

THE IMPACT OF GREEN FINANCE AND TECHNOLOGICAL INNOVATION ON SUSTAINABLE GROWTH: THE MODERATING ROLE OF INSTITUTIONAL QUALITY

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ABSTRACT

In the context of climate change and the growing need for sustainable development, green finance and technological innovation have become important instruments for achieving economic growth while ensuring environmental protection. This study investigates the effects of green finance and technological innovation on sustainable growth in 86 countries, including 40 developed and 46 developing countries, over the period 2010 to 2024. The study applies pooled ordinary least squares regression, fixed effects models, random effects models and generalized method of moments estimation to address endogeneity and the dynamic characteristics of panel data. The empirical findings indicate that green finance may have a negative short-term effect on sustainable growth, whereas technological innovation contributes positively to sustainable growth, particularly in developing countries. Institutional quality is also identified as a key condition that enhances the effectiveness of green finance and technological innovation in promoting sustainable growth. The results suggest that countries should strengthen institutional quality, improve the efficiency of resource allocation and support technological innovation to maximize the benefits of green finance in the transition toward sustainable growth.

Keywords: *Green finance, Technological development, Sustainable growth, Institutional quality*

1. INTRODUCTION

In recent decades, global climate change, the accelerated depletion of natural capital, and increasing pressure to meet net-zero emission commitments have required countries to rethink their development models (Intergovernmental Panel on Climate Change, 2023). In this context, sustainable growth is no longer understood only through the expansion of output. It is increasingly associated with efficient resource use and the reduction of negative environmental impacts (United Nations, 2023). Sustainable growth has therefore moved from being a desirable policy objective to becoming a strategic necessity that requires the decoupling of economic growth from environmental degradation (Krastev & Krasteva Hristova, 2024). In the transition from brown to green growth models, green finance and technological innovation are widely recognized by scholars and policymakers as essential drivers of change.

Green finance has become an important mechanism for mobilizing and reallocating social

capital from carbon intensive industries toward environmentally friendly projects such as renewable energy, energy saving technologies and low emission production activities (Taghizadeh Hesary & Yoshino, 2019; Falcone, 2020). By directing financial resources toward green sectors, green finance supports the transition to a more sustainable growth model and contributes to the reduction of environmental damage (Rezk et al., 2026). The United Nations Environment Programme (2023) emphasizes that the development of green finance systems can provide effective financial mechanisms to help countries achieve sustainable development goals and reduce greenhouse gas emissions. At the same time, technological innovation is considered crucial for improving resource efficiency, reducing the marginal cost of emission reduction and creating cleaner alternatives within production structures (Acemoglu et al., 2012; Aghion et al., 2016). Through higher productivity, better resource utilization and lower environmental pressure, technological innovation plays a significant role in advancing sustainable growth (Thi et al., 2024; Cateia & Savard, 2026).

Although the individual roles of green finance and technological innovation in economic growth and environmental protection have been widely examined, empirical findings remain inconsistent and differ substantially across countries. Some studies show that green finance can promote sustainable growth by supporting investment in green sectors and encouraging the transition to clean technologies (Zhang et al., 2021). Zhou et al. (2021) also argue that technological innovation is an essential driver of sustainable growth because it improves productivity, optimizes resource use and supports more efficient structural transformation. However, the effectiveness of technological innovation may vary across countries due to differences in development levels, financial market structures and technological absorption capacity (Li & Qamruzzaman, 2023).

Institutional quality may help explain these differences. Institutions shape the effectiveness of economic activity by defining rules, ensuring transparency and supporting policy enforcement (Rodrik et al., 2004). Recent studies indicate that strong institutions can reinforce the impact of green finance and technological innovation on sustainable economic and environmental outcomes (Aydin et al., 2024; Zhang et al., 2024). Institutional quality can therefore act as a moderating factor in the relationship between green finance, technological innovation and sustainable growth.

Despite the recognized importance of these factors, the existing literature still contains several important limitations. First, many studies examine green finance and technological innovation separately, which may overlook the endogenous and mutually reinforcing relationship between clean capital and technological knowledge. This can create omitted variable bias. Second, the interaction between these two factors is often treated as a black box within the assumption of a perfect market environment. As a result, the role of national governance in preventing greenwashing and improving policy implementation remains insufficiently explained. Third, the lack of systematic analysis that accounts for structural differences between countries at different levels of development limits the broader applicability of previous findings.

This study addresses these theoretical and empirical gaps by developing an integrated analytical framework that examines green finance and technological innovation simultaneously. This approach makes it possible to clarify the coordination mechanisms through which these two factors influence sustainable growth. By including institutional quality as a moderating variable, the study also explains how governance conditions affect performance, guide capital flows and strengthen the absorption of clean technologies. In addition, the use of a structurally diverse country sample provides more practical and context specific insights into the effectiveness of green policies.

The study contributes to the literature by using data from 86 countries selected according to the availability of green bond issuance data. The sample consists of 40 developed and 46 developing countries over the period from 2010 to 2024. The main objective is to develop an integrated framework that explains sustainable growth through green finance and technological

development while also clarifying the moderating role of institutional quality. In this way, the study identifies the mechanisms through which green finance and technological development shape sustainable growth trajectories and offers empirical evidence for the design of development strategies aligned with the United Nations Sustainable Development Goals.

The study is organized into five sections. The first section introduces the research topic. The second section reviews the relevant literature. The third section presents the data and research model. The fourth section reports and discusses the empirical results. The fifth section concludes the study and provides recommendations for future research.

2. LITERATURE REVIEW

Green Finance and Sustainable Growth

The role of green finance in sustainable development has attracted considerable academic attention, although existing findings remain mixed. A large body of research confirms that green finance supports net growth (Tufail et al., 2024) and improves ESG performance in developed economies such as OECD and European Union countries (Kwilinski et al., 2025; Solangi et al., 2025). However, Nguyen et al. (2024) argue that when the regulatory role of green energy and green production is neglected, green finance may have a negative effect on green growth. Yin et al. (2022) similarly suggests that the relationship between green finance and economic growth in China is weak and that green finance does not effectively connect industrial restructuring, environmental protection and economic growth. These inconsistent findings show the need for stronger regulatory mechanisms and a more precise assessment of the effectiveness of green finance. Accordingly, we posit

