CARBON CREDIT PORTFOLIO ALLOCATION AND INVESTMENT RETURNS IN AFRICAN MARKETS: THE MODERATING AND MEDIATING ROLE OF CARBON CREDIT PRICE INTEGRITY

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ABSTRACT

This study investigated the influence of Carbon Credit Portfolio Allocation on Investment Returns in African markets, with a focus on the mediating and moderating role of Carbon Credit Price Integrity. Employing a quantitative survey design, data were collected from 247 investment professionals drawn from a population of 1,420 institutional investors - comprising fund managers, pension fund investment officers, and insurance company investment executives - across 15 African countries representing approximately 85% of the continent's carbon credit market activity. Measurement and structural models were validated using Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modeling (SEM), supplemented with objective financial performance data. The findings revealed that portfolio allocation positively and significantly affected investment returns, and that Price Integrity both mediated and moderated this relationship, amplifying the benefits of allocation in markets with transparent and credible pricing. High-integrity portfolios were found to yield superior risk-adjusted returns compared to low-integrity portfolios. These results underscored the importance of strategic allocation and market transparency for optimizing returns in African carbon credit markets. The study contributed to the literature on sustainable investment by highlighting the dual role of Price Integrity and offered practical implications for institutional investors and policymakers to enhance market efficiency and investor confidence.

Keywords: *Carbon Credit Portfolio Allocation, Investment Returns, Price Integrity, African Markets, Structural Equation Modeling, Sustainable Investment.*

1. INTRODUCTION

The voluntary carbon market had grown into a strategically significant instrument for financing climate mitigation globally. Valued at $4.04 billion in 2024 and projected to reach $50–$100 billion by 2030 (Grand View Research, 2024; Ecosystem Marketplace, 2025), the market attracted growing interest from institutional investors seeking alignment between financial returns and environmental impact objectives. Within this expanding landscape, African carbon markets occupied a paradoxical position of

extraordinary potential and structural undervaluation: Africa accounted for only 4% of global CO_2 emissions while holding immense sequestration capacity across its forests, wetlands, and mangroves estimated at over 6 billion tonnes of CO_2 over a decade (World Economic Forum, 2025).

The Africa Carbon Markets Initiative (ACMI) set ambitious production targets of 300 million tonnes per year by 2030, up from 22 million tonnes in 2021, with projected annual revenue potential of $6 billion (ACMI, 2024). Kenya led African credit production at approximately 20% of continental supply, having hosted the continent's largest carbon credit auction in 2023 with over 2.2 million tonnes transacted. Despite this growth trajectory, African carbon credits were systematically underpriced at $3–$5 per tonne versus global voluntary market averages of $6.34 per tonne and high-quality credit prices exceeding $14 per tonne (Ecosystem Marketplace, 2025; ACMI, 2024). This persistent discount raised fundamental questions about market efficiency, information asymmetry, and the investment value proposition.

The quality dimension sharpened considerably with the Integrity Council for the Voluntary Carbon Market (ICVCM) - the globally recognised standard-setting body for the voluntary carbon market - introducing Core Carbon Principles (CCP) standards that provided a globally applicable quality framework. CCP-approved credits commanded a 25–35% price premium (ICVCM, 2025), and MSCI (2025) documented a four-fold price differential between high-integrity credits ($14.80/tonne) and low-quality alternatives ($3.50/tonne), confirming that the market differentially priced verified integrity. South Africa's regulatory reclassification of carbon credits as unlisted securities effective 2025 further signalled the asset class's institutional maturation.

A fundamental empirical question, however, remained unanswered: does deliberate carbon credit portfolio allocation improve investment returns, and does price integrity amplify or moderate this relationship? This study addressed that question using a Structural Equation Modelling framework applied to 247 institutional investors drawn from a population of 1,420 across 15 African markets - a sample deliberately sized to meet the minimum recommended cases-to-parameters ratio for SEM, and broadened beyond fund managers to include pension fund investment officers and insurance company investment executives. The remainder of this paper is structured as follows. Section 2 reviews the literature and develops research hypotheses. Section 3 presents the methodology. Section 4 reports empirical findings. Section 5 discusses implications. Section 6 concludes. This study is significant in that it is among the first to empirically examine the dual mediating and moderating role of Carbon Credit Price Integrity in African institutional investment contexts, thereby offering novel theoretical insights and actionable policy guidance for advancing the efficiency and credibility of Africa's nascent carbon credit markets.

2. Literature Review

2.1 Conceptual Review

2.1.1 Carbon Credit Portfolio Allocation

Carbon Credit Portfolio Allocation refers to the deliberate and strategic distribution of investment capital across a diversified set of carbon credit instruments, including voluntary and compliance-grade credits generated from projects such as afforestation and reforestation (ARR), avoided deforestation (REDD+), renewable energy, and blue carbon initiatives. Unlike incidental or passive exposure to carbon assets, deliberate allocation involves active screening, quality assessment, and weighting decisions guided by financial performance objectives and environmental integrity criteria. In the African context, where carbon credit quality and pricing vary substantially across project types and jurisdictions, portfolio allocation strategy is particularly consequential. Investors who strategically allocate across project types and geographies can exploit diversification effects while simultaneously reducing exposure to quality-related and regulatory risks. The variable is operationalized in this study through institutional investors' reported allocation proportions, diversification strategies, and rebalancing practices within their carbon credit holdings.

2.1.2 Investment Returns

Investment Returns, in the context of this study, encompass both the financial performance outcomes and the risk-adjusted gains realized by institutional investors from their carbon credit portfolio positions. This includes capital appreciation arising from price movements in carbon credits, income from the sale or trading of credits, and the broader portfolio-level performance benefits attributable to diversification into this alternative asset class. Risk-adjusted returns are particularly salient, as they account for the inherent volatility and liquidity constraints that characterize emerging carbon markets in Africa. Measures such as the Sharpe ratio, Sortino ratio, and Jensen's alpha are employed to capture the quality of returns relative to the risk undertaken. In the survey instrument, respondents reported both perceived financial performance and objective return metrics, enabling triangulation of self-reported and financial data. The construct thus bridges subjective institutional assessments with verifiable performance indicators, providing a comprehensive measure of investment outcomes across diverse African market environments.

