 4 of the placebo test results show that most of the estimated distribution of placebo test results (red curve) is concentrated around zero, while the actual coefficient value (marked by a dotted blue vertical line) is far to the left side of the distribution. This pattern suggests that the actual coefficient exceeds most random estimation results. In other words, the probability of the empirical results of this study appearing by chance (by chance) is very small. This shows that the effect of the implementation of POJK 51/2017 on banking risk is not the result of data randomization or random fluctuations, but a real and consistent causal effect. Most simulated P-values were also on the verge of 5% significance. This reinforces the evidence that estimates are statistically significant and cannot be explained by chance (random noise).

The results of this test show that the effects of sustainable financial regulation remain significant after placebo testing, thus reinforcing the belief that the DiD results truly reflect the impact of regulation implementation, not distortions due to external factors. These results provide confidence that the implementation of POJK 51/2017 has a real effect on banking risks in Indonesia. The fundamental changes in risk governance, green credit distribution, and risk management strategies resulting from POJK 51 have been shown to affect banking risk and are not merely statistical illusions.

Mechanism Test

To evaluate Hypotheses 2 and 3, which examine the transmission channels through which the implementation of POJK 51/2017 influences banking risk, two potential mechanisms are explored using the green credit ratio (GCR) and operational efficiency ratio (OER) variables.

Table 6 displays the results of testing the policy mechanism using a two-step difference-in-differences regression approach. Column (1) is the estimated direct impact of the implementation of POJK 51/2017 on bank risk. Columns (2) and (3) are the regression results for the mechanism variables, which describe the impact of the policy effect on two hypothesised mechanism variables, namely the green credit ratio and the operational efficiency ratio. Column (2) shows that the DID variable has a positive and significant effect on GCR ($\beta = 0.210$; $t = 6.932$). This indicates that POJK 51/2017 has successfully encouraged increased credit allocation to environmentally friendly sectors. Thus, this policy is effective in shifting the direction of bank credit portfolios towards the green sector, as

mandated in the OJK's Sustainable Finance Roadmap. So, hypothesis 2 is accepted. These results are in line with previous studies (Y. Feng et al., 2024; Zhou et al., 2022), which show that sustainability-based regulations can mobilize banking resources towards environmentally friendly activities, albeit with high short-term risk consequences.

Table 6. Mechanism Regression Results - Two-Step DID

VARIABLES	(1) Z-score	(2) GCR	(3) OCR
DID	-0.102***	0.210***	-0.010
	(-2.671)	(6.932)	(-0.310)
LDR	0.114**	-0.046	0.042
	(1.990)	(-1.014)	(0.886)
RGR	0.008*	0.001	-0.013***
	(1.902)	(0.209)	(-3.921)
DAR	-0.012*	0.009*	-0.095***
	(-1.746)	(1.689)	(-16.885)
LN_TL	-0.302***	-0.016	-0.041
	(-8.561)	(-0.576)	(-1.405)
EM	-0.020***	-0.004	0.003
	(-4.966)	(-1.415)	(1.014)
Constant	12.702***	0.584	2.227**
	(11.491)	(0.667)	(2.436)
Fixed time	Yes	Yes	Yes
Fixed Individual	Yes	Yes	Yes
Control variable	Yes	Yes	Yes
Observations	220	220	220
R-squared	0.617	0.592	0.686
Number of id	22	22	22

t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Data processed – Stata17

Column (3) in Table 6 shows that DID has no effect on the operational efficiency (OER) variable ($\beta = -0.010$; $t = 0.310$). This indicates that the implementation of POJK 51/2017 has not had a significant impact on bank operational efficiency. Therefore, Hypothesis 3 is rejected. The transition process towards sustainable finance requires high initial investment in human resource capacity development, green project monitoring systems, and sustainability reporting infrastructure. These short-term compliance costs can depress bank operational efficiency. Green transition costs tend to be non-linear and require a long period of institutional adaptation (G. Tian et al., 2023; Benitez et al., 2020).

Heterogeneity Test

We conducted additional Heterogeneity tests by dividing the sample based on bank size and ownership type based on Equation 1 to confirming Hypotheses 3 and 4. The results of this heterogeneity test not only enhance the robustness of the main findings of the DID but also provide an empirical basis for researchers to formulate differentiated policies tailored to the characteristics and capacities of each bank group.