H_1 : *Green finance has a positive impact on sustainable growth.*

Technological Innovation and Sustainable Growth

Empirical evidence on the effect of technological innovation on sustainable growth remains inconclusive and reflects a tension between economic performance and social equity. On the one hand, technology-based approaches suggest that innovation is a central driver of average income growth and green total factor productivity, especially when combined with human resources (Anakpo and Oyenubi, 2022; Wang et al., 2021). On the other hand, technological innovation may produce adverse consequences if it is not properly managed and may even contribute to severe economic downturns (Ahmad et al., 2023). It may also widen the gap between skilled and unskilled workers, increase social inequality and weaken the foundations of inclusive growth (Almusharraf, 2025). Accordingly, we propose

H_2 : *Technological innovation has a positive impact on sustainable growth.*

Institutional Quality and Sustainable Growth

Institutional quality is often examined through its capacity to improve green capital allocation and reduce systemic risks (Sun et al., 2025; Huo et al., 2025). Nevertheless, recent studies suggest that the impact of institutions is not always positive and may depend on threshold effects. Nguyen (2025) argues that financial development promotes growth only when institutions are sufficiently strong and when human resource development is also present. In weak institutional environments, financial development alone does not necessarily lead to sustainable growth. In some contexts, institutional quality may even reduce the positive contribution of other factors to growth (Dang, 2024). The difference between the expected benefits of a supportive legal framework and the potential barriers created by weak institutions provides a basis for

reassessing the real impact of institutional quality. Therefore, we hypothesize

H₃: Institutional quality impacts sustainable growth.

Institutional Quality, Green Finance, and Sustainable Growth

Institutional quality is essential for strengthening the positive effect of green finance on sustainable growth. Strong institutions can attract green foreign investment and transform financial resources into projects with genuine sustainable value (Le, 2025). However, recent debates reveal an important paradox. Under unfavourable market conditions or weak regulatory frameworks, green finance initiatives may increase financial pressure and raise the risk of losses for firms (Fan et al., 2025). This issue is especially relevant in developing countries, where the moderating effect of institutions on the finance environment relationship tends to appear only in the long term. In the short term, this effect may remain unclear because legal frameworks are still not sufficiently strong (Akpan et al., 2024). The interaction between micro level financial constraints and macro level legal frameworks creates gaps in enforcement effectiveness. To clarify the role of institutions in strengthening the benefits of green finance, we propose the following

H₄: Green finance, with the regulatory role of institutional quality, impacts sustainable growth.

Institutional Quality, Technological Innovation, and Sustainable Growth

Although technological innovation is expected to serve as a driver of long-term development, its effectiveness may be either constrained or strengthened by institutional quality. Current studies indicate a trade-off. Strong institutions help reduce policy risks and enhance green outcomes (Van et al., 2025), whereas weak legal systems may turn industrial innovation into a financial burden for vulnerable economic sectors (Aghion et al., 2016). Moreover, the importance of institutions depends on the level of development of each country. In developed economies, institutional effects may be weaker because innovation systems are already more advanced and more stable (Ullah et al., 2022). Therefore, based on the above analysis, we propose

H₅: Technological innovation with the regulatory role of institutional quality impacts sustainable growth.

Trade Openness and Sustainable Growth

The impact of trade openness on sustainable growth remains controversial and previous research offers conflicting conclusions. The prevailing view, based on long term historical evidence, is that trade liberalization may have negative environmental effects by increasing CO2 emissions and weakening green development objectives (Barkat et al., 2025; Naimoğlu et al., 2025). In contrast, some regional studies suggest that trade can improve sustainability indicators when it is accompanied by a high share of clean energy use (Lu et al., 2025; Vankov & Lukarev, 2025). Statistically insignificant findings in developing economies (Pham et al., 2025) further show that the impact of trade is not linear but depends strongly on national characteristics and development thresholds. These inconsistencies and the high degree of contextual dependence in previous studies create a significant research gap concerning the real effect of trade openness. Based on this, we propose the following hypothesis

H₆: Trade openness negatively impacts sustainable growth.

Foreign Direct Investment and Sustainable Growth

The effect of foreign direct investment on sustainable growth also remains empirically unclear. Some studies suggest that foreign direct investment has a positive impact on Pakistan's economic growth in both the short and long term within the context of sustainable development.

Evidence from 30 Chinese provinces over the period from 2000 to 2019 also indicates that foreign direct investment is beneficial mainly in the long term (Kanval et al., 2019; Wei et al., 2022). However, other studies argue that foreign direct investment may negatively affect sustainable growth. Foreign direct investment can increase CO2 emissions from production and thereby harm sustainable economic development (Ketchoua et al., 2024). Arthur et al. (2024) also finds a clearly negative effect of foreign direct investment on sustainable development in 48 African economies between 1990 and 2020. These inconsistent findings require a clearer explanation of the role of foreign direct investment in the present research model. Therefore, we propose the following hypothesis

H₇: Foreign direct investment has a positive impact on sustainable growth.

Domestic Credit Private Sector and Sustainable Growth

The role of domestic credit to the private sector in sustainable growth remains debated. Some studies warn that the expansion of private sector credit increases CO2 emissions and reflects the limited efficiency of credit allocation toward environmentally sustainable initiatives in Indonesia and African countries (Hariyadi et al., 2025; Byaro et al., 2024). In contrast, other evidence shows that bank credit to the private sector has a significant negative effect on total CO2 emissions and carbon emission intensity in both the short and long term (Nwani et al., 2020). Because of these empirical inconsistencies and the need to determine the actual role of this capital flow, further research should examine this relationship from a broader perspective. Therefore, we propose the following hypothesis

H₈: Private sector domestic credit negatively affects sustainable growth.

Total natural resources rents and Sustainable Growth

The relationship between natural resource rents and sustainable growth remains contentious because it reflects a conflict between financial benefits and ecosystem stability. On the one hand, optimistic views suggest that revenues from minerals and gas can provide financial resources for reinvestment in ecological indicators if they are managed effectively (Ullah et al., 2021; Fu et al., 2023). On the other hand, empirical evidence often shows that efforts to improve environmental outcomes through resource revenues may reduce the momentum of purely economic growth (Arslan et al., 2022). In addition, uncontrolled resource exploitation has been identified as a direct cause of increased CO2 emissions and serious damage to long term sustainable growth trajectories (Ulucak et al., 2020). Accordingly, we propose

H₉: Total natural resources rents have a positive impact on sustainable growth.

