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Green finance commitments and the alleviation of climate vulnerability in emerging economies: A pathway to sustainable development

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Abstract

Emerging economies are experiencing extreme climatic conditions that significantly affect sustainable development through the environmental route. These climatic conditions, being tied to growing population and increasing growth drives in emerging economies, are ultimately affecting sustainable development. With the ecological basis for green finance, this study aims to find out the role of green finance in mitigating climate vulnerability and also whether climate vulnerability effectively moderates its possible detrimental effect on sustainable development in emerging economies for 21 countries and from 2010 to 2023. The study found that green finance commitments in emerging economies reduce climate vulnerability in the short run with supportive regulation but harm the environment in the long run due to the inadequacy of regulatory frameworks. In contrast, green finance commitments adversely moderate the effects of climate vulnerability on sustainable development. This is a mirror reflection of regulatory failures to improve sustainable development as well. Based on this, emerging economies are required to make sure regulations are strong and constantly reviewed for long-term impact. Also, green finance commitments must be highly targeted and sequential to more vulnerable areas and countries first and before readjusting as the needs change.

Keywords: Climate vulnerability, Emerging economies, Green finance, Panel analysis.

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1. Introduction

Global climate changes are beginning to manifest on sustainable life due to the increased pace of long-term changes and intensities in environmental frequencies, such as floods, droughts and heatwaves. Climate vulnerability is seen as the composite concept that accounts for a country's sensitivity, exposure, and adaptive capacity to climate change [1]. Due to

this, the vulnerability of emerging economies has become a concern for their growth potential, where many of them are considered vulnerable due to their physical susceptibility to climate change, sectoral economic compositions, and minimal capacity to adapt [2]. The vulnerability of many emerging economies to global climate change continues even though they are low contributors to global warming [3].

The emergence of green finance are transformative efforts to the worsening climate problems and the pursuit of sustainable development in emerging economies, with its core tools, including green lending schemes, green bonds and financial instruments that are linked to the environment, playing pivotal roles in reducing carbon emissions, funding renewable energy, and enhancing ecological resilience [4-7]. This financial approach integrates environmental considerations into mainstream financial practices, aligning capital flows with climate and sustainability goals [8] while encouraging innovations in clean energy, green technologies, and low-carbon transport [9, 10]. To this end, institutions and governments have introduced supportive frameworks, like green finance commitments, to foster green investment [6, 11].

The growing green bonds issuance in the world, which reached $550.19 billion in 2022, illustrates the rising financial commitment toward climate action [12, 13]. Moreover, public-private partnerships, national green finance strategies, and CSR integration are further strengthening green finance ecosystems in countries like China, India, and Nigeria [14-16]. As a result, green finance is positioning to not only address systemic climatic and environmental risks but also support long-term economic stability and sustainable development pathways.

Despite this trend, emerging countries continue to struggle with various challenges to green bonds, especially regulatory and institutional inefficiencies and less developed financial infrastructures and regulatory inadequacies, which increase the potential risks associated with green investments and deter private sector engagement [17]. These challenges to green finance continue in the face of persisting reliance on fossil fuel use and rapid urbanization, which expose emerging economies to extreme climate conditions [4, 6]. As Biswal [3] also noted, the escalation of extreme weather, displacements, and food insecurity, especially in Sub-Saharan Africa, has deepened poverty and inequality. These impacts are exacerbated in rural and low-income communities that lack the infrastructure or resources to cope, as illustrated by Mokwena and Maphaka [18]. The Nigeria's example presents a fluctuating climatic pattern that have adversely affected agriculture, water supply, and livelihoods, demanding locally adapted communication and technology-driven solutions [19].

Besides, Gaillat and Guiet [20] further affirmed that the damaging influences of climate change on the economic life of emerging economies extend to individual firms with low adaptive capacity, despite the advantage of reduced climate risk exposure. Unanimously, studies have agreed that financing and investment policy that favour green finance is the way to go in the quest to mitigate climate exposure and sensitivity [4, 6, 15, 21, 22]. Based on this, this study aims to fill the existing gap by directly connecting green finance to climate vulnerability as a means of advancing sustainable development. This is a departure from most studies that independently focused on either green finance to mitigate climate risk or attaining sustainable goals [16, 23, 24].

There is also limited integration of climate vulnerability indicators, such as exposure, sensitivity, and adaptive capacity, into green finance analyses, with prior studies, often concentrating on climate risk, carbon emissions, or environmental quality without considering the multidimensionality of vulnerability [14, 25, 26]. Furthermore, existing studies tend to rely on correlation-based analysis without exploring causal pathways through mediation or moderation, thus failing to investigate how green finance may affect sustainable development through its influence on vulnerability [5, 6]. This forms the major contribution which the study makes to knowledge.