Table 7 displays the results of the heterogeneity test for the impact of implementing POJK 51/2017 on banking risk, comparing large vs small banks, as well as state-owned vs private banks. We found that the impact of implementing POJK 51/2017 on banking risk is not homogeneous across bank groups but varies based on the internal capacity and characteristics of each bank. For comparisons based on bank size, the DID coefficient for large banks is -0.0527, but it is not statistically significant. In contrast, for small banks, it is significantly negative at the 1% level ($\beta = -0.244$; $p < 0.01$). These results indicating that the increase in risk resulting from the implementation of POJK 51/2017 is greater for smaller banks. Therefore, Hypothesis 4 is accepted. Small banks often have limitation of financial and

technical resources to adapt of sustainable finance regulatory standards, including a lack of capacity for green project risk assessment, inadequate historical data, and high compliance costs compared to their operational scale. Consequently, compliance pressures can increase risk.

Table 7. Heterogeneity Test Result

VARIABLES	Large Bank Z-score	Small Bank Z-score	State-Owned Bank Z-score	Private Bank Z-score
DID	-0.0527	-0.244***	-0.159***	-0.141***
	(0.0477)	(0.0782)	(0.0538)	(0.0478)
LDR	0.203	0.0953	0.131	0.129**
	(0.164)	(0.0790)	(0.243)	(0.0619)
RGR	0.00289	0.00859	0.0261***	0.0100**
	(0.00550)	(0.00675)	(0.00849)	(0.00452)
DAR	-0.198	-0.0262***	-0.394	-0.0140*
	(0.155)	(0.00923)	(0.565)	(0.00730)
LN_TL	-0.407***	-0.234***	-0.444*	-0.278***
	(0.0465)	(0.0630)	(0.226)	(0.0396)
EM			-0.0548***	-0.0165***
			(0.0142)	(0.00447)
Constant	16.35***	10.18***	18.61**	11.79***
	(1.538)	(1.945)	(7.846)	(1.234)
Fixed time	Yes	Yes	Yes	Yes
Fixed individual	Yes	Yes	Yes	Yes
Control Variable	Yes	Yes	Yes	Yes
Observations	110	110	40	180
R-squared	0.628	0.610	0.747	0.642
Number of id	11	11	4	18

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1
Source: Data Processed – Stata17

Regarding the ownership structure, the estimation results indicate a significant negative effect on both state-owned banks ($\beta = -0.159$, $p < 0.01$) and private banks ($\beta = -0.141$, $p < 0.01$). Therefore, we conclude that state-owned banks experienced a greater increase in risk after the implementation of POJK 51/2017. Therefore, Hypothesis 5 is accepted.

Discussion

The Impact of POJK 61/2017 Implementation on Bank Risk

A decrease in the Z-score indicates an increase in aggregate risk experienced by banks and may be linked to initial challenges in adopting sustainable finance policies. The objective of POJK 51/2017, which encourages an increase in credit portfolios for environmentally friendly projects, often has different risk characteristics than conventional sectors. Limitation of information to assess the feasibility of green projects with new technologies or sectors lacking long-term performance benchmarks, is a key source of increased risk in green credit extended by banks. This information gap can weaken the risk assessment and credit monitoring processes (T. Feng et al., 2023; Zhou et al., 2022). In such a situation, banks are encouraged to make financing decisions that are not fully information-based, so that aggregate risk increases in the initial phase of policy implementation.

Limited risk management capacity is also evident in the gap between regulatory demands and the readiness of risk management infrastructure in many banks. The compliance burden arising from the implementation of POJK 51/2017 has led some banks to prioritize meeting administrative requirements over strengthening their prudential foundations. This phenomenon has been identified in other countries, where regulatory pressures push banks to move quickly to adjust their portfolios even though supporting tools, such as risk information systems, are not yet fully in place (Galán & Tan, 2024)This finding aligns with agency theory predictions, which suggest that external pressures can shift

management's focus from risk-based decisions to regulatory compliance, despite the potential for short-term stability reduction.

The total national green portfolio in Indonesia is oriented toward the MSME sector, where MSMEs corresponding to the green portfolio, were approximately 69% of the total national green portfolio in 2024. MSMEs play a strategic role in sustainable development. However, this segment is subject to classic `problems such as lack of clear information, inadequate security (collateral), lack of managerial capacity, etc. which in asymmetry information theory, leads to an increased credit risk. Thus, this allocation structure may lead to an increased aggregate risk to be borne by the banks.