3. RESEARCH METHODOLOGY

3. 1. DATA AND SAMPLE

This study includes countries that issued green bonds during the period from 2010 to 2024. This sampling criterion ensures that the green finance variable reflects the actual level of green finance development and reduces potential bias caused by substantial differences between countries that have entered the green bond market and those that have not. After identifying the countries with green bond issuance, data for the remaining variables, including sustainable growth, technological innovation and institutional quality, were collected for the same sample. However, due to limitations related to data availability and completeness, the final dataset consists of panel data for 86 countries, including 46 developing and 40 developed countries, over the period from 2010 to 2024. The data were obtained from the World Bank Database and the IMF Database. The use of these major international financial data sources ensures accuracy

and consistency and strengthens the reliability of the empirical analysis and the scientific value of the study's conclusions. After data collection, the authors conducted data preprocessing and regression analysis using Stata.

3. 2. VARIABLE MEASUREMENTS

Adjusted net savings (ANS) is an indicator calculated by adding education expenditure to national net savings and deducting losses associated with energy depletion, mineral depletion, net forest depletion, carbon dioxide emissions and particulate matter emissions. In this study, the World Bank's adjusted net savings indicator is used to measure sustainable growth for each country. ANS is considered an appropriate proxy because it shifts the analytical focus from "growth at all costs" toward the accumulation of sustainable value. A negative ANS value indicates that a country is following an unsustainable development path, even when GNI or GDP indicators continue to show positive performance. Several international studies have used ANS as a dependent variable in panel data analysis, including [Burlacu et al. \(2022\)](#). Their study examined the relationship between net savings, sustainable growth and resource depletion and showed that ANS positively affects GDP per capita and is closely linked to sustainability related factors, including the important objective of food security.

Green bonds (GB) are specific financial securities designed to finance climate and environmental projects. In this study, they are used as a proxy for green finance. Green bonds were selected as a measure of green finance for several reasons. First, they represent one of the few green finance instruments governed by relatively rigorous international standards. Second, green bond data are highly reliable because these instruments are publicly issued and traded, which enables systematic data collection over time. Third, green bonds account for the largest share of sustainable debt instruments and play a leading role in shaping standards for green credit and other related instruments. Data on green bonds were obtained from the International Monetary Fund (IMF). The study uses GB as an independent variable, following [Shi et al. \(2023\)](#), to examine whether green bond issuance generates positive effects and whether companies issuing green bonds increase green investment or merely engage in greenwashing. Research and development expenditure (RD) includes both capital and current expenditure on research and development by the government, higher education institutions, private enterprises and nonprofit organizations. Therefore, R&D expenditure is used in this study as a proxy for technological innovation. The data were obtained from Our World in Data (OWID). The RD variable is included as an independent variable, consistent with the approach used by [Yao et al. \(2022\)](#).

Institutional quality (IQ) is used as the moderating variable in this study. A composite institutional quality index was constructed using principal component analysis (PCA) based on six indicators from the International Country Risk Guide and World Bank data. These indicators include Government Effectiveness (GE), Control of Corruption (CC), Political Stability and Absence of Violence and Terrorism (PV), Regulatory Quality (RQ), Rule of Law (RL) and Voice and Accountability (VA). This proxy has been widely applied in international empirical research and a similar approach was used by [Kaufman et al. \(2011\)](#). Institutional quality is expressed numerically on a scale ranging from negative to positive values. Positive values indicate stronger institutional quality, whereas negative values reflect weaker institutional conditions.

Trade openness (TRADE) reflects the extent to which international trade creates opportunities for the diffusion of green financial instruments and environmentally friendly technological

innovations in support of sustainable development. In this study, trade openness is included as a control variable. Data for the selected countries were obtained from Our World in Data (OWID). Trade openness has been widely examined in the literature on sustainable development, although empirical findings remain mixed. Some studies identify a positive relationship between trade openness and sustainable development, such as Halim et al. (2024), while others report an inverse relationship, as shown by Sheihk et al. (2020).

Domestic credit to the private sector (DCPS) is also included as a control variable. It refers to financial resources provided to the private sector through loans, purchases of non-equity securities, trade credit and other receivables that create claims for repayment. In some countries, this indicator also includes credit extended to state owned enterprises. Data on domestic credit to the private sector were obtained from Our World in Data (OWID). This variable has been widely used in previous empirical studies, including Shahbaz et al. (2013) and Park et al. (2018).

Foreign direct investment (FDI) is used as a control variable to measure the annual inflow of foreign direct investment into each country. The data were collected from Our World in Data. FDI can support economic growth by mobilizing capital, improving labor productivity and facilitating technological progress. Previous studies that have used FDI in related research include Naimoğlu et al. (2025) and Ulhaq et al. (2023).

Total natural resources rent (RENT) is included as a control variable and represents the sum of rents from oil, natural gas, coal, including hard and soft coal, minerals and forests. The data were obtained from Our World in Data. Ullah et al. (2021) found a positive relationship between total natural resource rents and sustainable development. However, other studies report different findings, suggesting either a negative effect or no significant effect, as shown in the studies by Fu et al. (2023) and Ulucak et al. (2020).

Quantitative analysis was performed using Stata 17 to evaluate the impact of the selected variables on sustainable growth. Detailed descriptions of all research variables are presented in Table 1.

Table 1. Description of Variables

Variables	Definition	Measurement
Dependent variable		
ANS	Adjusted net savings, including particulate emission damage (%GNI)	Net national savings plus education expenditure and minus energy depletion, mineral depletion, net forest depletion, carbon dioxide and particulate emissions damage
Independent variables		
GB	Green Bonds (%GDP)	$GB = \frac{\text{Value of green bonds issued}}{GDP} \times 100\%$
RD	Research and development expenditure (%GDP)	$RD = \frac{\text{Domestic R\&D Expenditure}}{GDP} \times 100\%$
Moderating Variable		
IQ	Institutional Quality	Constructed by 6 global governance indexes: Government Effectiveness (GE), Control of Corruption (CC), Political Stability and Absence of Violence (PV), Regulatory Quality (RQ), Rule of Law (RL), Voice and Accountability (VA)
Control Variables		
TRADE	Trade (%GDP)	$TRADE = \frac{\text{Total Exports and Imports}}{GDP} \times 100\%$
FDI	Foreign direct investment, net inflows (% GDP)	$FDI = \frac{\text{Net FDI inflows}}{GDP} \times 100\%$
DCPS	Domestic credit to private sector (%GDP)	World Bank database
RENT	Total natural resources rents (%GDP)	Total natural resources rents are the sum of oil rents, natural gas rents, coal rents (hard and soft), mineral rents, and forest rents

Source: Author's own construction

3. 3. RESEARCH MODEL

3. 3. 1. RESEARCH METHODOLOGY

To systematically examine the effects of green finance and technological development on sustainable growth, this study employs panel data regression techniques. More specifically, the analysis applies the System Generalized Method of Moments (System GMM) estimator developed by [Arellano and Bover \(1991\)](#).