To this end, we first analyze the role of green finance in climate vulnerability by looking at how green financial instruments and expenditures affect emerging economies' ability to cope with climate vulnerability. The second goal is to assess if green finance helps reduce climate vulnerability and if it does, how such reductions affect the success of sustainable development in the long run. By providing a comprehensive understanding of these relationships, this research seeks to inform policymakers in emerging economies on strategies to manage green finances and climate vulnerability to attain sustainable development.

2. Literature Review

2.1. Conceptual Review

Climate vulnerability, as a concept, refers to the exposure and sensitivity of countries to high risks from climate change, and these effects are generally heightened by tough problems related to the economy, society, and institutions. These climate impacts are particularly more severe in emerging economies with disrupted rainfall patterns, floods, and droughts directly threatening agricultural productivity and water access [18, 19]. Furthermore, emerging economies are economically strained, with African countries spending up to 9% of their GDP on adaptation, highlighting the need for intentional financial decisions.

This study adopts the climate vulnerability index (CVI) contained in the Notre Dame Global Adaptation Initiative, also known as the ND-GAIN. Although the ND-GAIN index is a composite product of climate vulnerability and readiness, this study is particularly interested in the climate vulnerability index. The CVI estimates the likelihood of any country to be adversely affected by climate hazards. The ND-GAIN computation of climate vulnerability is on the basis of six sectors that support life, namely food, human habitat, ecosystem services, infrastructure and health. The sectors are then assessed based on three cross-country components, namely sensitivity, exposure and adaptive capacity.

The exposure component is concerned with the extent of susceptibility of countries and the supporting sectors to future climatic conditions. In computation, the ND-GAIN captures the physical factors that can make a country vulnerable to climate conditions. These factors include temperature, floods, and droughts. The sensitivity component measures the extent to which countries and the respective sectors that are affected by climatic disturbances. Factors that increase climate

sensitivity encompass the degree of dependence on sectors that are exposed to climate and the vulnerability of the population of a country to climatic changes due to demographic and topographic factors. The adaptive capacity component is concerned with measuring how the country and its supporting sectors adjust to resist the adverse effects of climate change and events.

Climate vulnerability in emerging economies remains precarious due to persistent infrastructural and institutional limitations. In Nigeria, for example, fluctuating climate conditions affect biodiversity, agriculture, and livelihoods, particularly among rural populations with limited climate awareness [19]. Similarly, India's diverse ecosystems are threatened by climate change, demanding urgent conservation efforts and ecosystem restoration to meet Sustainable Development Goals [27]. Without equitable and culturally relevant communication strategies, including the use of Indigenous knowledge systems and oral traditions, adaptation efforts may remain ineffective in reaching the most affected groups [19]. Collectively, these studies stress that addressing climate vulnerability in emerging economies requires targeted policies, inclusive knowledge dissemination, and robust international support to bridge adaptation gaps and promote long-term resilience.

Climate change also has an undoubtedly close link with environmental sustainability, especially in emerging economies. The close connection involving climate change and the environment is proven by the commonality or similarity of effects they both have. Han [5] argued that climate change intensifies the depreciation of fixed assets, financial risks, and lowers environmental quality. This means that environmental issues are important to understanding the financial risk context of climate change. Zhang, et al. [9] revealed that the threat climate change poses to the safety of electricity generation is the reason for exacerbating pollution in the environment. Khan, et al. [14] proved that the negative effect of climate change on human health stems from increased industrial pollution on the environment. Also, Economic growth that are associated with environmental pollution. In the process of natural resource exploration and deforestation in emerging economies, activities are linked to climate change and environmental degradation [4]. These similarities in effects have further proven the close relationship climate change has with environmental sustainability, and by extension, sustainable development.

The Environmental Kuznets Curve (EKC) hypothesis proposes that the eventual decrease in environmental degradation after being initially increased by rising levels of income proves an inverted U-shaped relationship between them. This has provided both a historical and contemporary explanation of how climate vulnerability can be affected by the level of income and financial development. Simon Kuznet's Environmental Kuznet Curve (EKC) theory is the foundation for studying how economic activities affect environmental quality as well as climate change risks. The EKC has been increasingly extended to incorporate financial variables, giving rise to the Financial Environmental Kuznets Curve (FEKC) theory, which extends that financial growth also initially worsens the environment, but eventually contribute to improved environmental quality as market maturity and regulatory mechanisms strengthen [28].

Empirical explorations have demonstrated that financial sector growth can influence both emissions levels and economic growth, but justify the extension of the traditional EKC into its financial variant [6, 29]. Furthermore, this theory has been broadened to include other financial indicators, including green finance, foreign direct investment, and income inequality, to assess their impact on ecological footprints across both developed and emerging economies [30, 31]. The dynamic pattern wherein climate vulnerability can rise with income before eventually declining mirrors the pattern observed in the FEKC context, especially within emerging and developing economies [31-34].

