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The Impact of Climate Change on Commercial Real Estate Performance In Sub-Saharan Africa VECM Aprroach

Abdulfatai Saad[1] Sani Inusa Milala[2] Abdulwahab Sherifat Oluwakemi[3] Ibifunmilola Yetunde Titilayo[4]

[1] Department of Industrial Design, University of Maiduguri, Borno State, Nigeria
[2]Faculty of technology Management and Business,
Center of Research Excellence, Real Estate & Facilities Management
University Tun Hussein Onn Malaysia,
Pari Raja 86400, Johor Malaysia
[3,4]School of Environmental Technology, Estate Management and Valuation
Dept, Federal Polytechnic Offa
Email:
[1]abdulfataiSaad1432@gmail.com , [2]sinusamilala@gmail.com , [3]Kemiabdulwahabb@gmail.com
[4]*yetunde2156@gmail.com*

ABSTRACT

Climate change poses increasing risks to commercial real estate (CRE) markets worldwide, with Sub-Saharan Africa being particularly vulnerable due to rapid urbanization and limited adaptive infrastructure. Rising temperature anomalies, rainfall variability, extreme weather events, and increasing carbon emissions threaten property values, yet empirical evidence on their effects in the region remains limited. Understanding these impacts is critical for investors, policymakers, and urban planners seeking resilient and sustainable CRE markets. This study assesses the impact of climate change on commercial real estate performance in Sub-Saharan Africa, focusing on Nigeria, Secondary data from 2001 to 2023 were collected, including commercial real estate price indices from national property market reports, climate variables from national meteorological agencies and global databases, carbon emissions from environmental statistics, and macroeconomic controls such as GDP growth and interest rates from the World Bank and IMF. The Augmented Dickey-Fuller tests confirm that all variables are integrated of order one, I(1), while the Johansen cointegration test identifies a single long-run equilibrium relationship. Long-run VECM results show that a 1% increase in temperature anomalies reduces CRE prices by 0.84% ($t = -3.93$, $p < 0.01$), rainfall variability by 0.32% ($t = -2.44$, $p < 0.05$), and extreme weather events by 0.28% ($t = -2.65$, $p < 0.05$). Carbon emissions also negatively affect property values (−0.49%, $t = -2.85$, $p < 0.01$), while GDP growth positively influences CRE performance (0.62%, $t = 2.95$, $p < 0.01$). Short-run dynamics indicate a moderate adjustment speed, correcting 47% of deviations annually (ECT = −0.472, $p < 0.01$). The findings underscore that climate change significantly undermines commercial real estate performance in Sub-Saharan Africa. Policymakers and investors should integrate climate risk assessment, resilient infrastructure, and green finance instruments to safeguard property values and market stability.

Keywords: Climate change, Commercial real estate, Sub-Saharan Africa, VECM, Property performance

INTRODUCTION

As noted by Sayce et al. (2022), the intersection of ecological sustainability pressures with innovative practices in real estate is emerging as a critical factor shaping commercial property ecosystems, particularly in Sub-Saharan Africa. The commercial real estate (CRE) sector is a major contributor to carbon emissions and is uniquely exposed to both physical and transitional risks posed by climate change (Clayton et al., 2021). Consequently, the ability of CRE assets to adapt to climate change is no longer peripheral but central to their long-term financial performance and resilience (Sirmans et al., 2025). This study examines these dynamics by analyzing the effects of climate variables on commercial property performance in countries including Nigeria. The physical impacts of climate change, from acute shocks such as floods and storms to chronic stresses like rising temperatures and rainfall variability, are increasingly being quantified in property markets (Holtermans et al., 2024). Evidence shows that these climate-related risks are progressively incorporated into property valuations, challenging traditional approaches that rely on historical data (Clayton et al., 2022). Simultaneously, the transition toward low-carbon economies, driven by regulatory reforms and market preferences, adds complexity to property investment decisions (Akhtyrska & Fuerst, 2024). Real estate investment trusts (REITs) and institutional investors in Sub-Saharan Africa face growing scrutiny regarding exposure to these multi-dimensional climate risks (Feng et al., 2025). Ecopreneurial approaches are emerging as a proactive strategy for climate adaptation in the CRE sector. Through green building initiatives, resilient infrastructure, and sustainable property management practices, ecopreneurs integrate environmental innovation into their business models (Warren-Myers & Hurlimann, 2022). These strategies go beyond regulatory compliance, serving as tools to mitigate asset risks while creating market opportunities (Westcott et al., 2020). For instance, climate-resilient properties can achieve higher rental premiums, lower vacancy rates, and more stable valuations over time (Ling et al., 2024).

PROBLEM STATEMENT

Across Sub-Saharan Africa, commercial real estate (CRE) markets are increasingly exposed to severe and unprecedented threats from climate change, posing significant risks to asset values, investment security, and long-term financial stability (Sayce et al., 2022). Acute physical climate events such as floods, storms, and heatwaves can cause direct damage to properties, disrupt business operations, and lead to higher insurance premiums or even withdrawal of coverage (Holtermans et al., 2024). At the same time, transition risks arising from policy reforms, technological shifts, and evolving market expectations are rendering carbon-intensive or poorly located assets economically vulnerable (Akhtyrska & Fuerst, 2024). Despite growing evidence that these climate-related hazards are increasingly reflected in property valuations, many valuation and investment models in the region still rely on historical data that fail to capture long-term climate trajectories (Clayton et al., 2022). This misalignment exposes investors, lenders, and occupiers to potential financial losses and systemic instability within regional property markets (Feng et al., 2025). Moreover, the diversity of climate impacts across countries and property types in Sub-Saharan Africa complicates the development of standardized risk assessment and adaptation strategies (Ling et al., 2024).

Although climate change is now widely recognized as a material financial risk, CRE markets in the region remain poorly equipped to implement effective adaptation measures (Westcott et al., 2020). Ecopreneurial innovations, such as green building certifications, climate-resilient infrastructure, and sustainable property management practices, provide pathways to mitigate climate risk and enhance property performance; however, their adoption is fragmented and inconsistent across markets (Warren-Myers & Hurlimann, 2022). High upfront costs, uncertain returns on investment, and limited regulatory guidance continue to constrain widespread uptake of adaptive strategies (Addoum et al., 2024). Consequently, a significant gap persists between the theoretical benefits of climate adaptation and the ongoing vulnerability of CRE portfolios to escalating climate impacts (Sirmans et al., 2025), challenging both individual investment performance and the stability of financial systems linked to real estate markets (Clayton et al., 2021).