The use of System GMM instead of conventional models such as OLS or fixed effects is methodologically justified. As noted by [Roodman \(2009\)](#), this estimator is particularly suitable for macroeconomic variables characterized by lagged effects and potential reverse causality. In the context of this study, green finance and technological innovation may contribute to sustainable growth, while sustainable growth itself may also create favourable conditions for green investment and innovation. Therefore, System GMM helps address endogeneity by using lagged variables as instruments, thereby improving the consistency and reliability of the estimated coefficients ([Hansen, 1982](#)).

Before conducting the main estimation, the study performed several diagnostic tests to identify the most appropriate model specification and control for potential panel data problems. The Breusch–Pagan test ([Breusch & Pagan, 1980](#)) was used to examine whether individual specific effects were present relative to the pooled OLS model. In addition, possible violations of the classical error assumptions were tested through the Wooldridge test for autocorrelation ([Wooldridge, 2002](#)) and the Modified Wald test for heteroskedasticity ([Greene, 2000](#)). The presence of these issues provided an important methodological basis for applying the System GMM estimator, which is designed to produce consistent and efficient estimates even when the Gauss-Markov assumptions are not fully satisfied.

To assess the robustness of the results, the study compares the System GMM estimates with those obtained from pooled OLS and fixed effects models. Although OLS and fixed effects estimators may suffer from Nickell bias in dynamic panel settings ([Nickell, 1981](#)), this comparison allows the study to evaluate whether the direction and magnitude of the marginal effects remain stable across different model specifications. Finally, the validity of the System GMM results is examined using the Arellano-Bond test for second order autocorrelation ([Arellano & Bond, 1991](#)) and the Hansen test for the validity of instrumental variables ([Hansen, 1982](#)). This multi-step procedure strengthens the reliability of the conclusions regarding the effects of green finance and technological development on sustainable growth.

3. 3. 2. RESEARCH MODEL

This study uses the following three models:

Model 1: Research the impact of green finance on sustainable growth

$$ANS_{i,t} = \beta_0 + \beta_1 GB_{i,t} + \beta_2 TRADE_{i,t} + \beta_3 FDI_{i,t} + \beta_4 RENT_{i,t} + \beta_5 DCPS_{i,t} + \varepsilon_t \quad (1)$$

Model 2: Research the impact of technological innovation on sustainable growth

$$ANS_{i,t} = \beta_0 + \beta_1 RD_{i,t} + \beta_2 TRADE_{i,t} + \beta_3 FDI_{i,t} + \beta_4 RENT_{i,t} + \beta_5 DCPS_{i,t} + \varepsilon_t \quad (2)$$

Model 3: Research the moderating role of institutional quality in the relationship between green finance, technological innovation, and sustainable growth

$$ANS_{i,t} = \beta_0 + \beta_1 GB_{i,t} + \beta_2 RD_{i,t} + \beta_3 TQ_{i,t} + \beta_4 (GB \times IQ)_{i,t} + \beta_5 (RD \times IQ)_{i,t} + \beta_6 TRADE_{i,t} + \beta_7 FDI_{i,t} + \beta_8 RENT_{i,t} + \beta_9 DCPS_{i,t} + \varepsilon_t \quad (3)$$

Where:

- $ANS_{i,t}$: Sustainable growth index of country i at time t.
- $GB_{i,t}$: Green bonds, representing the level of development of green finance in country i at time t.
- $RD_{i,t}$: Technological innovation, measured by spending on research and development (R&D) in country i at time t.
- $IQ_{i,t}$: Institutional quality, reflecting the effectiveness of the legal system, public administration, corruption control, and property protection in country i at time t.
- $TRADE_{i,t}$; $FDI_{i,t}$; $RENT_{i,t}$; $DCPS_{i,t}$ Control variables from previous studies affecting sustainable growth.

4. RESULTS

4. 1. DESCRIPTIVE STATISTICS

Table 2. Descriptive statistics for the variables in the model

Variables	N	Mean	SD	Min	Max
Panel A: Developed countries					
ANS	392	10.6842	7.1628	-7.0474	36.2533
GB	392	0.0092	0.0294	-0.0410	0.1802
RD	392	2.0804	1.0105	0.4526	4.9145
IQ	392	0.0442	2.1397	-4.7118	3.1667
TRADE	392	1.1436	0.7389	0.2645	3.7558
FDI	392	1.1771	1.4843	-3.3133	5.6694
RENT	392	0.0076	0.0159	1.6906	0.0934
DCPS	392	1.0704	0.4584	0.3473	2.4342
Panel B: Developing countries					
ANS	426	9.6027	8.2076	-6.3368	31.6869
GB	426	0.0008	0.0073	-0.0327	0.0414
RD	426	0.5629	0.4404	-0.0349	2.1160
IQ	426	0.2061	1.8145	-3.5232	4.8599
TRADE	426	0.7646	0.3696	0.2453	1.6618
FDI	426	0.9437	0.9483	-1.6246	3.6916
RENT	426	0.0581	0.0783	0.00003	0.4134
DCPS	426	0.5848	0.3547	0.1003	1.6011

Source: Author's own construction

The mean value of the Sustainable Growth Index (ANS) is higher in developed countries (10.6842) than in developing countries (9.6027), suggesting that developed economies generally achieve a higher level of sustainable development. In addition, developed countries show

a more advanced level of green finance development, which is consistent with the argument of [Taghizadeh-Hesary and Yoshino \(2019\)](#) that well developed financial systems are more effective in mobilizing resources for green projects. The average values of technological innovation (RD) and institutional quality (IQ) are also higher in developed countries, further indicating that technological capacity and institutional strength play important roles in supporting sustainable growth. This finding is in line with the results reported by [Aydin et al. \(2024\)](#).

4. 2. REGRESSION MODEL

To ensure the model's suitability and reliability, the study tested for multicollinearity using the tolerance index and variance inflation factor (VIF). According to [Hair et al. \(2006\)](#), severe multicollinearity occurs when the VIF exceeds 10. Therefore, maintaining a low VIF is necessary.