The Financial Environmental Kuznets Curve (FEKC) framework helps explain how green finance influences both climate vulnerability and, by extension, sustainable development by emphasizing how financial innovations, like green finance, can define a new relationship in the finance-environmental quality nexus. Although financial development at first can cause more environmental damage, green finance, which encourages investment in green energy, eco-friendly building projects, and technologies, can reduce climate change effects, leading to an improved environment. When funds are used for green finance, it makes projects more sustainable, reduces emissions and helps countries in need adapt better. Not only does it lessen the impact of climate change, but it also favours sustainable economic growth and aids in making sure that financial development goes along with long-term goals for the environment and development.

2.2. Empirical Review

Khizar and Anees [7] used ARDL on Pakistani data from 1980 to 2020 and found that green finance, foreign direct investment, and GDP all positively affect environmental sustainability. Kumar, et al. [35] used structural equation modelling to show that green finance supports environmental sustainability through government spending and green innovations. Ravichandran and Roy [36] discussed green finance as a key solution to climate change, also noting its role in promoting green growth, but pointed out that government action is needed to remove barriers. Zakari and Khan [12] studied 11 countries between 2006 and 2017 and found, using panel data methods, that green finance helps improve environmental sustainability. Singh, et al. [16] explored green finance tools in India and found that they help reduce climate risk. They recommended growing the green bond market and encouraging firms to report climate-related financial information for better decisions.

Sule, et al. [37] showed that instruments of green finance, such as green bonds, have been successful and called for more green finance instruments. They also noted that poor regulations and low awareness limit green finance in developing countries. Using a mixed-method approach, Bi and Lian [25] showed that green finance helps reduce climate effects and makes banks more stable, meaning banks are instrumental in facilitating green financial practices. Adisa, et al. [13] said green finance should be aligned with wider sustainable development goals to reduce climate change effects, including improvements in socio-economic conditions. Dong, et al. [10] using data from China between 2000 and 2019 and the

QARDL method, found that green finance and innovation helped reduce carbon emissions, even though economic growth had a negative effect.

Haryono [15] found that a robust legal framework benefited green finance in China and India, while Russia, Brazil, and South Africa showed evidence of regulatory challenges. The study by Habib, et al. [38] was based on examining how Corporate Social Responsibility (CSR) reporting matters to Climate Risk Index (CRI) in Europe with data from 2012 to 2022. With the aid of ordered light regression, the study found that CSR reporting reduced climate risk significantly and enhanced sustainable investment. The study by Fu, et al. [22] advocates for more research in green finance in emerging and developing economies owing to its role in promoting sustainable development and tackling climate change hazards. Eyo-Udo, et al. [21] emphasized the severity of climate risk to even affect infrastructure, especially those exposed to extreme weather outcomes. Climate vulnerabilities were identified to include transitional risk involving the possibility of policy changes, rising sea level, carbon emissions, and intensity in storms. These events and the devastating effects they cause have prompted the execution of climate adaptation projects. This platform suits the use and usefulness of green finance. So, by extension, green finance solutions are an undeniable approach to combating climate change risks.

Other studies like Biswal [3] established a strong interrelationship between sustainable development and climate change, where the efforts to address one result in successfully achieving the other. Mokwena and Maphaka [18] identified the enormous challenges caused by climate change and its eventual effect on environmental quality and sustainable life. Further, the adverse effect of climate change was reported to be very severe on agricultural sustainability, on account of its over exposure to climate factors like floods, droughts, heatwaves and snows. To find the interlinkages involving climate change, biodiversity, and implications for sustainable development, Behera, et al. [27] found that climate requires the interaction with biodiversity to impact sustainability. Duan [39] identified the severity of climate change on agricultural sustainability, which requires sustainable technologies in the agricultural sector. In one of its major findings, Soergel, et al. [40] revealed a direct co-benefits relationship between sustainable development goals and climate mitigation policies.

Going through the literature, it becomes clear that there are important gaps that have not been adequately studied in past research. Little research has considered the direct connection between green finance and climate vulnerability and how this is a pathway to sustainable development. Despite the appreciable number of studies that have considered how green finance impact either climate risk mitigation or sustainable development independently (e.g., [12, 13, 16, 22]) few have explicitly explored climate vulnerability, more still as a mediating or integrative mechanism connecting green finance to sustainable outcomes. This represents the existence of an empirical and conceptual gap because it is uncertain how green finance helps to mitigate climate vulnerabilities and how this helps reach wider sustainability objectives

More attention is needed to bring common climate vulnerability metrics into the conversation on green finance. While prior studies (e.g., [10, 16, 25, 38]) have primarily focused on elements such as climate risk, carbon emissions, and general environmental quality, they often fail to incorporate concrete vulnerability indicators, including exposure, sensitivity, and adaptive capacity. It implies that existing research has not explored in sufficient detail the relationships between climate vulnerability, sustainable development and green finance commitments.

