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Climate Change and Monetary Policy in Indonesia: Evidence from Asymmetric Time Varying Granger Causality

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ABSTRACT

This study examines the asymmetric time-varying climate change shocks on monetary policy in Indonesia over the period January 1990 to March 2025. Performing a recent novel asymmetric time-varying Granger causality (AS-TVGC) technique, we capture the asymmetric climate change leading to monetary policy proxied by M0, M1, M2, and BI policy rate significantly. Empirical findings reveal that date stamping of climate change to monetary policy from TVGC estimations. In addition, the AS-TVGC profoundly exposes how the monetary policy responds to both positive and negative climate change shocks significantly. Specifically, we reveal that the monetary policy responds variously to climate change-positive, but persistently to climate change-negative. Consequently, in addition to addressing the exposure of asymmetric causal climate change to monetary policy, the central bank policy makers should take the mandate to design new climate-based monetary operations to set price stability and sustainable growth in the net-zero central banking framework.

Keywords: Climate Change, Monetary Policy, Asymmetric Time-Varying Granger Causality
JEL Classifications: C22, C58, G17, Q54

1. INTRODUCTION

Earth is getting warmer at an augmented pace. The WMO (2025) and NOAA (2025) reports of the global temperatures in the last decade spotlight the determination of climate change. Climate change is non-negotiable (Nordhaus, 2007) and has a wide and severe impact on the stability of the economy (Nordhaus, 2019) and the financial system (Dafermos et al., 2018; Monasterolo, 2020; Zhou et al., 2023). Therefore, climate change stances as a crucial challenge for researchers and policymakers in designing economic and financial policy. Dafermos et al. (2018) argued that climate change has a direct impact on real economic activities, thereby distracting financial systems and prompting financial disruptions. With numerous events of extreme weather and its wide escalation damage, climate change risks cannot be mistreated (Nordhaus, 2019). In this context, not only is Indonesia known as an emerging market, but it is also the largest archipelagic state (Khaliq et al., 2025), making it highly vulnerable to climate change risks. Thus, climate change constitutes a weighty threat to the stability of the Indonesian economy and financial system, requiring coordinated economic and financial policies and actions. The critical question is how monetary policy responds to climate change in order to mitigate the consequences of climate change on the economy and the financial system.

Monetary policy is considered one of the most essential tools to stabilize the economy and financial system, caused to climate change risks (Boneva et al., 2022; Quorning, 2024; Song and Fang, 2024). Investigating the thought of climate change consequences on economic and financial systems brings enlightened direction for climate-based monetary policy architectures (Hansen, 2022) and a climate-neutral economy (McConnell et al., 2022). Intensive literatures show that recent central bank views worldwide have incorporated climate change into new monetary policy, called climate-based monetary policy (DiLeo et al., 2023). Vyshnevskyi and Sohn (2025) discuss a comprehensive review of the literature that discusses how central banks act in response to climate action. However, there is no consensus on how central bank responses (Jabko and Kupzok, 2024), principally concerning monetary policy (Boneva et al., 2022). Furthermore, regarding Indonesia, to the best of our knowledge, there is no published study investigating climate-based monetary policy yet. Therefore, it is quite a challenge to fill this research gap.

In this study, we deliver empirical confirmation on the causality of climate change and monetary policy responses by identifying specific time-varying and asymmetric shocks. We use temperature to signify climate change. In empirical exploration, to capture the date-stamping Granger causality of climate change to monetary policy, we engage time-varying Granger causality (TVGC) (Shi et al., 2020). We utilize asymmetric time-varying Granger causality (AS-TVGC) to pinpoint the asymmetric shocks of climate change to monetary policy (Chen and Xiao, 2025). To holistically discuss monetary policy responses, we pay attention to $M0$ referred to as the monetary base, $M1$ stated to as narrow money, $M2$ denoted to as store value, and Bank Indonesia's policy rate (*BI*). Thus, our objective is to highlight a nuanced portrayal of the economic inferences of climate change in Indonesia.

Our study contributes to the literature on how monetary policy responds to climate change in two main strands. First, we investigate the dynamic Bank Indonesia policy reactions to climate change. Our study is the first to capture the date stamping of Bank Indonesia's monetary policy in response to climate change. Hence, we retain the recursive evolving Granger causality test suggested by Shi et al. (2020). Second, we postulate a deep analysis of the asymmetric consequence of climate change on monetary policy by introducing a novel AS-TVGC test developed by Hong et al. (2022) and Chen and Xiao (2025). Almost sure. We are also the first to investigate the asymmetric impact of climate change on Bank Indonesia's monetary policy. The AS-TVGC technique allows us to discover the asymmetric configuration of climate change and its transmission process to Bank Indonesia monetary policy instruments, contributory to a few new empirical studies in the field of green monetary economics applying the AS-TVGC method (Chen and Xiao, 2025).

The remainder of the paper is set up as follows. Section 2 highlights interrelated empirical literature, while Section 3 builds research methods and data. Empirical results and discussion are presented in Part 4. Section 6 concludes the research and proposes some policy suggestions.

2. LITERATURE REVIEW

The threat of climate change has attracted the attention of the academic community (Vyshnevskyi and Sohn, 2025). Research academics have rapidly explored the various responses of central bank policy to climate change over the last decade. Two strands of debate relate to the study of climate change and monetary policy. First, questioning whether climate change is a monetary phenomenon, and respecting climate-related monetary policy as complementary. Second, proposing climate-related monetary policy acts as a new integral instrument of monetary policy, acting as an objective function of the central bank.

Concerning the first strand, several studies spotlight why the central bank should incorporate climate change as an element of the monetary policy mandate (Dikau and Volz, 2021; NFGS, 2022; 2024). Dikau and Volz (2021) argue that the monetary policy performs an essential role in addressing climate-related risks to prevent economic and financial instability. NFGS (2024) states that monetary policy should be involved in tackling climate change risks due to its impacts on prices and financial stability. Qi et al., (2025) show climate change affects inflation through the central bank's interest rate. Furthermore, Thiemann et al. (2023) discuss how climate change could impact the central bank's balance sheet and reserve requirement. Not only adopting climate change into monetary policy as a complementary policy, but also important to set up appropriate monetary instruments related to climate change (Baranzini et al., 2017; Boneva et al., 2022; Song and Fang, 2024), Benmir and Roman (2020) and Chan (2020) argue that monetary policy is viewed as a proper tool to deliver climate-related risks. Shobande (2022) explore that monetary policy could help tranquil the transition to a low-carbon economy through credit and interest rate channels.

Connecting with the second strand, although there is no compromise on whether the central bank should take a mandate related to climate change, the central bank in advanced economies has been involved in a limited mandate, and emerging economies have an extensive mandate to engage in climate change risks and support sustainable growth (Dikau and Volz, 2021). Böser and Colesanti Senni (2020) and Boneva et al. (2022) insinuate that climate change into monetary policy by initiating green financial instruments to mitigate climate change risks. Jackson et al. (2024) recommend a new initiative of the central bank to net-zero central banking. The net-zero central banking leads to a green monetary policy (Rosa, 2025). The central bank could initiate the instrument of green monetary policy through collateral haircuts (McConnell et al., 2022), digital currency and green bonds issued (Xin et al., 2024), green asset purchase and lending operations (Boneva et al., 2022).

However, publications on the impacts of climate change on monetary policy are presently reasonably rare. Climate change impacts the central bank's capacity to predict inflation, which leads to ineffective monetary policy (McKibbin et al., 2020). Song and Fang (2024) show that monetary policy regimes depend on climate change shocks. The monetary policy is less effective when the climate change effect is broad and severe. Climate change swiftness affects the central bank's monetary policy, called "climate swift" (Quorning, 2024). A major in previous studies concerns the central bank in advanced economies; hence, there is little research on studies of climate change and monetary policy in emerging markets, nor have any studies analysed the central bank of Indonesia's monetary policy reactions to climate change. To fill this gap, we expect to detect date-stamping monetary policy responses to climate change shocks using asymmetric time-varying Granger causality (AS-TVGC) techniques.