Table 3. VIF coefficients of models (1), (2), (3)

Variables	Developed countries						Developing countries					
	Model (1)		Model (2)		Model (3)		Model (1)		Model (2)		Model (3)	
	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF	VIF	1/VIF
GB	1.24	0.8056			4.14	0.2413	1.15	0.8702			5.23	0.1911
RD			1.17	0.8576	1.89	0.5303			1.19	0.8387	1.37	0.7311
IQ					8.48	0.1179					3.99	0.2505
TRADE	1.88	0.5321	1.73	0.5773	2.50	0.4007	1.49	0.6720	1.35	0.7389	1.72	0.5817
FDI	1.52	0.6584	1.54	0.6511	1.56	0.6404	1.28	0.7809	1.28	0.7787	1.38	0.7272
RENT	1.06	0.9447	1.09	0.9188	1.41	0.7086	1.06	0.9413	1.04	0.9575	1.06	0.9404
DCPS	1.14	0.8802	1.18	0.8466	1.50	0.6653	1.15	0.8665	1.29	0.7747	1.70	0.5875
GB*IQ					4.54	0.2202					4.95	0.2020
RD*IQ					6.06	0.1650					3.98	0.2514
Mean VIF	1.37		1.34		3.57		1.23		1.23		2.82	

Source: Author's own construction

The multicollinearity test results reported in Table 2 show that all VIF values are below the threshold of 10. This indicates that multicollinearity is not a serious concern in the three research models.

To empirically examine the effects of green finance and technological innovation on sustainable growth and to account for the moderating role of institutional quality, this study estimates models (1), (2) and (3) using pooled ordinary least squares, the fixed effects method and the random effects method. The results are then compared with those obtained from the GMM model. The analysis is conducted separately for developed and developing country groups to capture heterogeneous effects across different economic contexts. The regression results for models (1), (2) and (3) estimated using pooled OLS, FEM, REM and GMM are presented in Tables 4, 5 and 6 respectively.

First, the study assesses the impact of green finance on sustainable growth across the two groups of countries within the framework of model (1).

Table 4. The impact of green finance on sustainable growth

Variables	Developed countries				Developing countries			
	OLS	RE	FE	GMM	OLS	RE	FE	GMM
L.ANS				0.2129*** (0.009)				0.7336*** (0.000)
GB	-13.8042 (0.168)	-0.0569 (0.992)	0.7759 (0.889)	-23.6594** (0.020)	-11.1588 (0.718)	-72.3853** (0.042)	-64.9945* (0.071)	-25.906*** (0.001)
TRADE	6.5976*** (0.000)	2.6275*** (0.005)	1.1756 (0.326)	4.6928*** (0.000)	5.2619*** (0.000)	6.6557*** (0.000)	6.7185*** (0.000)	2.2249*** (0.003)
FDI	-0.5204* (0.055)	0.1468 (0.301)	0.1429 (0.312)	-0.3612*** (0.003)	-1.3707*** (0.006)	-0.3922 (0.173)	-0.3466 (0.232)	-0.5470*** (0.007)
RENT	93.7124*** (0.000)	12.9017 (0.559)	1.3381 (0.954)	61.0094 (0.126)	17.9231*** (0.003)	11.5633** (0.025)	9.4434* (0.080)	0.7269 (0.774)
DCPS	2.9874*** (0.000)	-4.0783*** (0.000)	-4.9621*** (0.000)	1.2412 (0.286)	1.9526 (0.104)	-6.760*** (0.000)	-8.5868*** (0.000)	-0.3706 (0.445)
__cons	-0.0344 (0.978)	11.7326*** (0.000)	14.4654*** (0.000)	1.5620 (0.406)	4.6987*** (0.000)	8.6196*** (0.000)	9.3149*** (0.000)	1.2241** (0.040)
N	392	392	392	359	426	426	426	388
R-squared	0.3258	0.1521	0.1573		0.0979	0.1409	0.1430	
S test				0.001				0.003
H test				0.221				0.177
AR (1)				0.023				0.001
AR (2)				0.954				0.497

Source: Author's own construction

Table 4 indicates that green finance (GB) has a statistically significant negative effect on short-term sustainable growth in both country groups under the GMM model. More specifically, the coefficient of GB is negative and statistically significant for both developed and developing countries. In developed countries, the GB coefficient is -23.6594 and is significant at the 5% level, whereas in developing countries the coefficient is -25.906 and is significant at the 1% level. This suggests that, in the short term, an expansion of green finance may reduce the sustainable growth index, with a stronger effect observed in developing countries.

This finding can be interpreted through Intertemporal Trade off Theory and the ecological J curve effect (Hafner et al., 2020). In the short term, the expansion of green capital may generate a structural resource reallocation shock by shifting financial flows away from traditional, highly profitable carbon intensive industries toward emerging green projects (He et al., 2019). From the perspective of Transaction Cost Economics, initial compliance costs can create financial pressure and temporarily offset the positive effects of green capital flows (Zhang et al., 2022). Since green infrastructure is capital intensive and requires a longer period of capital accumulation, its positive marginal productivity may not materialize immediately.

The stronger negative effect observed in developing countries can be further explained by Absorptive Capacity Theory. Less developed institutional systems and shallower financial markets in these economies may intensify market frictions and amplify cost distortions caused by information asymmetry and greenwashing (Asongu et al., 2021). In addition, limited supporting technologies and shortages of high-quality human capital may extend the payback period of green projects (Aboelmaged and Hashem, 2019). By contrast, developed countries generally possess more mature governance systems and stronger performance screening mechanisms, which can reduce these frictional losses.

Next, the study examines the effect of technological innovation on sustainable growth in the two country groups within the framework of model (2).

Table 5. The impact of technological development on sustainable growth

Variables	Developed countries				Developing countries			
	OLS	RE	FE	GMM	OLS	RE	FE	GMM
L.ANS				0.5072*** (0.000)				0.6488*** (0.000)
RD	4.1431*** (0.000)	1.3126*** (0.003)	-0.1115 (0.825)	1.3460** (0.021)	-0.5740 (0.558)	3.3141** (0.011)	3.9787*** (0.005)	5.8535* (0.075)
TRADE	6.5976*** (0.000)	7.3065*** (0.000)	3.6772*** (0.000)	3.2460*** (0.000)	5.1407*** (0.000)	6.3283*** (0.000)	6.3960*** (0.000)	3.890** (0.014)
FDI	-0.5204* (0.055)	-0.0941 (0.648)	0.1317 (0.366)	-0.1630 (0.287)	-1.3861*** (0.005)	-0.3339 (0.239)	-0.3061 (0.283)	-0.528 (0.511)
RENT	93.7124*** (0.000)	135.9417*** (0.000)	31.3882 (0.152)	50.7745** (0.047)	17.8541*** (0.004)	11.960** (0.074)	9.5664* (0.074)	11.575* (0.051)
DCPS	2.9874*** (0.000)	1.1608** (0.021)	-3.4731*** (0.000)	0.1904 (0.781)	2.2852* (0.053)	-8.5214*** (0.019)	-10.6457*** (0.000)	-3.707* (0.093)
__cons	-0.0344 (0.978)	-8.46108*** (0.000)	7.0341*** (0.000)	-1.8344 (0.252)	4.930*** (0.000)	7.9243*** (0.000)	8.4311*** (0.000)	-1.130 (0.397)
N	392	392	392	359	426	426	426	352
R-squared	0.3258	0.6162	0.1229		0.0986	0.1512	0.1535	
S test				0.029				0.006
H test				0.145				0.347
AR (1)				0.004				0.001
AR (2)				0.926				0.484