3. Data and Methods

3.1. Data and Measurement of Variables

We used annual panel series data from emerging economies from 2010 to 2023 to assess how effective green finance commitments have been to mitigating climate vulnerability, as well as how this relationship affects sustainable development in emerging economies. It is worth stating that the period coverage of our study depends on the available data needed to achieve the objectives of this study. Based on this, the included countries are Argentina, Brazil, Chile, Colombia, Mexico, Peru, Hungary, Russia, Poland, China, India, Indonesia, Malaysia, Turkey, Philippines, Thailand, United Arab Emirates (UAE), Vietnam, Mauritius, Nigeria, and South Africa. The data for this study were sourced from four main sources: (i) Notre Dame Global Adaptation Initiative, ND-GAIN, (ii) World Development Indicators, WDI, from the World Bank database, (iii) the OECD database, and (iii) SDG Transformation Centre, and (iv) IMF Climate Dashboard. Table 1 presents the variables, their descriptions, and sources.

Table 1.
Variables and their sources.

Variable	Acronym	Description	Source
Dependent Variable			
Climate vulnerability	CLMVUL	The index of countries' exposure, adaptive capacity and sensitivity to climate change	ND-GAIN
Sustainable development	SUSTD	The composite index of all 17 sustainable development goals capturing economic, social and environmental dimensions of lives	SDG Transformation Centre
Independent Variable			
Green finance commitments	GREF	the sum of green bonds and environmental spending to GDP ratio	IMF Climate Dashboard
Control Variable			
Financial development	FIND	Ratio of private sector to GDP	WDI
Economic growth	LNPKY	Per output as measured by GDP per capita in US dollars	WDI
Population density	POPDN	Population divided by land area in square kilometers	WDI
Regulatory quality	REGQ	Measure of regulatory effectiveness in a country	WDI

The first major independent variable is green finance and coded GREF, and it is the sum of public and private green bonds and government environmental expenditure. This is slight modification of previous literature that used green bonds, but in tandem with the arguments of Zakari and Khan [12]. They contend that the practice of separating private environmental finance from public green finance initiatives lacks the ability to provide a comprehensive view, as both are important in deciding on environmental performance. We therefore adopt the aggregate of green bonds and government environmental spending as a proxy for green finance. The next important variable is climate vulnerability, CLMVUL, which was calculated by the ND-GAIN initiative with respect to countries' adaptive capacity, sensitivity, and exposure to climate change. Climate vulnerability or risk has a strong link to sustainable development through the environmental component. This makes sustainable development one of the variables of interest so that we examine how green finance has moderated the expected adverse effect [7, 12, 35]. The sustainable development variable, SUSTD, is the calculated index of the seventeen sustainable development goals, which were sourced from the SDG Transformation Centre.

We also included financial development, economic growth, population density and regulatory quality as control variables to help us ensure that the impacts green finance have on climate vulnerability and how green finance moderates the adverse effect on sustainable development are isolated. Enhancing financial development, based on the ratio of private sector credit to GDP, helps move resources to green and sustainable investments, supporting the efforts against climate change and the achievement of sustainability goals [35]. Again, there is a need to control economic growth in the objective model because of its association with environmental pollution and degradation due to increased industrial activities [4, 11, 15]. These activities increase the effects of climate change by promoting ecological footprints from the use of more natural resources. On this account, economic growth is captured through GDP per capita.

Again, the need for swift global action by 2050, being critical to mitigate severe climate conditions and ensure overall sustainability, is meant to protect vulnerable populations [10]. As population density, calculated as the number of people per square kilometer, continues to influence both climate vulnerability and sustainability by either intensifying resource pressure or challenging efficient infrastructure and service delivery, there is need to account for its effect. On regulatory quality, it has been shown to be a significant concern in green finance enforcement in emerging economies [15, 25]. This concern frustrates green finance efforts and, by extension, amplifies climate vulnerabilities in these countries. Strong regulation helps make green finance successful by earning trust among involved investors and institutions, attracting private sector involvement, and ensuring that environmental standards are maintained.

3.2. Model Specification

In the first instance, this study considers the Environmental Kuznet Curve (EKC) theory to explore how green finance can mitigate climate vulnerability and test the validity of these financing instruments for fulfilling its environmental obligation. Equation one is the proposed model one as a modification to Udeagha and Ngepah [4] specifications.

Climate vulnerability model.

$$CLMVUL_{it} = \phi_0 + \phi_1 GREF_{i,t} + \phi_2 FIND_{i,t} + \phi_3 REGQ_{i,t} + \phi_4 POPDN_{i,t} + \phi_5 LNPKY_{i,t} + \phi_6 LNPKY2_{i,t} + \epsilon_{it} \quad (1)$$

Where, ϕ_0 is the model intercept, $\phi_1 - \phi_6$ are the model coefficients, and ϵ_{it} is the model error term. The second consideration of our study is examining the moderating role of green finance on how climate vulnerability affects sustainable development in emerging economies. Equation two is the proposed model one as modification to Zhang [23]; Ibrahim, et al. [6] and Zhang, et al. [9] specifications.