3. RESEARCH METHOD AND DATA

3.1. Research Method

We capture the asymmetric dynamic influence of climate change on monetary policy; hence, we employ the AS-TVGC approach following Hong et al. (2022) and Chen and Xiao (2025), which modifies the novel TVGC test proposed by Shi et al. (2020). In this study, climate change is proxied by physical temperature (T_t) and monetary policy is signified by money supply (MS_t: $M0_t$, $M1_t$, $M2_t$) and Bank Indonesia policy rate (BI_t). We suppose that T_t, MS_t, and BI_t are random walks minus drift.

$$\mathcal{T}_t = \mathcal{T}_{t-1} + \varepsilon_{1t} = \mathcal{T}_0 + \sum_{i=1}^{t} \varepsilon_{1i} \quad (1)$$

$$MS_t = MS_{t-1} + \varepsilon_{2t} = MS_0 + \sum_{i=1}^{t} \varepsilon_{2i} \quad (2)$$

$$BI_t = BI_{t-1} + \varepsilon_{3t} = BI_0 + \sum_{i=1}^{t} \varepsilon_{3i} \quad (3)$$

Where $t = 1,2,\ldots,T$. T_0, MS_0, and BI_0 represent the initial conditions of T_t, MS_t, and BI_t, respectively. ε_{1i}~NID(0,1), ε_{2i}~NID(0,1), and ε_{3i}~NID(0,1)

Next, to have the positive and negative shocks of T_t, MS_t, and BI_t, we propose

$$\varepsilon_{1i}^{+} = max\left(\varepsilon_{1i}, 0\right), \varepsilon_{1i}^{-} = min\left(\varepsilon_{1i}, 0\right) \quad (4)$$

$$\varepsilon_{2i}^{+} = max\left(\varepsilon_{2i}, 0\right), \varepsilon_{2i}^{-} = min\left(\varepsilon_{2i}, 0\right) \quad (5)$$

$$\varepsilon_{3i}^{+} = max\left(\varepsilon_{3i}, 0\right), \varepsilon_{3i}^{-} = min\left(\varepsilon_{3i}, 0\right) \quad (6)$$

This means that $\varepsilon_{1i} = \varepsilon_{1i}^{+} + \varepsilon_{1i}^{-}$, $\varepsilon_{2i} = \varepsilon_{2i}^{+} + \varepsilon_{2i}^{-}$, and $\varepsilon_{3i} = \varepsilon_{3i}^{+} + \varepsilon_{3i}^{-}$. Thus, we define

$$\mathcal{T}_t = \mathcal{T}_{t-1} + \varepsilon_{1t} = \mathcal{T}_0 + \sum_{i=1}^{t} \varepsilon_{1i}^{+} + \sum_{i=1}^{t} \varepsilon_{1i}^{-} \quad (7)$$

$$MS_t = MS_{t-1} + \varepsilon_{2t} = MS_0 + \sum_{i=1}^{t} \varepsilon_{2i}^{+} + \sum_{i=1}^{t} \varepsilon_{2i}^{1} \quad (8)$$

$$BI_t = BI_{t-1} + \varepsilon_{3t} = BI_0 + \sum_{i=1}^{t} \varepsilon_{3i}^{+} + \sum_{i=1}^{t} \varepsilon_{3i}^{-} \quad (9)$$

For simplicity, we suppose that the positive and negative shocks to climate change and monetary policy are designated by $\mathcal{T}^{+} = \sum_{i=1}^{t} \varepsilon_{1i}^{+}$, $\mathcal{T}^{-} = \sum_{i=1}^{t} \varepsilon_{1i}^{-}$, $MS^{+} = \sum_{i=1}^{t} \varepsilon_{2i}^{+}$, $MS^{-} = \sum_{i=1}^{t} \varepsilon_{2i}^{-}$, and $BI^{+} = \sum_{i=1}^{t} \varepsilon_{3i}^{+}$, $BI^{-} = \sum_{i=1}^{t} \varepsilon_{3i}^{-}$. Then, by this definition, we implement asymmetric investigations. For example, we design a bivariate lag-augmented vector-autoregression (VAR) technique for climate change and money supply (T^{+}, MS^{+}) as follows

$$\mathcal{T}_t^{+} = \alpha_{10} + \alpha_{11} t + \sum_{i=1}^{k+d} \beta_{1i} \mathcal{T}_{t-1}^{+} + \sum_{i=1}^{k+d} \delta_{1i} MS_{t-1}^{+} + u_{1t} \quad (10)$$

$$MS_t^{+} = \alpha_{20} + \alpha_{21} t + \sum_{i=1}^{k+d} \beta_{2i} MS_{t-1}^{+} + \sum_{i=1}^{k+d} \delta_{2i} \mathcal{T}_{t-1}^{+} + u_{1t} \quad (11)$$

With the same idea, we also could set a bivariate lag-augmented vector-autoregression (VAR) technique for climate change and Bank Indonesia policy rate (T^{+}, BI^{+}) as follows

$$\mathcal{T}_t^{+} = \alpha_{10} + \alpha_{11} t + \sum_{i=1}^{k+d} \beta_{1i} \mathcal{T}_{t-1}^{+} + \sum_{i=1}^{k+d} \delta_{1i} BI_{t-1}^{+} + u_{1t} \quad (12)$$

$$BI_t^{+} = \alpha_{20} + \alpha_{21} t + \sum_{i=1}^{k+d} \beta_{2i} BI_{t-1}^{+} + \sum_{i=1}^{k+d} \delta_{2i} \mathcal{T}_{t-1}^{+} + u_{1t} \quad (13)$$

Where k stands for the optimal lag and u_t defines the error term. d represents the cointegration in VAR. The estimation model can be reworded as

$$Z^{+} = \tau\Gamma' + X^{+}\Phi_{as}' + Y^{+}\Psi_{as}' + \varepsilon_i \quad (14)$$

In this context, the null hypothesis is

$$H_0: Rv(\Phi_{as}) = 0 \quad (15)$$

Where $v(\cdot)$ signifies the row vectorization. Hence, the null hypothesis will be reject if $\mathcal{T}_t^{+}$ Granger causes MS_t^{+} or if $\mathcal{T}_t^{+}$ Granger causes BI_t^{+}. The null hypothesis will be calculated by means of the Wald test following the recursive evolving windows process as suggested by Shi et al. (2020). In this process, the Wald test over $[f_1, f_2]$ with a sample size segment of $f_w = f_2 - f_1 \geq f_0$ is noticed by $Wf_2(f_1)$ and the sup-Wald statistic is stated as below

$$SW_f\left(f_0\right) = \frac{sup}{\left(f_1, f_2\right) \in \hat{0}, f_2 = f} \left\{ w_{f_2}\left(f_1\right) \right\} \quad (16)$$

Were $\hat{0} = \left\{ \left(f_1, f_2\right) : 0 < f_0 + f_1 \leq f_2 \leq 1, \text{and } 0 \leq f_1 \leq 1 - f_0 \right\}$

In this setting, it is thinkable to define $\hat{f}_e$ and $\hat{f}_f$ as below

$$\hat{f}_e = \frac{inf}{f_e\left[f_0, 1\right]} \left\{ f : SW_f\left(f_0\right) > scv \right\} \text{ and}$$

$$\hat{f}_f = \frac{inf}{f_e\left[\hat{f}_e, 1\right]} \left\{ f : SW_f\left(f_0\right) > scv \right\} \quad (17)$$

Thus, we examine the probable connection between climate change and monetary policy. In the case of AS-TVGC, we investigate sixteen combinations: $\left(\mathcal{T}_t^{+}, M0_t^{+}\right)$, $\left(\mathcal{T}_t^{+}, M0_t^{-}\right)$, $\left(\mathcal{T}_t^{-}, M0_t^{+}\right)$, $\left(\mathcal{T}_t^{-}, M0_t^{-}\right)$, $\left(\mathcal{T}_t^{+}, M1_t^{+}\right)$, $\left(\mathcal{T}_t^{+}, M1_t^{-}\right)$, $\left(\mathcal{T}_t^{-}, M1_t^{+}\right)$, $\left(\mathcal{T}_t^{-}, M1_t^{-}\right)$, $\left(\mathcal{T}_t^{+}, M2_t^{+}\right)$, $\left(\mathcal{T}_t^{+}, M2_t^{-}\right)$, $\left(\mathcal{T}_t^{-}, M2_t^{+}\right)$, $\left(\mathcal{T}_t^{-}, M2_t^{-}\right)$, $\left(\mathcal{T}_t^{+}, BI_t^{+}\right)$, $\left(\mathcal{T}_t^{+}, BI_t^{-}\right)$, $\left(\mathcal{T}_t^{-}, BI_t^{+}\right)$, and $\left(\mathcal{T}_t^{-}, BI_t^{-}\right)$. To evaluate the bivariate and time-varying Granger causality between climate change and monetary policy, we utilized the TVGC module developed by Otero et al. (2024).