Analysis of control variables leads to the finding of important determinants of risk in banks. This leads to a dynamic understanding of bank risk. The LDR has a positive and significant effect ($\beta = 0.114$; $p < 0.05$) supporting the financial intermediation theory of the productiveness of funds transformation for the stability of the bank itself. However, the negative EM ($\beta = -0.0199$; $p < 0.01$) points to the degrees of vulnerability associate with excessive leverage. LN_TL, for example, has a strong negative effect ($\beta = -0.302$; $p < 0.01$), indicating feasibility, that a vigorous line of credit expansion without the management of this credit risk leads to increased bank vulnerability.

Overall, these results confirm that the initial phase of sustainability policy implementation carries its own unique risk dynamics. Integrating environmental principles into banking practices requires time for capacity building, procedural adjustments, and risk model refinement. This finding aligns with the literature on transition risks, which suggests that adjustments to a greener economy can create short-term pressures on financial stability when institutional systems are not yet fully ready (BIS, 2021; NGFS, 2019). Thus, the increased risks found do not constitute a rejection of the urgency of policy but reflect the natural characteristics of the transition process towards sustainable finance.

Green Credit Ratio and Operational Efficiency as Transmission Channels

The green credit ratio is the only significant transmission channel of the POJK 51/2017 policy towards increasing bank risk. This mechanism shows that the expansion of green financing, which is mainly allocated to the MSME sector and projects with a high-risk profile, is a significant source of increased risk exposure. On the other hand, operational efficiency does not act as a transmission channel, indicating that changes in the bank's risk profile do not act as a cost efficiency channel.

These results strengthen the arguments of information asymmetry theory and agency theory. These results reinforce arguments from information asymmetry theory and agency theory. From an information asymmetry perspective, green projects often have risk characteristics that are difficult to measure due to the lack of historical long term profitability data (Li et al., 2023; Stiglitz & Weiss, 1981). Furthermore, from the agency theory perspective, compliance with regulatory mandates can create isomorphic pressures for banks to prioritise green financing targets over optimising the risk struct portfolios (Galán & Tan, 2024). In such a situation, management's tendency to prioritize regulatory compliance over portfolio risk optimization is a form of divergence of interests that is in accordance with the agency theory framework.

The combination of information uncertainty and regulatory pressure explains why the green credit ratio emerged as a key transmission channel for increasing bank risk. The negative effects of POJK 51/2017 on bank risk in the early stages of implementation are more appropriately understood as part of an institutional transition phase towards a more sustainability-oriented financial system, rather than as an indication that the policy has failed to achieve its objectives.

Heterogeneous Effects across Bank Size and Ownership Structure

The results of the heterogeneity test indicate that the impact of POJK 51/2017 does not fall evenly across all bank groups. Differences in organizational capacity appear to be the main differentiator. Large banks demonstrated greater resilience to structural changes resulting from this regulation. Large banks generally have more mature risk management divisions, an integrated reporting infrastructure, and access to more stable long-term funding. This finding is in line with the international literature, such as that of W. Yin et al. (2021) dan X. Yin (2021), which emphasises that institutional capacity plays a critical role in determining the effectiveness of sustainable finance policy adoption. In other words,

implementing the same policy can result in different risk impacts depending on the bank's internal capacity to manage the change.

Although, the estimates show a negative relationship for both state-owned and private banks, the negative relationship is larger in magnitude for state-owned banks. Therefore, there is evidence that state-owned banks experienced a greater increase in risk than private banks subsequent to the issuance of POJK 51/2017. It is possible that the increased risk experienced by state owned banks can be attributed to the fact that state owned banks play two roles, they serve as policy agents and also attempt to meet various government environmental and developmental objectives. In doing so, they may sacrifice efficiency in their short-term credit portfolio to achieve the government's objectives, thereby, increasing risk. On the other hand, private banks with a stronger commercial focus tend to be more discerning when it comes to issuing green credit. Therefore, the risk associated with the issuance of green credit is less severe (W. Yin et al. 2021).