Research Gap

Despite the growing body of literature on climate change and real estate adaptation strategies, significant gaps remain in understanding how ecopreneurial initiatives influence the performance outcomes of commercial properties in Sub-Saharan Africa. Most existing studies have primarily focused on pricing climate risks within property markets (Holtermans et al., 2024; Ling et al., 2024) or on the performance advantages of green-certified buildings (Feng et al., 2025). However, these strands of research have largely progressed independently, with limited integration investigating how proactive, entrepreneurial adaptation measures mediate the relationship between climate risk exposure and financial returns (Thanasi, 2025).

Furthermore, current studies have inadequately addressed the decision-making processes of CRE stakeholders regarding climate adaptation investments, particularly under the uncertainty of future climate scenarios and regulatory changes (Wieteska-Rosiak, 2020). Comparative analyses across different countries or regions in Sub-Saharan Africa are also scarce, leaving important variations in regulatory frameworks, market maturity, and climate risk profiles unexplored, which limits the generalizability of existing findings (Akhtyrska & Fuerst, 2024).

Critically, no prior research has systematically conceptualized and empirically tested a unified framework positioning ecopreneurship as the key mechanism linking climate change adaptation imperatives to improved commercial real estate performance (Warren-Myers & Hurlimann, 2022). Addressing this gap is essential for understanding how climate-resilient entrepreneurial practices can enhance asset value, investment security, and overall market stability in the CRE sector across Sub-Saharan Africa.

This study is novel as it is the first to integrate the theoretical domains of ecopreneurship, climate change adaptation, and commercial real estate (CRE) performance into a single conceptual and empirical framework within the context of Sub-Saharan Africa. While previous research has often examined these phenomena separately, this study synthesizes insights from valuation studies, climate science, and entrepreneurial theory to demonstrate how proactive ecological innovation functions as both a risk-reduction strategy and a value-creation mechanism.

Unlike prior work that primarily focuses on climate risk pricing, this research investigates the adaptive behavior of CRE market participants, addressing the critical question of how stakeholders can actively shape their climate futures rather than passively endure them. By drawing on foundational studies, including Sayce et al. (2022), Clayton et al. (2021), and Feng et al. (2025), and incorporating emerging evidence from Holtermans et al. (2024) and Addoum et al. (2024), this study offers new directions for empirical research in the region.

In doing so, it reframes commercial real estate in Sub-Saharan Africa not merely as a sector vulnerable to climate impacts but as a dynamic arena for ecopreneurial innovation. Through the adoption of green building practices, resilient infrastructure, and climate-responsive management strategies, CRE stakeholders can enhance property performance, improve financial returns, and contribute to broader climate resilience. This transformative perspective provides both a theoretical and practical contribution by positioning climate-adaptive entrepreneurial strategies at the core of sustainable CRE development in emerging markets.

LITERATURE REVIEW

Climate change and real estate investment

Takona (2024) offers detailed methodological insight on qualitative, quantitative and mixed method approaches that underpins rigorous examination of climate change impacts on real estate investment. Thanasi (2025) finds through master's level research that climate change is a multidimensional threat that affects the real estate sector in many ways; from damage to assets, increased regulatory compliance costs, and new occupier preferences that impact investment returns. Tran, Tien, and Chi (2022) demonstrate in their examination of Novaland Real Estate Group how real estate companies need strategic flexibility to navigate changing market conditions, a vital factor in climate adaptation. Troise, Jones, Candelo, and Sorrentino (2023) show how entrepreneurial alertness, digital platform capability, and business model innovation significantly enhance firm performance in dynamic markets, informing how real estate investors can act to address climate risks. We know from Usman, Kess-Momoh, Ibeh, Elufioye, Ilojianya, and Oyeyemi (2024) that technology and globalization are shaping new business ventures around the world and there are opportunities for climate-focused innovation in real estate.

Voland, Saad, and Eicker (2022) show that public policy and incentives are essential to facilitating socially responsible new business models adopted in market-driven real estate for climate-smart green building projects. According to Wang, Zhao, Jiang, and Li (2022), new evidence is available around the world confirming that green finance can drive the emergence of sustainable development, and that financial mechanisms are increasingly providing support for environmentally responsible real estate developments. Warren-Myers and Hurlimann (2022) comprehensively and methodically demonstrate that climate change causes material risks for real estate assets, demanding systematic integration of climate considerations into the investment decision-making process. Wu, Luo, Zhang, and Cheng (2024) show that entrepreneurial bricolage and business model innovation enhance entrepreneurial performance, with market orientation serving as a mediating mechanism relevant to real estate adaptation strategies. Zeiada, Hamad, Khalil, and Hassan (2022) propose a green pavement rating system in the UAE which has shown that sustainability innovations tailored to certain industries can facilitate improvements in environmental impact and increased resilience of infrastructure. Zhou, Endendijk, and Botzen (2023) provide a comprehensive review of financial sector impacts on climate-related risks and confirm that climate change poses systemic threats to financial stability with respect to real estate, and thus adaptation investments can mitigate these risks. The collected evidence reflects that climate change reshapes real estate investment fundamentally in physical, transitional, and regulatory means, with entrepreneurial innovation, green finance, and supportive policy environments that enable adaptive strategies enhancing long-term performance and resilience.

Commercial Real Estate Performance and Climate Change: A Comparative Analysis

Analytical Framework

The analysis follows the deductive model, opening on the premise that climate change constitutes a material financial risk to commercial real estate assets worldwide (Sayce et al., 2022). Based on this foundational assumption, analysis moves to the examination and comparison of empirical evidence from a variety of geographic contexts, property types, and methodological approaches. The deductive format allows for a systematic testing of how theoretical climate risk transmission mechanisms (physical risks, transition risks, and liability risks) manifest in observable commercial real estate performance outcomes across different market settings (Clayton et al., 2021). This comparative approach provides insight into both universal patterns and context-specific variations in how climate change shapes property valuations, investment returns, and stakeholder decision-making worldwide.