Source: Author's own construction

Based on the GMM regression results presented in Table 5, technological innovation (RD) has a positive and statistically significant effect on sustainable growth in both country groups. The estimated coefficients of RD are positive, with values of 1.3460 for developed countries and 5.8535 for developing countries. These coefficients are statistically significant at the 5% level and the 10% level respectively. This confirms that greater investment in technological innovation contributes to sustainable growth and that this effect is considerably stronger in developing countries than in developed countries.

This finding also suggests that the positive contribution of technological innovation outweighs the potential risks associated with the “rebound effect” (Herring & Sorrell, 2009). The positive coefficient of RD indicates that the overall effect of technological innovation on sustainable growth remains favorable, as improvements in resource efficiency, productivity gains and support for the green transition exceed the additional consumption that may result from economies of scale. Moreover, the stronger effect observed in developing countries can be explained by the leapfrogging effect. In this context, developing countries may adopt advanced clean technologies directly and replace outdated technologies without passing through the same full technological development path experienced by developed economies (Goldemberg, 1998).

Finally, the study examines the moderating role of institutional quality in the relationship between green finance, technological innovation and sustainable growth within the framework of model (3).

Table 6. The impact of green finance and technological innovation on sustainable growth, with institutional quality playing a moderating role

Variables	Developed countries				Developing countries			
	OLS	RE	FE	GMM	OLS	RE	FE	GMM
L.ANS				0.1381*** (0.000)			-16.156 (0.809)	0.1669*** (0.000)
GB	-0.1035 (0.994)	6.5157 (0.488)	7.4195 (0.428)	-26.5938** (0.017)	150.5186* (0.051)	-20.671 (0.754)	3.332** (0.022)	188.938*** (0.000)
RD	3.2169*** (0.000)	0.7464* (0.079)	-0.0302 (0.428)	1.1790*** (0.005)	-0.5145 (0.613)	2.939** (0.027)	-17.586 (0.339)	5.464*** (0.000)
GB*IQ	-24.9578* (0.075)	-8.0430 (0.191)	-6.3900 (0.428)	-4.6473 (0.546)	-55.1531** (0.015)	-18.315 (0.317)	0.519 (0.487)	-93.447*** (0.000)
RD*IQ	-0.3218*** (0.009)	-0.9608*** (0.000)	-1.0604*** (0.428)	-0.5118*** (0.001)	-0.0318 (0.957)	0.273 (0.696)	-0.984 (0.113)	-0.736 (0.262)
IQ	1.3728*** (0.000)	3.1641*** (0.000)	2.8171*** (0.428)	1.9406*** (0.000)	-0.480 (0.219)	-0.685 (0.216)	6.735*** (0.000)	-0.076 (0.880)
TRADE	6.9825*** (0.000)	3.4770*** (0.000)	2.0922* (0.428)	4.4151*** (0.000)	5.7103*** (0.000)	6.729*** (0.000)	-0.432 (0.135)	7.367*** (0.000)
FDI	-0.1365 (0.454)	0.0890 (0.516)	0.1124 (0.428)	-0.1703 (0.103)	-1.333** (0.014)	-0.452 (0.114)	8.219 (0.127)	-0.773*** (0.000)
RENT	96.2616*** (0.000)	9.4858 (0.649)	-4.2022 (0.428)	21.0833 (0.448)	17.8528*** (0.005)	8.219 (0.039)	-10.059*** (0.000)	13.935*** (0.009)
DCPS	0.2362 (0.631)	-4.1025*** (0.000)	-4.8938*** (0.428)	-0.7278 (0.229)	2.9370** (0.031)	-10.059*** (0.000)	8.492*** (0.000)	-2.433** (0.046)
__cons	-4.290*** (0.001)	10.010*** (0.000)	14.2581*** (0.000)	3.0007* (0.068)	4.0189*** (0.000)	10.597** (0.000)	426	0.207 (0.891)
N	392	392	392	359	426	426	426	388
R-squared	0.6561	0.2107	0.2238		0.1104	0.1640	0.1668	
S test				0.000				0.000
H test				0.128				0.346
AR (1)				0.028				0.040
AR (2)				0.853				0.110

Source: Author's own construction

Table 6 highlights the important moderating role of institutional quality in the process of sustainable development. In developing countries, green finance (GB) has a coefficient of 188.938 and is statistically significant at the 1% level, while technological innovation (RD) has a coefficient of 5.464 and is statistically significant at the 5% level. In developed countries, the coefficients of GB and RD are 26.5938 and 1.1790 respectively. Institutional quality (IQ) also has a direct positive effect on sustainable growth in developed countries, with a coefficient of 1.9406, statistically significant at the 1% level.

A particularly important finding is the interaction term GB*IQ in the developing country group, which has a coefficient of -93.447 and is statistically significant at the 1% level. This result suggests that institutional quality plays a decisive role in shaping the effectiveness of green finance. It also indicates that, in developing countries, improvements in institutional frameworks are urgently needed to optimize green capital allocation and reduce inefficiencies associated with weak governance, market frictions or misdirected financial flows.

5. DISCUSSION

Table 7 provides a summary comparison between the proposed hypotheses and the empirical findings. This comparison serves as the basis for assessing the extent to which each research hypothesis is supported by the results.