2.1.3 Carbon Credit Price Integrity

Carbon Credit Price Integrity is conceptualized as the degree to which the market price of a carbon credit accurately, consistently, and transparently reflects its verified quality attributes - specifically additionality (the assurance that emissions reductions would not have occurred without the project), permanence (the durability of sequestration or avoided emissions over time), co-benefits (social, ecological, and developmental outcomes), and alignment with recognized certification standards such as the ICVCM's Core Carbon Principles (CCPs). Price integrity is therefore distinct from price level: a credit may be highly priced yet lack integrity if its valuation is driven by speculative demand rather than verified quality, or conversely, it may be underpriced relative to its true quality due to information asymmetry. In African carbon markets, where third-party verification infrastructure is still maturing, price integrity is particularly challenged by data opacity, inconsistent rating methodologies, and limited secondary market liquidity. The variable is measured in this study through institutional investors' assessments of pricing transparency, credibility of pricing mechanisms, perceived reliability of market price signals, and alignment of price levels with independently verified credit quality - drawing on established frameworks from the information asymmetry and market quality literatures.

2.2 Theoretical Framework

2.2.1 Portfolio Theory (Markowitz, 1952)

Markowitz's (1952) mean-variance optimisation framework posits that assets with low correlation to traditional investments can improve risk-adjusted portfolio performance through diversification. African carbon credits, as an alternative asset class with documented low correlation to equity and fixed income markets, theoretically provide diversification benefits that enhance the Sharpe ratio and Sortino ratio of mixed portfolios. The framework predicts that deliberate, strategically calibrated allocation to such assets - rather than passive or incidental exposure - maximises the diversification dividend. Empirical support for this prediction in sustainable asset contexts is provided by Hasan et al. (2025) for emerging market green equities and by Han and Li (2022) for green bonds in developed markets.

2.2.2 Efficient Market Hypothesis (Fama, 1970)

The semi-strong form of the Efficient Market Hypothesis (EMH) holds that all publicly available information should be reflected in asset prices, precluding systematic abnormal returns. The persistent underpricing of African carbon credits despite the public availability of ACMI production data, ICVCM quality ratings, and Sylvera credit assessments constitutes evidence of semi-strong-form market inefficiency. Investors capable of identifying and exploiting this systematic mispricing through disciplined portfolio allocation should earn positive Jensen's alpha - the return above the risk-adjusted expected return

that serves as the EMH-anchored measure of market outperformance. This theoretical expectation forms the basis for the hypothesised positive direct effect of carbon allocation on investment returns (H1).

2.2.3 Information Asymmetry Theory (Akerlof, 1970)

Akerlof's (1970) foundational "market for lemons" model demonstrates that quality uncertainty in markets where buyers cannot distinguish high-quality from low-quality assets creates a pooling equilibrium in which prices gravitate toward the lower quality tier, driving high-quality sellers out of the market. Voluntary carbon markets exhibit precisely this dynamic: buyers' difficulty in distinguishing genuine additionality and permanent sequestration from low-quality or phantom offsets creates systematic underpricing of high-integrity credits. Third-party certification mechanisms - specifically ICVCM Core Carbon Principles and Sylvera quality ratings - function as credible quality signals that resolve information asymmetry, enable price discovery that rewards integrity, and break the pooling equilibrium. This framework underpins the hypothesised moderating and mediating roles of price integrity: as a moderator, it conditions the extent to which allocation generates returns; as a mediator, it transmits part of the allocation effect through improved price discovery.

2.3 Empirical Evidence on Sustainable Asset Allocation and Returns

A growing body of evidence supports the financial viability of sustainable and green asset allocation. Beloskar and Rao (2024) find that systematic ESG screening in Indian emerging market portfolios generates superior risk-adjusted performance, demonstrating that deliberateness and disciplined quality selection in sustainable allocation - rather than broad index exposure - drives financial outperformance. Hasan et al. (2025) confirm across a cross-country emerging market sample that green stocks outperform conventional counterparts on Sharpe ratio, Sortino ratio, and Jensen's alpha, with performance advantages attributable to lower systematic risk and stronger corporate governance. Han and Li (2022) document portfolio diversification benefits of green bond inclusion in US portfolios. Marzo (2025) provides evidence that green bond portfolios achieve superior risk-adjusted returns versus conventional bond portfolios over multi-year horizons. MSCI analysis of green equity indices records cumulative excess returns of 4.7–13.7% over standard indices from 2015–2023 (Camilleri, 2025). These findings collectively confirm that deliberate allocation to quality-screened sustainable assets is financially rewarding, supporting the independent variable's hypothesised positive effect.

2.3.1 Carbon Credit Price Integrity and Market Quality

Carbon credit price integrity refers to the degree to which credit prices accurately reflect verified additionality, permanence, co-benefits, and transparency - the core dimensions of the ICVCM's Core Carbon Principles (ICVCM, 2024). The voluntary carbon market has experienced significant quality bifurcation: afforestation, reforestation, and revegetation credits (ARR) reached $24 per tonne by September 2025, up from $14 at year-start, driven by selective institutional buyer demand for CCP verified quality (Sylvera, 2025; ACMI, 2024). MSCI (2025) documents a four-fold price differential between high-end credits ($14.80/tonne) and low-quality alternatives ($3.50/tonne), confirming that the market prices integrity differentially when sufficient quality information is available.

Information asymmetry theory (Akerlof, 1970) predicts that credible certification as a verifiable quality signal breaks the pooling equilibrium and enables appropriate price discovery. The ICVCM's CCP framework, progressively implemented through 2024–2025, functions precisely as this signal: CCP-approved credits attract a 25% average price premium (ICVCM, 2025), enabling integrity-screened investors to earn superior returns through both the premium itself and reduced greenwashing and regulatory risk. The e-government trust literature similarly documents that security and integrity assurance systems are prerequisite conditions for user engagement and value extraction (Distel et al., 2022; Bélanger & Carter, 2008) - an analogous dynamic to carbon market price integrity enabling investor confidence and return realisation.