Valuation Challenges

One analytical theme that has emerged across the literature is the ongoing and systematic mispricing of climate risk in commercial real estate valuation practices throughout the world (Sayce et al., 2022). Traditional approaches to valuation, which predominantly depend on historical transaction data and backward-looking income capitalisation, are inherently insufficient to encapsulate forthcoming climatic uncertainties (Clayton et al., 2022). This methodological limitation generates a wide gap between the current market climate risk exposure and reported asset values, putting investors at risk to unrecognised financial vulnerabilities. There is considerable variation in what different markets do in relation to this valuation challenge. Professional valuation bodies are increasingly integrating climate risk within a mature market structure like the UK and the US, yet there is significant variation in what constitutes meaningful integration into these valuation tools (Sayce et al., 2022). In comparison, developing markets may not have the regulatory or professional infrastructure to integrate climate considerations into valuation practice, which could lead to risk mispricing (Warren-Myers & Hurlimann, 2022). This divergence demonstrates that commercial real estate performance measures can be systematically distorted between jurisdictions, with assets located in areas with poor climate risk governance seeming artificially more valuable than their fundamentally riskier but better-regulated counterparts.

Physical Risk Impacts

The capitalisation of physical climate risks in the commercial property markets presents an exceptionally strong empirical confirmation of a direct effect from climate change on commercial property value (Holtermans et al., 2024). Deductive analysis shows that properties exposed to acute climate hazards (flooding, hurricanes, wildfires) receive substantial and durable valuations lower than equal unexposed properties. One landmark event study on Hurricane Sandy's impact on commercial property shows that effects from physical climate shocks create lasting impacts on market price and investor behaviour (Addoum et al., 2024). Properties located within flood zones affected by the disaster also recorded severe declines in value and persistence of negative values for years after the event, suggesting that the participants in the market adjust their risk perception based on the flood experiential information from the actual impact of the disaster. This result also corresponds to wider evidence that climate shocks serve as key learning events that change forever the way investors determine physical risk assessment and price (Sirmans et al., 2025).

Comparative analysis of geographic contexts also identifies significant divergences in the capitalization of physical risk. United States markets present more sophisticated pricing of flood and hurricane risk, especially following major disaster events (Ling et al., 2024). European markets exhibit more fragmented risk pricing, given their exposure to multiple hazard profiles, including coastal flooding and heat stress, partly attributable to stronger public insurance mechanisms and social safety nets that mute direct market signals (Westcott et al., 2020). In contrast, Asian markets with serious climate risk, like typhoons in coastal Chinese cities, are exhibiting emerging signs of risk pricing, albeit with significant opacity and data limitations hindering accurate assessment (Holtermans et al., 2024).

Transition Risk Effects

In addition to the physical risks, a second major channel through which climate change impacts commercial real estate performance is transition risks related to climate policy and regulatory evolution (Akhtyrska & Fuerst, 2024). The worldwide shift toward decarbonisation through building energy performance standards, carbon pricing mechanisms, and disclosure requirements directly impacts asset values by rendering carbon-intensive properties potentially obsolete. However, an analysis of comparative policy documents demonstrates striking differences in exposure to transition risk across jurisdictions. The EU’s ambitious regulatory framework including the Energy Performance of Buildings Directive and upcoming Energy Performance Certificate reforms presents distinct and escalating transition risk to commercial properties that do not meet its efficiency standards (Akhtyrska & Fuerst, 2024). Owners of poorly-performing buildings are exposed to rental discounts, decreased marketability, and potential stranding because of regulatory requirements. On the other hand, the United States presents a more fragmented regulatory environment, where state-level actions taken by states such as California and New York contrast with minimal intervention in other jurisdictions and, as such, result in diverse transition risk vulnerability within that nation (Clayton et al., 2021).

There is empirical support that regulatory signals do lead to measurable performance differentials. Green-certified buildings carry significant rental premiums, achieve higher occupancy rates, and offer superior investment returns than their conventional peers (Feng et al., 2025). The study of investments in Real Estate Investment Trusts shows that portfolios with greater exposure to energy-efficient assets outperform others, which implies that markets increasingly reward transition-preparedness (Feng et al., 2025). This performance premium systematically differs across regulatory environments, with stronger effects in jurisdictions with ambitious climate policy frameworks (Akhtyrska & Fuerst, 2024).

REIT Performance

Real Estate Investment Trusts can be an important lens through which to study impacts of climate change on commercial real estate performance, since they exist as publicly traded and transparent vehicles with diversified portfolios of properties (Feng et al., 2025). Climate risk exposure

is a significant determinant of investment returns, portfolio volatility, and investor sentiment revealed with a deductive perspective of REIT performance. More specifically, research of data to date shows that higher concentration of REITs in climate-vulnerable geographic regions or property types correlates with poorer risk-adjusted return than REITs with diversified or climate-resilient assets (Feng et al., 2025). The performance variance will be further exacerbated following climate shock events when investors adjust their expectations and transfer funds to the safer-asset segments. Moreover, studies at the REIT level show exposure to climate risk affects cost of capital, with more vulnerable trusts having higher borrowing costs and limited access to financing (Clayton et al., 2021). Comparison across REIT markets reveal significant international differences. The United States REITs benefit from extensive data availability and sophisticated investor bases resulting in relatively advanced climate risk pricing (Feng et al., 2025). European REITs are subject to stricter regulatory frameworks that mandate climate risk disclosure, which could make transparency in such policies and better risk pricing more likely through more accurate risk pricing (Akhtyrska & Fuerst, 2024). Despite the rapid growth in Asian REIT markets, due to lack of climate data, less stringent disclosure requirements, and concentrated geographic exposures that could further complicate climate vulnerability (Holtermans et al., 2024).

Stakeholder Perceptions

The transmission of climate risk into commercial real estate performance depends fundamentally on stakeholder perceptions and behavioural responses (Sirmans et al., 2025). Deductive analysis confirms that climate risk pricing requires not only objective physical exposure but also market participants' awareness and interpretation of that exposure. Comparative evidence reveals significant variation in climate risk perception across stakeholder groups and geographic contexts. Institutional investors in developed markets increasingly demand climate risk disclosure and integrate climate considerations into investment decisions, driving performance differentiation between climate-prepared and climate-vulnerable assets (Westcott et al., 2020). Occupiers similarly demonstrate growing preference for resilient, sustainable buildings, translating into rental premiums and reduced vacancy risk for adapted properties (Warren-Myers & Hurlimann, 2022). Lenders and insurers, facing direct financial exposure to climate-related losses, increasingly adjust terms based on climate risk assessments, further amplifying performance differentials (Sayce et al., 2022).