3.2. Data

The sample period starts from January 1990 to March 2025, a total of 423 monthly observations. Like the study of Chen and Xiao (2025), we complement by taking into account the bank's central policy rate. Hence, we use monthly temperature (*T*) and monetary policy proxied by money supply (*M*0, *M*1, *M*2), and Bank Indonesia policy rate represented by interest rate (*BI*). The money supply and BI policy rate are commonly used instruments constructed by Bank Indonesia as a part of the monetary policy in responding to inflation. The money supply and interest rate are available publicly from www.bi.go.id, and the temperature data is accessible from https://ourworldindata.org/. All variables except the Bank Indonesia policy rate are transformed to the natural logarithm (for more lists, Table 1). Table 1 shows the descriptive statistics, which vindicate the employing data-driven techniques, including the TVGC method. Thus, Baum et al. (2025) argue that the TVGC demands acquaintance with integration order, the unit root test, and the linearity test. Tables 2-5 present unit root tests and linearity tests, respectively. The unit root tests serve to implement the TVGC approach, and the linearity tests extend to conduct the AS-TVGC methods. To find the number of optimal lags, we set $m_{max} = int\{12(423/100)^{0.25}\} = 17$.

According to cointegration tests, we conclude that the integration order is at least one and at most 2, which is d = 1,2. In our study purposes, we set d = 2. The optimal lag number (p) for the TVGC is $(T_t, M0_t) = p(5)$, $(T_t, M1_t) = p(8)$, $(T_t, M2t) = p(2)$, and $(T_t, BI_t) = p(8)$. Furthermore, the selected optimal lag number (p) for each combination of the AS-TVGC testing is

Table 1: Descriptive statistics

Statistic	*T*	*M0*	*M1*	*M2*	*BI*
Mean	3.226	12.232	12.651	14.067	10.790
Min	3.183	7.253	9.845	10.980	3.433
Max	3.276	14.389	14.860	16.060	69.605
Standard deviation	0.018	1.609	1.468	1.439	8.799
Pr (skewness)	0.079	0.000	0.019	0.000	0.000
Pr (kurtosis)	0.255	0.000	0.000	0.000	0.000
Jarque-Bera	4.279 (0.118)	34.520*** (0.000)	28.030*** (0.000)	29.670*** (0.000)	7089.000*** (0.000)
Observation	423	423	423	423	423

The number in bracket is *P* value. ***,**,* present significant at 1%, 5%, and 10% level
Source: Authors' calculation

Table 2: Standard unit root test results

Variables	Augmented Dickey Fuller		Phillip-Perron		Kwatkowski-Phillips-Schmidt-Shin	
	Level	First difference	Level	First difference	Level	First difference
T						
None	0.437	−5.711***	1.098	−46.700***		
Intercept	−2.622*	−5.719***	−6.762***	−48.169***	2.198***	0.097
Trend and intercept	−6.041***	−5.705***	−9.773***	−48.080***	0.055	0.077
*M*0						
None	4.112	−18.121***	3.781	−41.238***		
Intercept	−1.839	−15.895***	−1.504	−60.932***	2.508***	0.330
Trend and intercept	−1.070	−14.234***	−4.305***	−84.192***	0.574***	0.167**
*M*1						
None	4.036	−2.429**	8.884	−22.366***		
Intercept	−2.157	−5.246***	−3.566***	−27.223***	2.561***	0.607
Trend and intercept	−0.888	−5.657***	−1.484	−30.249***	0.591***	0.060
*M*2						
None	2.838	−2.400**	8.306	−20.404***		
Intercept	−4.846***	−4.035***	−5.001***	−20.755***	2.516***	1.409***
Trend and intercept	−1.830	−21.414***	−1.834	−21.401***	0.524***	0.096
BI						
None	−2.770***	−5.666***	−2.121**	−10.507***		
Intercept	−4.485***	−5.662***	−3.210**	−10.492***	1.164***	0.020
Trend and intercept	−5.692***	−5.654***	−3.907**	−10.480***	0.085	0.019

***,**,* present significant at 1%, 5%, and 10% level
Source: Authors' calculation

Table 3: ADFmax unit roots test results

Variables	FIXED		AIC		SIC		GTS05		GTS10	
	Statistics	P-value	Statistics	P-value	Statistics	P-value	Statistics	P-value	Statistics	P-value
Levels										
T	−2.022	0.114	−2.765	0.026	−2.765	0.021	−2.765	0.028	−2.765	0.029
*M*0	1.509	0.997	1.304	0.996	1.173	0.995	1.173	0.994	1.770	0.999
*M*1	2.417	1.000	2.417	1.000	1.863	0.999	2.417	1.000	2.417	1.000
*M*2	2.921	1.000	2.921	1.000	4.302	1.000	2.921	1.000	2.921	1.000
BI	−2.656	0.026	−2.824	0.023	−4.457	0.000	−2.808	0.025	−2.808	0.026
First−difference										
T	−6.489	0.000	−6.489	0.000	−5.646	0.000	−5.646	0.000	−6.489	0.000
*M*0	−5.031	0.000	−13.893	0.000	−15.614	0.000	−13.893	0.000	−13.893	0.000
*M*1	−5.011	0.000	−5.126	0.000	−5.126	0.000	−5.224	0.000	−5.224	0.000
*M*2	−2.758	0.019	−2.944	0.017	−3.145	0.007	−2.944	0.018	−2.944	0.019
BI	−6.283	0.000	−7.462	0.000	−5.504	0.000	−7.462	0.000	−5.977	0.000

Source: Authors' calculation

Table 4: Zivot-Andrews structural unit root test results

Series	Constant		Trend		Constant and trend	
	Min t-statistics	Break	Min t-statistics	Break	Min t-statistics	Break
T						
Level	−5.369***	1998m11	−5.185***	1997m6	−5.918***	1998m10
Difference	−21.931***	1998m6	−21.803***	1995m8	−22.105***	1998m6
*M*0						
Level	−3.502	1997m12	−3.836	2007m10	−3.907	1997m12
Difference	−14.291***	1995m12	−14.330***	1996m3	−14.522***	1998m8
*M*1						
Level	−4.440	1997m11	−4.000	2007m7	−4.937*	1997m12
Difference	−12.645***	2008m1	−12.694***	1995m9	−13.415***	1998m7
*M*2						
Level	−3.595	1995m6	−3.248	1998m2	−4.802	1997m12
Difference	−9.339***	1998m8	−8.536***	2003m3	−10.220***	1998m8
BI						
Level	−4.753*	1997m8	−4.516**	1998m4	−5.777***	1999m4
Difference	−10.360***	1998m8	−9.592***	2019m12	−11.087***	1998m8

***, **, and * denote significant level at 1%, 5%, and 10%.

Source: Authors' calculation

Table 5: Brock-Dechert-Scheinkman-LeBaron (BDS) test results

Dimension	BDS statistic	Standard error	z-statistic	Prob.	Raw Epsilon	Pairs with Epsilon	Triples with Epsilon
T							
2	0.095048	0.002946	32.26115	0.0000			
3	0.144779	0.004666	31.03115	0.0000			
4	0.166691	0.005534	30.12096	0.0000	0.026095	125801.0	39703841
5	0.173128	0.005744	30.13809	0.0000		V-statistic	V-statistic
6	0.177622	0.005517	32.19790	0.0000		0.703078	0.524580
*M*0							
2	0.202174	0.002513	80.45741	0.0000			
3	0.344138	0.003984	86.38940	0.0000			
4	0.443402	0.004729	93.75263	0.0000	2.482622	126051.0	39515777
5	0.512556	0.004914	104.3133	0.0000		V-statistic	V-statistic
6	0.560767	0.004723	118.7409	0.0000		0.704475	0.522095
*M*1							
2	0.204456	0.002131	95.94860	0.0000			
3	0.348677	0.003378	103.2178	0.0000			
4	0.450315	0.004010	112.2957	0.0000	2.303153	126149.0	39277301
5	0.522036	0.004165	125.3259	0.0000		V-statistic	V-statistic
6	0.572818	0.004003	143.1097	0.0000			
*M*2							
2	0.207683	0.002561	81.10122	0.0000			
3	0.353203	0.004045	87.32283	0.0000			
4	0.455328	0.004785	95.16266	0.0000	2.303153	126149.0	39277301
5	0.527167	0.004953	106.4341	0.0000		V-statistic	V-statistic
6	0.577906	0.004743	121.8380	0.0000		0.705023	0.518944
BI							
2	0.190879	0.004411	43.27304	0.0000			
3	0.321629	0.007030	45.75060	0.0000			
4	0.409624	0.008396	48.78844	0.0000	7.705627	126235.0	41101213
5	0.467578	0.008777	53.27364	0.0000		V-statistic	V-statistic
6	0.504552	0.008490	59.43168	0.0000		0.705503	0.543042