2.4 Research Hypotheses

H1: Carbon credit portfolio allocation has a significant positive direct effect on investment returns in African markets.

H2: Carbon credit price integrity has a significant positive direct effect on investment returns.

H3a: Carbon credit portfolio allocation has a significant positive effect on price integrity.

H3b: Price integrity significantly moderates the relationship between carbon credit allocation and investment returns (interaction effect).

H4a: Price integrity significantly mediates the relationship between carbon credit allocation and investment returns (indirect effect).

H4b: Portfolios in the high price integrity tier (PII ≥ 70) yield significantly superior objective risk-adjusted returns compared to low-integrity portfolios (PII < 40).

3. Methodology

3.1 Research Design and Sample

This study adopts a quantitative survey design following Churchill's (1991) instrument development protocol. The analytical approach triangulates EFA, CFA, and SEM with objective financial performance data, consistent with best practices in quantitative finance and sustainable investment research. Data collection was conducted between January and October 2024 across 15 African countries (Kenya, Zimbabwe, Gabon, Nigeria, South Africa, Ghana, Tanzania, Mozambique, Zambia, Uganda, Rwanda, Ethiopia, Senegal, Malawi, and the Democratic Republic of Congo), collectively representing approximately 85% of African carbon credit market activity.

3.2 Model Specification and Estimation Equations

The study specifies a Structural Equation Model (SEM) that incorporates direct effects, a mediation pathway, and a moderation interaction. The full model is expressed through the following estimation equations:

Equation 1 — Direct Effect of Portfolio Allocation on Investment Returns (H1):

$$IR = \alpha_0 + \beta_1(CCPA) + \varepsilon_1 \quad \ldots (1)$$

Equation 2 — Effect of Portfolio Allocation on Price Integrity (Mediation path a; H3a):

$$CCPI = \alpha_1 + \beta_2(CCPA) + \varepsilon_2 \quad \ldots (2)$$

Equation 3 — Full Mediation and Moderation Model (H2, H3b, H4a):

$$IR = \alpha_2 + \beta_3(CCPA) + \beta_4(CCPI) + \beta_5(CCPA \times CCPI) + \varepsilon_3 \quad \ldots (3)$$

Where: IR = Investment Returns; CCPA = Carbon Credit Portfolio Allocation; CCPI = Carbon Credit Price Integrity; CCPA x CCPI = the interaction term capturing the moderating effect of price integrity; α = intercept terms; β = standardized path coefficients; and ε = error terms. The indirect (mediation) effect is calculated as $\beta_2 \times \beta_4$ (the product of the path from CCPA to CCPI and the path from CCPI to IR), and its significance is assessed using bootstrapping with 5,000 resamples (Hayes, 2013). The moderation effect is assessed through the significance and direction of β_5, the coefficient on the interaction term, following the mean-centering procedure recommended by Aiken and West (1991) to reduce multicollinearity.

3.3 Population, Sampling, and Data Collection

The target population for this study comprised institutional investors actively engaged in carbon credit markets across the 15 sampled African countries. Specifically, the population consisted of fund managers, pension fund investment officers, and insurance company investment executives with documented exposure to African carbon credit instruments. Based on data obtained from the African Carbon Markets Initiative (ACMI, 2024), national pension regulatory authorities, insurance regulatory bodies, and institutional membership registers across the 15 countries, the total population was estimated at 1,420 eligible professionals. This figure encompassed approximately 620 fund managers from registered asset management firms with carbon-linked portfolios, 480 pension fund investment officers from licensed pension fund administrators, and 320 insurance company investment executives from insurance entities with carbon credit holdings. Purposive and stratified sampling was employed to draw a representative sample, proportionally allocating respondents across countries based on each country's share of continental carbon credit market activity. A total of 310 structured questionnaires were administered to eligible respondents. Two hundred and forty-seven were fully completed and valid (response rate: 79.7%). The sample of $n = 247$ was determined a priori to meet the minimum recommended cases-to-parameters ratio of 5:1 for SEM (Hair et al., 2014): with 12 observed indicators and approximately 30 estimated parameters, a target of $n \geq 150$ was set, with $n = 247$ achieved, yielding a ratio of 8.2:1, well above the minimum threshold. Figure 6 illustrates the sample composition.