Significant perception gaps still remain, though. Climate risk awareness of small investors and private market participants is often limited, which could lead to overvaluation of vulnerable assets (Sirmans et al., 2025). There is an important geographic relationship between climate risk perception and disaster experience, with recent climate shocks demonstrating more sophisticated risk pricing in affected versus comparable unaffected markets (Addoum et al., 2024). This behavioural dimension infuses temporal dynamics into the climate risk pricing mechanism, with performance impacts intensifying following salient events and potentially fading during periods of relative calm.

Adaptation Outcomes

The link between climate adaptation investment and commercial real estate performance is an important analytical frontier (Warren-Myers & Hurlimann, 2022). According to deductive thinking, properties that have adaptive attributes (e.g. flood resilience solutions, energy savings, and climate-resilient design) should perform better due to lesser risk exposure and increased marketability. This hypothesis is generally borne out by empirical evidence, but that evidence is not without essential qualification. Green building certified properties that integrate both mitigation and adaptation mechanisms tend to achieve rental premiums of around 4–7 percent and sale price premiums of 10–15 percent across multiple markets (Feng et al., 2025). Reduced value discounts tend to be correlated with more specific adaptation investments (e.g. flood defences, elevated mechanical systems) in hazard exposed areas (Addoum et al., 2024). Nonetheless, the gains from adaptation investment remain crucial and depend on context with best adaptation for different hazard type, regulatory environment and market characteristics (Wieteska-Rosiak, 2020).

A comparative analysis indicates considerable diversity in adaptation investment patterns. Adaptation uptake in the Northern European markets is relatively higher, reflecting effective regulatory signals and a history of flood risk awareness (Wieteska-Rosiak, 2020). United States markets exhibit more uneven adaptation, with progressive coastal cities investing significantly while inland markets lag (Ling et al., 2024). Emerging markets experience acute adaptation difficulties, combining high physical risk exposure with limited financial capacity and technical expertise to implement effective measures (Thanasi, 2025).

When combining the comparative evidence, it is possible to discern several systematic trends about the impacts of climate change on commercial real estate performance globally. First, climate risk pricing demonstrates strong geographic heterogeneity, where markets with higher levels of disaster experience, a stronger regulatory regime, and more sophisticated investor bases demonstrate more accurate risk capitalization (Clayton et al., 2021; Ling et al., 2024). Second, property-level characteristics have markedly moderated climate impacts, and energy-efficient, certified, and adapted assets have performance premiums across most market settings (Feng et al., 2025; Warren-Myers & Hurlimann, 2022). Third, temporal dynamics do matter: climate shocks act as critical inflection points that expedite risk pricing and performance divergence (Addoum et al., 2024; Holtermans et al., 2024).

This comparative literature bears great importance for investors, policymakers, and industry practitioners. For investors, the knowledge of geographic and property-based variability in climate risk exposure leads to more rational capital allocation and risk management (Westcott et al., 2020). For policymakers, the understanding of the impact of regulatory regimes on market reactions to climate-related risks guides the designing of feasible intervention strategies (Akhtyrska & Fuerst, 2024). Embracing and respecting the complexity and heterogeneity of climate impacts is useful for valuers and advisors for more sensitive and defensible property valuations (Sayce et al., 2022). Finally, this comparative literature suggests that climate change is not a monolithic menace, but a multilayered and site-specific one and continues to evolve commercial real estate performance throughout numerous interacting pathways in heterogeneous global business conditions

METHODOLOGY

This study employs a quantitative, longitudinal research design to examine the impact of climate change on commercial real estate (CRE) performance across five Sub-Saharan African countries: Nigeria. The panel data covers the period from 2001 to 2023, selected to capture recent climate trends alongside post-2000 economic stabilization and urbanization patterns in the region. The Vector Error Correction Model (VECM) is adopted as the primary analytical framework, appropriate for handling non-stationary series that are cointegrated, thereby allowing simultaneous estimation of both long-run equilibrium relationships and short-run dynamic adjustments.

Data for this study were obtained from secondary sources. The dependent variable commercial real estate performance is proxied by country-level CRE price indices, extracted from national property market reports published by central banks, real estate regulatory authorities, and private property consultancies such as Knight Frank and CBRE. Climate change variables include annual temperature anomalies, rainfall variability indices, and frequency or intensity measures of extreme weather events; these were sourced from national meteorological agencies across the five countries, supplemented by global climate databases including the Climatic Research Unit (CRU) at the University of East Anglia and the Global Precipitation Climatology Centre (GPCC). Carbon emissions data (measured in metric tons per capita or total CO_2 equivalent) were obtained from environmental statistics compiled by the Emissions Database for Global Atmospheric Research (EDGAR) and national environmental protection agencies. Macroeconomic control variables specifically GDP growth rates and central bank interest rates were sourced from the World Bank's World Development Indicators (WDI) and the International Monetary Fund's International Financial Statistics (IFS) databases. All variables were transformed using natural logarithms prior to analysis to normalize distributions and interpret estimated coefficients as elasticities.

The econometric procedure proceeded in three stages. First, the Augmented Dickey-Fuller (ADF) unit root test was applied to each variable to determine the order of integration; results confirmed that all series were integrated of order one, I(1). Second, the Johansen cointegration test was employed to identify the presence and number of long-run equilibrium relationships among the variables, which indicated a single cointegrating vector. Third, given the I(1) and cointegrated properties, a VECM was specified, including an error correction term (ECT) to capture the speed at which deviations from long-

run equilibrium are corrected in the short run. All statistical tests were evaluated at conventional significance levels ($p < 0.05$ and $p < 0.01$), with t-statistics reported for coefficient estimates. Diagnostic checks, including tests for serial correlation and normality of residuals, were conducted to ensure model validity.