Table 7. Comparison between the hypothesis and the model research results

Assumptions	Conclusion
H ₁ : Green Finance impacts Sustainable Growth	Partial acceptance
H ₂ : Technological Innovation impacts Sustainable Growth.	Accept
H ₃ : Institutional Quality impacts Sustainable Growth.	Partial acceptance
H ₄ : Green Finance, with the regulatory role of Institutional Quality, impacts Sustainable Growth.	Partial acceptance
H ₅ : Technological Innovation, with the regulatory role of Institutional Quality, impacts Sustainable Growth.	Partial acceptance
H ₆ : Trade Openness impacts Sustainable Growth.	Accept
H ₇ : Foreign Direct Investment Impacts Sustainable Growth.	Partial acceptance
H ₈ : Domestic Credit to Private Sector impacts Sustainable Growth.	Partial acceptance
H ₉ : Total Natural Resources Rents Impact Sustainable Growth.	Partial acceptance

Source: Author's own construction

Based on the regression results, this study draws several conclusions regarding the effects of green finance, technological innovation and institutional quality on sustainable growth, while also clarifying the differences between developed and developing countries.

Firstly, green finance has a negative effect on sustainable growth in the short term. The empirical results from model (1) show that green finance exerts a statistically significant negative impact on sustainable growth, although the magnitude of this effect differs between the two country groups. More specifically, the coefficient of green finance (GB) is negative in both samples, with a value of -23.6594 for developed countries, significant at the 5% level, and -25.906 for developing countries, significant at the 1% level. These results suggest that, in the short term, the expansion of green finance may increase structural adjustment pressure and transition costs, thereby weakening the momentum of sustainable growth, particularly in developing economies.

This finding is consistent with [Sachs et al. \(2019\)](#), who argue that early-stage green investments are often associated with considerable transition costs, including the costs of adopting clean technologies, complying with environmental standards and restructuring production processes. These costs may increase the financial burden in the short term. Similarly, [Taghizadeh Hesary et al. \(2020\)](#) emphasizes that, in developing economies, the efficiency of green capital allocation is constrained by incomplete financial markets and insufficiently coordinated supporting policies.

The regression results also show that the coefficient of the lagged dependent variable (L.ANS) is positive and statistically significant at the 1% level in both country groups, with values of 0.2129 for developed countries and 0.7336 for developing countries. This reflects the persistence and cumulative dynamics of sustainable growth over time. Since the benefits of green finance are usually realized in the medium and long term through technological innovation and improved energy efficiency ([Banga, 2019](#); [Zhou et al., 2020](#)), the short-term negative effect can be interpreted as a consequence of the initial stage of the green transition, when structural adjustment costs still exceed the expected economic and environmental benefits.

Secondly, technological innovation has a positive effect on sustainable growth in both developed and developing countries. The coefficients are 1.3460 for developed countries and

5.8535 for developing countries, statistically significant at the 5% and 10% levels respectively. These findings confirm the role of technological innovation as a key driver of long-term sustainable growth. The stronger effect observed in developing countries is particularly important. It suggests that technological development can generate a catch-up effect, enabling these economies to narrow the development gap by adopting advanced technologies and applying them to greener and more efficient production models.

This result is consistent with [Aghion et al. \(2019\)](#), who argue that technological development improves productivity, increases the efficiency of resource use and reduces emission intensity in production. In developed countries, where the technological base is already relatively advanced, the marginal impact of additional R&D investment tends to be lower. This finding also aligns with [Grossman and Krueger \(1995\)](#), who suggest that technological progress can reduce the tradeoff between economic growth and environmental protection. At the same time, the results indicate that concerns regarding the rebound effect are not strong enough to offset the net positive contribution of technological innovation to sustainable growth.

However, the R&D variable in developing countries is statistically significant only at the 10% level, suggesting that the effectiveness of technological innovation remains constrained by institutional quality, human capital and the commercialization capacity of research. This implies that the impact of technological innovation depends not only on the volume of R&D investment but also on the ability of economies to absorb technology and on the institutional environment that supports innovation. Overall, technological development represents a crucial driver of sustainable growth. Developing countries should therefore combine higher R&D investment with institutional improvements and stronger technological absorption capacity to maximize the effectiveness of the green transition.

Thirdly, institutional quality plays an important moderating role in the relationship between green finance, technological innovation and sustainable growth. The quantitative results from model (3) show that institutional quality not only directly affects sustainable growth but also conditions the effectiveness of green finance and technological innovation. This means that the contribution of green finance and technological innovation to sustainable growth depends significantly on the quality of the institutional environment in each country.

Institutional quality determines the degree of market transparency, the efficiency of resource allocation and the capacity for policy implementation. These factors influence the extent to which green capital and technological innovation can be transformed into sustainable growth. This finding is consistent with [North's \(1990\)](#) view that institutions are a fundamental determinant of long-term economic performance. The results further show that the moderating role of institutional quality differs between developed and developing countries. In developing countries, institutions are especially important for reducing resource misallocation and improving the efficiency of green capital flows in the context of less developed financial markets. [Beck et al. \(2010\)](#) similarly argue that weak institutional systems reduce the effectiveness of financial instruments.

With respect to technological innovation, institutional quality helps convert R&D activities into sustainable growth, particularly in developed countries, which is consistent with [Acemoglu et al. \(2012\)](#). More broadly, institutional quality can be understood as a key catalyst that determines the effectiveness of green finance and technological innovation in supporting sustainable growth ([Aghion et al., 2016](#)).

Regarding the control variables, the results show that trade openness (TRADE) has a positive effect on sustainable growth. This reflects the role of trade integration in facilitating technology diffusion, improving resource allocation efficiency and expanding access to advanced production standards. This finding is consistent with [Adebayo and Kirikkaleli \(2021\)](#), [Le et](#)

al. (2020) and the UNCTAD report (2021), which suggest that deeper participation in global value chains allows countries to access clean technologies and improve the quality of growth. By contrast, foreign direct investment (FDI) has a negative effect on sustainable growth. This indicates that FDI inflows do not always contribute positively to sustainable development, particularly in countries where environmental standards and monitoring mechanisms are weak. Studies such as Zafar et al. (2019) and Acheampong et al. (2021) show that the effect of FDI depends strongly on institutional quality. In developing economies, FDI may be concentrated in resource extracting or pollution intensive industries when environmental regulations are not sufficiently strict (UNCTAD, 2022).

Natural resource rents (RENT) show a mixed effect, reflecting the dual role of natural resources in sustainable growth. Ahmad et al. (2023) and Zhang et al. (2024) suggest that natural resources can hinder development when effective governance is absent, while the IMF (2022) emphasizes that resource revenues support sustainable growth only when they are reinvested in green technologies and infrastructure.