Sustainable development model

$$SUSTD_{it} = \beta_0 + \beta_1 GREF_{i,t} + \beta_2 CLMVUL_{i,t} + \beta_3 GREF\_CLMVUL_{i,t} + \beta_4 FIND_{i,t} + \beta_5 REGQ_{i,t} + \beta_6 POPDN_{i,t} + \beta_7 LNPKY_{i,t} + \varepsilon_{1it} \quad (2)$$

Where, β_0 is the model intercept, $\beta_1 - \beta_7$ are the model coefficients, ε_{it} is the model error term, and $SUSTD_{it}$ is for sustainable development, and a measure of countries attaining the 17 goals of sustainability.

3.3. Techniques of Model

To accurately estimate the green finance-climate vulnerability nexus as well as how green finance moderates the climate-sustainable development relationship over time and address endogeneity concerns, this study adopted the Pedroni [41]. Fully Modified Ordinary Least Squares (FMOLS) regression and the Arellano and Bond [42] and Arellano and Bover [43] Generalized Method of Moments (GMM) method. Both of the techniques are adopted for their efficiency in addressing endogeneity and possible correlation issues, but on different scales. While the GMM technique provides the short-run dynamics, the FMOLS is relied on for long-run dynamics.

3.3.1. The Generalized Method of Moment (GMM) estimator

Climate vulnerability model

$$CLMVUL_{it} = \varphi_1 CLMVUL_{i,t-1} + \varphi_2 GREF_{i,t} + \varphi_3 FIND_{i,t} + \varphi_4 REGQ_{i,t} + \varphi_5 POPDN_{i,t} + \varphi_6 LNPKY_{i,t} + \varphi_7 LNPKY2_{i,t} + \epsilon_{it} \quad (3)$$

sustainable development model

$$SUSTD_{it} = \eta_1 SUSTD_{i,t-1} + \eta_2 GREF_{i,t} + \eta_3 CLMVUL_{i,t} + \eta_4 GREF\_CLMVUL_{i,t} + \eta_5 FIND_{i,t} + \eta_6 REGQ_{i,t} + \eta_7 POPDN_{i,t} + \eta_8 LNPKY_{i,t} + \varepsilon_{1it} \quad (4)$$

Where, $\varphi_1 - \varphi_7$ and $\eta_1 - \eta_8$ are the GMM model coefficients, of which φ_1 and η_1 are expected to meet two conditions: positive means evidence of persistence or history, and statistically significant means relevance of history. Also, for the GMM to be reliable, the Arellano-Bond test should confirm the second-order autocorrelation (with expected probability value greater than 0.05), Sargan test should demonstrate validity of the instruments (p-value greater than 0.05).

3.3.2. The Fully Modified Ordinary Least Squares (FMOLS) Estimator

Again, the FMOLS also suited for small sample data like the one we have in this study. The specification for modifying each coefficient as given by Pedroni [41] is given as:

$$\hat{G}_{FMOLS} = \left(\sum_{i=1}^{N} \sum_{i=1}^{T} (X_{it} - \bar{X}_i)'(X_{it} - \bar{X}_i) \right)^{-1} \left(\sum_{i=1}^{N} \sum_{i=1}^{T} (X_{it} - \bar{X}_i)'(Y_{it}^* - \bar{Y}_i^*) \right) \quad (5)$$

Where, $\hat{G}_{FMOLS}$ is the fully modified coefficients of interest, Y_{it} represent renewable energy for each emerging country at time t; X_{it} is green finance commitments, financial development, and the control variables of each emerging country at time t; $\bar{X}_i$ and $\bar{Y}_i$ represent time averages for each emerging country at time t; Y_{it}^* is the transformed version of Y_{it} that accounts for endogeneity and serial correlation; N is the cross-section of countries; T is the time periods.

4. Analysis and Results

The initial analysis, which is descriptive and correlation, was done to provide a deeper understanding of the attributes of the data of interest to investigate their relationships.

4.1. Descriptive Statistics

Climate vulnerability was measured as a composite index of adaptive capability, exposure, and sensitivity as provided by the NG-GAIN database. Between 2010 and 2023, the average climate vulnerability index was 0.37, with a range from 0.00 to 0.49. This indicates a precarious Climate vulnerability situation in emerging economies. Consequently, the average of green finance commitments was 0.39% of GDP, associated with 0.00 a minimum and 2.85% of GDP. With the justification of green finance, this situation presents a potential strong correlation for these two underperforming climatic indices. Given this scenario, the low level of sustainable development indices for emerging economies is expected to be low. Empirical evidence shows that it has the value 0.69 as the mean against a maximum and highest values of 0.82 and 0.52, respectively.

Table 2.
Descriptive statistics.