Source: Authors' estimation

$\left(\mathcal{T}_t^+, M0_t^+\right) = p(5)$, $\left(\mathcal{T}_t^+, M0_t^-\right) = p(5)$, $\left(\mathcal{T}_t^-, M0_t^+\right) = p(1)$, $\left(\mathcal{T}_t^-, M0_t^-\right) = p(1)$, $\left(\mathcal{T}_t^+, M1_t^+\right) = p(5)$, $\left(\mathcal{T}_t^+, M1_t^-\right) = p(5)$, $\left(\mathcal{T}_t^-, M1_t^+\right) = p(8)$, $\left(\mathcal{T}_t^-, M1_t^-\right) = p(8)$, $\left(\mathcal{T}_t^+, M2_t^+\right) = p(7)$, $\left(\mathcal{T}_t^+, M2_t^-\right) = p(5)$, $\left(\mathcal{T}_t^-, M2_t^+\right) = p(8)$, $\left(\mathcal{T}_t^-, M2_t^-\right) = p(8)$, $\left(\mathcal{T}_t^+, BI_t^+\right) = p(7)$, $\left(\mathcal{T}_t^+, BI_t^-\right) = p(5)$, $\left(\mathcal{T}_t^-, BI_t^+\right) = p(8)$, and $\left(\mathcal{T}_t^-, BI_t^-\right) = p(8)$. The cointegration and selected optimal lag are used in the TVGC and AS-TVGC estimations. The detailed results of cointegration tests and optimal lags are available upon request.

4. RESULTS AND DISCUSSION

4.1. Empirical Results of Time-Varying Granger Causality

Table 6 exhibits the results of the causal influence of climate change on different instruments of monetary policy. Predictably, we emphasize the existence of the Granger causality effect at 5% significance level based on the recursive evolution window process following Phillips et al. (2015) to reach the best results (Shi et al., 2020). We refuse the null hypothesis of no Granger causality between climate change and monetary policy. In other words, the study detects that climate change has a statistically meaningful Granger causality effect on money supply (M0, M1, and M2), and BI policy rate refers to the sequence of forward window (FE), rolling window (RO), and recursive window (RE). This study finds that the Wald test values of RO and RE strongly predict the response of monetary policy to climate change shocks.

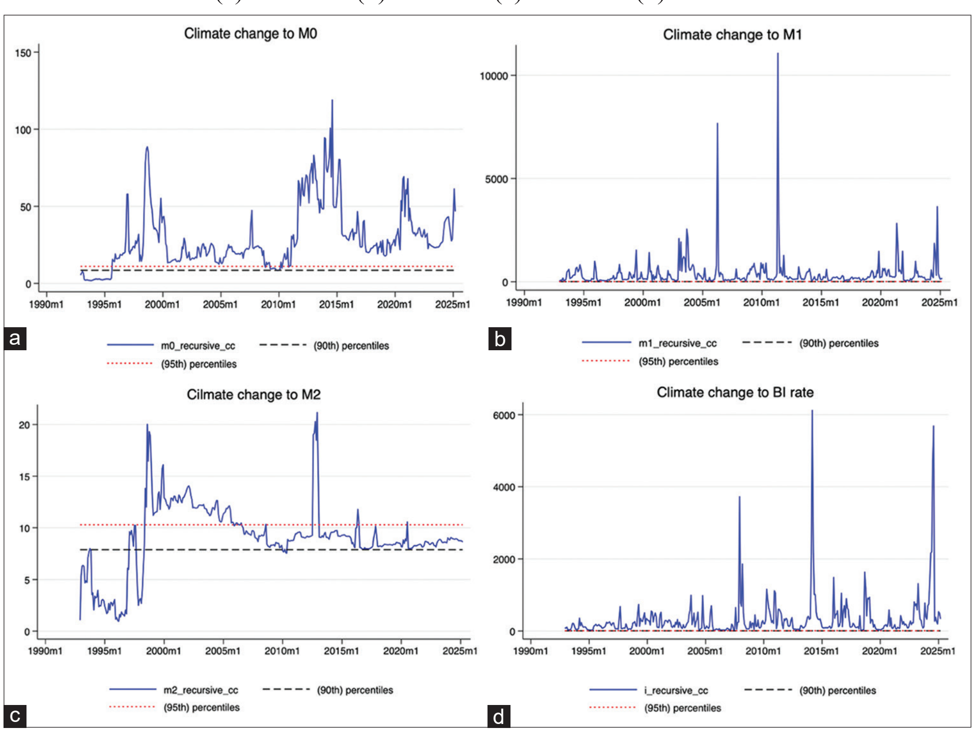
Table 6: Estimation results of TVGC for climate change to monetary policy

Direction of causality	Max Wald FE	Max Wald RO	Max Wald RE
$\mathcal{T} \xrightarrow{GC} M0$	36.221***	118.977***	118.977***
	(8.220)	(8.074)	(8.567)
	[11.040]	[10.381]	[11.070]
	{16.320}	{16.699}	{17.915}
$\mathcal{T} \xrightarrow{GC} M1$	100.588***	11070.610***	11070.610***
	(8.336)	(7.982)	(8.362)
	[10.965]	[10.319]	[10.965]
	{14.836}	{14.370}	{14.836}
$\mathcal{T} \xrightarrow{GC} M2$	13.102***	21.095***	21.165***
	(7.217)	(7.209)	(7.884)
	[9.769]	[9.838]	[10.300]
	{14.902}	{14.061}	{15.043}
$\mathcal{T} \xrightarrow{GC} BI$	135.731***	6118.068***	6118.068***
	(6.917)	(6.552)	(6.917)
	[9.342]	[8.613]	[9.342]
	{17.045}	{16.797}	{17.045}

(.), [.], and {.} are 90th, 95th, and 99th percentiles, respectively, *** significant at 1% level
Source: Authors' Estimation

The direction of Granger causality from climate change shocks to monetary policy instruments varies from January 1990 to March 2025, see Figure 1. Climate change persistently directs Granger causal relationships with narrow money M1 and BI policy interest rate over the entire sample period. However, the Granger causal direction from climate change to monetary base M0 and store value M2 fluctuates over the sample period. There are five episodes regarding strong Granger causal association from climate change to M0, specifically, May 1995-October 2008, December 2008-March 2009, May 2010-March 2010, and December 2010-March 2025. The max Wald recursive evolving is 118. 98 in August 2014. The longest episode is from December 2010 to March 2015. While there are seven episodes related to Granger causal relationship from climate change to M2, interestingly, June 1998-November 2005, January 2006 to May 2006, July 2006, August 2008, August 2012-January 2013, May 2016-June 2016, and July 2020. The maximum Wald recursive evolving is 21.16 in December 2012. The longest episode of M2 that responds to climate change ran from June 1998 to November 2005. The evidence imply that the Bank Indonesia reacts to climate change shocks through policy instruments that differ from M0 and M2 to M1 and the BI policy rate. The response of Bank Indonesia to climate change is a part of its main mandate to maintain price stability as a consequence of climate change-related real economic activities, which is in line with the argument of Dikau and Volz (2021).