FINDINGS AND DISCUSSIONS

Unit Root Test Results (ADF Test)

The results of the Augmented Dickey-Fuller unit root tests reveal that all variables, including the commercial real estate price index (lnCREPI), temperature anomaly (lnTEMP), rainfall (lnRAIN), extreme weather events (lnEXTREME), carbon emissions ($lnCO_2$), GDP growth, and interest rate (INT), are non-stationary in levels. However, upon first differencing, each series becomes stationary at the 1% significance level, indicating that all variables are integrated of order one, I(1). These findings confirm the suitability of the data for cointegration analysis and justify the application of a Vector Error Correction Model (VECM) to explore both short- and long-term relationships between climate factors and commercial real estate performance in Sub-Saharan Africa

Table 1: Augmented Dickey-Fuller Unit Root Test

Variable	Level t-stat	1st Diff t-stat	Order of Integration	Decision
lnCREPI	-1.82	-5.94***	I(1)	Stationary at 1st diff
lnTEMP	-2.01	-4.87***	I(1)	Stationary at 1st diff
lnRAIN	-1.56	-5.12***	I(1)	Stationary at 1st diff
lnEXTREME	-1.44	-6.01***	I(1)	Stationary at 1st diff
lnCO2	-2.10	-5.66***	I(1)	Stationary at 1st diff
GDP	-1.92	-4.98***	I(1)	Stationary at 1st diff
INT	-2.22	-5.33***	I(1)	Stationary at 1st diff

Johansen Cointegration Test

The Johansen cointegration test results indicate the presence of a long-run equilibrium relationship among the variables. The trace statistic for the null hypothesis of no cointegration ($r = 0$) is 128.54, which exceeds the 5% critical value of 95.75, leading to the rejection of the null hypothesis. Conversely, the trace statistic for the null hypothesis of at most one cointegrating relationship ($r \leq 1$) is 62.33, which is below the 5% critical value of 69.81, and therefore, the null cannot be rejected. These results confirm the existence of a single cointegrating equation, justifying the use of a Vector Error Correction Model (VECM) to examine the long-run and short-run dynamics between climate change indicators and commercial real estate performance.

Table 2: Johansen Cointegration Results

Hypothesis	Trace Statistic	5% Critical Value	Prob	Decision
$r = 0$	128.54	95.75	0.000	Reject
$r \leq 1$	62.33	69.81	0.112	Do not reject

Note: One cointegrating equation confirmed, Long-run equilibrium relationship exists

Long-Run Cointegration Equation

The long-run cointegration results indicate that climate change variables exert a significant negative impact on commercial real estate performance in Sub-Saharan Africa. Specifically, a 1% increase in temperature anomaly (lnTEMP) is associated with a 0.84% decline in the commercial real estate price index (lnCREPI), while higher rainfall variability (lnRAIN) and the frequency of extreme weather events (lnEXTREME) reduce property values by 0.32% and 0.28%, respectively. Similarly, carbon emissions ($lnCO_2$) have a significant negative effect, lowering property prices by approximately 0.49%. Among the control variables, GDP growth positively influences CRE performance, with a 1% increase in GDP driving a 0.62% rise in property values, whereas higher interest rates exert a dampening effect, reducing prices by 0.35%. These findings highlight the long-term sensitivity of commercial real estate markets to both climate and macroeconomic conditions.

Table 3: Normalized Long-Run Coefficients (Dependent Variable: lnCREPI)

Variable	Coefficient	Std. Error	t-Statistic	Significance
lnTEMP	-0.842	0.214	-3.93	***
lnRAIN	-0.315	0.129	-2.44	**
lnEXTREME	-0.276	0.104	-2.65	**
lnCO2	-0.491	0.172	-2.85	***
GDP	0.623	0.211	2.95	***
INT	-0.354	0.141	-2.51	**

*Note ***p < 0.01, *p < 0.05 A 1% increase in temperature anomaly reduces commercial property prices by 0.84% in the long run. Extreme weather events significantly depress CRE performance. GDP positively drives commercial property growth. Higher interest rates reduce CRE values.*

Error Correction Model (Short-Run Dynamics)

The short-run dynamics captured by the Vector Error Correction Model (VECM) indicate that deviations from the long-run equilibrium are corrected at a significant and moderate pace. The error correction term (ECT (-1)) is negative and statistically significant at −0.472 ($p < 0.01$), suggesting that approximately 47% of any disequilibrium from the long-run relationship is corrected within one year. In the short run, increases in temperature anomaly (ΔlnTEMP), rainfall variability (ΔlnRAIN), extreme weather events (ΔlnEXTREME), and carbon emissions ($\Delta lnCO_2$) all exert negative and significant effects on commercial real estate prices. Specifically, ΔlnTEMP reduces property prices by 0.28%, ΔlnRAIN by 0.18%, ΔlnEXTREME by 0.14%, and $\Delta lnCO_2$ by 0.20%. On the other hand, short-term GDP growth positively influences commercial real estate performance, increasing prices by 0.31%, whereas higher interest rates negatively affect property values, reducing them by 0.20%. These results highlight that climate-related shocks and macroeconomic conditions have immediate impacts on commercial property markets, while the error correction mechanism ensures convergence toward long-term equilibrium.

Table 4: VECM Short-Run Results (Dependent Variable: ΔlnCREPI)

Variable	Coefficient	Std. Error	t-Statistic	Significance
ECT (-1)	-0.472	0.113	-4.17	***
ΔlnTEMP	-0.284	0.119	-2.38	**
ΔlnRAIN	-0.176	0.092	-1.91	*
ΔlnEXTREME	-0.143	0.071	-2.01	**
ΔlnCO2	-0.202	0.089	-2.27	**
ΔGDP	0.311	0.142	2.19	**
ΔINT	-0.198	0.087	-2.27	**

Note: ***p < 0.01, **p < 0.05, *p < 0.10*

Model Diagnostics

Diagnostic tests confirm the robustness and reliability of the estimated Vector Error Correction Model. The LM test for serial correlation indicates no autocorrelation in the residuals (LM = 1.42, p = 0.27), while the Jarque–Bera test confirms that the residuals are normally distributed (JB = 2.11, p = 0.35). The heteroskedasticity test shows no evidence of variance instability (1.68, p = 0.19), and the eigenvalue stability condition is satisfied, indicating that the system is stable. The error correction coefficient (ECT = −0.472) further suggests that approximately 47% of any short-run disequilibrium is corrected annually, reflecting a moderate speed of adjustment toward the long-run equilibrium. These diagnostic results provide confidence in the validity of the VECM findings and the interpretation of both short- and long-term relationships between climate change variables and commercial real estate performance.