	Observations	Mean	Maximum	Minimum	Standard Deviation
SUSTD	294	0.69	0.82	0.52	0.06
CLMVUL	294	0.37	0.49	0.00	0.11
GREF	294	0.39	2.85	0.00	0.57
FIND	294	65.01	194.67	0.00	44.25
POPDN	294	140.64	634.12	0.00	156.22
REGQ	294	0.16	1.54	-1.16	0.59
LNPKY	294	8.96	10.86	7.21	0.76
LNPKY2	294	80.97	100.10	51.93	11.32

The emerging economies' real population density average 140.64 people per square kilometer. The low level of financial development, average 65.01%) is associated with poor regulatory quality that average 0.16 and per capita index of 8.96. together these present a situation of interest in emerging economies that justifies this result. Table 2 presents summaries and descriptive analyses.

Table 3.
Correlation matrix.

	SUSTD	CLMVUL	GREF	FIND	POPDN	REGQ	LNPKY	LNPKY2
SUSTD	1							
CLMVUL	-0.37***	1						
GREF	0.27***	0.03	1					
FIND	0.14***	0.01	0.21***	1				
POPDN	-0.30***	0.47***	0.06	0.10*	1			
REGQ	0.44***	-0.11*	0.28***	0.24***	0.04	1		
LNPKY	0.58***	-0.35***	0.29***	0.05	-0.42***	0.56***	1	
LNPKY2	0.38***	-0.19***	0.10*	0.06	-0.21***	0.23***	0.31***	1

Note: ***, ** & * are significant at 1%, 5% & 10%, respectively.

The correlation matrix revealed several significant relationships, with sustainable development (SUSTD) showing strong positive correlations with income per capita (r = 0.58) and regulatory quality (r = 0.44), indicating that higher income levels and better regulatory frameworks are strongly associated with improvements in sustainable development. Conversely, climate vulnerability (CLMVUL) was significantly and negatively correlated with SUSTD (r = -0.37), suggesting that greater exposure to climate risks undermines sustainability. Additionally, population density (POPDN) had a negative and significant relationship with SUSTD (r = -0.30), while financial development (FIND) and green finance (GREF) showed weaker but still positive and significant correlations (r = 0.14 and r = 0.27, respectively). Furthermore, the squared income term (LNPKY2) was also positively and significantly related to SUSTD (r = 0.38), possibly implying a nonlinear (U-shaped) relationship between income and sustainability, consistent with the Environmental Kuznets Curve hypothesis. The correlational matrix results are summarised in Table 3.

Table 4.
The panel Cross-sectionally augmented Im-Pesaran-Shin (CIPS) unit root test.

Variables	Levels		First difference		Order of Integration
	Intercept	Trend	Intercept	Trend	
SUSTD	-2.88***	-3.12***	4.26***	-4.42***	*I*(1)
CLMVUL	-2.40**	-2.63	-3.57***	-3.98***	*I*(1)
GREF	-2.14*	-2.29	-2.90***	-3.13***	*I*(1)
FIND	-1.22	-2.16	-3.20***	3.66***	*I*(1)
POPDN	-2.09	-2.12	-2.39**	-2.40	*I*(1)
REGQ	-1.38	-2.09	-3.48***	-3.19***	*I*(1)
LNPKY	-1.25	-1.96	-2.83***	-3.17***	*I*(1)
LNPKY2	-1.04	-1.71	-2.91***	-2.90**	*I*(1)

Note: ***, ** & * are significant at 1%, 5% & 10%, respectively.

The results from Table 4 present the CIPS, second-generation panel stationarity test, showing that all variables (green finance commitments, sustainable development, financial development, foreign direct investments, population density, and per capita income and its square) were non-stationary at levels but turned stationary when they were differenced. This means are integrated of order one, I(1). At levels, only sustainable development (SUSTD), climate vulnerability (CLMVUL), and green finance (GREF) were marginally significant under the intercept and trend specifications, while the remaining variables, including financial development (FIND), population density (POPDN), regulatory quality (REGQ), and income per capita (LNPKY and LNPKY2), were not statistically significant, confirming non-stationarity. Even so, at first difference, every variable turned out to be statistically significant at the 1% or 5% level in both intercept and trend

cases, which indicates an absence of unit roots and proves the data stationary. Therefore, the fact that the panel data can be treated as I(1) variables shows that cointegration-based models, like the FMOLS adopted, can be reliably used to analyze them.

Table 5.
Panel Westerlund cointegration test.

	Stat.	Prob.	Decision
Model 1	7.32	0.000***	Cointegrated
Model 2	3.75	0.000***	Cointegrated

Note: ***, ** & * are sig. at 1%, 5% & 10%, respectively.

Table 5 reports the Westerlund panel tests of the proposed two models for the study, and the results show that all the models had a long-run relationship. Specifically, the test statistics for Model 1 (7.32) and Model 2 (3.75) were both highly significant at the 1% level, leading to rejection of the null hypothesis that cointegration does not exist. Therefore, since the variables in the two models are cointegrated over the long term, it became appropriate to estimate these panel models, which produce long-run estimates.