Figure 1: Estimation results of varying Granger causality for climate change to monetary policy.
(a) $\mathcal{T} \xrightarrow{GC} M0$ (b) $\mathcal{T} \xrightarrow{GC} M1$ (c) $\mathcal{T} \xrightarrow{GC} M2$ (d) $\mathcal{T} \xrightarrow{GC} BI$



Source: Authors' estimation

4.2. Empirical Results of Asymmetric Time-Varying Granger Causality

In the case of AS-TVGC, we investigate the asymmetric causality of climate change on four monetary policy instruments, that is, first, on monetary base M0: $\left(\mathcal{T}_t^+, M0_t^+\right)$, $\left(\mathcal{T}_t^+, M0_t^-\right)$, $\left(\mathcal{T}_t^-, M0_t^+\right)$, $\left(\mathcal{T}_t^-, M0_t^-\right)$. Second, on M1: $\left(\mathcal{T}_t^+, M1_t^+\right)$, $\left(\mathcal{T}_t^+, M1_t^-\right)$, $\left(\mathcal{T}_t^-, M1_t^+\right)$, $\left(\mathcal{T}_t^-, M1_t^-\right)$. Third, on M2: $\left(\mathcal{T}_t^+, M2_t^+\right)$, $\left(\mathcal{T}_t^+, M2_t^-\right)$, $\left(\mathcal{T}_t^-, M2_t^+\right)$, $\left(\mathcal{T}_t^-, M2_t^-\right)$. Finally, on Bank Indonesia policy rate: $\left(\mathcal{T}_t^+, BI_t^+\right)$, $\left(\mathcal{T}_t^+, BI_t^-\right)$, $\left(\mathcal{T}_t^-, BI_t^+\right)$, and $\left(\mathcal{T}_t^-, BI_t^-\right)$. The objective of involving all sixteen previous combinations is to provide a comprehensive and nuanced view that directly implies macroeconomic activity and the financial markets due to the presence of climate change shocks. In addition, the various monetary measures and interest policy rate describe the distinctive influence of climate change on economic and financial development (Chen and Xiao, 2025; Lu et al., 2024).

Table 7 demonstrates the results of the causality effect of climate change on M0. Obviously, we emphasize the presence of the Granger causality effect at 5% significance level. We discard four null hypotheses of no asymmetric Granger causality between climate change and M0, ($\mathcal{T}(+)\overset{GC}{\rightarrow}M0(+)$, $\mathcal{T}\left(+\right)\overset{GC}{\rightarrow}M0(-)$, $\mathcal{T}\left(-\right)\overset{GC}{\rightarrow}M0(+)$, and $\mathcal{T}\left(-\right)\overset{GC}{\rightarrow}M0(-)$), which refers to the sequence of forward window (FE), rolling window (RO), and recursive window (RE). The results of the max Wald forward window are various between climate change positive and climate change negative, which is strongly significant for climate change positive, while climate change negative is statistically insignificant. However, theoretically, the rolling window and recursive window produce better results as predicted by Shi et al. (2020).

Table 7: Estimation results of AS-TVGC for climate change to money supply M0

Direction of causality	Max Wald FE	Max Wald RO	Max Wald RE
$\mathcal{T}(+)\overset{GC}{\rightarrow}M0(+)$	19.342***	133.665***	138.296***
	(8.234)	(7.851)	(8.431)
	[10.208]	[9.707]	[10.511]
	{13.910}	{14.345}	{14.559}
$\mathcal{T}\left(+\right)\overset{GC}{\rightarrow}M0(-)$	16.237***	128.788***	133.947***
	(7.581)	(7.387)	(7.606)
	[10.147]	[9.872]	[10.318]
	{14.212}	{14.013}	{15.028}
$\mathcal{T}\left(-\right)\overset{GC}{\rightarrow}M0(+)$	4.556	18.593***	36.946***
	(8.123)	(8.529)	(9.063)
	[10.180]	[10.456]	[11.009]
	{17.142}	{16.710}	{17.142}
$\mathcal{T}\left(-\right)\overset{GC}{\rightarrow}M0(-)$	4.299	18.219***	24.476***
	(7.982)	(8.387)	(8.877)
	[9.819]	[9.959]	[10.467]
	{16.739}	{15.919}	{16.739}

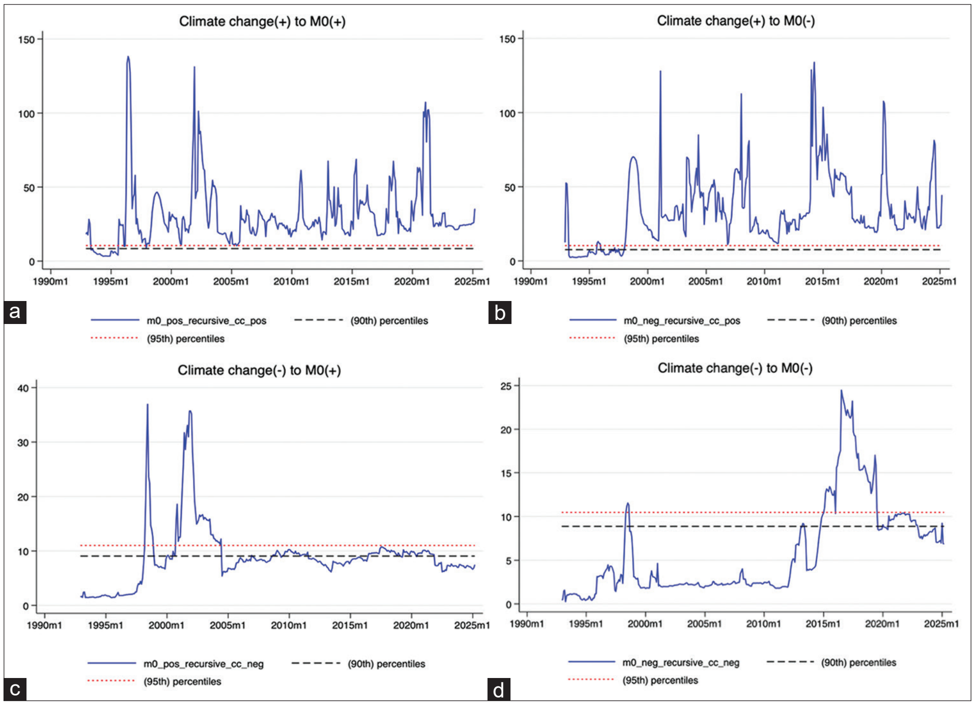
(.), [.], and {.} are 90th, 95th, and 99th percentiles, respectively, *** significant at 1% level
Source: Authors' Estimation

Figure 2 shows the path of asymmetric Granger causality from climate change shocks to monetary base M0 varies from January 1990 to March 2025. The positive climate change persistently directs Granger causal relationships with the monetary base M0 over the entire sample period. But, the Granger causal pathway from negative climate change to the monetary base M0 vacillates over the sample period. There are five episodes regarding strong Granger causal association from positive climate change to positive M0, specifically, December 1992-April 1993, September 1995-January 1996, April 1996-November 1997, January 1998-May 2005, and July 2005-March 2025. The max Wald recursive evolving is 138.30 in June 1996. The longest episode is from July 2005 to March 2025. While there are three episodes related to Granger causal relationship from positive climate change to negative M0, interestingly, December 1992-March 1993, September 1995-December 1995, and February 1998-March 2025. The maximum Wald recursive evolving is 103.65 in January 2015. The longest episode of negative M0 that responds to positive climate change ran from February 1998 to March 2025. On the other hand, there are only two episodes regarding strong Granger causal association from negative climate change to positive M0, specifically, April 1998-November 1998 and October 2000-June 2004. The max Wald recursive evolving is 36.95 in June 1998. The longest episode is from October 2000 to June 2004. While there are three episodes related to Granger causal relationship from negative climate change to negative M0, interestingly, June 1998-August 1998, February 2015-December 2015, and February 2016-July 2019. The maximum Wald recursive evolving is 24.48 in July 2016. The longest episode of negative M0 that responds to negative climate change ran from February 2016 to July 2019.

Table 8 displays the results of the causality effect of climate change on M1. Predictably, we emphasize the subsistence of the Granger causality effect at 5% significance level. We discourage the four null hypotheses of no asymmetric Granger causality between climate change and M1, ($\mathcal{T}\left(+\right)\overset{GC}{\rightarrow}M1(+)$, $\mathcal{T}\left(+\right)\overset{GC}{\rightarrow}M1(-)$, $\mathcal{T}\left(-\right)\overset{GC}{\rightarrow}M1(+)$, and $\mathcal{T}\left(-\right)\overset{GC}{\rightarrow}M1(-)$), which denotes the structure of forward window (FE), rolling window (RO), and recursive window (RE).