Table 5: Diagnostic Tests

Test	Statistic	Probability	Decision
LM Serial Correlation	1.42	0.27	No autocorrelation
Jarque–Bera Normality	2.11	0.35	Residuals normal
Heteroskedasticity Test	1.68	0.19	No heteroskedasticity
Stability (Eigenvalue Modulus)	< 1	—	Stable

Note: Speed of Adjustment Interpretation ECT coefficient = -0.472 This implies that approximately 47.2% of short-run disequilibrium is corrected annually, indicating moderate speed of convergence toward long-run equilibrium.

The Augmented Dickey–Fuller (ADF) unit root tests confirm that all variables commercial real estate price index (lnCREPI), temperature anomaly (lnTEMP), rainfall variability (lnRAIN), extreme weather events (lnEXTREME), carbon emissions ($lnCO_2$), GDP growth, and interest rate are non-stationary at levels but become stationary after first differencing, indicating that all series are integrated of order one, I(1). This satisfies the requirement for the Johansen cointegration test, which reveals the existence of one cointegrating equation at the 5% significance level (trace statistic: 128.54 > critical value: 95.75), confirming a long-run equilibrium relationship between climate change indicators and commercial real estate performance in Sub-Saharan Africa over 2001–2023. The long-run normalized coefficients show that climate variables exert statistically significant negative effects: a 1% increase in temperature anomaly reduces property prices by 0.84%, a 1% increase in rainfall variability is associated with a 0.32% decline, and extreme weather events and carbon emissions similarly depress performance, indicating that persistent climate stress undermines long-term asset value and stability. Among control variables, GDP growth has a positive and significant effect, while interest rates exhibit a negative relationship, implying that tighter monetary conditions reduce investment demand. The short-run dynamics, captured by the error correction model, show a negative and statistically significant error correction term (−0.472), meaning that approximately 47.2% of deviations from long-run equilibrium are corrected within one year, with short-run changes in climate variables also negatively influencing performance. Diagnostic tests confirm no evidence of serial correlation, heteroskedasticity, or instability, and the eigenvalue stability condition is satisfied, indicating that the estimated Vector Error Correction Model (VECM) is statistically reliable and structurally stable. Overall, the empirical findings demonstrate that climate change significantly undermines commercial real estate performance in Sub-Saharan Africa in both the short and long run, confirming that climate risk is not merely a short-term disturbance but a structural determinant of real estate market performance.

The negative long-run effect of temperature anomalies and extreme weather events is consistent with the growing body of international literature demonstrating that climate risk is increasingly capitalized into property markets. For example, Real Estate Economics documents how major climate shocks such as Hurricane Sandy significantly reduced commercial property values in exposed regions (Addoum et al., 2024). Similarly, evidence synthesized in Journal of Portfolio Management suggests that markets adjust property prices downward in response to rising climate exposure (Clayton et al., 2021).

Our findings extend this literature by demonstrating that even gradual climate stress—such as persistent temperature increases and rainfall variability has measurable adverse pricing effects in emerging commercial property markets. While most prior studies focus on developed economies (e.g., the United States and Europe), this study confirms that climate risk pricing mechanisms are also emerging in developing markets, albeit within structurally weaker institutional contexts.

The significant and negative coefficient on extreme weather events aligns with recent empirical work in Journal of Regional Science (Holtermans et al., 2024), which quantifies how climate shocks disrupt regional commercial real estate performance. The present study shows that in Sub-Saharan Africa, such shocks generate both immediate short-run depreciation effects and long-run equilibrium adjustments.

Moreover, the significant error correction term indicates that approximately 47% of disequilibrium adjusts annually, suggesting moderate market responsiveness. This speed of adjustment is comparable to findings in developed markets reported in Journal of Real Estate Research (Feng et al., 2025), though adjustment in Sub-Saharan Africa appears slower, possibly reflecting lower market transparency, weaker insurance penetration, and limited climate disclosure frameworks.

Importantly, the positive impact of GDP growth confirms that macroeconomic expansion partially offsets climate-related depreciation pressures. This interaction effect supports arguments in British Journal of Management (Orazalin et al., 2024), which highlight how sustainability governance mechanisms can mitigate climate-related valuation losses.

Conclusion

This study provides compelling evidence that climate change poses a significant threat to commercial real estate (CRE) performance in Sub-Saharan Africa, particularly in Nigeria. The long-run VECM analysis indicates that rising temperatures, extreme weather events, rainfall variability, and increasing carbon emissions have a pronounced negative effect on property values, while economic growth positively supports CRE performance. The short-run dynamics further reveal that deviations from long-term equilibrium are corrected moderately over time, emphasizing that CRE markets are responsive but vulnerable to ongoing climate stressors. These results highlight that climate change is no longer a peripheral concern; it is a central determinant of asset valuation, investment security, and long-term market stability in the region.

Recommendations

To mitigate these risks, policymakers, investors, and developers must integrate climate resilience into CRE planning and management. This includes the promotion of green building practices, adoption of climate-resilient infrastructure, and the use of comprehensive climate risk assessment in property valuation and investment decisions. Ecopreneurial strategies, such as innovative property management and proactive adaptation initiatives, should be incentivized to enhance financial performance and market stability. Furthermore, regional cooperation across Sub-Saharan Africa is essential to harmonize regulations, share knowledge, and develop standardized adaptation tools that reflect the diverse climate and market conditions. By implementing these measures, stakeholders can safeguard property values, reduce financial losses, and foster a more sustainable, resilient, and forward-looking CRE sector capable of thriving under evolving climate challengesWrite your content here (single spacing, 11pt Times New Roman, justify)

REFERENCES

Sayce, S. L., Clayton, J., Devaney, S., & van de Wetering, J. (2022). Climate risks and their implications for commercial property valuations. *Journal of Property Investment & Finance*, *40*(4), 430-443.

Clayton, J., Devaney, S., Sayce, S., & Van de Wetering, J. (2021). Climate risk and real estate prices: what do we know?. *Journal of Portfolio Management*, *47*(10).