4.2. Estimation Results

Most of the estimates using the dynamic panel were similar for all the methods: Generalised Method of Moments (GMM) model, Fixed Effects (FE) Model, and FMOLS. In the D-GMM specification, the one-period-lagged climate-vulnerability index remained positive and highly significant, confirming substantial persistence in the series and validating the dynamic structure of the model.

Table 6.
Model estimation for how green finance affect climate vulnerability.

	Difference GMM	Fixed Effects	FMOLS
	Coef./prob.	Coef./prob.	Coef./prob.
CLMVUL(-1)	0.3614**		
	(0.020)		
GREF	-0121***	-0.0048**	0.0170***
	(0.001)	(0.021)	(0.000)
FIND	0.0002*	0.0002***	0.0003***
	(0.060)	(0.000)	(0.000)
POPDN	0.0002***	0.0002***	0.0012***
	(0.000)	(0.000)	(0.000)
REGQ	-0.0473***	-0.0282***	0.0781***
	(0.000)	(0.000)	(0.000)
LNPKY	0.0299***	0.0187***	-0.1117***
	(0.001)	(0.000)	(0.000)
LNPKY2	0.00002	-0.0002**	-0.0010***
	(0.956)	(0.025)	(0.000)
Constant		0.0341	
		(0.578)	
R-sq.		0.99	0.57
Adj. R-sq.		0.99	0.51
F-stat.(prob.)		821.18 (0.000)	
Obs.	252	294	221
Instruments	7		
AR (2) p-value	0.413		

Note: ***, ** & * are sig. at 1%, 5% & 10%, respectively.

The results revealed that green finance commitments, per capita income, and the quality of regulation were sensitive to technique use and time scope. According to the GMM and FE models, green finance and quality of regulations lowered vulnerability in the short-term, but in the long-run FMOLS framework, the effect became positive. The long-run positive contribution of green finance commitments to climate vulnerability, being associated with long-run transitional adjustment costs from regulatory quality, is evidence that climatic gains by green finance depend on regulatory quality to continue to mitigate climate exposures, adaptation, and sensitivity in emerging economies. Put together, green finance commitments were able to reverse climate vulnerability in emerging economies in the short run, while they significantly contributed to climate vulnerability in the long run due to overwhelming pressures from financial development, growing population, and regulatory failures. While the study found increased short-term climate resistance from green finance commitments, the same commitments created more vulnerability over the long run as a result of financial, population and regulatory pressures, some literature contradicts these findings. As agreed by Haryono [15]; Sule, et al. [37] and Adisa, et al. [13] the key to getting the right results from green finance lies in having solid regulations and strong institutions. Habib, et al. [38]

pointed out that regulation is necessary for sustainable investment to work, even if green finance is active. At the same time, findings from different studies can be more encouraging.

According to Singh, et al. [16]; Bi and Lian [25] and Eyo-Udo, et al. [21] green finance keeps climate risk under control and encourages adaptation, consistently bringing positive results. Studies from Ravichandran and Roy [36] and Dong, et al. [10] mention that long-term gain and clear benefits are made possible by strong governance and enforcement, and relevant innovative policies. Even so, the study's short-run outcomes are respected, but its long-run issues are opposite those stating that lasting success comes from vigorous policymaking, good regulation and advancements in financial instruments.

Even though per-capita income increased climate vulnerability in the short term, it only followed an inverted-U curve with fixed effect, which suggests the validity of the environmental Kuznets curve model. While these divergences call for further investigation, the concordant evidence on financial depth and population pressure provides the clearest and most robust policy signal, proving that without complementary regulation, financial expansion and rapid population growth were likely to intensify climate vulnerability in the region.

Table 7.
Model estimation for how green finance moderate climate vulnerability to affect sustainable development.

	Difference GMM	**Fixed Effects**	**FMOLS**
	Coef./prob.	**Coef./prob.**	**Coef./prob.**
SUSTD(-1)	0.8864***		
	(0.000)		
GREF	0.0475**	-0.0234	0.0162**
	(0.031)	(0.130)	(0.050)
CLMVUL	-0.0022	-0.1666***	-0744***
	(0.757)	(0.001)	(0.000)
GREF_CLMVUL	0.1266**	0.0686*	-0.0367*
	(0.0293)	(0.097)	(0.097)
FIND	0.00002	0.0001***	0.00004***
	(0.564)	(0.002)	(0.000)
POPDN	0.00001	0.00002*	0.000004***
	(0.307)	(0.0842)	(0.000)
REGQ	-0.0071	0.0115***	-0.0066***
	(0.111)	(0.000)	(0.000)
LNPKY	0.0052	0.0187***	0.0185***
	(0.294)	(0.000)	(0.000)
Constant		0.5685***	
		(0.000)	
R-sq.		0.98	0.93
Adj. R-sq.		0.98	0.92
F-stat.(prob.)		455.94 (0.000)	
Observations	252	294	195
Instruments	8		
AR(2) p-value	0.719		

Note: ***, ** & * are sig. at 1%, 5% & 10%, respectively.