The pathway of asymmetric Granger causality from climate change shocks to narrow money M1 varies from January 1990 to March 2025, see Figure 3. The negative climate change assiduously directs Granger causal relationships with the narrow money M1 over the entire sample period. But, the Granger causal direction from positive climate change to the narrow money M1 fluctuates over the sample period. There are seven occurrences of strong Granger causal association from positive climate change to positive M1, specifically, January 1993-March 1993, June 1993, August 1993-September 1996, November 1996-March 2003, May 2003-June 2003, October 2003-November 2004, and January 2005-March 2025. The max Wald recursive evolving is 48.82

Figure 2: Estimation results of asymmetric time-varying Granger causality for climate change to money supply M0.
(a) $\mathcal{T}(+)\xrightarrow{GC} M0(+)$ (b) $\mathcal{T}(+)\xrightarrow{GC} M0(-)$ (c) $\mathcal{T}(-)\xrightarrow{GC} M0(+)$ (d) $\mathcal{T}(-)\xrightarrow{GC} M0(-)$



Source: Authors' estimation

Table 8: Estimation results of AS-TVGC for climate change to money supply M1

Direction of causality	Max Wald FE	Max Wald RO	Max Wald RE
$\mathcal{T}(+)\xrightarrow{GC} M1(+)$	12.789**	142.864***	143.478***
	(7.745)	(7.407)	(8.276)
	[10.217]	[10.217]	[10.835]
	{15.069}	{14.322}	{15.069}
$\mathcal{T}(+)\xrightarrow{GC} M1(-)$	20.504***	247.947***	254.935***
	(7.672)	(7.325)	(7.888)
	[10.487]	[9.926]	[10.758]
	{14.579}	{14.107}	{14.708}
$\mathcal{T}(-)\xrightarrow{GC} M1(+)$	103.031***	20612.250***	20612.250***
	(7.970)	(7.389)	(7.970)
	[9.802]	[9.594]	[9.802]
	{14.817}	{14.547}	{14.817}
$\mathcal{T}(-)\xrightarrow{GC} M1(-)$	355.045***	55641.064***	55641.064***
	(7.944)	(7.727)	(8.031)
	[10.253]	[9.739]	[10.253]
	{14.586}	{14.108}	{14.586}

(.), [.], and {.} are 90^{th}, 95^{th}, and 99^{th} percentiles, respectively, *** and ** are significant at 1% and 5% levels
Source: Authors' Estimation

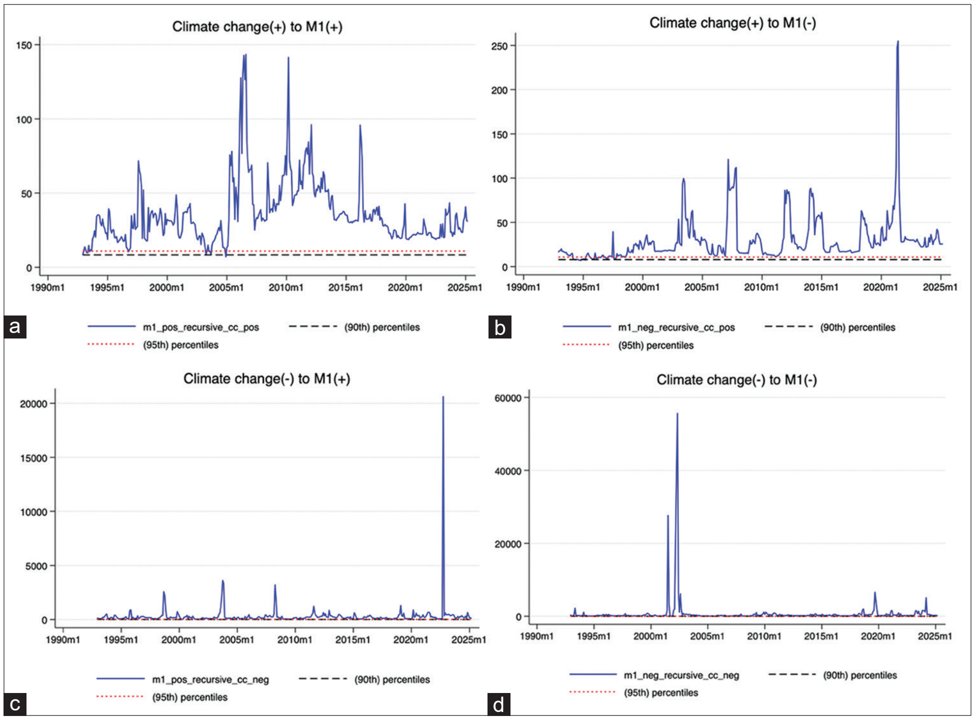
in October 2010. The longest episode is from January 2005 to March 2025. While there are seven incidences related to Granger causal relationship from positive climate change to negative M1, interestingly, December 1992-February 1994, April 1995-July 1995, January 1996, August 1996-September 1996, March 1997-July 1997, November 1997-July 1998, August 1998-March 2025. The maximum Wald recursive evolving is 294.94 in June 2021. The longest episode of negative M1 that responds to positive climate change ran from August 1998 to March 2025.

Table 9 displays the results of the causality effect of climate change on M2. Predictably, we emphasize the existence of the Granger causality effect at 5% significance level. We slight the four null hypotheses of no asymmetric Granger causality between climate change and M2, ($\mathcal{T}(+)\xrightarrow{GC} M1(+)$, $\mathcal{T}(+)\xrightarrow{GC} M1(-)$, $\mathcal{T}(-)\xrightarrow{GC} M1(+)$, and $\mathcal{T}(-)\xrightarrow{GC} M1(-)$), denotes to the categorization of forward window (FE), rolling window (RO), and recursive window (RE).

Figure 4 presents the path of asymmetric Granger causality from climate change shocks to M2 is persistent from January 1990 to March 2025, except for positive climate change to negative M2. The positive climate change varies directly in Granger causal associations with the negative M2 over the entire sample period. There are ten episodes of strong Granger causal association from positive climate change to negative M2, particularly July 1993, November 1993-February 1994, July 1994-February 1995, April 1995-September 1996, November 1996-February 1997, September 1998, November 1998-June 2006, August 1998-September 2008, November 2000-June 2002, and October 2002-March 2025. The max Wald recursive evolving is 442.19 in January 2012. The longest episode is from October 2002 to March 2025.

Table 10 reveals the results of the causality effect of climate change on the BI policy rate. Predictably, we emphasize the existence of

Figure 3: Estimation results of asymmetric time-varying Granger causality for climate change to money supply M1.
(a) $\mathcal{T}(+)\xrightarrow{GC}M1(+)$ (b) $\mathcal{T}(+)\xrightarrow{GC}M1(-)$ (c) $\mathcal{T}(-)\xrightarrow{GC}M1(+)$ (d) $\mathcal{T}(-)\xrightarrow{GC}M1(-)$



Source: Authors' estimation

Table 9: Estimation results of AS-TVGC for climate change to money supply M2

Direction of causality	Max Wald FE	Max Wald RO	Max Wald RE
$\mathcal{T}(+)\xrightarrow{GC}M2(+)$	23.751***	1476.391***	1476.391***
	(8.389) [10.567] {16.994}	(8.020) [10.089] {15.175}	(8.502) [10.567] {16.994}
$\mathcal{T}(+)\xrightarrow{GC}M2(-)$	17.737***	442.190***	442.190***
	(7.561) [9.636] {14.389}	(7.230) [8.886] {14.170}	(7.651) [10.043] {16.203}
$\mathcal{T}(-)\xrightarrow{GC}M2(+)$	89.724***	19665.860***	19665.860***
	(8.255) [9.992] {15.295}	(7.749) [9.770] {14.029}	(8.256) [10.002] {15.295}
$\mathcal{T}(-)\xrightarrow{GC}M2(-)$	201.374***	10772.100***	10772.100***
	(7.721) [10.118] {14.872}	(7.504) [9.899] {14.549}	(7.956) [10.118] {14.872}