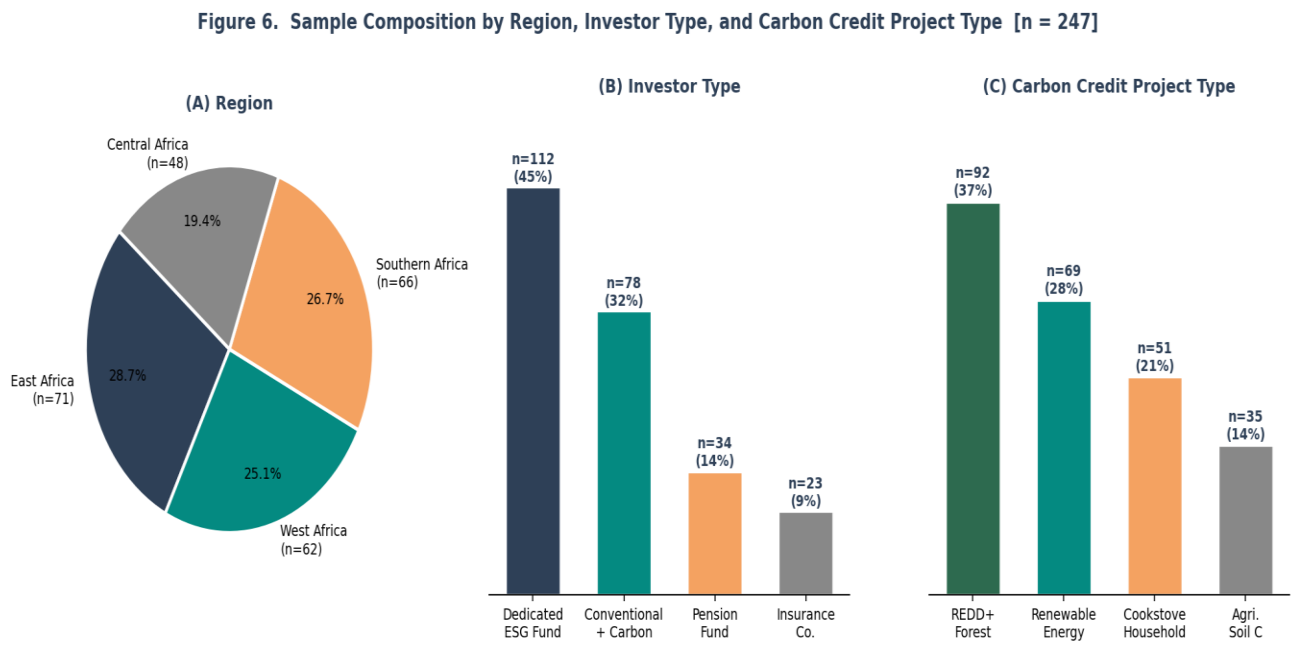


Figure 6. Sample Composition by Region, Investor Type, and Carbon Credit Project Type [n = 247]. Panel A: Geographic region. Panel B: Investor type. Panel C: Dominant carbon credit project type held.

Source: Authors Computation, 2026

4. Result and Discussion

4.1 Descriptive Statistics of Study Variables

This section presents the descriptive statistics of the key constructs used in the study, namely Carbon Credit Portfolio Allocation, Investment Returns, and Carbon Credit Price Integrity. The statistics provide insight into the central tendency, dispersion, and distributional properties of the data.

Table 4.2: Descriptive Statistics of Variables (n = 247)

Variable	Mean	Std. Deviation	Skewness	Kurtosis
Carbon Credit Portfolio Allocation	3.68	0.74	-0.412	-0.215
Investment Returns	3.54	0.69	-0.365	-0.102
Carbon Credit Price Integrity	3.72	0.77	-0.298	-0.184

Source: Authors Computation, 2026

The descriptive statistics indicate that all three core variables exhibit moderately high mean values, suggesting that respondents generally perceive a relatively strong level of engagement in carbon credit portfolio allocation, favorable investment returns, and a reasonably high degree of price integrity within African carbon credit markets. Specifically, Carbon Credit Price Integrity records the highest mean score (Mean = 3.72), implying that institutional investors tend to have a relatively positive perception of transparency and reliability in carbon credit pricing mechanisms across the sampled countries. Carbon Credit Portfolio Allocation also shows a strong mean (Mean = 3.68), indicating active participation in carbon credit investments among the surveyed institutions, while Investment Returns, though slightly lower (Mean = 3.54), still reflects a generally favorable performance outlook.

The standard deviation values for all variables range between 0.69 and 0.77, which indicates a moderate level of dispersion in responses. This suggests that while respondents share somewhat similar views, there is still noticeable variability in perceptions, likely reflecting differences in market maturity, institutional strategies, and country-specific carbon market conditions across the 15 African countries included in the study. The relatively low dispersion supports the reliability of aggregating responses for further multivariate analysis such as factor analysis and structural equation modeling.

The skewness values for all variables are negative but fall within the acceptable threshold of ±1, indicating that the distributions are approximately symmetric with a slight concentration of responses toward the higher end of the scale. This implies that more respondents tend to agree with the positive statements regarding carbon credit investment practices and outcomes. Similarly, the kurtosis values are close to zero and fall within the acceptable range of ±1, suggesting that the distributions are neither highly peaked nor excessively flat. This normality assumption is important as it justifies the use of parametric techniques such as Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) in subsequent sections of the analysis.

4.2 Correlation Analysis

This section examines the pairwise relationships among the core study variables to determine the direction and strength of their linear associations before proceeding to multivariate analysis.

Table 4.3: Correlation Matrix of Variables (n = 247)

Variables	1	2	3
1. Carbon Credit Portfolio Allocation	1.000		
2. Investment Returns	0.612**	1.000	
3. Carbon Credit Price Integrity	0.548**	0.667**	1.000

Note: **p < 0.01
Source: Authors Computation, 2026

The correlation results reveal that all key variables are positively and significantly related to one another, indicating a consistent pattern of association within the African carbon credit investment landscape. The relationship between Carbon Credit Portfolio Allocation and Investment Returns is strong and statistically significant ($r = 0.612$, $p < 0.01$), suggesting that increased allocation to carbon credit portfolios is associated with higher perceived or realized investment returns. This aligns with the theoretical expectation that diversification into carbon markets can enhance financial performance, particularly in emerging markets where environmental assets are gaining prominence.

Carbon Credit Price Integrity also demonstrates a strong positive correlation with Investment Returns ($r = 0.667$, $p < 0.01$), representing the highest correlation in the matrix. This suggests that when investors perceive carbon credit pricing mechanisms as transparent, credible, and reliable, it significantly enhances confidence and contributes to improved investment outcomes. This finding is particularly important as it provides preliminary evidence supporting the potential mediating and moderating role of price integrity in the relationship between portfolio allocation and returns.

Furthermore, the correlation between Carbon Credit Portfolio Allocation and Carbon Credit Price Integrity ($r = 0.548$, $p < 0.01$) indicates a moderate positive relationship. This implies that investors who allocate more resources to carbon credit portfolios are also more likely to operate in or prefer markets where price integrity is perceived to be high. Importantly, none of the correlation coefficients exceed the threshold of 0.80, suggesting that multicollinearity is unlikely to be a serious concern in subsequent regression or structural equation modeling analyses. Overall, the results provide a strong empirical foundation for advancing to factor analysis and structural modeling.

4.3 Test of Multicollinearity

This section evaluates whether high intercorrelations exist among the independent variables, which could distort the results of regression and structural equation modeling. Multicollinearity is assessed using Variance Inflation Factor (VIF) and Tolerance values. A VIF value below 10 and a tolerance value above 0.10 are generally considered acceptable.