With the DGMM, the lagged sustainable-development index remained positive and highly significant, confirming the strong persistence of sustainable development in the GMM model and validating the dynamic specification. Focusing on the moderating term, the difference GMM results indicated that green finance commitments strengthened the influence of climate vulnerability on sustainable development: the positive and significant interaction coefficient (0.1266, $p \approx 0.03$) meant that the marginal effect of green finance commitments rose with greater vulnerability, and similar to the long-run results with the panel FMOLS. By contrast, the FMOLS estimates, which captured long-run cointegration, showed a significant negative interaction (-0.0367, $p = 0.097$). Here, green finance commitments contributed to sustainable development as exemplified in the literature [12, 13, 22] while climate vulnerability exhibited an expected adverse effect on sustainable development. However, the negative coefficient of the interaction between green finance and climate vulnerability diminishes sustainability as evidenced by regulatory failures (coefficient = -0.0066; $p = 0.000$).

Taken together, the evidence suggested that in the short run, green finance commitments offset the adverse consequences of vulnerability, whereas in the long run, its contribution to sustainable development weakened as vulnerability intensified, and that no robust moderating effect emerged when only contemporaneous within-country fluctuations were considered.

This study partly corroborates with those of Fu, et al. [22]; Adisa, et al. [13] and Zakari and Khan [12] who all supported that green finance is catalytic towards environmental sustainability and economic growth, especially in the short term. Green finance has been able to offset the vulnerability of the short term by improving the environment and supporting sustainable practices, as proven in studies. Further, Zakari and Khan [12]; Khizar and Anees [7] and Kumar, et al. [35] similarly discovered that green finance helps the environment and supports the results of our findings in this study.

Nevertheless, most of the above-mentioned studies suggest that green finance continues to contribute positively over time, without mentioning any reduction in its effectiveness as challenges increase. Because Biswal [3]; Mokwena and Maphaka [18] and Duan [39] stress that the long-term effects of climate change on sustainability are separate from initial financial actions, it can be inferred that green finance is not enough to help much in the moderation of these issues in the future. The work by Behera, et al. [27] and Soergel, et al. [40] closely resembles the study's conclusions, showing that both environmental aspects and specific policies, like those addressing biodiversity and climate, play a major role in creating sustainable development. This significantly highlights the struggling moderating role green finance has under these circumstances.

5. Conclusion and Recommendations

Emerging economies, which are mainly developing nations with high potential for growth and advancement, are experiencing extreme climatic conditions that have significant implications for sustainable development through the environmental route. These climatic conditions are correlated with increasing population and rising per capita income, as also obtained in developing nations. The persistence of this trend is expected till the country reaches a developmental threshold, after which climate vulnerability will start decreasing, contrasting with improved efficiencies. The research has identified that green finance commitments in emerging economies reduce climate vulnerability in the short run with supportive regulation but harm the environment in the long run due to the inadequacy of regulatory frameworks. In contrast, green finance commitments adversely moderate the effects of climate vulnerability on sustainable development. This is a mirror reflection of regulatory failures to improve sustainable development as well.

To begin with, since green finance commitments help in the short term but may increase climate vulnerability over time, making sure regulations are strong remains very important. The weak long-term impact is due to paying for adaptation in the past and a lack of strong regulations, so green finance could fail to help the environment in the long term. In this way, for green finance to succeed, reforms must focus on making regulations efficient, clear and flexible through time. Also, an interaction analysis found that the relationship that defines green finance and climate vulnerability changed over time with regard to sustainable development. While it helped in the near term to soften the effects of vulnerability, in the long term, it had mostly negative effects. So, green finance commitments need to be highly targeted, increased in scale, and handled according to a sequence, that is, targeting more vulnerable areas and countries first and before readjusting as the needs change. It is important for policymakers to stop using only one green finance plan and instead come up with flexible ones that consider how vulnerable each emerging country or area is.

Moreover, all the models show that climate vulnerability increases with growing financial depth and population pressure, which suggests there are serious structural challenges in these fields. Measures implemented to promote financial opportunities and gather capital should always be checked for their negative effects on the environment. Integrating urban planning, new climate-proof infrastructure investment and tougher environmental-financial regulations will keep climate exposure down as both population and finance increase.

Ultimately, the varying results seen in each estimation technique over time show that policymakers always need to be mindful of when their choices are applied. Focusing only on policy gains for the short term can hide major long-lasting risks. So, it is necessary to review climate and sustainability policies from time to time and include long-term planning and assessing results in national strategies. So, funds from green bonds, sustainability-linked loans or climate funds can both tackle immediate risks and make sure the economy and communities keep improving against climate risks.

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