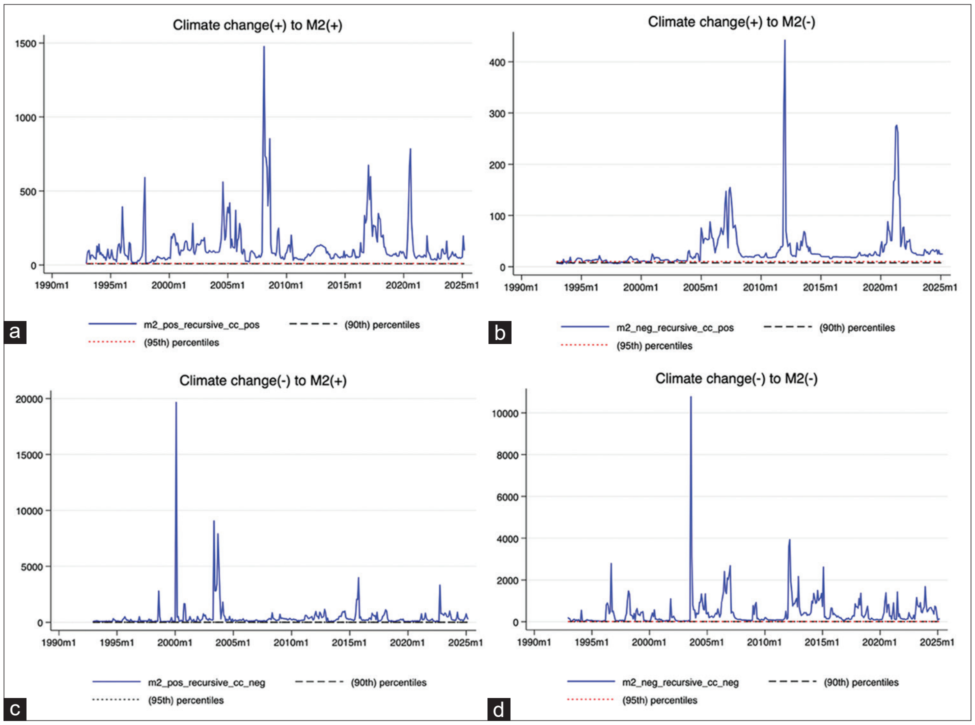
(.), [.], and {.} are 90th, 95th, and 99th percentiles, respectively, *** significant at 1% level
Source: Authors' Estimation

the Granger causality effect at 5% significance level. We spurn the four null hypotheses of no asymmetric Granger causality between climate change and the BI policy rate, ($\mathcal{T}(+)\xrightarrow{GC}BI(+)$, $\mathcal{T}(+)\xrightarrow{GC}BI(-)$, $\mathcal{T}(-)\xrightarrow{GC}BI(+)$, and $\mathcal{T}(-)\xrightarrow{GC}BI(-)$), signifies to the arrangement of forward window (FE), rolling window (RO), and recursive window (RE).

Figure 5 detects the path of asymmetric Granger causality from climate change shocks to the BI policy rate, which is persistent from January 1990 to March 2025, except for positive climate change to negative BI policy rate. The positive climate change varies directly in Granger causal relations with the negative BI policy rate over the entire sample period. There are ten episodes of strong Granger causal association from positive climate change to negative BI policy rate, particularly August 1993-October 1998, December 1998-September 2016, February 2017-July 2017, May 2018-January 2020, April 2020, June 2020, October 2020, June 2021-July 2021, January 2022-April 2023, and January 2025-March 2025. The max Wald recursive evolving is 442.19 in January 2012. The longest episode is from December 1998 to September 2016.

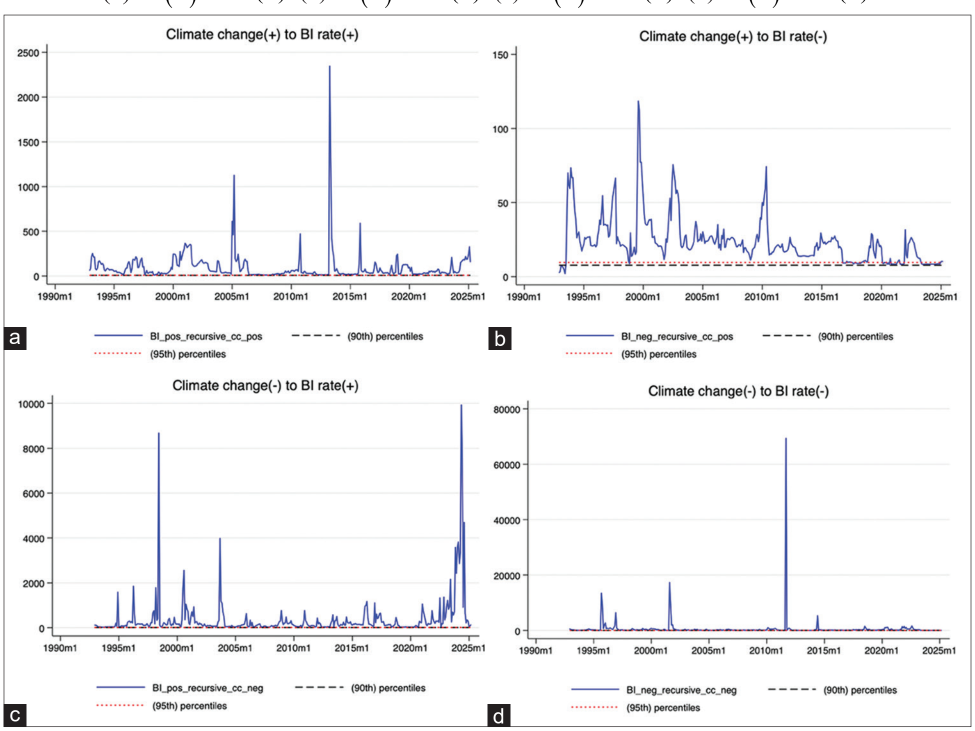
Among the monetary policy instruments, M0, M1, M2, and BI policy rate, we confirm that M2 and BI policy rate seem to have the same pattern in responding to climate change shocks. We identify various date-stamping of asymmetric Granger causality running from positive climate change to negative M2 and BI policy rate. A potential reasoning relates to the fact that climate change shocks drive potential damage to real economic activities, leading to price instability (Dikau and Volz, 2021; Qi et al., 2025). Hence, there is a strong rationale for Bank Indonesia to adopt the climate-related inflation targeting, which is the main mandate of Bank Indonesia to address inflation and exchange rate stabilization through M2 and BI policy rate instruments.

Figure 4: Estimation results of asymmetric time-varying Granger causality for climate change to money supply M2.
(a) $\mathcal{T}(+)\overset{GC}{\rightarrow}M2(+)$ (b) $\mathcal{T}(+)\overset{GC}{\rightarrow}M2(-)$ (c) $\mathcal{T}(-)\overset{GC}{\rightarrow}M2(+)$ (d) $\mathcal{T}(-)\overset{GC}{\rightarrow}M2(-)$



Source: Authors' estimation

Figure 5: Estimation results of asymmetric time-varying Granger causality for climate change to BI policy rate.
(a) $\mathcal{T}(+)\overset{GC}{\rightarrow}BI(+)$ (b) $\mathcal{T}(+)\overset{GC}{\rightarrow}BI(-)$ (c) $\mathcal{T}(-)\overset{GC}{\rightarrow}BI(+)$ (d) $\mathcal{T}(-)\overset{GC}{\rightarrow}BI(-)$



Source: Authors' estimation

The main economic inferences of our results are that climate change would alter the monetary policy undertaken by the central bank through the sample period. The preemptive monetary policy is commenced by the central bank during positive climate change shock episodes, indicated by either expansionary or contractionary monetary policy. Our findings have essential propositions for central bank policymakers to uphold economic and financial system stability. In fact, central bank policymakers should reflect

Table 10: Estimation results of AS-TVGC for climate change to BI policy rate

Direction of causality	Max Wald FE	Max Wald RO	Max Wald RE
$\mathcal{T}(+)\overset{GC}{\rightarrow}BI(+)$	79.132***	2346.607***	2346.607***
	(7.769)	(7.452)	(7.769)
	[9.035]	[8.950]	[9.035]
	{16.545}	{15.156}	{16.545}
$\mathcal{T}(+)\overset{GC}{\rightarrow}BI(-)$	7.312	118.407***	118.407***
	(7.367)	(7.226)	(7.684)
	[9.187]	[9.001]	[9.523]
	{15.500}	{15.402}	{15.500}
$\mathcal{T}(-)\overset{GC}{\rightarrow}BI(+)$	121.721***	9930.669***	9930.669***
	(8.109)	(7.764)	(8.109)
	[10.777]	[10.278]	[10.777]
	{16.351}	{15.943}	{16.351}
$\mathcal{T}(-)\overset{GC}{\rightarrow}BI(-)$	725.105***	69381.495***	69381.495***
	(8.016)	(7.502)	(8.016)
	[10.287]	[9.715]	[10.287]
	{16.081}	{15.805}	{16.081}

(.), [.], and {.} are 90th, 95th, and 99th percentiles, respectively, *** significant at 1% level
Source: Authors' Estimation

the AS-TVGC approach between climate change and monetary policy in order to ensure that the economic and financial system is appropriately addressed. Identifying the existence of date-stamping and the asymmetric direction of climate change to monetary policy would help the central bank to take precautionary measures to circumvent the shock of climate-related risks. The central bank should initiate climate-related monetary policy by introducing various micro- and macroprudential instruments (Vyshnevskyi and Sohn, 2025).