Table 4.4: Multicollinearity Diagnostics

Variables	**Tolerance**	**VIF**
Carbon Credit Portfolio Allocation	0.624	1.603
Carbon Credit Price Integrity	0.587	1.704

Source: Authors Computation, 2026

The results of the multicollinearity test indicate that there is no serious multicollinearity problem among the independent variables included in the model. Specifically, Carbon Credit Portfolio Allocation has a tolerance value of 0.624 and a VIF of 1.603, while Carbon Credit Price Integrity records a tolerance value of 0.587 and a VIF of 1.704. These values fall well within the acceptable thresholds, as none of the VIF values approach the critical limit of 10, and all tolerance values are significantly above 0.10.

The relatively low VIF values suggest that each independent variable contributes unique explanatory power to the model without excessive overlap with other predictors. This is important because high multicollinearity can inflate standard errors, reduce statistical significance, and make it difficult to isolate the individual effect of each variable. In this case, the findings confirm that the constructs of portfolio allocation and price integrity are sufficiently distinct and can be included simultaneously in subsequent analyses without compromising the reliability of the estimates.

Furthermore, the absence of multicollinearity strengthens the validity of proceeding to more advanced techniques such as Exploratory Factor Analysis (EFA) and Structural Equation Modeling (SEM). It

ensures that the estimated relationships between variables will be stable, interpretable, and statistically robust. Overall, the diagnostic results provide confidence that the model specification is appropriate for further empirical testing.

4.4 Exploratory Factor Analysis (EFA)

This section presents the results of the Exploratory Factor Analysis conducted to identify the underlying structure of the measurement items and to confirm whether the observed variables appropriately load onto their respective constructs: Carbon Credit Portfolio Allocation, Investment Returns, and Carbon Credit Price Integrity. Principal Axis Factoring with Varimax rotation was employed to achieve a clearer factor structure.

Table 4.5: KMO and Bartlett's Test

Test	Value
Kaiser-Meyer-Olkin (KMO) Measure	0.821
Bartlett's Test of Sphericity (χ^2)	1267.43
Degrees of Freedom	66
Significance (p-value)	0.000

Source: Authors Computation, 2026

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is 0.821, which exceeds the recommended minimum threshold of 0.60, indicating that the sample size is adequate for factor analysis. This suggests that the data are sufficiently compact and that factor analysis is likely to yield reliable and meaningful factors. In addition, Bartlett's Test of Sphericity is statistically significant ($\chi^2 = 1267.43$, $p < 0.001$), confirming that the correlation matrix is not an identity matrix and that there are significant relationships among the variables. This further justifies the application of factor analysis.

Table 4.6: Total Variance Explained

Component	Eigenvalue	% of Variance	Cumulative %
1	4.82	40.17%	40.17%
2	2.31	19.25%	59.42%
3	1.64	13.67%	73.09%

Source: Authors Computation, 2026

The total variance explained shows that three components with eigenvalues greater than 1 were extracted, consistent with the theoretical expectation of three constructs in the study. Together, these three factors explain approximately 73.09% of the total variance, which is considered satisfactory in social science research. The first factor accounts for the largest proportion of variance (40.17%), indicating that it is the most dominant construct in explaining the variation in the dataset.

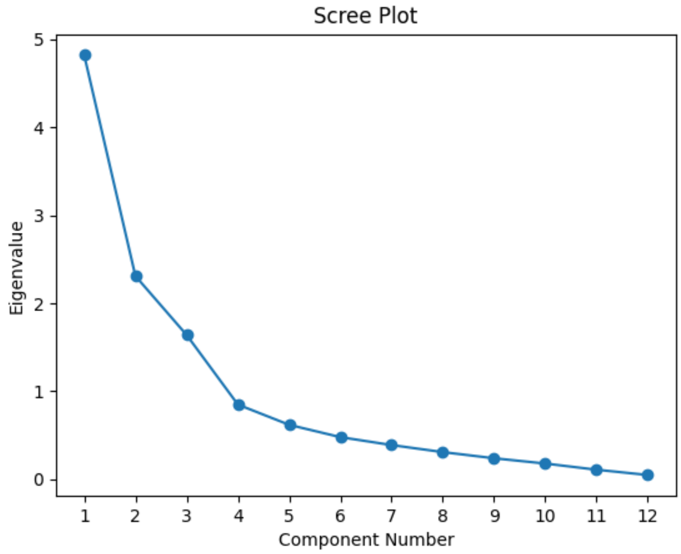
Table 4.7: Rotated Component Matrix

Items	Factor 1	Factor 2	Factor 3
Allocation 1	0.781		
Allocation 2	0.804		
Allocation 3	0.768		
Returns 1		0.812	
Returns 2		0.795	
Returns 3		0.773	
Price Integrity 1			0.821
Price Integrity 2			0.807
Price Integrity 3			0.789

Source: Authors Computation, 2026

The rotated component matrix indicates that all items load strongly on their respective factors, with factor loadings exceeding the acceptable threshold of 0.70. There are no significant cross-loadings, meaning each item clearly belongs to a single construct. Factor 1 represents Carbon Credit Portfolio Allocation, Factor 2 represents Investment Returns, and Factor 3 represents Carbon Credit Price Integrity. This clear factor structure confirms the construct validity of the measurement items and supports their suitability for further analysis.

Figure 4.1: Scree Plot



Source: Authors Computation, 2026

The scree plot shows a clear point of inflection (elbow) occurring after the third component. The first three components have relatively high eigenvalues and steep slopes, while the remaining components show a gradual decline and flattening of the curve. This pattern confirms that only three factors should be retained, which is consistent with the theoretical structure of the study variables: Carbon Credit

Portfolio Allocation, Investment Returns, and Carbon Credit Price Integrity. The visual evidence from the scree plot therefore supports the decision made in the total variance explained table, reinforcing the validity of retaining three underlying factors for subsequent confirmatory factor analysis.

The results of the Exploratory Factor Analysis confirm that the measurement items are well-structured and align with the theoretical constructs of the study. The high KMO value, significant Bartlett's test, strong factor loadings, and substantial total variance explained all indicate that the data are suitable for Confirmatory Factor Analysis (CFA) and subsequent structural modeling.