Sirmans, C. S., Sirmans, G. S., Smersh, G. T., & Winkler, D. T. (2025). Perceptions of climate change and the pricing of disaster risk in commercial real estate. *The Journal of Real Estate Finance and Economics*, 1-33.

Holtermans, R., Niu, D., & Zheng, S. (2024). Quantifying the impacts of climate shocks in commercial real estate markets. *Journal of Regional Science*, *64*(4), 1099-1121.
Clayton, J., Devaney, S., & van de Wetering, J. (2022). Climate risk and commercial property values: a review and analysis of the literature.
Feng, Z., Lu-Andrews, R., & Wu, Z. (2025). Commercial real estate in the face of climate risk: Insights from REITs. *Journal of Real Estate Research*, *47*(4), 435-463.
Westcott, M., Ward, J., Surminski, S., Sayers, P., Bresch, D. N., & Claire, B. (2020). Be prepared: exploring future climate-related risk for residential and commercial real estate portfolios. *The Journal of Alternative Investments*, *23*(1), 24-34.
Addoum, J. M., Eichholtz, P., Steiner, E., & Yönder, E. (2024). Climate change and commercial real estate: Evidence from Hurricane Sandy. *Real Estate Economics*, *52*(3), 687-713.
Warren-Myers, G., & Hurlimann, A. (2022). Climate change and risk to real estate. In *A research agenda for real estate* (pp. 139-164). Edward Elgar Publishing.
Warren-Myers, G., & Hurlimann, A. (2022). Climate change and risk to real estate. In *A research agenda for real estate* (pp. 139-164). Edward Elgar Publishing.
Ling, D. C., Robinson, S., Sanderford, A. R., & Wang, C. (2024). Climate change and commercial property markets. *Journal of Regional Science*, *64*(4), 1066-1098.
Thanasi, L. (2025). *The impact of climate change on real estate sector* (Master's thesis, Πανεπιστήμιο Πειραιώς).
Wieteska-Rosiak, B. (2020). Real estate sector in the face of climate change adaptation in major Polish cities. *Real Estate Management and Valuation*, *28*(1), 51-63.
Akhtyrska, Y., & Fuerst, F. (2024). The effectiveness of climate change regulations in the commercial real estate market. *Energy Policy*, *185*, 113916.
Addoum, J. M., Eichholtz, P., Steiner, E., & Yönder, E. (2024). Climate change and commercial real estate: Evidence from Hurricane Sandy. *Real Estate Economics*, *52*(3), 687-713.
Afzal, A., Rasoulinezhad, E., & Malik, Z. (2022). Green finance and sustainable development in Europe. *Economic research-Ekonomska istraživanja*, *35*(1), 5150-5163.
Akomea-Frimpong, I., Adeabah, D., Ofosu, D., & Tenakwah, E. J. (2022). A review of studies on green finance of banks, research gaps and future directions. *Journal of Sustainable Finance & Investment*, *12*(4), 1241-1264.
Al-Awlaqi, M. A., & Aamer, A. M. (2022). Individual entrepreneurial factors affecting adoption of circular business models: An empirical study on small businesses in a highly resource-constrained economy. *Journal of Cleaner Production*, *379*, 134736.
Ansari, M. R., Rahim, K., Bhoje, R., & Bhosale, S. (2022). A study on research design and its types. *International Research Journal of Engineering and Technology (IRJET)*, *9*(7), 1132-1135.
Ansari, M. R., Rahim, K., Bhoje, R., & Bhosale, S. (2022). A study on research design and its types. *International Research Journal of Engineering and Technology (IRJET)*, *9*(7), 1132-1135.
Antoniuk, Y., & Leirvik, T. (2024). Climate change events and stock market returns. *Journal of Sustainable Finance & Investment*, *14*(1), 42-67.
Barkham, R., Bokhari, S., & Saiz, A. (2022). Urban big data: city management and real estate markets. In *Artificial intelligence, machine learning, and optimization tools for smart cities: Designing for sustainability* (pp. 177-209). Cham: Springer International Publishing.
Bauer, M. D., & Rudebusch, G. D. (2023). The rising cost of climate change: evidence from the bond market. *Review of Economics and Statistics*, *105*(5), 1255-1270.
Bertoni, F., Bonini, S., Capizzi, V., Colombo, M. G., & Manigart, S. (2022). Digitization in the market for entrepreneurial finance: Innovative business models and new financing channels. *Entrepreneurship Theory and Practice*, *46*(5), 1120-1135.
Burnell, D., Stevenson, R., & Fisher, G. (2023). Early-stage business model experimentation and pivoting. *Journal of Business Venturing*, *38*(4), 106314.
Calandra, D., Secinaro, S., Massaro, M., Dal Mas, F., & Bagnoli, C. (2023). The link between sustainable business models and Blockchain: A multiple case study approach. *Business Strategy and the Environment*, *32*(4), 1403-1417.

Chali, M. T., Eshete, S. K., & Debela, K. L. (2022). Learning how research design methods work: A review of Creswell's research design: Qualitative, quantitative and mixed methods approach. *The Qualitative Report*, *27*(12), 2956-2960.

Coulson, E., Palacios, J., & Zheng, S. (2024). Climate change and real estate: An introduction to the special issue. *Journal of Regional Science*, *64*(4), 991-993.

Dias, Á., Silva, G. M., Patuleia, M., & González-Rodríguez, M. R. (2023). Developing sustainable business models: Local knowledge acquisition and tourism lifestyle entrepreneurship. In *Knowledge management, organisational learning and sustainability in tourism* (pp. 37-56). Routledge.

DiBella, J. (2020). The spatial representation of business models for climate adaptation: An approach for business model innovation and adaptation strategies in the private sector. *Business Strategy & Development*, *3*(2), 245-260.

Fu, C., Lu, L., & Pirabi, M. (2023). Advancing green finance: a review of sustainable development. *Digital Economy and Sustainable Development*, *1*(1), 20.

Gregori, P., Holzmann, P., & Audretsch, D. B. (2024). Sustainable entrepreneurship on digital platforms and the enactment of digital connectivity through business models. *Business Strategy and the Environment*, *33*(2), 1173-1190.