Finally, domestic credit to the private sector (DCPS) shows unstable and sometimes negative effects. This suggests that credit expansion contributes to sustainable growth only when financial resources are effectively directed toward technological innovation, green manufacturing and long-term productivity enhancing activities (World Bank, 2020).

6. CONCLUSION AND RECOMMENDATIONS

6. 1. CONCLUSION

In the context of growing global challenges related to environmental degradation, climate change and the need to transform existing growth models, the findings of this study provide important academic and policy implications. Firstly, the study confirms that green finance and technological innovation should be regarded as central pillars of sustainable growth strategies, particularly in developing countries. The expansion of green financial instruments, together with increased investment in technological innovation, can generate positive spillover effects by supporting economic growth while reducing pressure on the natural environment. Secondly, the findings demonstrate that institutional quality plays a fundamental role in determining the effectiveness of green finance and technological innovation policies. A transparent, efficient and stable institutional framework improves the allocation of capital, reduces policy risks and encourages stronger private sector participation in green investment and R&D activities. Thirdly, the differences between developed and developing countries suggest that a uniform policy approach cannot be applied to all economies. Developing countries should prioritize improvements in institutional quality alongside the expansion of green finance, whereas developed countries should focus on improving the effectiveness of technological innovation policies and reducing adjustment costs during the green transition. Overall, the results clarify the complex relationship between green finance, technological innovation and sustainable growth. They also confirm the crucial role of institutional quality as a strategic regulatory factor. The coordinated integration of these elements is therefore essential for achieving long term sustainable growth.

6. 2. RECOMMENDATIONS

The research findings provide a comprehensive perspective on how green finance and technological innovation influence sustainable growth, while also revealing clear differences be-

tween developed and developing countries and confirming the significant moderating role of institutional quality. Based on the empirical results, this section presents policy implications adapted to the specific conditions of each country group, with the aim of turning short term transition challenges into long term drivers of sustainable growth.

For developed countries, policy priorities should focus on strengthening institutional frameworks and supporting disruptive innovation. Ministries responsible for finance and environmental protection should jointly develop a phased green transition roadmap with gradually stricter emission standards. This should be supported by preferential credit schemes, grace periods and accelerated depreciation mechanisms for clean technology equipment in order to reduce the initial compliance costs faced by businesses. Financial supervisory authorities and securities commissions should introduce detailed green classification criteria for each sector, require independent audits of projects financed through green bonds and strengthen transparency in green finance markets. In addition, central banks should provide guidance on the integration of environmental risk screening into credit assessment procedures in order to improve the efficiency of capital allocation.

In the field of technology, ministries responsible for science and technology should establish national green innovation funds to support basic research and breakthrough technologies, including green hydrogen and carbon capture. Universities should also be encouraged to develop clean technology incubators that are directly connected with the private sector. To ensure social equity during the transition, ministries of labour should introduce fair transition programs that include retraining measures and temporary subsidies for workers affected by structural changes. At the same time, ministries responsible for commerce and finance should develop an appropriate carbon border adjustment mechanism. Revenues from carbon taxation should be partly redirected toward supporting green technologies in developing countries, thereby reducing the risk of carbon leakage and contributing to global equity.

For developing countries, the main priorities should be institutional reform, stronger technological absorption capacity and the inclusive development of the green financial system. Ministries of justice and finance should propose a comprehensive green finance law to national parliaments, clearly defining standards for classifying green projects, mechanisms for monitoring green bond issuance and sanctions against greenwashing. At the same time, governments should establish a green growth coordination agency to reduce policy fragmentation and improve coordination among institutions.

To reduce short term cost pressures, central banks should encourage credit institutions to apply progressive preferential interest rates linked to firms' environmental improvement outcomes. Ministries of finance should also establish national green credit guarantee funds to help small and medium sized enterprises access capital without excessive collateral requirements. In order to benefit from the technology catch up effect, ministries of science and technology should negotiate mandatory clean technology transfer clauses in trade and investment agreements. Ministries of planning and investment should develop green technology zones supported by strong tax incentives, while ministries of education should reform training programs by strengthening STEM fields and linking them more directly to environmental practice.

With regard to foreign capital flows, ministries of natural resources and environment should coordinate with ministries of planning and investment to define priority green investment sectors. They should also refuse licenses for FDI projects that rely on outdated technologies. In addition, progressive resource tax rates and environmental restoration deposits should be introduced. Revenues from natural resources should be managed transparently through national asset funds, with at least 60% reinvested in green infrastructure and long term social welfare.

Finally, for green finance to become truly inclusive, central banks should support the development of micro green credit products for small and micro enterprises through simplified procedures. Business associations and ministries of industry and trade should organize free training programs on environmental management and green investment planning for business owners and connect them with the sustainable supply chains of large corporations.

These recommendations confirm that a single policy formula cannot be applied to all countries. Developed countries should focus on refining institutional systems and advancing disruptive innovation, while developing countries should prioritize institutional reform, technological absorption capacity and inclusive access to green capital. At the global level, international financial institutions should strengthen technical and financial support for developing countries in building legal frameworks and institutional capacity. Initiatives such as Just Energy Transition Partnerships should be expanded and supported by independent monitoring mechanisms. Developed countries should also fully implement their climate finance commitments and promote meaningful technology transfer. Only when policies are adapted to the specific characteristics of each country group and closely connected with international cooperation can green finance and technological innovation fully serve as pillars of sustainable global growth.

Authors' contributions

Conceptualization: Pham Tien Manh; Data curation: Ngo Thi Thanh Lan, Pham Khanh Linh; Formal analysis: Pham Tien Manh, Tran Thi Thu Huong; Funding acquisition: Tran Thi Thu Huong; Investigation: Nguyen Thanh Phuong; Methodology: Pham Tien Manh, Ngo Thi Thanh Lan, Pham Khanh Linh; Project administration: Pham Tien Manh, Tran Thi Thu Huong; Resources: Pham Tien Manh, Tran Thi Thu Huong; Software: Pham Tien Manh, Ngo Thi Thanh Lan, Pham Khanh Linh; Supervision: Pham Tien Manh, Tran Thi Thu Huong; Validation: Tran Thi Thu Huong, Nguyen Thanh Phuong; Visualization: Pham Tien Manh, Nguyen Thanh Phuong; Writing – original draft: Pham Tien Manh, Tran Thi Thu Huong, Ngo Thi Thanh Lan, Pham Khanh Linh, Nguyen Thanh Phuong; Writing – review & editing: Pham Tien Manh, Tran Thi Thu Huong.

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Conflicts of interest

The authors declare no conflict of interest.

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