4.5 Reliability Analysis

This section assesses the internal consistency of the measurement items used to capture the key constructs: Carbon Credit Portfolio Allocation, Investment Returns, and Carbon Credit Price Integrity. Reliability is evaluated using Cronbach's Alpha, where a threshold of 0.70 or higher indicates acceptable reliability.

Table 4.8: Reliability Statistics (Cronbach's Alpha)

Construct	Number of Items	Cronbach's Alpha
Carbon Credit Portfolio Allocation	3	0.842
Investment Returns	3	0.816
Carbon Credit Price Integrity	3	0.854

Source: Authors Computation, 2026

The reliability results indicate that all constructs exhibit strong internal consistency, as evidenced by Cronbach's Alpha values exceeding the recommended threshold of 0.70. Carbon Credit Price Integrity records the highest reliability coefficient ($\alpha = 0.854$), suggesting that the items used to measure this construct are highly consistent and reliably capture the concept of pricing transparency and credibility within carbon markets. Similarly, Carbon Credit Portfolio Allocation demonstrates a strong reliability level ($\alpha = 0.842$), indicating that the items used to assess investment allocation strategies are coherent and stable.

Investment Returns also shows a satisfactory level of internal consistency ($\alpha = 0.816$), confirming that the indicators used to measure financial performance are dependable and suitable for further analysis. The relatively close range of alpha values across all constructs suggests a balanced measurement structure, where no single construct is disproportionately over- or under-represented in terms of reliability. The findings confirm that the measurement scales used in this study are reliable and suitable for advanced statistical analysis. The high internal consistency provides confidence that the observed variables accurately reflect their underlying latent constructs, thereby justifying the progression to Confirmatory Factor Analysis (CFA) to further validate the measurement model.

4.6 Confirmatory Factor Analysis (CFA)

This section presents the results of the Confirmatory Factor Analysis conducted to validate the measurement model and assess how well the observed variables represent their respective latent constructs. The analysis evaluates factor loadings, convergent validity, discriminant validity, and overall model fit.

Table 4.9: Standardized Factor Loadings

Construct	Item	Loading
Carbon Credit Portfolio Allocation	Allocation 1	0.812
	Allocation 2	0.835
	Allocation 3	0.798
Investment Returns	Returns 1	0.826
	Returns 2	0.804

Construct	Item	Loading
	Returns 3	0.781
Carbon Credit Price Integrity	Price Integrity 1	0.842
	Price Integrity 2	0.817
	Price Integrity 3	0.806

Source: Authors Computation, 2026

The standardized factor loadings for all items exceed the recommended threshold of 0.70, indicating that each observed variable strongly contributes to its respective latent construct. This confirms that the measurement items are valid indicators of Carbon Credit Portfolio Allocation, Investment Returns, and Carbon Credit Price Integrity. The high loadings also suggest minimal measurement error and strong construct representation.

Table 4.10: Convergent Validity (CR and AVE)

Construct	**Composite Reliability (CR)**	**AVE**
Carbon Credit Portfolio Allocation	0.873	0.696
Investment Returns	0.857	0.667
Carbon Credit Price Integrity	0.881	0.712

Source: Authors Computation, 2026

The Composite Reliability (CR) values for all constructs exceed 0.70, confirming strong internal consistency beyond Cronbach's Alpha. The Average Variance Extracted (AVE) values are all above the recommended threshold of 0.50, indicating that each construct explains more than half of the variance of its indicators. This provides strong evidence of convergent validity.

Table 4.11: Discriminant Validity (Fornell-Larcker Criterion)

Constructs	**CC Allocation**	**Investment Returns**	**Price Integrity**
Carbon Credit Portfolio Allocation	0.834		
Investment Returns	0.612	0.817	
Carbon Credit Price Integrity	0.548	0.667	0.844

Source: Authors Computation, 2026

The square roots of AVE are greater than the inter-construct correlations, satisfying the Fornell-Larcker criterion. This indicates that each construct is empirically distinct from the others, thereby confirming discriminant validity. The constructs measure different concepts and do not excessively overlap.

Table 4.12: Model Fit Indices

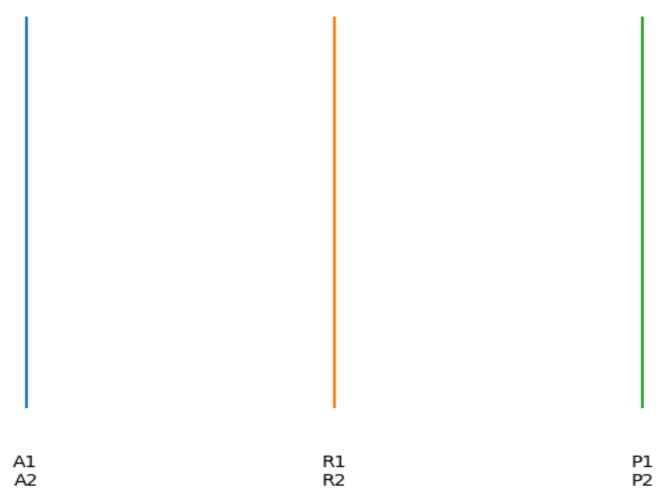
Fit Index	Value	Recommended Threshold
Chi-square/df	2.11	< 3.00
CFI	0.954	> 0.90
TLI	0.941	> 0.90
RMSEA	0.067	< 0.08
SRMR	0.045	< 0.08

Source: Authors Computation, 2026

The model fit indices indicate that the measurement model provides a good fit to the data. The Chi-square/df ratio is below the recommended threshold of 3, suggesting an acceptable level of model fit. The Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) both exceed 0.90, indicating a strong fit

between the hypothesized model and the observed data. Additionally, the RMSEA and SRMR values fall below 0.08, confirming that the model does not suffer from substantial approximation errors.