Gupta, G., & Bose, I. (2022). Digital transformation in entrepreneurial firms through information exchange with operating environment. *Information & Management*, *59*(3), 103243.

Hunziker, S., & Blankenagel, M. (2024). Cross-sectional research design. In *Research design in business and management: A practical guide for students and researchers* (pp. 187-199). Wiesbaden: Springer Fachmedien Wiesbaden.

Hunziker, S., & Blankenagel, M. (2024). Cross-sectional research design. In *Research design in business and management: A practical guide for students and researchers* (pp. 187-199). Wiesbaden: Springer Fachmedien Wiesbaden.

Khan, M. A., Riaz, H., Ahmed, M., & Saeed, A. (2022). Does green finance really deliver what is expected? An empirical perspective. *Borsa Istanbul Review*, *22*(3), 586-593.

Kiviaho, A., & Toivonen, S. (2023). Forces impacting the real estate market environment in shrinking cities: possible drivers of future development. *European Planning Studies*, *31*(1), 189-211.

Lew, Y. K., Zahoor, N., Donbesuur, F., & Khan, H. (2023). Entrepreneurial alertness and business model innovation in dynamic markets: international performance implications for SMEs. *R&D Management*, *53*(2), 224-243.

Liu, C., & Wu, S. S. (2023). Green finance, sustainability disclosure and economic implications. *Fulbright Review of Economics and Policy*, *3*(1), 1-24.

Meo, M. S., & Abd Karim, M. Z. (2022). The role of green finance in reducing CO2 emissions: An empirical analysis. *Borsa Istanbul Review*, *22*(1), 169-178.

Namugenyi, I., Coenen, L., & Scholderer, J. (2022). Realising the transition to bioenergy: integrating entrepreneurial business models into the biogas socio-technical system in Uganda. *Journal of Cleaner Production*, *333*, 130135.

Ngoc, N. M., Tien, N. H., & Hieu, V. M. (2023). The relevance of factors affecting real estate investment decisions for post pandemic time. *International journal of business and globalisation*, *1*(1), 1-15.

Nguyen, D. D., Ongena, S., Qi, S., & Sila, V. (2022). Climate change risk and the cost of mortgage credit. *Review of Finance*, *26*(6), 1509-1549.

Olawale, S. R., Chinagozi, O. G., & Joe, O. N. (2023). Exploratory research design in management science: A review of literature on conduct and application. *International Journal of Research and Innovation in Social Science*, *7*(4), 1384-1395.

Olawale, S. R., Chinagozi, O. G., & Joe, O. N. (2023). Exploratory research design in management science: A review of literature on conduct and application. *International Journal of Research and Innovation in Social Science*, *7*(4), 1384-1395.

Orazalin, N. S., Ntim, C. G., & Malagila, J. K. (2024). Board sustainability committees, climate change initiatives, carbon performance, and market value. *British Journal of Management*, *35*(1), 295-320.

Ozili, P. K. (2022). Green finance research around the world: a review of literature. *International Journal of Green Economics*, *16*(1), 56-75.

Paul, C., Bartkowski, B., Dönmez, C., Don, A., Mayer, S., Steffens, M., ... & Helming, K. (2023). Carbon farming: are soil carbon certificates a suitable tool for climate change mitigation?. *Journal of Environmental Management*, *330*, 117142.

Salamzadeh, A., Mortazavi, S., Hadizadeh, M., & Braga, V. (2023). Examining the effect of business model innovation on crisis management: the mediating role of entrepreneurial capability, resilience and business performance. *Innovation & Management Review*, *20*(2), 132-146.

Salter, M. B. (2023). Research design. In *Research Methods in Critical Security Studies* (pp. 19-27). Routledge.

Salter, M. B. (2023). Research design. In *Research Methods in Critical Security Studies* (pp. 19-27). Routledge.

Simonian, S., & Lundbäck, A. (2022). The Pursuit Towards Circular Business Models in the Real Estate Industry: Challenges and Enablers in Commercial Tenant Adaptations.

Snihur, Y., & Bocken, N. (2022). A call for action: The impact of business model innovation on business ecosystems, society and planet. *Long Range Planning*, *55*(6), 102182.

Takona, J. P. (2024). Research design: qualitative, quantitative, and mixed methods approach. *Quality & Quantity*, *58*(1), 1011-1013.

Thanasi, L. (2025). *The impact of climate change on real estate sector* (Master's thesis, Πανεπιστήμιο Πειραιώς).

Tran, N. Q., Tien, N. H., & Chi, D. T. P. (2022). Analysis of sales management strategy of Novaland real estate group. *International Journal of Multidisciplinary Research and Growth Evaluation*, *4*(3), 420-429.

Troise, C., Jones, P., Candelo, E., & Sorrentino, M. (2023). The role of entrepreneurial alertness, digital platform capability, organisational agility and business model innovation on young innovative companies' performance. *Technology Analysis & Strategic Management*, 1-14.

Usman, F. O., Kess-Momoh, A. J., Ibeh, C. V., Elufioye, A. E., Ilojianya, V. I., & Oyeyemi, O. P. (2024). Entrepreneurial innovations and trends: A global review: Examining emerging trends, challenges, and opportunities in the field of entrepreneurship, with a focus on how technology and globalization are shaping new business ventures. *International Journal of Science and Research Archive*, *11*(1), 552-569.

Voland, N., Saad, M. M., & Eicker, U. (2022). Public policy and incentives for socially responsible new business models in market-driven real estate to build green projects. *Sustainability*, *14*(12), 7071.

Wang, K. H., Zhao, Y. X., Jiang, C. F., & Li, Z. Z. (2022). Does green finance inspire sustainable development? Evidence from a global perspective. *Economic Analysis and Policy*, *75*, 412-426.

Warren-Myers, G., & Hurlimann, A. (2022). Climate change and risk to real estate. In *A research agenda for real estate* (pp. 139-164). Edward Elgar Publishing.

Wu, S., Luo, Y., Zhang, H., & Cheng, P. (2024). Entrepreneurial bricolage and entrepreneurial performance: The role of business model innovation and market orientation. *Heliyon*, *10*(4).

Zeiada, W., Hamad, K., Khalil, M. A., & Hassan, L. M. (2022). Development of green pavement rating system in the UAE. *Innovative Infrastructure Solutions*, *7*(1), 46.

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