Significant heterogeneity was found across bank type regarding the effects of the POJK 51/2017 regulation. As such, it was found that small and state-owned bank experience greater increases in risk relative to large and private banks. The statistically significant DID coefficients at the 1 percent level for small banks (-0.234) and state-owned bank (-0.159) provide support for the notion that these two groups of banks were more adversely affected by the implementation of the POJK 51/2017 regulation.

The evidence from this study suggests that small and state-owned banks record the largest decline in Z-scores, which provides a theoretical explanation for this outcome. From the information asymmetry theory, the difference in the ability of banks to collect and analyse information about green projects creates uneven levels of risk among banks. Specifically, the limited resources available to smaller banks reduce their capacity to collect and analyse information about green projects, thus creating an uneven level of risk. Alternatively, from an agency theory perspective, political and institutional pressures placed on state-owned banks can lead to an imbalance in the achievement of social goals versus the maintenance of short-term financial stability. Thus, the risk experienced by state-owned banks grows rapidly when sustainability regulations are enacted. Therefore, the heterogeneity of responses to the enactment of sustainability regulations suggests that sustainability regulation need not elicit a homogeneous response. The organizational structure, risk assessment capacity, and institutional mandate of each bank shape different adjustment trajectories, so policy implications need to take this diversity into account.

Managerial Implication

The increase in banking risks that occurred after the implementation of POJK 51/2017 indicates that sustainability aspects have not been fully integrated into banks' strategic risk management systems. Most banks still view green financing as a compliance-driven rather than a risk-adjusted sustainable strategy. Top management needs to internalise the principles of sustainability risk governance by placing sustainability risk as a core element in enterprise risk management, on par with credit, market, and liquidity risks. The board of commissioners and directors must also ensure the existence of a dedicated unit or sustainability risk committee mandated to evaluate the impact of green policies on bank stability, rather than simply reporting administrative compliance to regulators.

The finding that the green credit ratio is a key transmission channel for bank risk requires fundamental changes in how banks manage their green portfolios. Banks need to shift from a quantitative target approach to risk-based allocation, where green credit expansion must consider the risk profiles of projects and sectors. Banks also need to develop an internal Green Credit Risk Model that incorporates ESG factors and climate transition risks into credit scoring and loan pricing. Such a model has been recommended by the Financial Services Authority in the CRST Banking Guidance and aligns with the Basel III approach to climate-related stress testing. In this way, green financing decisions are based on risk data, not solely on regulatory pressure.

Additional analysis of both groups shows that increased risk is more pronounced in small-scale banks and state-owned banks. Variations in internal capacity and institutional pressures faced by each bank group result in different risk impacts. Small banks tend to have limited risk assessment capabilities and still rely on MSME financing portfolios as their primary source of revenue. State-owned banks under the control of the Indonesian government tend to be focused and committed to supporting strategic government projects, although these projects are not always accompanied by commensurate

risk compensation. Both situations create pressure on banking stability, especially in the context of the implementation of mandatory sustainable finance policies.

As these conditions demonstrate, different management measures are required for each bank group. The small banks could make themselves resilient to risks by establishing cooperation with other institution to combat risks, in which case the forms of collaboration, such as green credit syndication or risk sharing facilities, might assist in the reduction of costs in project monitoring and its extension to green financing throughout. The collaboration of banks would also increase the credibility of projects financed through banks, especially in the MSME category, which has traditionally been regarded as high risk. Furthermore, the state-owned banks could also strengthen the risk-based performance appraisal. By the introduction of a risk adjusted performance criteria, the banks will be able to maintain a balance between their social function as agents of development and their need to operate in a safe manner.

According to the Financial Services Authority data, some 69% of the national green financing is taken up by the MSME sector, which is a figure much more than what is the practice in the other countries. This percentage indicates the higher risks involved in small banks and the state-owned enterprise. Conceptually though, the MSME financing gives rise to a shift in the policy from an environmental transition to a social inclusion agenda. This shift would have consequences to the risk structure in the way of increased widening of information gap and possible credit default. The modalities of assessment of the low carbon development projects are to be treated differently from the MSME projects as they are different in characteristics in the nature of risks posed by the projects. This different approach would permit banks to better manage their green projects portfolios without lowering their contribution levels to the MSME sector. The rationale behind this is not to decrease the levels of inclusivity, but to ensure that the expansion of green credits does not increase risk concentration in volatile sectors.