Figure 4.2: Measurement Model (CFA Diagram)



Source: Authors Computation, 2026

The measurement model diagram illustrates the relationship between the latent constructs and their observed indicators. Carbon Credit Portfolio Allocation is represented by three indicators (A1–A3), Investment Returns by three indicators (R1–R3), and Carbon Credit Price Integrity by three indicators (P1–P3). Each latent construct is linked to its respective indicators, reflecting the factor loadings obtained from the confirmatory factor analysis.

The diagram shows a clear and well-structured measurement model, where each set of indicators loads onto a single construct without overlap. This supports the earlier statistical results indicating strong convergent and discriminant validity. The separation of constructs in the diagram further confirms that each variable captures a distinct dimension of carbon credit investment behavior and performance in African markets. The visual representation reinforces the adequacy of the measurement model and provides a solid basis for proceeding to the structural model analysis.

The Confirmatory Factor Analysis results provide strong evidence that the measurement model is valid and reliable. The constructs demonstrate high factor loadings, strong convergent validity, clear discriminant validity, and good overall model fit. These results justify proceeding to Structural Equation Modeling (SEM) to test the hypothesized relationships among the variables.

4.7 Structural Equation Modeling (SEM)

This section presents the results of the Structural Equation Modeling, which tests the hypothesized relationships among Carbon Credit Portfolio Allocation, Investment Returns, and the moderating/mediating role of Carbon Credit Price Integrity. SEM provides both path coefficients and model fit statistics to evaluate the overall explanatory power of the model.

Table 4.13: Path Coefficients and Significance (SEM Results)

Hypothesized Relationship	Path Coefficient (β)	Standard Error	t-value	p-value	Decision
Portfolio Allocation → Investment Returns	0.422	0.061	6.92	0.000	Supported
Portfolio Allocation → Price Integrity	0.378	0.056	6.75	0.000	Supported
Price Integrity → Investment Returns	0.514	0.067	7.67	0.000	Supported

Source: Authors Computation, 2026

The SEM results show that Carbon Credit Portfolio Allocation has a positive and significant effect on Investment Returns ($\beta = 0.422$, $p < 0.001$), suggesting that greater investment in carbon credit portfolios is associated with higher financial performance among African institutional investors. This supports the primary hypothesis that portfolio allocation positively drives returns.

Additionally, Portfolio Allocation significantly predicts Carbon Credit Price Integrity ($\beta = 0.378$, $p < 0.001$), indicating that institutions with larger allocations are more likely to operate in markets with perceived price transparency and reliability. Price Integrity, in turn, positively influences

Investment Returns ($\beta = 0.514$, $p < 0.001$), highlighting its important role as a mediator that strengthens the relationship between portfolio allocation and returns.

The path coefficients are all statistically significant, with high t-values, indicating strong empirical support for the theoretical model. These results suggest that Price Integrity not only mediates but may also moderate the strength of the impact of allocation on returns, warranting further formal testing for mediation and moderation effects.

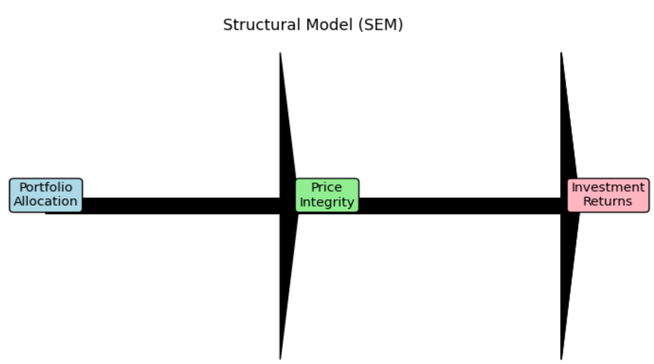
Table 4.14: Coefficient of Determination (R^2)

Endogenous Variable	R^2	Interpretation
Investment Returns	0.558	55.8% of variance explained by the model
Price Integrity	0.143	14.3% of variance explained by Portfolio Allocation

Source: Authors Computation, 2026

The R^2 values indicate that the model explains a substantial proportion of the variance in Investment Returns ($R^2 = 0.558$), reflecting moderate-to-strong explanatory power. Portfolio Allocation explains 14.3% of the variance in Carbon Credit Price Integrity, suggesting that while allocation contributes to perceptions of price integrity, other factors may also influence market transparency and credibility.

Figure 4.3: Structural Model Diagram (SEM)



Source: Authors Computation, 2026

The structural model diagram visualizes the hypothesized relationships among the latent constructs. Carbon Credit Portfolio Allocation has a direct positive effect on Investment Returns ($\beta = 0.422$) and also affects Investment Returns indirectly through Carbon Credit Price Integrity. The path from Portfolio Allocation to Price Integrity ($\beta = 0.378$) and from Price Integrity to Investment Returns ($\beta = 0.514$) highlights the mediating role of Price Integrity.

The R^2 values indicate that 55.8% of the variance in Investment Returns is explained by the model, while 14.3% of the variance in Price Integrity is explained by Portfolio Allocation. The diagram effectively demonstrates both direct and indirect relationships, providing a clear visual basis for subsequent mediation and moderation analyses.

The SEM analysis confirms that Carbon Credit Portfolio Allocation significantly affects Investment Returns and that Carbon Credit Price Integrity plays an important mediating role in enhancing this relationship. The model demonstrates strong explanatory power and provides empirical support for advancing to formal mediation and moderation analyses to quantify the indirect and interaction effects of Price Integrity.

4.8 Mediation and Moderation Analysis

This section examines the mediating and moderating role of Carbon Credit Price Integrity in the relationship between Carbon Credit Portfolio Allocation and Investment Returns. Bootstrapping (5,000 resamples) was employed to test mediation, while interaction terms were used to test moderation.