5. CONCLUSION

Presently, climate change is non-negotiable and becoming an important concern in designing the central bank's climate-based monetary policy. Considering that the influence of climate change on monetary policy may vary over time, hence, this study investigates the asymmetric time-varying climate change shocks on monetary policy in Indonesia over the period January 1990 to March 2025. Presenting a recent novel time-varying Granger causality (TVGC) and asymmetric time-varying Granger causality (AS-TVGC) techniques, we portray the asymmetric monetary policy proxied by M0, M1, M2, and BI policy rate responds to climate change shocks. The TVGC and AS-TVGC are operated to perceive major events of climate change on monetary policy in Indonesia.

The empirical outcomes expose that date stamping of climate change to monetary policy from TVGC estimations. In addition, the AS-TVGC strongly portrays how the monetary policy reacts to both positive and negative climate change shocks. Specifically, this study notes that the monetary policy responds variously to climate change-positive, but persistently to climate change-negative. Therefore, central bank policy makers should take the mandate to design new climate-based monetary operations to set price stability and sustainable growth in the net-zero central banking framework. Due to the availability of data, the limitations of this study do not capture the specific central bank's climate-related risks and climate policy uncertainty. Thus, we recommend that future research explore climate-related risks and climate policy uncertainty faced by the central bank. In addition, the study of various micro- and macroprudential instruments related to climate change is also an important agenda for academicians and central bank policy makers.

REFERENCES

Baranzini, A., Van den Bergh, J.C., Carattini, S., Howarth, R.B., Padilla, E., Roca, J. (2017), Carbon pricing in climate policy: Seven reasons, complementary instruments, and political economy considerations. Wiley Interdisciplinary Reviews: Climate Change, 8(4), e462.

Baum, C.F., Hurn, S., Otero, J. (2025), The dynamics of U.S. industrial production: A time-varying Granger causality perspective. Econometrics and Statistics, 33, 13-22.

Benmir, G., Roman, J. (2020), Policy interactions and the transition to clean technology. Working Paper - Grantham Research Institute on Climate Change and the Environment, 337.

Boneva, L., Ferrucci, G., Mongelli, F.P. (2022), Climate change and central banks: What role for monetary policy? Climate Policy, 22(6), 770-787.

Böser, F., Colesanti Senni, C. (2020), Emission-based Interest Rates and the Transition to a Low-Carbon Economy. Economics Working Paper Series, 20/337.

Chan, Y.T. (2020), Are macroeconomic policies better in curbing air pollution than environmental policies? A DSGE approach with carbon-dependent fiscal and monetary policies. Energy Policy, 141, 111454.

Chen, J., Xiao, Z. (2025), Is the business cycle getting hit by climate policy uncertainty in China? Finance Research Letters, 71, 106344.

Dafermos, Y., Nikolaidi, M., Galanis, G. (2018), Climate change, financial stability and monetary policy. Ecological Economics, 152, 219-234.

Dikau, S., Volz, U. (2021), Central bank mandates, sustainability objectives and the promotion of green finance. Ecological Economics, 184, 107022.

DiLeo, M., Rudebusch, G., van't Klooster, J. (2023), Why the Fed and ECB Parted Ways on Climate Change. Hutchins Center Working Paper No. 88.

Hansen, L.P. (2022), Central banking challenges posed by uncertain climate change and natural disasters. Journal of Monetary Economics, 125, 1-15.

Hong, Y., Wang, L., Ye, X., Zhang, Y. (2022), Dynamic asymmetric impact of equity market uncertainty on energy markets: A time-varying causality analysis. Renewable Energy, 196, 535-546.

Jabko, N., Kupzok, N. (2024), Indirect responsiveness and green central banking. Journal of European Public Policy, 31(4), 1026-1050.

Jackson, J., Bailey, D., Paterson, M. (2024), Climate-related risks to central bank independence: the depoliticisation and repoliticisation of the Bank of England in the transition to net zero. New Political Economy, 30(3), 1-15.

Khaliq, A., Karimi, S., Werry, D.T., Ridwan, E. (2025), You can't live alone: Spatial climate change shock and economic growth in the largest archipelagic state. International Journal of Energy Economics and Policy, 15(2), 171-181.

Lu, Y., Zhao, Z., Tian, Y., Zhan, M. (2024), How does the economic structure break change the forecast effect of money and credit on output? Evidence based on machine learning algorithms. Pacific-Basin Finance Journal, 84, 102325.

McConnell, A., Yanovski, B., Lessmann, K. (2022), Central bank collateral as a green monetary policy instrument. Climate Policy, 22(3), 339-355.

McKibbin, W.J., Morris, A.C., Wilcoxen, P.J., Panton, A.J. (2020), Climate change and monetary policy: Issues for policy design and modelling. Oxford Review of Economic Policy, 36(3), 579-603.

Monasterolo, I. (2020), Climate change and the financial system. Annual Review of Resource Economics, 12(1), 299-320.

NFGS. (2022), Climate Scenarios for Central Banks and Supervisors. Available from: https://www.ngfs.net/en/publications-and-statistics/publications/ngfs-climate-scenarios-central-banks-and-supervisors [Last accessed on 2025 Apr 07].

NFGS. (2024), The Green Transition and the Macroeconomy: A Monetary Policy Perspective. Available from: https://www.ngfs.net/en/publications-and-statistics/publications/green-transition-and-macroeconomy-monetary-policy-perspective [Last accessed on 2025 Apr 07].

NOAA. (2025), Climate Change: Global Temperature. Available from: https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature

Nordhaus, W.D. (2007), A review of the Stern review on the economics of climate change. Journal of Economic Literature, 45(3), 686-702.

Nordhaus, W.D. (2019), Climate change: The ultimate challenge for economics. American Economic Review, 109(6), 1991-2014.

Otero, J., Baum, C., Hurn, S. (2024), TVGC: Stata Module to Perform Time-Varying Granger Causality Tests, Statistical Software Components S458916. Boston: Boston College Department of Economics, Revised.

Phillips, P.C.B., Shi, S., Yu, J. (2015), Testing for multiple bubbles: Limit theory of real-time detectors. International Economic Review, 56(4), 1079-1134.

Qi, C., Ma, Y., Du, M., Ma, X., Xu, Y., Zhou, X. (2025), Impacts of climate change on inflation: An analysis based on long and short term effects and pass-through mechanisms. International Review of Economics and Finance, 98, 103846.

Quorning, S. (2024), The ‘climate shift’in central banks: How field arbitrageurs paved the way for climate stress testing. Review of International Political Economy, 31(1), 74-96.

Rosa, S.M. (2025), Green monetary policy measures and central bank mandates: A comparative political economy analysis. Politics and Governance, 13, 8919.

Shi, S., Hurn, S., Phillips, P.C. (2020), Causal change detection in possibly integrated systems: Revisiting the money-income relationship. Journal of Financial Econometrics, 18(1), 158-180.

Shobande, O.A. (2022), Is climate change a monetary phenomenon? Evidence from time series analysis. International Journal of Sustainable Development and World Ecology, 29(2), 99-111.

Song, X., Fang, T. (2024), Climate change and the influence of monetary policy in China. Journal of Applied Economics, 27(1), 2329840.

Thiemann, M., Büttner, T., Kessler, O. (2023), Beyond market neutrality? Central banks and the problem of climate change. Finance and Society, 9(1), 14-34.

Vyshnevskyi, I., Sohn, W. (2025), Central banks’ support for climate action: A literature review and key issues. Journal of Economic Surveys, 1-17. doi: 10.1111/joes.12709

WMO. (2025), State of the Global Climate 2024. Available from: https://wmo.int/publication-series/state-of-global-climate-2024

Xin, B., Jiang, K., Gonzalez, E.D.S. (2024), The coevolution effect of central bank digital currency and green bonds on the net-zero economy. Energy Economics, 134, 107587.

Zhou, F., Endendijk, T., Botzen, W.W. (2023), A review of the financial sector impacts of risks associated with climate change. Annual Review of Resource Economics, 15(1), 233-256.