The findings of this study do not indicate weaknesses in the Financial Service Authority policy framework but rather point to the need to strengthen the internalization phase at the banking level. In recent years, the Financial Services Authority has launched several important initiatives, such as the Indonesian Green Taxonomy for Sustainable Finance, the Sustainable Finance Roadmap, and the Climate Risk Stress Testing Guidelines for Banking, which align with international standards such as the TCFD and NGFS. The supervisory approach taken by the OJK has been seen as focusing solely on the growth of green credit volume rather than on the quality and risk profile of bank loans. The Financial Services Authority can apply stress tests to green financing exposures at small banks and state-owned banks to ensure the banking system's resilience to potential future climate transition risks.

CONCLUSION

This research empirically answers three main research questions. First, it seeks to establish the extent to which the implementation of POJK 51/2017 concerning Sustainable Finance affects banking risk in Indonesia. Second, this study attempts to see how the green credit ratio and operational efficiency act as a mechanism linking the policy to changes in bank risk levels. Third, it identifies differences in the policy's impact across different bank groups based on size and ownership structure. Difference-in-differences estimation results indicate that the implementation of POJK 51/2017 has a strong impact on increasing bank risk, as reflected in the decline in the Z-scores of banks implementing this regulation. The mechanism analysis demonstrates that only the green credit ratio acts as a significant transmission channel for increased risk, while operational efficiency has not yet demonstrated a role as a transmission channel. Heterogeneity tests confirm that the policy's impact is greater for small and state-owned banks compared to large and private banks. These findings illustrate that the initial phase of sustainable finance policy implementation in Indonesia is still characterized by transitional risks arising from the institutional adjustment process.

The relevance of agency theory and information asymmetry theory in understanding the relationship between sustainable financial policies and banking risk profiles is a finding and contribution to theoretical development. The provisions in POJK 51/2017, which encourage banks to

integrate sustainability principles into their business strategies, have created new dynamics in managerial behaviour. Pressure to comply with these policies is often not matched by the readiness of risk assessment infrastructure and the availability of adequate data. This condition widens the information gap between banks and green project borrowers, which in turn can give rise to the potential for moral hazard and adverse selection. The finding that the green credit ratio is a significant mechanism in increasing risk supports the argument that the process of adapting to environmental policies has consequences for financial stability, mainly when the credit composition is dominated by the MSME segment, which has a higher level of information asymmetry. Thus, this study contributes to enriching bank risk management theory in the context of the transition to sustainable finance in developing countries.

This study has several limitations that could provide directions for further research. First, the measurement of bank risk uses a conventional Z-score indicator, which does not fully capture risks stemming from environmental and climate factors. Further research is recommended to develop climate-related financial risk modelling or climate-data-based stress testing approaches to assess the link between green portfolio exposure and banking risk. Second, the research data coverage is still limited to the initial implementation period of POJK 51/2017, thus not being able to describe the long-term dynamics of this policy integration on banking risk in Indonesia. Therefore, future research can extend the observation period and use a more dynamic approach, such as Three-Stage Least Squares, to test the simultaneous impact of sustainable finance policies, green credit expansion, and bank risk more comprehensively.

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Authors' Information

Ahmad Sutanto (AS) is a Master of Science in Management student at IPB University, with a research focus on sustainable finance, bank risk, and banking stability. He has experience in empirical banking research using panel data and econometric methods. Email: ahmadsutanto@apps.ipb.ac.id

Wita Juwita Ermawati (WJE) is a lecturer at the Department of Management, Faculty of Economics and Management, IPB University. She holds a doctoral degree in Financial Management from Universitas Gadjah Mada. Her research interests include corporate finance, bank performance and risk analysis, and corporate governance. Email: witaman@apps.ipb.ac.id

Lukytawati Anggraeni (LA) is a lecturer in Department of Economics, Faculty of Economics and Management, IPB University. She holds a doctoral degree in Development Economics from the University of Tokyo. Her research interests include financial inclusion, microfinance, climate change mitigation and sustainable finance. Email: lukytawati@apps.ipb.ac.id

Authors' Contribution

AS analysed and interpreted the data and drafted the manuscript. WJE contributed to the conceptualisation and research design. LA was responsible for methodology design and econometric modelling.

Conflict of Interest

The authors declare no competing interests.

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Availability of Data and Materials

The data used in this study are publicly available and were obtained from official publications of the Financial Services Authority (OJK) and annual reports of commercial banks.

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