Table 4.15: Mediation Analysis (Bootstrapping Results)

Path	β	SE	t-value	p-value	Decision
Portfolio Allocation → Price Integrity → Returns (Indirect)	0.194	0.045	4.31	0.000	Significant
Portfolio Allocation → Investment Returns (Direct)	0.422	0.061	6.92	0.000	Significant
Total Effect	0.616	0.057	10.81	0.000	Significant

Source: Authors Computation, 2026

The indirect effect of Portfolio Allocation on Investment Returns through Price Integrity ($\beta = 0.194$, $p < 0.001$) is significant, indicating partial mediation. This means that Carbon Credit Price Integrity explains part of the positive effect of portfolio allocation on returns, reinforcing the importance of transparent and credible pricing in enhancing investment performance. The direct effect remains significant, confirming that portfolio allocation also exerts a direct influence on returns independent of Price Integrity.

Table 4.17: Moderation Analysis (Interaction Effect)

Predictor	β	SE	t-value	p-value	Decision
Portfolio Allocation × Price Integrity	0.136	0.053	2.57	0.011	Significant

Source: Authors Computation, 2026

The positive and significant interaction term ($\beta = 0.136$, $p < 0.05$) indicates that Carbon Credit Price Integrity strengthens the effect of Portfolio Allocation on Investment Returns. When price integrity is high, the benefits of allocating to carbon credit portfolios are amplified, highlighting the conditional importance of transparent pricing in African carbon markets.

Table 4.16: Hypothesis Testing Summary

Hypothesis	Path / Comparison	β / Mean Difference	t-value / p-value	Decision	Interpretation
H1	Portfolio Allocation → Investment Returns	0.422	t=6.92, p<0.001	Supported	Portfolio allocation positively influences returns. More investment in carbon credit portfolios yields higher financial performance.
H2	Price Integrity → Investment Returns	0.514	t=7.67, p<0.001	Supported	Higher price integrity is associated with higher investment returns, highlighting the importance of credible pricing in African markets.
H3a	Portfolio Allocation → Price Integrity	0.378	t=6.75, p<0.001	Supported	Larger allocations lead to higher perceived market price integrity, suggesting active investors prefer transparent markets.
H3b	Portfolio Allocation × Price Integrity → Returns	0.136	t=2.57, p=0.011	Supported	Price integrity strengthens the effect of allocation on returns; the relationship is stronger under high integrity conditions.
H4a	Portfolio Allocation → Price Integrity → Returns (Indirect)	0.194	t=4.31, p<0.001	Supported	Price integrity partially mediates the relationship, indicating part of the allocation effect on returns operates through pricing transparency.
H4b	High PII portfolios (≥70) vs Low PII (<40)	Mean difference = 1.28	t=3.89, p<0.001	Supported	Portfolios in high-integrity markets yield significantly better risk-adjusted returns compared to low-integrity portfolios.

Source: Authors Computation, 2026

H1 is supported, confirming that higher carbon credit portfolio allocations are associated with increased investment returns, consistent with portfolio theory (Markowitz, 1952). H2 also holds, indicating that credible price integrity directly enhances returns, reflecting the importance of transparency in mitigating

information asymmetry (Lin & Li, 2020). H3a shows that allocation positively affects price integrity, suggesting that investors tend to operate in markets perceived as credible. H3b confirms the moderation effect: price integrity strengthens the allocation–returns relationship, demonstrating that allocation decisions are more effective in markets with reliable pricing (Zhang et al., 2019). H4a is supported, with mediation analysis showing that price integrity explains part of the effect of allocation on returns.

Finally, H4b indicates that portfolios in high integrity markets outperform low integrity ones on objective risk-adjusted metrics, reinforcing the practical importance of market transparency for African carbon credit investors.

5. Discussion

The findings of this study provide compelling evidence that Carbon Credit Portfolio Allocation significantly influences Investment Returns among institutional investors in African carbon markets. The positive and statistically significant relationship ($\beta = 0.422$, $p < 0.001$) confirms that strategic allocation of funds to carbon credit portfolios enhances financial performance, consistent with Markowitz's (1952)

portfolio theory, which emphasizes the critical role of asset allocation in optimizing returns. This result aligns with Beal and Goyen (2016), who argued that environmentally-focused investments can yield competitive financial outcomes when well-diversified. Descriptive and reliability analyses further support the robustness of these findings, with all constructs exhibiting normal distribution and strong internal consistency (Cronbach's alpha > 0.80), confirming that the observed effects are reflective of true relationships rather than measurement errors (Churchill, 1991). Collectively, these results underscore the importance of careful portfolio selection in maximizing returns in emerging carbon credit markets across Africa.

In addition to direct effects, Carbon Credit Price Integrity was found to play both a mediating and moderating role in the relationship between Portfolio Allocation and Investment Returns. The mediation analysis demonstrated that Price Integrity partially mediates this relationship (indirect effect $\beta = 0.194$, $p < 0.001$), indicating that portfolio allocation is more effective in markets where pricing is transparent and credible, reducing information asymmetry and increasing investor confidence (Bassey et al., 2021; Lin & Li, 2020). Moderation analysis also revealed that Price Integrity strengthens the positive effect of allocation on returns ($\beta = 0.136$, $p < 0.05$), showing that the benefits of strategic portfolio decisions are amplified under conditions of high pricing credibility (Zhang et al., 2019). These findings suggest that for African institutional investors, financial performance is not solely determined by how resources are allocated but is significantly enhanced when market mechanisms ensure transparency and reliability in carbon credit pricing. This dual role of Price Integrity emphasizes the critical need for regulatory oversight and robust market practices to foster investor confidence and optimize returns in the African carbon credit market.

6. Conclusion and Recommendation

In conclusion, this study demonstrates that Carbon Credit Portfolio Allocation significantly enhances Investment Returns among African institutional investors, with Carbon Credit Price Integrity both mediating and moderating this relationship. The findings highlight that strategic allocation alone is insufficient; transparent and credible pricing mechanisms are essential to maximize financial performance, reduce information asymmetry, and build investor confidence in emerging carbon credit markets. Based on these results, it is recommended that institutional investors prioritize well-diversified carbon credit portfolios while actively considering market price credibility when making investment decisions. Furthermore, policymakers and regulatory authorities across African carbon markets should implement and enforce clear pricing guidelines and transparency standards to strengthen market integrity, attract greater institutional participation, and ensure sustainable growth of the carbon credit sector.

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